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CarerNet - a systems approach to achieving an integrated & intelligent telecare system

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CarerNet - A Systems Approach to Achieving An Integrated & Intelligent Telecare System

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For

Mam and Dad

Thanks for everything.

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Summary

The re-engineering of healthcare delivery in the UK, with its shift away from institutionalised settings towards the community has resulted in the creation of a 'new' tier of intermediate care. Furthermore, there is increasing interest in extending the provision of care services into the home itself using telecare. However, current telecare technologies often work in isolation and are incapable of supporting the range of services anticipated in an integrated manner.

This thesis is concerned with the development of a generic system architecture for (second-generation) telecare services in the home, which promotes the concepts of integration at the systems level and serves to identify the nature of the devices and system intelligence required. A viewpoint analysis of stakeholder needs and requirements is presented and analysed to establish a spectrum of potential telecare services. These are used in conjunction with a domain analysis of the home environment to identify domain properties with significance for telecare, allowing the identification of system-elements within the home. The resulting system analysis (including a consideration of stakeholder conflict and safety) enables a model for a next-generation telecare system to be proposed based on local (and distributed) intelligence in the home.

Methods of implementing telecare services are identified and characterised using object-oriented techniques in order to establish a modular, adaptable, component-based architecture. It has been established that many second-generation telecare services possess similar requirements that can be implemented by re-using a relatively small number of class-based components, either in isolation or in a hybrid arrangement. Some of these have been realised in the form of a telecare demonstrator system, consisting of a virtual integrated care environment and a range of prototype sensors. The virtual environment enables the simulation of a virtual client in a virtual domain and has been developed for system testing purposes. The preliminary results of the simulation testing and the extension of this work into several UK field trials are reported.

Contents

“The frontline in healthcare is the home”

The NHS Plan, July 2000.

Chapter One

Introduction

The United Kingdom's National Health Service (NHS) came into being on July 5th, 1948 thanks in no small part to the efforts of Aneurin Bevan who later described it as "... *the most civilised achievement of modern government.*" Over 50 years on, the NHS is very much a victim of its own success. The initial expectation was that the creation of a National Health Service would lead to a healthier nation with a subsequent reduction in the demand for healthcare. With hindsight, it is clear that this original premise was flawed - the tremendous achievements and successes of the NHS mean that, with people living longer, there is an ever greater demand for healthcare.

The key problem for the NHS is that improvements in healthcare and an increasingly ageing population have resulted in the focus of care shifting from diseases that are communicable such as influenza, diphtheria and smallpox to diseases that are chronic and attributable, in some part, to lifestyle, such as: cancer, cardiovascular disease, diabetes, hypertension and dementia [1-3]. Many of these require long-term treatments; some require complex surgery with an obligatory lengthy stay in hospital.

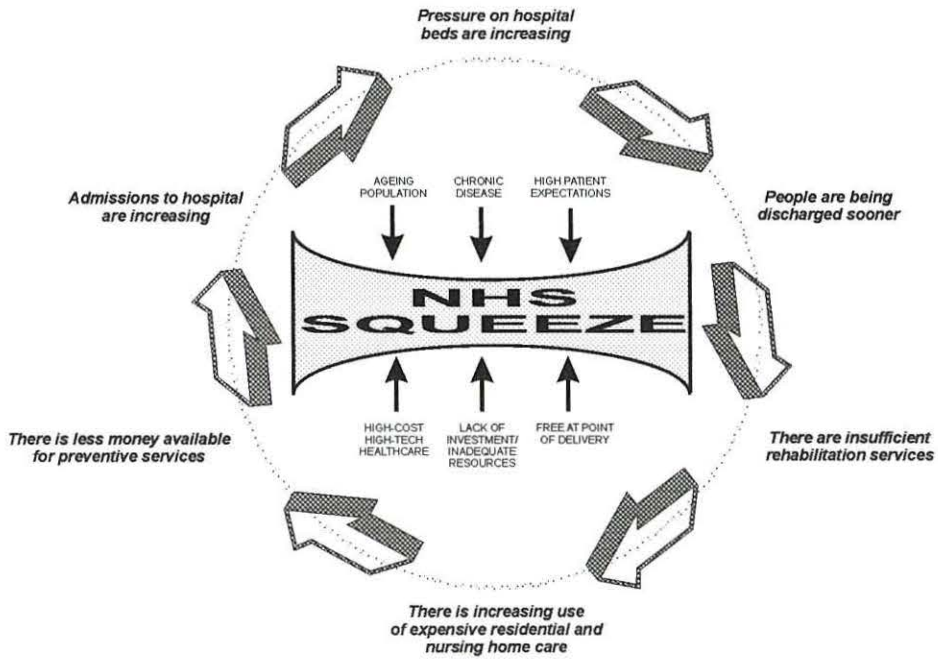

Figure 1.1. Conflicting pressures are squeezing the resources of the NHS.

In response to these new health challenges, surgical and therapeutic techniques are constantly improving, and new drug therapies are continually being found to help manage chronic conditions. Survival rates are improving; acute conditions, which might once have resulted in a patient's death, are now operated on and treated successfully, some routinely. Unfortunately, this success places yet greater pressure on the system, see Figure 1.1 (adapted from [4]).

At the dawn of a new millennium, the notion that the NHS should provide care to all, from the cradle to the grave, is looking increasingly like an unachievable ideal. This comprehensive service, free at the point of delivery, is however exactly what is expected by an increasingly health-conscious population. The NHS is in danger of being overwhelmed by a spiral of decline where resources are insufficient to keep up with demand whilst, perversely, the more successful it becomes the greater are the demands placed upon it.

How can this spiral of decline be halted? One solution being considered is the more effective use of available resources through the adoption of new methods of service delivery [5]. This calls for a certain re-engineering of the healthcare process, allowing resources to be utilised in more innovative and cost-effective ways but without compromising the care afforded to its patients. One symptom of this reorganisation is an increasing trend towards care in the community and one of the service delivery mechanisms being considered to bring this about is intermediate care [6].

1.1 Intermediate Care

The healthcare system has not traditionally coped well with individuals who require an intermediate level of care. The outdated demarcations between various care professions and a slow take up of information technology have resulted in artificial barriers between services. Most often, individuals who require an intermediate level of care are elderly, with care requirements that rarely fall neatly into that of 'medical' or 'social' care, but rather straddle both. This frequently results in their needs falling frustratingly between the responsibilities of the various care providers which means that they fail to receive the integrated and continuous care required.

This problem is perhaps most noticeable when an older individual who is reasonably independent and living alone suffers some form of acute medical episode or accident which requires their admission to hospital. Following treatment, one of the following scenarios is typical [4], [7]:

1. The individual is discharged from hospital too early and with insufficient support or risk management and ultimately ends up being re-admitted ('revolving-door syndrome');
2. The individual is kept in hospital unnecessarily, often in an acute care bed, where they lose the ability to care for themselves ('pyjama paralysis'). This results in 'bed blocking';
3. The individual is discharged into inappropriate settings, such as a residential or nursing home, or community hospital, when they could (with appropriate support) return to their own home or a sheltered care alternative and retain their independence.

The aim of the third standard of the National Service Framework (NSF) for Older People [8] is:

"To provide integrated services to promote faster recovery from illness, prevent unnecessary acute hospital admissions, support timely discharge and maximise independent living."

The NSF outlines new initiatives in intermediate care, including: 'step-down' facilities that are intended to ease the transition from hospital to home and from medical dependence to functional independence (from 'stable' to 'able'), and 'step-up' facilities that aim to prevent admission to hospital in the first place, see Figure 1.2. But there is also an emphasis on attempting to provide support to an individual in their own home, where this is appropriate. Indeed, most intermediate care is expected to be provided in people's own homes, a point recently reinforced in the Chancellor's spending review of 2002 which offered further support for even more vulnerable people living in their own home [9]. The two components of this strategy that are particularly relevant to telecare are:

- **Rapid response** – A multidisciplinary care team based in the community that aims to respond within hours of referral to people's identified care needs. This is often at a time of crisis (e.g. following an acute episode such as a fall) when arrangements are swiftly made to provide care and support for a defined period of time, usually in a person's home. The service aims to prevent inappropriate hospital admission.

- **Early or supported discharge** – A service that facilitates earlier discharge for those patients who are medically stable and are able to complete their recovery at home. It might include continuing nursing care, therapy, hospital-at-home services or rehabilitation alongside home-based personal care. Additionally, if appropriate, it may include the provision of various home-modifications or assistive technologies.

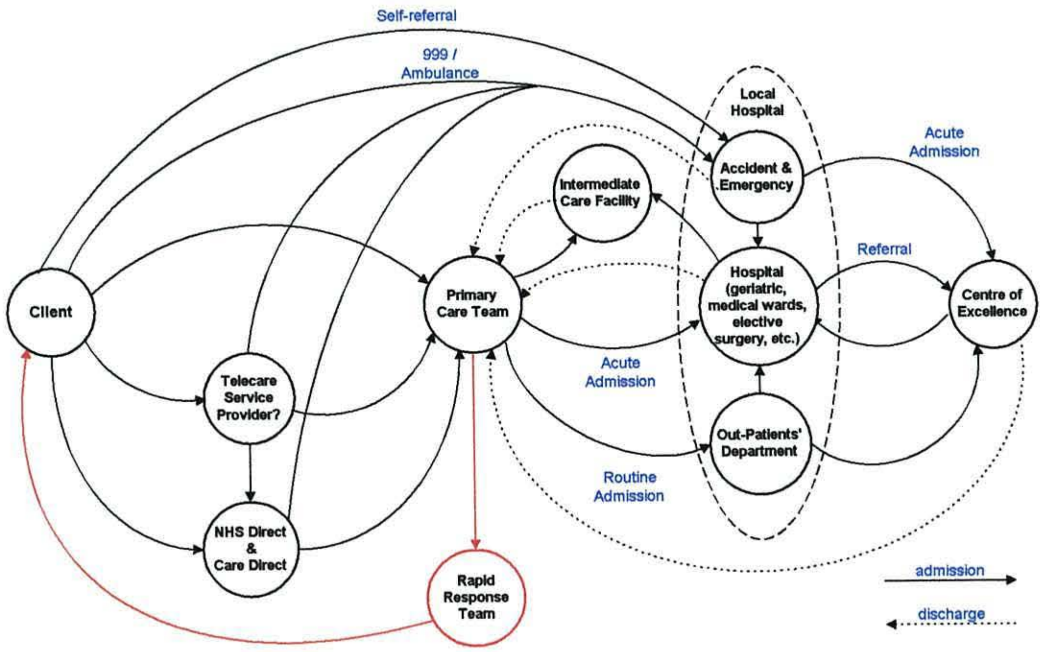

Figure 1.2. Admission and discharge pathways in the NHS.

One of the tools conceived to help facilitate this course of action and introduced in the NSF is the single assessment process (SAP) [8]. The purpose of SAP is to ensure that older people receive appropriate, effective and timely responses to their health and social care needs, and that professional resources are used effectively. It is an attempt at coordinating the multi-disciplinary and multi-tool nature of assessment into a more effective, client-centred, process.

The NSF states that by March 2004 there should be at least 150,000 additional people receiving intermediate care services promoting rehabilitation and supported discharge and at least 70,000 receiving intermediate care which prevents unnecessary admissions[1].

In order to achieve these figures, the capacity of community care will have to be extended. Some of this extra capacity will be realised by the creation of new community-based facilities. However, there is also increasing interest in extending the principles of community care right into the home itself; and the vehicle for realising this is likely to be telecare.

1.2 Telecare

1.2.1 Nomenclature

As the field of telecare is still comparatively young, its terminology is still fluid and can be confusing; a short explanation is therefore offered.

E-care is a term used to describe care services that are enabled via electronic means and which usually employ an element of Information and Communications Technology (ICT). A more widespread term is *telehealth*, whose literal definition is '*health at a distance*' but is generally understood to mean the remote delivery of health information or services using ICT [10]. The field of telehealth may be sub-divided further into two main categories: *telemedicine* and *telecare*[2]. Many (similar) definitions of telemedicine exist and they range in complexity from:

"Telemedicine is healthcare carried out at a distance" [11]

to:

"Telemedicine is the delivery of healthcare services, where distance is a critical factor, by all healthcare professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of healthcare providers, all in the interests of advancing the health of individuals and their communities." [12].

A precise definition of the term *telecare* is more difficult to come by in the literature. Although there is general agreement as to the distinction between it and telemedicine, which is essentially to do with the user/beneficiary of the service and their location. The term *telemedicine* is usually used to describe services that operate between care professionals in institutional settings (e.g. remote consultations or information transfer), whereas *telecare* is used to describe services provided to individuals in a community or primary care setting and often in their own home[3] [13, 14]. Its primary role is to provide support to the client[4] rather than to care professionals, although it does also offer potential advantages

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[1] *compared to 1999/2000 baseline figures.*
[2] *Sometimes referred to as tele-homecare in the USA.*
[3] *Using an e-commerce analogy, consider telecare to be a business-to-customer (b2c) service and telemedicine as being mainly a business-to-business (b2b) service. In other words, telecare = expert-to-client (e2c), telemedicine = expert-to-expert (e2e).*
[4] *The term client is used to describe an individual who is in receipt of telecare services (i.e. a patient in the community).*

towards the provision of care. Thus, within the context of this thesis, the term telecare is used to describe telehealth services provided to a client in the community, and is defined as:

"An integrated approach to the remote provision of care, monitoring and assistance in a community setting, via the use of appropriate technologies, in order to help assure client well being and/or support independence."

Doughty et. al. provide a framework within which to describe the evolution of telecare services, which they explain in terms of *three generations* of telecare [15]:

- *First generation* systems (currently the norm) provide simple alarm-based services, where the onus is on the client to trigger an alarm.
- *Second generation* services augment first generation services by introducing monitoring into the home in order to enable automatic (passive) alarms and lifestyle monitoring.
- *Third generation* systems add data-intensive services that take advantage of broadband communication technologies. These include video-based tele-consultations (for instance with a GP); a 'virtual neighbourhood' [16] or e-community to help isolated individuals remain socially active; and services such as e-banking and e-shopping. In other words, services that now operate over the Internet or via cable or digital/web-enabled television sets.

1.2.2 A Mechanism for Supporting Intermediate Care

The introduction of telecare into people's homes has been considered in the NHS' Information Strategy as a mechanism of supporting the principles of intermediate care [17]. However, the Strategy *does not elaborate in detail on any of the actual care services which might be required.* Furthermore, it is unclear how telecare services are to be integrated into the existing healthcare information and communications infrastructure (*infostructure*).

Telecare may support an individual's independence by providing services that include: managing risk; providing continuous monitoring and support; affording a timely and needs-matched response in an emergency; alerting carers to symptoms of concern at an early stage; and allowing remote consultation with distant carers (formal & informal). Thus, telecare services offered in the home will become an integral and active component of primary care. The precise scope of these services are discussed in Chapter 3, and defined in Chapter 5. Examples of which include:

- Fall detection and prevention;
- Medication reminder and compliance monitoring;
- Vital signs monitoring;
- Client distress monitoring;
- Environmental monitoring & control;
- Home automation;
- Client lifestyle monitoring and assessment.

The use of telecare in the home therefore has the potential to support intermediate care in a number of ways. However, in order for telecare to fully support intermediate care, it must be capable of integrating with a community/primary care infostructure. Only then will there be seamless integration of home-based telecare services for the client and associated support applications for carers located in the community. Thus, there is a need for an ICT gateway from the home to some form of community-based carer network, enabling information to be shared between care providers. Such an infostructure does not at present exist; although alarm-based information may be conveyed from the home to call centres using the existing community alarm infrastructure[5].

1.2.3 Telecare Literature

A review of the literature has established that the progression from one telecare generation to the next is not linear, as work has been undertaken in relation to each; although at the time of writing, simple *second* generation 'telecare systems' are still at the development/prototype or initial trial stage. A good overview to the field of home telecare and related issues may be gained by reading [15, 18, 19]. A short discussion of the literature follows in order to place the work presented in this thesis in context.

Extending First Generation Telecare

A number of projects have attempted to extend the functionality of *existing* community alarm systems:

- The SAFE 21 project investigated the potential of providing new home-care services using the existing community alarm infrastructure [20]. The most notable results being a home-based telemedicine monitor (see Chapter 4); a speech trigger[6], which allowed the user to communicate with the response centre in any part of the house or garden; and a mobile social alarm (effectively a combined GSM[7] mobile-phone/alarm-trigger with built-in GPS[8]). Other than the telemedicine monitor, these are essentially extending the functionality of *existing* services.

- Various other projects undertaken in the UK have developed the concept of *extended first generation* telecare. These have introduced 'smart' sensors into the home in order to generate 'passive' alarms using the existing community alarm system infrastructure [13]. Because of this, services are purely alarm-based and include: the detection of falls, heat extremities, abnormal bed occupancy/absence, and wandering [21].

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[5] *This work is predominantly concerned with the specification and implementation of systems and services that will operate within the client's home. It is therefore assumed that a suitable gateway will be made available for the transmission of data to and from the necessary information consumers and generators within the community care team.*
[6] *Community alarm systems employ an emergency telephone which is responsible for opening up a voice channel to the response centre upon receipt of an alarm signal. Unfortunately, the speakerphone system employed is ineffective if the client is in a different room to the phone at the time of the call. This invariably results in a response team or emergency services being called, often in vain.*
[7] *Global System for Mobile communication.*
[8] *Global Positioning System*

Telecare Devices

- The ability to non-intrusively and non-obtrusively monitor a range of physiological, environmental and behavioural parameters is key to the implementation of passive or automated telecare services. A significant number of devices have been conceived for use in home-based monitoring applications, including: bath-based and bed-based electrocardiogram monitors [22-24]; various bed occupancy/sleep assessment devices [25, 26], and even a toilet that measures a ballistocardiogram and also measures the weight of any urine or faeces excreted! [27]. In addition to devices designed to be incorporated into objects within the home, there are a number of novel body-worn devices currently available or in development. These devices include: a smart fall detector [28]; an ambulatory body-worn vest capable of monitoring multiple physiological parameters [29]; and various watch-based devices that can support a range of services, including: panic button, fall detection[9], extreme hot/cold detection, and wander detection [30, 31]. Intermittent or on-demand single or multi-parameter monitors are also available or undergoing development [32-35]; some of which are freely available[10].

- Client behaviour and environmental monitoring has been attempted using various combinations of passive infra-red (PIR) devices, magnetic proximity switches, ambient temperature, infra-red beams, and current transformers placed at various locations throughout the house [36-39] as well as body-worn activity monitors [40, 41]. Commercially available bed and chair occupancy sensors, usually (but not always) based on pressure pad technologies are also available, but these have very often been designed with institutional use in mind.

Telecare 'Systems'

- 'System' implementations include: a home electrocardiography and blood pressure monitoring network [42]; and a remote physiological monitoring network for investigating cardio-respiratory function during sleep in infants [43]. Several commercially available tele-monitoring services also exist, including remote cardiac, blood pressure, and pulmonary monitoring services, e.g. see [44]. The use of the Internet and the World Wide Web (WWW) as a medium for enabling telecare services have been investigated by various workers. Internet based services are typically a mixture of information access, videoconferencing and data transfer of client-side obtained physiological data for server-side processing. 'Second generation' systems under development or undergoing trials include: supporting the home care of people with diabetes [45, 46], web-enabled spirometry [47] and electrocardiogram (ECG) monitoring [48]. Furthermore, the use of a Web-Browser interface is being implemented as the standard front-end to a 'thin-client' application for interrogating a remote database of telecare data [49].

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[9] *Wrist-based fall detection is reportedly unreliable with minimum detection times sometimes as high as 30 minutes [31].*
[10] *For example see http://www.westons.com*

- The field of smart homes has obvious similarities with that of telecare [50, 51]. Some work has been undertaken on providing support in the home using assistive technologies in collaboration with smart home technologies [52-54]. Various 'show homes' have been established in the UK including the Gloucester Smart House [55] and the West Lothian Smart house[11]. Various assistive devices are available, including: memory reminder systems, often based on a pager concept, e.g. [56, 57] and medication reminder or dispensing systems[12]. One example of smart home technology used within the context of telecare is the BESTA project in Norway [58], which managed three problems associated with sufferers of dementia: the risk of fire; the risk of falling and of lying undetected; and the risk of wandering and becoming lost. Smart home schemes have in the main proved costly due to the communications infrastructure required, and therefore rarely go beyond the show-home stage.

- Celler et. al. performed a significant research project in relation to lifestyle monitoring for British Telecom (BT) in the mid 1990's [59]. The project was to establish the feasibility of monitoring the 'functional status' of an individual in their own home using lifestyle monitoring techniques based on the Activities of Daily Living (ADL). Large quantities of data were obtained, which led to data-smog and the need to develop complex data extraction algorithms [60]. The devices used were similar to those described above in relation to lifestyle monitoring and are described in [61].

- A small subset of Celler's work was ultimately implemented as part of the largest telecare trial to date in the UK - the BT/Anchor project [62], which consisted of 22 participants aged between 60 and 84 and which collected 5000 days of lifestyle data. The devices installed in the homes of the clients for the trials included:

    1. Room temperature monitors
    2. PIR motion detectors
    3. Magnetic door sensors
    4. Magnetic fridge-use monitor

  These devices were used to identify four scenarios of interest, primarily alarm based, namely: '*room temperature too low*'; '*less activity detected than normal*'; '*client still in bed after their usual get-up time*'; and '*use of refrigerator noticeably different*'. The off-line analysis also looked for significant changes in the pattern of movements in the dwelling. No processing was performed locally, a computer system at the BT research laboratories dialled-in to a purpose-built control unit every 30 minutes to upload all data for subsequent off-line analysis. During the duration of the trial, there were 60 alarm calls generated, all of which were false alarms. In addition, two clients fell, and luckily were able to raise an alarm manually to the response centre as the system itself failed to generate an alarm automatically (but might have done so after sufficient time had elapsed - worst case *at least* an hour after the event). One of the

[11] *Part of the "Opening doors for older people" project.*

weaknesses of the BT/Anchor project was its over-reliance on PIR data to determine client activity and mobility, without sufficient knowledge to place it in context (see Chapter 6).

- Glascock and Kutzik [37] describe experimental research into what they call 'behavioural telemedicine'. They set up a passive data acquisition system with a view to monitoring non-intrusively a small number of parameters related to the activities of daily living (ADL) and Instrumental ADL (I-ADL) of an individual. They used: 2 PIR's for monitoring client's mobility/transference throughout the home – one in the bathroom and one the kitchen; a 'caddy' designed to hold a number of medication bottles which were detected by way of an infra-red beam; and magnetic proximity switches to detect the use of the fridge and kitchen utensil drawer for the detection of meal preparation. The use of the bathroom was determined by the activation of the bathroom PIR. The fact that the client was out of bed in the morning was determined by the time of the first PIR activation in the kitchen. Statistical analysis showed data correlated well with actual events obtained by interview for a 13 day trial period with a 71 year old male.

Discussion

Telecare may be considered as the provision of *services* over a particular *infrastructure* upon which several *devices* have been connected. There is great scope for telecare services within the home, although research has mostly focussed on *individual application domains*, without the consideration of an *integrated systems* viewpoint at the device, systems, or indeed service level.

One of the driving factors likely to affect the take-up of telecare *systems* in relation to supporting intermediate care in the UK is the availability of a suitable range of services (*as yet undefined*) operating using a *common infrastructure*. People's needs change over time, and a telecare system should be capable of evolving accordingly. The service requirements are likely to start off small but should be capable of expansion, in a modular fashion, so as to grow in line with the needs and expectations of the client (and their carers). Likewise, the system services must be capable of being tailored to the individual needs of each client in line with their individual assessment.

The adoption of telecare en-masse is likely to only take off when such an integrated, modular, and adaptable system is available.

1.3 CarerNet - An Integrated Systems Approach

This thesis is concerned with the development of a generic system architecture for telecare services in the home, which promotes the concepts of integration at the systems level and serves to identify the nature of the devices and system intelligence required. The primary aim of such a system should be:

To improve and enhance the quality of life of individuals by the utilisation of technology in support of their ability to function independently within their local environment.

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[12] *For example see http://www.epill.com/*

Such a system should also have as its (secondary) aim:

To increase the efficiency of care services through the use of technology to provide care to clients within their local environment.

In order to achieve this, it is necessary to perform the following:

- Identify the potential scope for services within the home and establish the suitability (or otherwise) of first generation technologies in realising them;
- Use the above for eliciting system requirements from the viewpoint of key stakeholders and subsequently analyse in order to establish suitable service delivery and system models;
- Perform a requirements analysis in order to identify mechanisms of realising the services and also to identify, and compensate for, conflicting requirements between different stakeholder viewpoints (and modifying the system model accordingly).
- Expand the system model within the home into an architecture capable of supporting the services identified.
- Implement and validate the system architecture to show integrated services in operation.

1.4 Overview of Thesis

Figure 1.3 illustrates how each chapter of the thesis maps on to various stages of the system development process. A brief summary of each chapter follows.

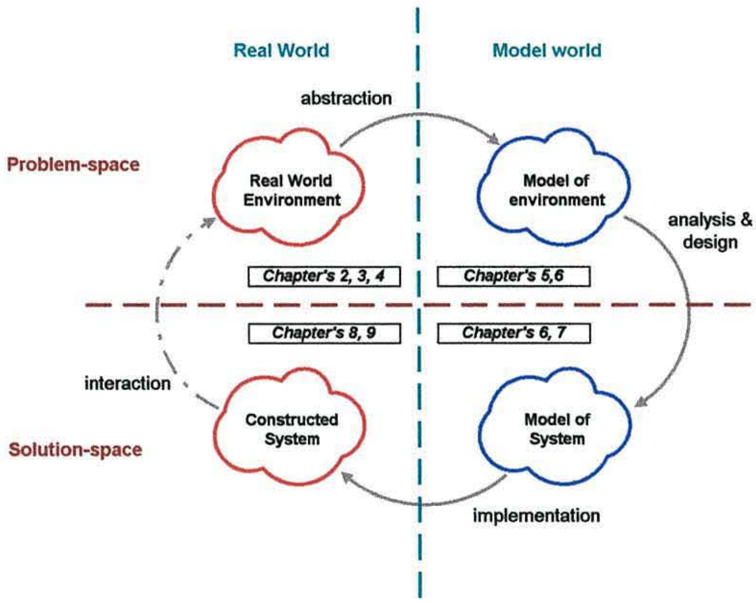

Figure 1.3. High-level system modelling & design process.

Chapter 2 presents background material describing the circumstances that have brought about interest in telecare. The increased demands placed on the NHS resulting in the re-engineering of the UK's healthcare system are discussed in relation to the changing needs of the healthcare 'consumers' of the twenty-first century. The new structure of primary care is described and the chapter concludes by introducing the key stakeholders in telecare and discusses their likely (high-level) needs.

Chapter 3 reviews the gerontological foundations of telecare and describes how the care requirements of the elderly are complex and inter-related. Methods of assessing an individual's well-being are investigated, including a discussion of the risks associated with elderly individuals living alone at home. The subsequent analysis identifies a 'spectrum' of telecare that provides responsive, supportive and preventative services.

Chapter 4 considers the characteristics of first-generation telecare technologies: community alarm systems, assistive technologies, home healthcare devices, and 'smart homes'. The analysis is used to establish the advantages and disadvantages of the services and infrastructure afforded by each. The suitability of each for supporting integrated telecare services is considered in relation to the spectrum of telecare conceived in chapter 3.

Chapter 5 presents stakeholder and service requirements in a formal manner. A domain analysis for the local telecare system is presented and vignettes are used to determine potential service delivery models. These are used together with the results of a viewpoint analysis as the basis for a high level model for CarerNet.

Chapter 6 presents the system requirements analysis. The realisation of telecare services are considered and domain properties with significance to telecare are identified. The results of a stakeholder conflict analysis is presented and used to shape the architecture of the local system.

Chapter 7 maps domain properties onto physical devices (sensors and actuators) and sets about defining their functionality. The architectural model proposed in chapter 6 is developed further via an object-oriented analysis which identifies common functionality and design patterns throughout system components. A selection of services that rely on system integration are defined in terms of their inter-component collaboration requirements.

Chapter 8 describes the implementation of the architecture of chapter 7. The CarerNet demonstrator system consists of various prototype sensors as well as a host of virtual devices implemented in software. A selection of telecare services are implemented as part of the Virtual Integrated Care Environment (V-ICE) – a research tool developed for implementing and validating prototype telecare services.

Chapter 9 describes the V-ICE software developed in order to test the demonstrator system in the laboratory using a scenario-based strategy. The results of tests performed by running simulated scenarios on the demonstrator system are presented. Various elements of the work described in this thesis have subsequently been (or shortly will be) employed in a number of field-trials of telecare technologies in the UK. These projects have varied from alarm-based systems designed to help support older people to remain safely in their own homes to the assessment of clients in an intermediate care setting prior to discharge back into the community. A brief discussion of these trial projects within the context of the work implemented from this thesis is given.

The final chapter provides an overview of the work presented in the thesis. The strengths and limitations of the approach adopted are debated and areas of future development and research are considered.

1.5 Research Contributions

The research contributions presented in this thesis include:

- The application of a systems-based methodology to the specification and design of an *integrated* telecare system. This has resulted in the identification and classification of a broad spectrum of telecare services and has established a model for the delivery of next generation telecare services. The matching of service requirements to the results of a domain analysis of the local environment has yielded a substantial list of domain properties with significance for telecare.

- The characterisation of telecare services using object-oriented techniques has identified the existence of common functionality and reusable design patterns. Their existence enables many telecare services to be designed and implemented using modular, reusable components (CareWare). This greatly reduces system complexity, improves testing and reliability, and may ultimately result in a lower cost of implementation. Furthermore, the operating properties of these components may be customised in-situ, ensuring that the system is capable of adapting to meet the individual (and changing) needs of the client.

- The development of a Virtual Integrated Care Environment (V-ICE) - an implementation of a next generation telecare *demonstrator* system. This consists of a combination of prototype sensors; a suite of *virtual* (software implemented) devices; and various CareWare components. Custom designed Active X components provide a method of visualising the status of the client within their local environment.

- V-ICE Scenario simulation software, for the validation and demonstration of telecare services in the laboratory. This enables the extensive testing of new services by presenting them with a range of scenarios. This software may be used to manually generate events (on-demand or randomly); to generate events according to a pre-defined simulation file; or replay actual field-obtained data in order to assess the performance of various aspects of the system CareWare.

- A review and assessment of some of the human factor and safety issues concerned with the provision of telecare services in the home. A preliminary safety classification system for telecare devices/services is proposed along with a selection of design guidelines believed to represent good practice.

1.6 Research Publications

The following is a list of publications resulting from (or partly resulting from) work presented in this thesis:

- **Williams G.**, Doughty K., Bradley D. A. "A systems approach to achieving CarerNet - An integrated and intelligent telecare system" *IEEE Transactions on Information Technology in Biomedicine*, Vol. 2, No.1, pp. 1-8, March, 1998.
- **Williams G.**, Bradley D. A., Doughty K. "The application of a systems methodology to the design and specification of an intelligent telecare system" *6th UK Mechatronics Forum International Conference,* University of Skovde, Mount Billingen, Skovde, Sweden, Sep. 9th – 11th, pp. 787-792, 1998.
- **Williams G.**, Doughty K., Cameron K., Bradley D. A. "A smart fall & activity monitor for home telecare applications" *Proceedings of the 20th Annual International Conference of the IEEE Engineering in Medicine & Biology Society*, Hong Kong, 29th Oct - 1st Nov, 1998.
- Brownsell S. J., **Williams G.**, Bradley D. A., Bragg R., Catlin P., Carlier J. "Future systems for remote health care" *Journal of Telemedicine and Telecare,* Vol. 5, No. 3, pp141-152, 1999.
- **Williams G.**, Doughty K., Bradley D. A. "Smart Sensors for application in Integrated Telecare Systems" *Hospital without walls – 2nd International Conference on Advances in the Delivery of Care,* City University, London, U.K., 24th – 26th March, 1999.
- Doughty K., Isak R., King P. J., Smith P., **Williams G**. "*MIDAS* – Modular Intelligent Domiciliary Alarm System – A practical application of telecare" *Proceedings of the 21st Annual International Conference of the IEEE Engineering in Medicine & Biology Society*, Atlanta, 13th – 16th Oct, 1999.
- Brownsell S., **Williams G.**, Bradley D. A. "Information strategies in achieving an integrated home care environment" *Proceedings of the 21st Annual International Conference of the IEEE Engineering in Medicine & Biology Society*, Atlanta, 13th – 16th Oct, 1999.
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Chapter Two

Re-Engineering the Healthcare System

This chapter will discuss key factors that have contrived to bring about the need for a re-organisation of the UK's healthcare system. Key topics will be discussed at a level necessary to provide an understanding of the problems facing modern healthcare delivery and to explain the emphasis placed on chronic ailments and the elderly throughout the remainder of this thesis. After a description of how the 'New NHS' might operate after re-organisation, the key stakeholders in telecare will be identified and their expectations of and motivation for its introduction discussed.

2.1 Changing Demography & Epidemiology

In order to fully appreciate the complex problems facing the NHS[1], it is helpful to briefly consider the changing demography of the UK (within a global context) and the resulting increase in the incidence of chronic, non-communicable disease. These factors have contrived along with others to place the NHS under increasing strain, which has led to recent plans for its re-organisation.

2.1.1 An Ageing Global & UK Population

The 20th Century witnessed a tremendous leap in the general health of the world's population thanks to developments in public health services such as sanitation and in the quality of housing. These advances coupled with higher levels of education, income, and nutrition has led to vastly improved standards of living in most of the developed and, to a lesser extent, developing world. These advances were enhanced by a great dissemination of knowledge throughout the 20th Century. This was responsible for a massive reduction in mortality throughout the world, with a subsequent increase in the life expectancy of both men and women, see Table 2.1. Projections made by the Government Actuary in 1996 anticipated that by 2041 life expectancy at birth in the UK could reach 78.7 years for males and 83.6 years for females [63].

Table 2.1. Life expectancy at birth, selected countries, circa 1910 and 1998 [64].

	Circa 1910		1998	
Country	Males	Females	Males	Females
Australia	56	60	75	81
England & Wales	49	53	75	80
Italy	46	47	75	81
Japan	43	43	77	83
New Zealand	60	63	74	80
Sweden	57	59	75	81
United States	49	53	73	80

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[1] *and, indeed, every healthcare system in the developed world.*

This increase in longevity has resulted in death-rates in the overall population being compressed into a shorter period towards the end of the human lifespan instead of being distributed more evenly throughout. However, this effect, known as the 'rectangularisation of survival', does not necessarily lead to compression in morbidity towards the final stages of life. Instead, older individuals are likely to suffer from prolonged periods of disability and dependency in their later years with an associated increase in the demands placed on both formal and informal care networks, as shown in Figure 2.1.

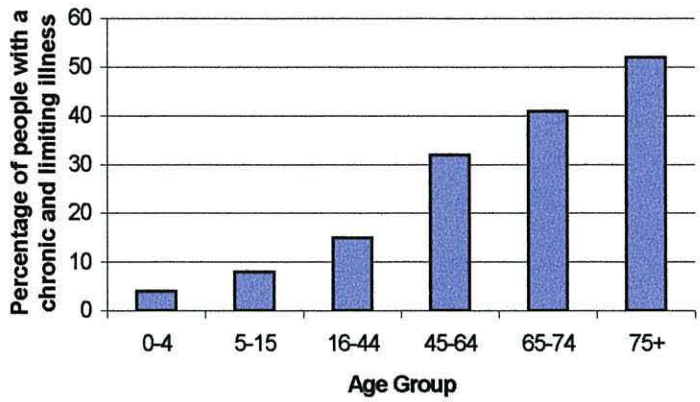

Figure 2.1. Chronic and limiting illness by age group (1996 General Household Survey [65]).

In order to distinguish between the healthy years of life and those marked by illness and disability, active life-expectancy is used. This is defined as the average number of years a person is likely to remain in an active or non-disabled state without significant long-standing illness. For example, it is estimated that a 65-year-old man has an average of eight further years of active life followed by six years of significant disability, and a woman ten years and nine years, respectively [66].

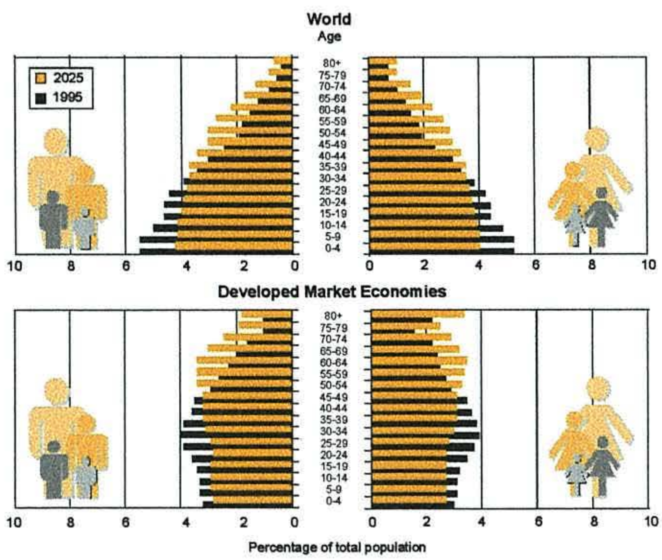

Figure 2.2. Population 'pyramids' for world and developed market economies in 1995 and 2025.

This global increase in life expectancy has been matched with a decrease in global fertility rates. The combined effect of which is a gradual ageing of the global population. The population 'pyramid' of Figure 2.2 [67] shows the percentages of population by age and gender for the entire world (top) and for developed market economies in isolation (bottom). The ageing global population manifests itself as a reduction in the base of the pyramid, with the mass of the population re-distributed throughout the upper levels. In the developed market economies, the effect is a vertical shift in the population age distribution.

The projected numbers of people aged 60 years and over in the UK during the period 1996-2026 is shown in Figure 2.3. During this period, the number of children under 14 years of age is projected to fall by approximately three quarters of a million (9%). During the same period, there is a projected increase of more than 2 million (30%) in the number of people aged 65.

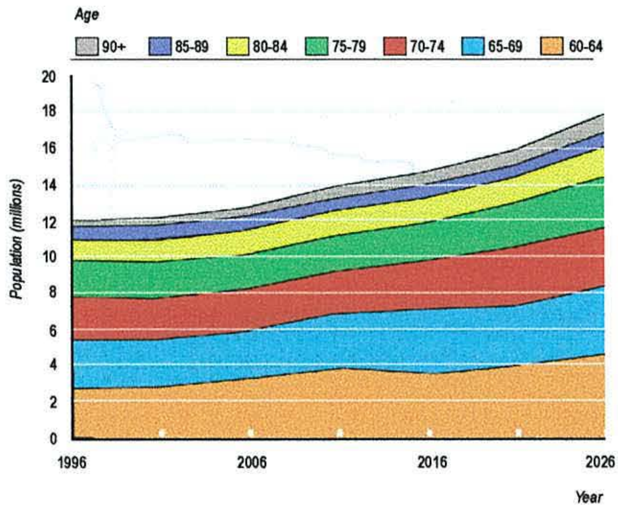

Figure 2.3. Projected numbers of people aged 60 years and over in the UK, 1996-2026 [68].

In 1996, 31% of the UK population were aged 50 and over and almost 16% were aged 65 and over. By 2026, 41% of the population will be aged 50 and over and 21% will be over pensionable age. Perhaps of greater significance, the 'old elderly' population, those aged over 75 years, is also increasing rapidly. For instance, the numbers aged over 80 are expected to rise by 85% between 1995 and 2040, although most of this increase is not expected until after 2020. Over the same period, this age group is also expected to increase as a proportion of total population from 1 in 25 being aged 80 or more in 1995, to 1 in 13 by 2040 [69].

2.1.2 The Epidemiological Shift towards Non-communicable & Chronic Disease

Figure 2.4 is based on data from the 1995 General Household Survey (GHS) and shows the range and distribution of chronic illness amongst the elderly in the UK [70]. According to the World Health Organisations' Health Report for 1999, non-communicable diseases are expected to account for an increasing share of disease burden, rising from 43% in 1998 to 73% by 2020 [64]. This steep epidemiological transition is largely driven by population ageing and compounded by the number of people who are exposed to what are now recognised as high-risk factors such as: obesity, physical inactivity, poor diet and high-stress. Non-communicable diseases generally have chronic long-term implications for an individual (and for society in general). These include a decline in functional capabilities which in the case of an elderly or disabled individual may impact on their ability to undertake the basic activities of daily living and therefore on their ability to remain independent.

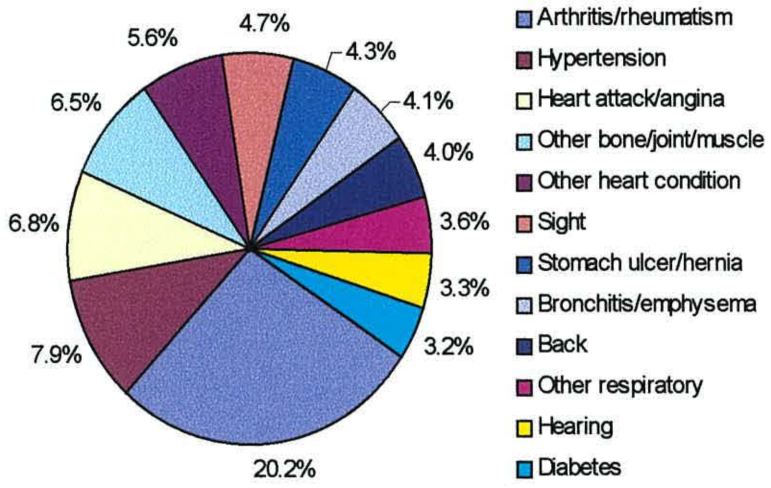

Figure 2.4. The most common longstanding chronic conditions reported by people over 60.

The World Health Organisation (WHO) uses the Disability-Adjusted Life Year (DALY) to assess the overall impact of a disease on society. One DALY represents one lost year of healthy life and takes into account the effects of premature mortality and the impact of any resulting disability. A DALY is calculated based on the age at which a disease or disability is acquired, the length of time for which the effects are present and the impact on the quality of life of the individual. It effectively acts as an indication of the total burden that a particular disease presents to society. In 1998, approximately 48% of all DALYs throughout the world were attributable to non-communicable disease. High-income countries are particularly susceptible with 81% of DALYs caused by non-communicable disease.

If the DALY for any given population is subtracted from the life expectancy for that population, the result is the Disability Adjusted Life Expectancy (DALE) for that population. The DALE for the world population for babies born in 1999 varies between 74.5 for Japan and 25.9 for Sierra Leone. The United Kingdom has an overall DALE of 71.7 and is ranked 14th in the world [71].

Appendix A discusses the specific health concerns of the elderly in greater detail.

2.2 The Increasing Cost of Quality Healthcare

The previous sections and the material in Appendix A highlight a number of reasons for the escalating costs associated with a modern healthcare system, see for instance Table 2.2 [72]. The two largest areas of expenditure for the NHS are labour (approximately two-thirds of total expenditure) and medicines (approximately £4 billion annually). The UK currently spends some 6.8% of GDP on healthcare compared with 10.7% for Germany and 9.6% for France and is significantly lower than the European Union (EU) average of approximately 8.6%, although the method of calculation may not be consistent in each member state [73]. It is government policy to increase the level of GDP spent on healthcare toward a European norm (8%) by 2006 [74]. During 1998-99, the total annual spend on the NHS was

£49 billion or £790 per head of population [75], this corresponds to approximately 17% of the total public expenditure in that period. The 2000 budget promised the longest sustained growth in investment in the NHS' history with the annual spend rising to £54.2 billion in 2001, £58.6 billion in 2002 and £68.7 billion in April 2003 [74].

Table 2.2. Costs associated with various chronic disease.

Disease	Prevalence in UK	Annual Cost of Care (£ Billions)	£ spent per sufferer per year on research
Alzheimer's	527,000	11	11
Heart Disease	2,053,000	4.05	28
Stroke	124,000	3.2	79
Cancer	655,000	1.6	289

Eighty two and a half percent of the NHS's funding comes from taxation. However, the population of the UK has, in the main, been reluctant to elect into government political parties that have advocated increases in direct taxation even for use on public services such as health. This creates a problem, both in terms of the availability of resources and the quality of service, for a public funded health service that is based on need rather than the ability to pay (refer back to Figure 1.1).

The Cost of Formal & Informal Care

Whereas currently around 1 person in 6 is aged at least 65, by 2020 this is expected to be 1 in 5, reaching 1 in 4 by 2030 [69]. This has serious implications for the provision of healthcare in the UK as this age group consumes a disproportionate amount of the total healthcare budget, as shown in Figure 2.5 [76]. This heavy consumption of healthcare resources is due in part to the nature of the chronic illnesses discussed previously. For example, results from the 1996 General Household Survey reported that 22% of people aged 75 and over had consulted with a GP in the previous 2 weeks and that 27% reported a home consultation in that same period [65]. This compares with 17% and 6% respectively for the 45-54 year age group.

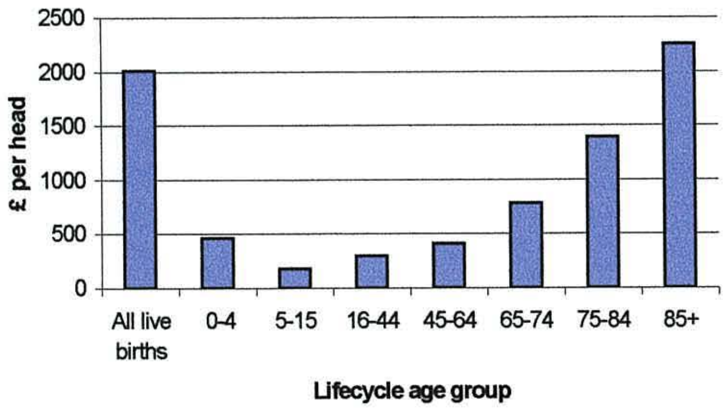

Figure 2.5. Estimated costs for hospital and community health services per head, 1997-98.

Perhaps more alarmingly, there are serious implications emerging for the caring capacity of the Nation's informal care networks, namely care provided in the community by friends and family. Britain has in the region of 6 million informal carers, with one carer in every six households, nearly 2 million of whom are caring for someone in the same household [77]. It is likely that the current capacity for informal care will not be sustainable due to an increase in the dependency ratio, defined as the ratio of people aged 65 and over (the cared-for) to those between 16-64 (the carers), as shown in Table 2.3 [78]. In fact, the 1998 World Health Report suggests that the proportion of elderly people requiring support from adults of working age will increase from 12.3% in 1995 to 17.2% in 2025 [79]. Additionally, because over half (58%) of informal carers are female, the effect of a greater number of women taking up both part-time and full-time employment may also have a significant effect on the numbers of informal carers.

Table 2.3. UK population distribution by age groups [78].

	1997	2007	2017	2027
Population ('000s)	57,062	58,110	58,869	59,616
Percentage aged:				
0 - 4	7.0	6.1	6.2	6.3
5 - 15	14.3	14.8	13.2	13.6
16 - 64	63.0	63.5	63.1	60.9
65 - 74	8.4	8.1	10.0	10.3
75 +	7.3	7.5	7.5	8.9
Dependency ratio (%)	**25.0**	**24.6**	**27.8**	**31.6**

Any drop in the number of informal carers in the community due to the ageing population or to changes in the patterns of society[2] will have to be offset by formal care provision. It is estimated that 16 million people in the UK subsidise care services by *voluntarily* providing the equivalent of 1.7 million full-time carers[3] [80]. When one considers the cost of care provided for free by the voluntary sector and the estimated 6 million informal carers in the UK, any significant drop in this provision will have a serious cost implication for the health and social services. It will also have a serious impact on resources, as the required number of formal carers may not be available to cover this shortfall in informal care.

Cost of Prescriptions

One of the consequences of an increase in chronic disease is an increase in the demand for suitable therapy. This is often provided in the form of medication, which is often dispensed without charge. For instance, over 510 million prescriptions were dispensed in England during 1998 with a net ingredient cost (NIC) of £4.7 Billion [81]. Of these, 85% were prescribed free of charge. This contrasts with an average NIC of only £1.9 billion in 1988 - an average increase of approximately 9.7% per annum.

Older people are by far the biggest consumers of drugs as the multiple pathologies that affect them increase the number of medications prescribed, resulting in polypharmacy. Figure 2.6 illustrates an average of 23.2 prescriptions per head of population for the elderly, compared with 9.4 for all ages (dispensed in the community only). Thus, an increasing elderly population will result in increasing numbers of prescriptions and hence a corresponding increase in the NIC.

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[2] *such as an increase in the number of single-parent families, the need to relocate in order to find a job, an increase in the number of women in full-time work or in the number of people living alone.*
[3] *with an associated cost-saving - UNISON estimates that the average pay of in-house home care staff to be £5.24 per hour.*

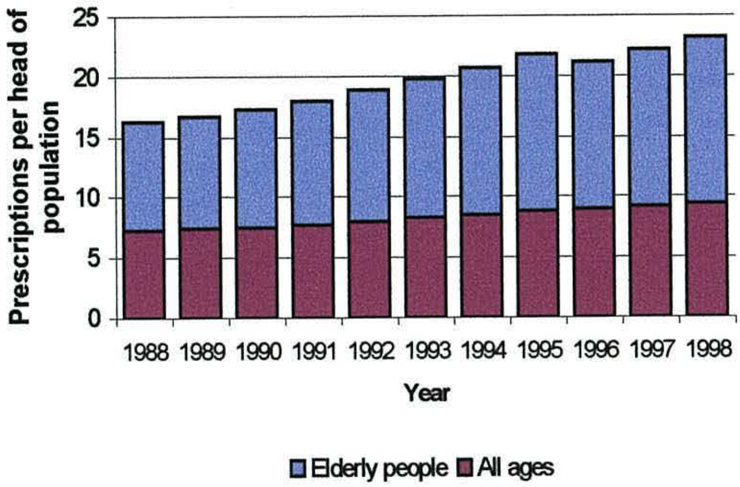

Figure 2.6. Number of prescriptions per head of population dispensed in the community by broad age group, 1998-1999[4] [81].

Unfortunately, the proliferation of polypharmacy in the elderly population often leads to prescription errors including: inappropriate doses, duplication, and harmful interactions. Furthermore, the elderly are well-known for their ability to stockpile medication, this is in part due to the common practice of unchecked repeat prescriptions. In [82] it was reported that:

- 60% of prescriptions to the elderly had been given for more than 2 years;
- 30% for greater than 5 years; and
- 16% for greater than 10 years.

Of these, 88% were repeat prescriptions and 40% had not been discussed with a doctor for 6 months. This problem is compounded by the fact that compliance within the elderly is generally poor in approximately a third of all cases due to poor motivation or understanding, practical problems with taking the drugs or a deliberate policy of non-compliance [82].

Long-Term Care of the Elderly

In 1997, the government ordered a Royal Commission into the funding of long-term care of the elderly. The commission reported to Government in March 1999 with several recommendations [83] on funding, help for carers and the provision of services, although it was split between a majority and a minority view. One recommendation concerned the costs of long term care, which it argued should be split between living costs, housing costs and personal care, with personal care being available after assessment, according to need, and paid for from general taxation. The rest should be subject to a co-payment according to means. Table 2.4 shows the estimated expenditure on long-term care services in the UK with associated sources of funding.

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[4] *For this graph, "elderly people" includes men aged 65 years and over and women aged 60 and over for data from 1988 to 1994 and men and women aged over 60 from 1995 onwards.*

Table 2.4. Estimated UK expenditure on long-term care services, 1995 [83].

Type of expenditure	NHS £M	Personal Social Services (net) £M	Private £M	Total £M
Home care	-	970	75	1,045
Community nurse	675	-	-	675
Day care	125	235	20	380
Private domestic	-	-	210	210
Meals	-	95	105	200
Chiropody	145	-	70	215
Total	**945**	**1,300**	**480**	**2,725**
Residential care homes	-	1,910	1,230	4,140
Nursing homes	195	1,300	1,280	2,755
Long-stay hospital	1,425	-	-	1,425
Total	**1,620**	**3,210**	**2,510**	**8,340**
Total	**2,565**	**4,510**	**3,985**	**11,065**

NHS expenditure on long-term services, which accounts for 36% of the total public expenditure, includes in-patient care for an estimated 34,000 long-stay[5] elderly patients, nursing home care for an estimated 11,000 NHS funded residents, community nursing services, hospital day care and chiropody [83]. Social care in the UK is currently means-tested as opposed to the NHS provision where care is free at the point of delivery. In 1996, almost half of local authority personal social services expenditure for England (£4.07 billion) was on services for the elderly [84]. The bulk of social services expenditure is on publicly funded residents of care homes in the UK.

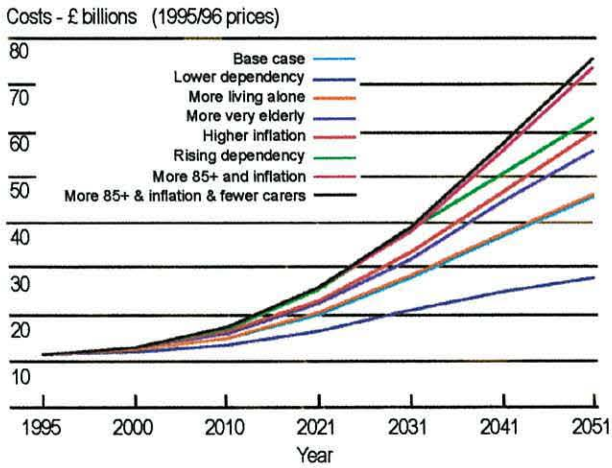

Figure 2.7. The 'funnel of doubt' - a sensitivity analysis showing the possible deviations in costs from the base case of the Royal Commission [83].

The Royal Commissions' base case[6] projects that the cost of long-term formal care for older people (paid for by both individuals and the state) could rise from £11.1bn (1.6% of GDP) in 1995 to £14.7 billion (1.5% GDP) in 2010 and £45.3 billion (1.9% of GDP) in 2051 [83]. The sensitivity analysis that accompanies these calculations is summarised in Figure 2.7. The boundaries of future costs of long-term care are defined by two extremes - the lowest costs are indicated in the bottom plot, which shows

[5] *long-stay has been defined as stays of more than 55 days [83]*

[6] *The details of which are described in section 2.43 of the Royal Commissions' Report "With Respect to Old Age"*

what would happen if health expectancy improved, i.e. if older people were less dependent in future. The highest costs are incurred if there were more people aged 85 and over than expected, if costs grew faster than assumed in the base case, and there were fewer carers. Irrespective of which plot is correct, the costs associated with long-term care of the elderly will increase.

There has been some criticism of the majority view of the Royal Commission with some observers being worried about funding implications if the provision of free care led to increased public expectations and an erosion of informal care. The UK Government indicated that it is likely to adopt the majority of the recommendations made by the Royal Commission, although it has rejected the main recommendation that the State should pay the cost of both personal and nursing care. Instead the UK Government only proposes to pay for nursing care in a nursing home (except Scotland).

2.3 The Re-Engineering of the Healthcare System

The process of healthcare delivery in the UK is undergoing one of the most radical changes in its history. This is attributable to a number of factors, not least those issues of resources and funding discussed earlier. The increasing demand on care services is compounded by a fragmented service, with little or ineffective cooperation between individual care providing bodies. This lack of communication and procedure is most apparent when the care must be provided rapidly and at short notice within a community setting. This is often the case with older people suffering from long-term ailments or disabilities and who prefer to lead active and independent lifestyles in their own home. Often, an elderly individual's care needs are passed between the NHS and social services, with neither organisation taking the lead role, and hence the necessary action to meet the needs of the client. For example, on one particular day in the NHS, five and a half thousand patients aged 75 and over were ready to be discharged from hospital but had to be retained in an acute hospital bed because of a lack of support services [6].

It is therefore essential to remove the artificial boundaries between 'medical' and 'social' care and to encourage a more integrated approach. Part of the solution lies in developing a more client focussed healthcare system, with an increasing number of services being offered in a community rather than an institutional setting by a multi-disciplinary team of care workers with access to pooled budgets. It is envisaged that information and communication technologies (ICT) will be able to play a crucial role in enabling this more integrated and cooperative approach.

2.3.1 Community & Domiciliary Care

In response to the changing needs of the population and the increasing demands on the care services, recent government policy has had as a common theme a gradual shift towards a community-based care strategy. These policy objectives (refer to Table 2.5) are important because they represent high-level requirements for primary care and hence have a fundamental bearing on the requirements of any proposed telecare system. Telecare involves the further diffusion of care services within the community towards the client by extending into the home environment itself. The points listed in Table 2.5 help place the concepts developed in this thesis within the wider context of the 'New NHS'.

Table 2.5. Key points from relevant government policy documents.

Policy Document	Key points
"Caring for People – Community Care in the next decade and beyond" (1989 / 1990)	Community care should : • Respond flexibly and sensitively to the needs of individuals and their carers • Allow a range of options for consumers • Intervene no more than is necessary to foster independence • Concentrate on those with greatest needs • Promote the development of domiciliary, day and respite services to enable people to live in their own homes wherever feasible and sensible • Ensure that service providers make practical support for carers a high priority • Make proper assessment of need and good case management the cornerstone of high quality care (packages of care should be designed in line with individual needs and preferences)
"The New NHS, Modern, Dependable" (1997) & "Information for health - an information strategy for the modern NHS 1998 – 2005 a national strategy for local implementation" (1998)	There should be lifelong electronic health records for every person in the country There should be 24-hour on-line access to patient records and information about best clinical practice for all NHS clinicians There is need for seamless care for patients through GP's, hospitals and community services sharing information across the NHS information highway Enable fast and convenient public access to information and care through on-line information services and telemedicine Easier access to health advice and information through NHS Direct, a 24 hour telephone advice line.
"Modernising Social Services – Promoting independence, improving protection, raising standards" (1998)	Care should be provided in a way that supports independence and respects dignity. Services should meet each individual's specific needs, pulling together social services, health, housing, education or any others as needed. People should have a say in what services they get and how they are delivered. Enable adults assessed as needing social care support to live as safe, full and as normal a life as possible, in their own home wherever feasible. Work with the NHS, users, carers and other agencies to avoid unnecessary admission to hospital, and an appropriate placement on leaving hospital; and to maximise the health status and thus independence of those they support. Enable informal carers to care or continue to care for as long as they and the client wish. Identify individuals with social care needs who are eligible for public support, to assess those needs accurately and consistently, and to review care packages as necessary to ensure that they continue to be appropriate and effective. Maximise the benefit to service users for the resources available, and to demonstrate the effectiveness and value for money of the care and support provided, and allow for choice and different responses for different needs and circumstances.
"The NHS Plan – A plan for investment, a plan for reform" (2001)	The front-line in healthcare is the home. By 2004 NHS Direct will be a one-stop gateway for out-of-hours healthcare, passing on calls, where necessary, to the appropriate GP co-operative. It will provide information via digital TV as well as from touch-screen information points in public areas. Care Direct will provide faster access to care, advice and support for the elderly. NHS and local social services should support older people, encouraging independence rather than institutional care, and providing reliable, high-quality on-going support at home. Every patient must have a discharge plan including an assessment of their care needs. It is the intention to introduce a single assessment process for health and social care Health and Social services need to recognise the specific needs of older people, demonstrating proper respect for the autonomy, dignity and privacy of the elderly. Smart cards, allowing easier access to health records, will be provided for patients when the necessary infrastructure has been put in place. Changes in primary care will help ease the pressure on hospitals so that they can concentrate on providing specialist care. Care Trusts will be able to commission and deliver primary and community healthcare as well as social care. There will be integrated home-care teams so that people receive the care they need when they are discharged from hospital to help them live independently at home.

"The NHS Plan – A plan for investment, a plan for reform" (2001) cont...	Rapid response and Hospital at Home teams made up of nurses, care workers, social worker, therapists and GP's will provide support care for people at home, helping to prevent any unnecessary hospital admissions. There will be a new level of intermediate care to promote the independence and improve the quality of care of older people. Step-down care facilities will provide a short-term solution for individuals who do not require hospital care but may not be quite well enough to return home. By 2004 all parts of the country will have intermediate care services. In future, social services will be delivered in new settings, such as GP surgeries, and social care staff will work alongside GPs and other primary and community health teams as part of a single local care network. There will be pooled budgets, lead commissioning (i.e. either the local authority or the health authority/primary care group will take the lead in commissioning care services on behalf of both bodies), and integrated care provision (the merging of services to deliver a one-stop package of care) There will be easy access to up-to-date and accurate information on patient's medical histories. Tests, patient referrals, and appointment booking will be available using Information and Communication Technologies. All GP practices will be connected to NHSNet by 2002, giving patients improved diagnosis, information and referral. Electronic prescribing of medicines by 2004 giving patients faster and safer prescribing as well as easier access to repeat prescriptions. Electronic patient records – to which patients hold a key – will enable nurses, therapists and doctors to maintain continuity of care and knowledge of their patients. Up to 1000 GP specialists will be taking referrals from fellow GP's by 2004

Community care was defined in the 1989 White paper "Caring for People" [85] as follows:

> *"Community care means providing the services and support which people who are affected by problems of ageing, mental illness, mental handicap or physical or sensory disability need to be able to live as* ***independently as possible in their own homes, or in 'homely' settings in the community.*** *"*

It is interesting to note that Sir William Beveridge's 1942 report [86] recommended that the aim of any National Health Service would be to ensure "*... that the best that science can do is available for the treatment of every citizen* ***at home*** *and in institutions, irrespective of his personal means.*" The Secretary of State for Health offered a similar opinion in the NHS' Information Strategy of 1998 [17]:

> *"It* [the strategy] *is designed to ensure that the NHS provides a* ***universal, prompt, high quality service*** *which is* ***as close to people's homes as can be achieved safely*** *with current and developing levels of expertise and equipment. Clearly* ***information technology has a crucial role to play.*** *"*

The 1997 white paper "The New NHS, Modern, Dependable" described a 10-year plan to re-establish the NHS as a universal, high quality service which would provide care as close as it is safe to do so to people's homes [5]. The legislation necessary to bring forth the implementation of many of the key themes introduced in the white paper was introduced in the Health Act of 1999 [88]. The white paper introduced Primary Care Groups (PCG's), which bring together the delivery of both primary and community health services under a unified budget in order to improve the delivery of healthcare services to communities of around 100,000 people.

PCG's are run by a multidisciplinary group of GP's and other health professionals (and including one lay-person) and are responsible for commissioning local services and which now control over 2/3 of local NHS budgets, replacing the role of health authorities. Most Primary Care Groups aim to become

Primary Care Trusts by April 2002, in order to achieve more autonomy and provide greater integration of primary and community services.

More recently, "The NHS Plan" (and associated legislation in The Health and Social Care Bill of 2000 [89]) provided further detail regarding the plan to re-engineer the healthcare system into a more modern, efficient and patient-centred enterprise. Its scope is large, but it does make specific policy statements concerning the future provision of primary and community based healthcare as well as social care in the UK (refer again to Table 2.5). The NHS Plan states that "*....the frontline in healthcare is the home*", and goes on to outline a number of changes which aim to support healthcare in the home and to help people remain at home for as long as possible. One of the pivotal services for this is NHS Direct, the 24-hour "*....one-stop gateway to healthcare*", available using the telephone and Internet. What's more, a newer service 'Care Direct' is available to provide information and advice specifically for elderly individuals.

There are many compelling arguments to support the diffusion of care into the home environment including social, logistical, economical, and medical reasons, a brief discussion of which follows.

Social Reasons & Personal Preference

Current social thinking supports an integrated and inclusive society that enables elderly individuals to fully participate within their communities, empowering them to retain their independence for as long as it is practicably possible. 1999 was the United Nation's *International Year of Older Persons*, the aim of which was to promote the United Nation's Principles on active ageing [90]. Two of these aims were that older persons should be able to reside at home for as long as possible and live in environments that are safe and adaptable to personal preferences and changing capacities.

Many forms of home exist other than the traditional private house and a brief description of the more popular options are provided in Table 2.6 (overleaf). The vast majority (over 75%) of the elderly population live in private dispersed housing in the community with the remainder living in some form of sheltered, residential or nursing home [65]. Of those in private housing, 39% live on their own, 48% live with their partner and 13% live with other people such as their children or siblings [65].

Evidence presented to the Royal Commission made it abundantly clear that the elderly value their independence highly and would generally prefer to remain in their own homes for as long as possible, a view that is also confirmed by other workers [91, 92]. A survey commissioned as part of the Age Concern's Debate of the Age [93] found 82% of respondents indicating that they would prefer to remain in their own homes even if they were unable to manage tasks of daily living without help.

Table 2.6. Types of home for the elderly.

Type of home	Description
Dispersed	A traditional house/flat in the community. The level of care provided ranges from none to intensive home support schemes for people with dementia or who are undergoing a lengthy period of rehabilitation. Care must be delivered to the home unless provided by a spouse/living partner as in the case of co-resident care.
Residential	These are for people who find it difficult to cope alone and need help with activities of daily living (e.g. washing, dressing, and going to the toilet). Although residential homes provide some help for residents who fall ill, they cannot usually give long-term, full-time nursing care. Local authorities provide residential accommodation for elderly or disabled people; they can also arrange for people to go into homes run by the voluntary or private sectors.
Nursing	Typically for people who require more intense medical-type care from qualified nurses 24 hours a day and who can no longer be cared for effectively in the community by primary healthcare teams or in a residential home staffed by non-nursing care staff. There are some health authority nursing homes, but most are run privately, with a small number of homes run by voluntary organisations.
Dual – registered	These homes offer both nursing and residential care: such an option may be considered if it is anticipated that the condition of a client may deteriorate in the future. The client will not then have to go through the trauma of moving if their care needs subsequently change (although it will probably mean paying more if nursing care is required). Such homes will be registered with both the local authority and the health authority.
Sheltered	Offers a compromise between independence and the need for appropriate levels of on-site care. Sheltered housing comprises of grouped dwellings, either individual bungalows or flats situated within a single building with a communal area, guest rooms and laundry facilities. The advantage of sheltered housing is that the client retains their independence as each individual self-contained flat has its own front door and locks. On-site support is provided by a warden who typically lives locally within the scheme. The warden is available to help the tenants as required, although this service is usually only available during office hours. An intercom system is usually available for clients to request help from the warden in the event of an emergency or if help is required. Calls are diverted to a community alarm control centre if the warden is off-duty.
Very sheltered/ Extra-care	A relatively new concept based on standard sheltered housing but care staff are available 24 hours a day, and there are more of them. Such schemes are suitable for clients with higher care needs and typically have more communal and specialist facilities and also some provide meals.
Retirement/ Continuing care communities	New to the UK with a small handful of trial sites, but are much more common in Australia and the USA. They are essentially small purpose-built towns with different types of housing collected together each with varying degrees of support. In addition, residential homes, nursing homes and even sometimes hospitals are also present.

Economical & Logistical Reasons

There are very real economic incentives for a growth in home-based care services. The use of home-based services and assistive technologies help increase and enhance an individual's capacity and level of independence. This in turn reduces the level of formal and informal care required which helps to reduce the burden of cost. In addition, changes in clinical treatments as well as the introduction of techniques such as keyhole surgery have facilitated faster patient recovery which has allowed patients to be discharged sooner and be cared for by community-based services as illustrated by Figure 2.8.

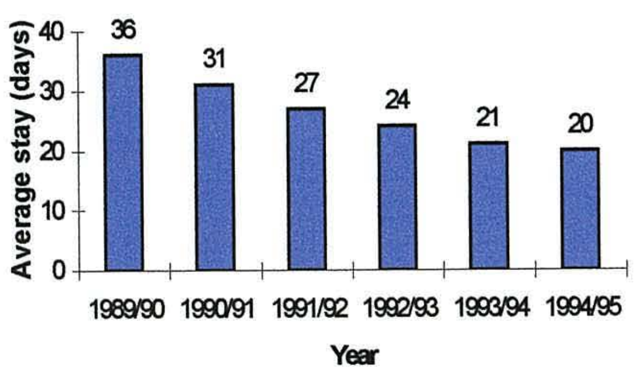

Figure 2.8. Average length of stay in geriatric wards.

This approach has resulted in a marked decrease in the number of geriatric beds available for elderly patients and is a major contributory factor towards the problem of 'bed-blockers', an unfortunate term, which describes the inappropriate occupancy of hospital beds, often by the elderly. Typically, 'bed-blockers' do not require further hospital care but are unable to return to the community due to a lack of community-based support. Delays in discharging such individuals prevent the admission of new patients in greater need of acute hospital services. NHS data show that each day, delayed discharge affects nearly 6,000 patients over the age of 75 (12% to 13% of all older patients in hospital) resulting in the loss of nearly 2.2 million bed days each year and costing trusts about £1 million a day [7] as shown in Figure 2.9.

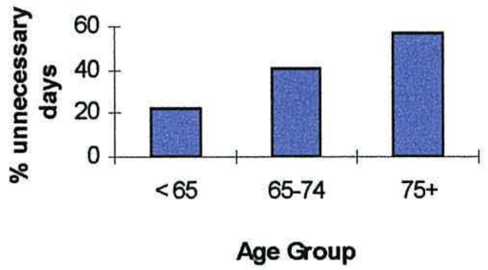

Figure 2.9. Inappropriate length of stay in two acute hospitals.

Delays in the discharge process are often caused by the complex discharge requirements of many elderly individuals in need of continuing care. These delays can prove expensive as the cost of providing care for people in an institutional setting is high compared to the alternatives. For instance, the cost of a geriatric care bed in a long-stay hospital in the UK during 1995/96 was approximately £800 per week [94]. If this is compared with a community-based solution, as set out in Table 2.7, then it is clear that significant cost savings are possible [83].

Table 2.7. A comparative cost analysis of care using 1995/96 prices[7].

Location	Cost/hour	Cost/week	Cost/year	Cost over average length of stay
Home (14 hours help per week)	£8.50	£119	£6,188	5 years @ £30,940
Residential home	-	£247	£12,844	3 years @ £38,532
Nursing home	-	£337	£17,524	18 months @ £26,286
Geriatric ward	-	£800	£41,600	40 days[8] @ £32,000

The number of people in all forms of residential care, including independent nursing homes and residential homes, local authority residential homes and NHS long-stay facilities, has dropped from a peak of 512,000 in 1995 to 487,000 in April 1998. In 1999 there were approximately 29,434 care homes of all varieties in the UK offering 609,146 places. In addition, there are approximately 500,000 people in sheltered housing accommodation [95].

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[7] *A survey of UK care homes undertaken by Laing & Buisson in March 1998 calculated the average fees for elderly residents in nursing homes at £352 per week and £252 per week for residential care homes.*

[8] *1994/95 average length of stay for people between 65-74 years of age – see figure 2.9.*

It is abundantly clear that there are therefore an insufficient number of beds available and, with the number of places continuing to fall due to financial hardships experienced by care home owners, the NHS will have to cope with increasing numbers of frail elderly individuals. This situation will deteriorate further as the population ages, further increasing the demand for hospital beds.

In conclusion, if it is safe and appropriate for an individual to return home, then this option is by far the most desirable and cost-effective. A comparison of the costs involved show that there is, in principle, a sufficient margin between home care and residential care (say), that allows a budget for telecare technologies to be installed in the homes of individuals, while still offering an overall cost saving[9]. Brownsell et. al. discuss the use of telecare in relation to the potential savings that might be possible as an alternative to admission into institutional care settings [96].

Medical Reasons

Some illnesses are better suited to treatment at home; for example Hospital at Home (HAH) schemes enable often acutely ill patients to receive medical therapy or support within their own home. A HAH scheme may be considered as appropriate for individuals who require long-term palliative care (e.g. dialysis, ventilation) or terminal care (e.g. cancer). Alternatively, it may be viewed as a means of freeing hospital resources (e.g. beds) by facilitating the early discharge of individuals who are capable of returning home, if a suitable level of support is made available. Conditions that may be considered for HAH include: cancer, myocardial infarction, stroke, minor surgical procedures, orthopaedics, paediatric and terminal care.

For some treatments, it has been shown that recovery can be more rapid in a domestic environment than in an institutional one, for instance stroke patients [97]. Furthermore, the home-monitoring of physiological parameters may yield more accurate readings to those performed in a clinical environment due to the 'white-coat' effect. For example, the effects of 'white-coat' hypertension are well known and may be responsible for as much as 10-20% of people diagnosed as hypertensive in a clinical setting. The use of ambulatory blood pressure monitoring (ABPM) has successfully been used as an alternative data gathering technique [98].

In addition to the problem of patient-throughput in the hospital system, there is also a problem with the management of nosocomial infections (those acquired during the stay in hospital). These are often caused by cross-contamination and are aided by the reduced resistance of individual patients as well as by antibiotic-resistant strains of bacteria found within hospitals (the so-called super bugs). Approximately 9% of inpatients acquire some form of infection that was not present at the time of admission whilst staying in the hospital (100,000 infections a year) [99]. Effects vary from discomfort for the patient to prolonged or permanent disability and a small proportion of patient deaths each year are primarily attributable to hospital-acquired infections. The costs of treating hospital acquired

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[9] *The difference in the annual cost is £6656. Most telecare installations are unlikely to cost anywhere near this amount. Furthermore, it is impossible to cost the value of an improvement in the quality of life for the client.*

infection, including the subsequent extended length of stay, are difficult to measure with certainty, but may be as much as £1 billion each year[10]. Plans suggested to combat such infections involve minimising the amount of time for which a patient is required to be present in the hospital. Schemes under consideration include: pre-admission monitoring for operations with same-day admission and post-operative ambulatory monitoring to monitor progress and to help identify infections [100].

2.3.2 The New NHS - An Integrated Client Focussed Approach to Care

In order to better manage the limited resources made available to the health services, a strategy of modernisation centred on the widespread adoption of telematics has been adopted. NHSNet is the private NHS intranet providing connectivity between the various healthcare organisations within the NHS [101]. In the first instance it has been used primarily for managerial purposes but increasingly will be used for the transfer of clinical information such as laboratory test results from hospitals to GP surgeries and the transfer of medical images from one site to another (telemedicine). The adoption of such an information-enabled approach to healthcare has many implications for how and where care is delivered within an integrated care service. There is great potential for improvements in resource allocation leading to an improvement in the efficiency of healthcare delivery.

Primary care services of the immediate future will be based around NHS Direct and Care Direct which will provide a convenient point of entry into the healthcare system. Fully trained nurses will provide advice on a range of health-related issues and will essentially perform tele-triage in order to ascertain the best course of action. The increasing use of electronic medical records will enable timely information sharing to occur and will result in clinicians being able to use their time more efficiently instead of spending approximately one-quarter of their time managing information [102]. The other key advantage is that it provides the infrastructure to support the storage of information from automated healthcare monitoring, where data is made available in an electronic form at source. It also provides the information infrastructure (infostructure) to enable an enterprise-wide information system, with a suitable gateway into the primary care network from any proposed community-based telecare system. In particular, the DGH, the primary carers, such as GP's and community nurses, and the social services need to be able to share relevant information in order to meet the holistic (i.e. medical and social) care needs of the public.

The Information Strategy [17] acknowledges that telehealth services, in the form of telemedicine and telecare will come to the fore as a means of providing services in the future. Telemedicine will be employed in a clinical setting to provide remote services within the NHS via the NHSNet. Telecare will be employed at the front-line of primary care to provide remote services within the community, supported by the primary care team. However, the strategy does not elaborate on any of the actual care services which telecare might actually provide.

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[10] *Not all hospital-acquired infection is preventable: the very old, the very young, those undergoing invasive procedures and those with suppressed immune systems are particularly susceptible.*

In order for telecare to provide an integrated service, its infrastructure will have to distribute information between the care personnel making up the multi-disciplinary care team. Many of these carers will be community-based rather than in hospitals and some will not be NHS employees. Therefore, it seems logical to extend the capabilities of NHSNet into the community in some fashion in order to support front-line care and to ensure a truly integrated service.

Telecare has potential within the community to allow the primary care team to better organise their efforts, filter demands on their resources, and prioritise their responses according to need. Individuals will benefit from being able to remain in their homes for longer, with the added benefit of an appropriate amount of tele-assisted care to supplement their more traditional care services.

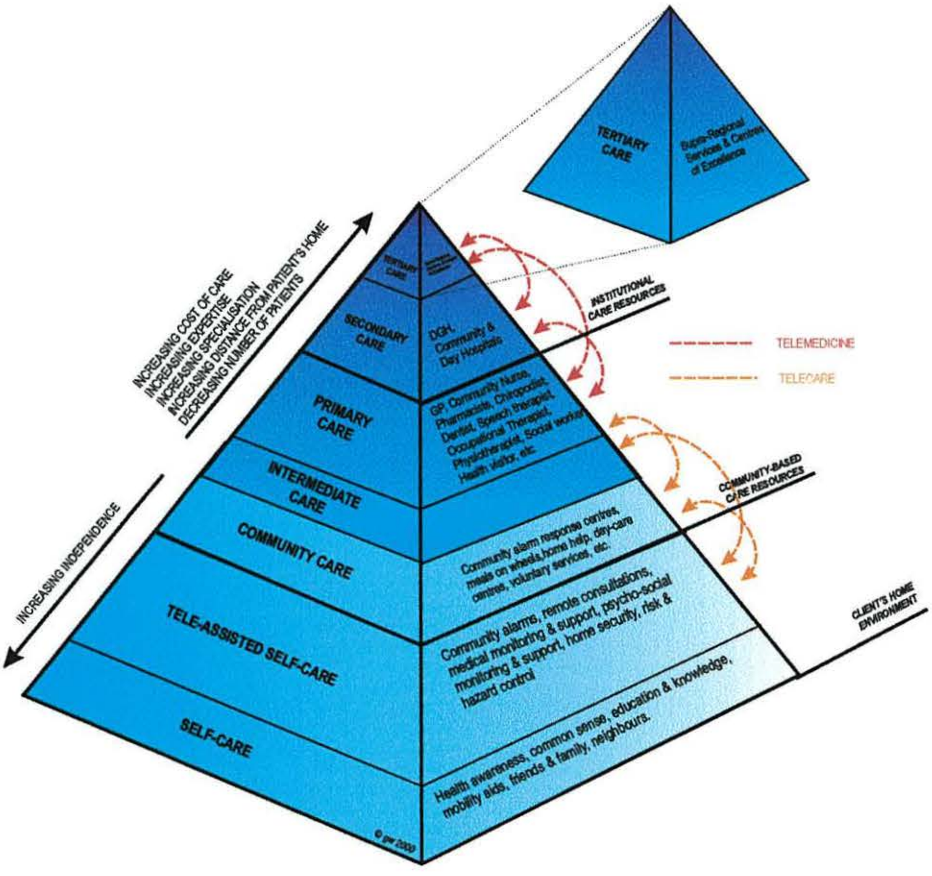

Figure 2.10. The new healthcare pyramid of the 21st century?

Thus, the traditional 'pyramid of care' that extends from the community to tertiary care may in future resemble Figure 2.10 with self-care and tele-assisted care as service levels in their own right.

2.4 Telecare Stakeholder Identification

There are a number of stakeholders associated with telecare, including: the people who are to receive and provide telecare services, those who pay for telecare, those commissioning telecare, those responsible for the development of standards and regulations pertaining to telecare and those responsible for creating the relevant healthcare policies for primary & community care. The viewpoints of several of the key stakeholder groups will now be considered.

2.4.1 Clients

Clients of next-generation telecare are the recipients of care[11]. There are many potential client-groups that may benefit from some form of telecare, including those listed in Table 2.8. It is apparent from this non-exhaustive list that their needs and requirements are likely to be varied and complex. In addition, it is clear that there will need to be an integrated support network capable of meeting these complex needs. This support network is likely to consist mainly of formal care providers who will also see telecare as a means to modify and improve their own working practices.

Table 2.8. List of potential client-groups for telecare.

Individuals living in rural areas and those who require services that are geographically remote;	Terminally ill individuals receiving palliative care at home;
Drug addicts undergoing a controlled course of treatment in order to control their addiction, e.g. methadone compliance monitoring;	Disabled/handicapped individuals who require assistive technologies in order to provide them with barrier-free housing and improved quality of life;
Individuals with mild forms of dementia who would benefit from some support technologies to help them to compensate for their symptoms and to help manage their everyday lives;	People who need to undergo a needs assessment in order for care service providers to allocate assistive technologies and other care resources to meet their need;
Individuals who are caring for somebody either part-time or full-time who themselves require appropriate levels of support. The health of the carer is very important for the health of the cared-for as well as for themselves;	Individuals affected by a change in personal circumstances that might influence their ability to function independently e.g. bereavement - especially in the case of an elderly individual who has lost his or her spouse (and hence primary informal carer);
Individuals who are temporarily incapacitated and require short-term assistance in order to return home;	Individuals supplied with equipment to speed-up their discharge from institutional care settings;
Individuals suffering from chronic ailments and who would benefit from some form of continuous assessment, e.g. people with: hypertension, asthma, diabetes, epilepsy and AIDS;	People (especially women and children) at risk of violence at home, including police protection schemes;
At-risk individuals, such as women with pregnancy complications (e.g. pre-eclampsia) or elderly individuals who are prone to falling, post-stroke victims, people who live in areas with high levels of crime.	General frail and/or infirm elderly who require re-assurance and risk-management techniques in order to support a continued and independent lifestyle in their own homes;
People with learning disabilities;	Lone workers;

In order to ensure that the client is the primary benefactor of telecare services, a client-centred approach has been used throughout this research in a deliberate attempt at empowering the client by positioning them and not the technology (or the carers) as the focal point of the CarerNet system. In this context, Hoyes *et. al.* [103] have defined the "*Ladder of Empowerment*" a modified version of which is shown in Figure 2.11, which describes the various degrees and levels of empowerment possible within the client-provider relationship. During this research, it has been assumed that client empowerment will reside towards the upper regions of this ladder.

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[11] The term 'client' has been chosen to tie-in with current terminology, and in any case, many of the likely recipients of telecare are unlikely to consider themselves as 'patients', especially when they are receiving care in their own home.

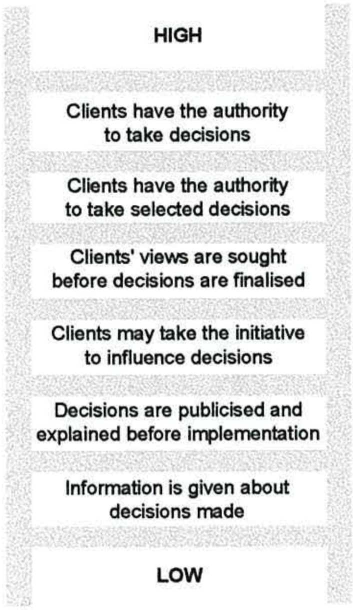

Figure 2.11. Ladder of client empowerment.

Elderly Clients

Arguably the client-group who stand to benefit the most from telecare services are the elderly. In particular those that live in their own home, either by themselves or with an elderly partner. The vast majority of elderly individuals live in private 'dispersed' housing with only approximately 5% living in some form of institutional accommodation such as a residential or nursing home [65]. In addition, about half-a-million live in sheltered accommodation [95].

Of those living in private housing, 39% live on their own, 48% live only with their partner and 13% live with another family member [65]. It is estimated that 365,000 elderly people live in poor housing conditions, occupying some 21% of all households that are classed as requiring essential modernisation [104]. Poor housing leads to a poor living environment caused by damp and by ineffective (and expensive) heating systems made worse through a lack of double-glazing and other means of insulation. Nevertheless, the notion of independence and the wish to remain in one's own home for as long as is practicable cannot be underestimated as one of the prime factors in the perceived quality of life of an individual [83].

However, in the case of the elderly there are often risks associated with this independence caused by an increased susceptibility to ill-health. Increased frailty, susceptibility to harsh environmental conditions, social isolation, monetary and 'fuel' poverty, chronic disease and a lack of appropriate care can contrive to generate potentially hazardous situations that may place the elderly individual at risk and seriously impair their quality of life. Telecare may be seen as a non-intrusive and cost-effective solution to manage some of these risks and to provide general support to elderly individuals who require some help with everyday tasks.

Table 2.9. Health services mostly used by the elderly.

Primary & community care		Secondary Care	Voluntary Sector
General Practitioner	Home help/domestic care	General medical & surgical	Macmillan nurses
Health promotion clinics	Meals on wheels	Oncology services	Community transport
Elderly screening services	Community alarm networks	Geriatric services (e.g. day care)	Lunch clubs
Well woman & man clinics	Laundry service for incontinence sufferers	A & E	Day centres
Cervical cytology	Day centres	Psycho-geriatric & Psychiatric services	Support groups
Community chiropody	Provision of aids for daily living	Orthopaedic services	
Community physiotherapy	Adaptations to the home	Rheumatology	
Community nursing	Services for carers e.g. respite care, night-sitting service, etc.	Rehabilitation (including physio- and occupational therapy)	
Continence adviser	Institutional care, e.g. residential care homes	Ophthalmology	
Community dental service	Counselling	Respite care	
		Hospice	
		Ambulance service	
		Hospital dental service	

Whilst it is apparent that the vast majority of the elderly population are sufficiently healthy to remain in their own homes, they are still prone to suffer from chronic health problems and often suffer from varying degrees of disability and/or impairment. Subsequently, they require specialised attention and rehabilitation and are thus heavy consumers of health services, both in the primary and secondary health sectors as set out in Table 2.9 [105]. The primary objective of rehabilitation is to restore as much as is possible an individual's function (physical or mental) or role (within family or society). Rehabilitation will involve clinical, therapeutic and social interventions and also addresses issues relevant to a person's physical and social environment. Effective rehabilitation needs to be responsive to the needs and wishes of the users.

Other Client Groups

Telecare will also be of benefit to client groups with various disabilities and chronic conditions that affect all ages such as asthma, COPD, diabetes, epilepsy, hypertension and heart irregularities. In addition, other groups may benefit from the temporary provision of telecare such as supporting a pregnancy, especially if suffering from pre-eclampsia; analysing sleeping disorders; managing nocturnal enuresis; or monitoring the effect of newly prescribed medication. Furthermore, the telecare infrastructure may provide a platform for undertaking research into new forms of therapy or as a means of developing and validating new screening and assessment techniques and parameters.

2.4.2 Carers

A multi-disciplinary team of carers serve the needs of the community-based population and provide a mix of informal and formal care as shown in Figure 2.12. Formal care is provided by professional carers from health, social and housing institutions. Informal (or voluntary) care can be provided by a range of people, including the client's husband or wife, children, friends, family and neighbours. In addition, there are a number of voluntary care organisations that provide care-related services.

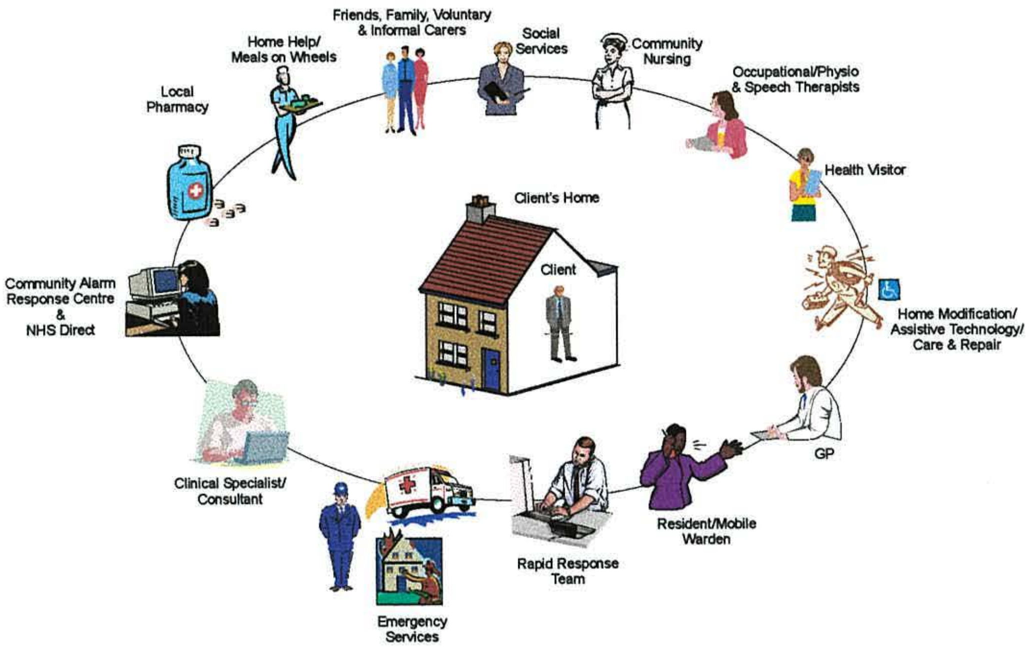

Figure 2.12. A ring of care to support the community.

Formal Carers

The formal carers of most relevance to telecare include those that work in the community, primary and the new intermediate care levels. These typically include the General Practitioner (GP), several classes of specialist nurse, occupational therapists, speech therapists, physiotherapists and health workers, and can also include the wardens of sheltered housing schemes, refer again to Table 2.9. These will increasingly take the form of rapid response teams, made up of nurses, care workers, social workers, therapists, GPs, etc. who will provide acute and on-going care for people at home and help prevent unnecessary hospital admissions. In addition, intensive rehabilitation services will help older people regain their health and independence after a stroke or major surgery. New intermediate care facilities will be used to help make the jump from institutional care back into the home. The distinction between community, primary and some secondary care services will become blurred as a more integrated care service is made available.

Formal care providers are under increasing pressure to improve efficiency by providing care for a greater number of clients but often without a corresponding increase in the level of resources. One of the most valuable resources available to a care provider is time, which is often used inefficiently because of the need to travel between consultations with clients who might live in geographically dispersed locations, by seeing clients who are perhaps not as needy as others, or by having to routinely perform lengthy assessment procedures. In addition, in order to better utilise resources, carers are often under pressure to move clients out of institutional care into appropriate intermediate or community based care. In order for this to be achieved safely it is sometimes necessary to put in place a support package, which might in future include some form of telecare. The nature of the care services that might be appropriate for consideration of telecare support are illustrated in Figure 2.13.

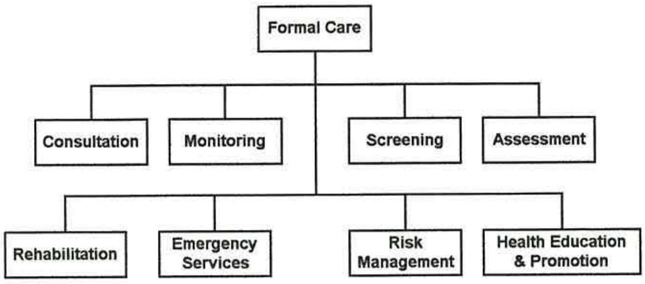

Figure 2.13. Types of formal care to be supported by telecare.

Informal Carers

The informal carer is an important member of the care team as very often they are able to determine the existence of a problem by detecting abnormalities in the behaviour of a client. Clients often rely heavily on the services of an informal carer for much of their care. The informal carer is typically a spouse, a member of the family or a friend who might live locally or be a neighbour. The desires of carers include the well-being of the client, the freedom to have a life of their own, and their own good health. The importance of informal carers is such that the Department of Health has produced a National Strategy for Carers [77] which incorporates three strategic elements, namely: information, support, and care, as they apply to the needs of the carers themselves.

Often the stress of caring for a particular client takes its toll on the carer and their needs should also be considered, particularly when they live in the same home as the client. Carers who provide substantial care on a regular basis have the right, on request, to an assessment of their own needs. This is important, not only for the good of the carer, but for the good of the client as well, as any illness that impacts on the carers ability to care for the client will clearly be detrimental to the client. It should be noted that in some circumstances an informal carer can themselves be the recipients of telecare services that support their ability to care for the client.

2.4.3 Telecare System Procurer & Service Provider

System Procurers

Organisations that are currently responsible for organising home-based care are particularly interested in the possibilities that telecare may provide. Telecare services are likely to be commissioned by several parties, including:

- Local authorities (social services departments & councils).
- Housing associations & Sheltered housing schemes.
- Residential & Nursing care homes.
- NHS (Care Trusts).
- Private individuals (client/client's relatives).

Without doubt, one of the driving factors for those with limited budgets will be to try and improve services via the use of technology but without compromising the quality of care provided. Local authorities are increasingly looking to provide a greater amount, and level, of care in the homes of their clients, where this is seen as a safe and practical solution. In terms of social care, many of the services that are anticipated include risk management technologies. In addition, telecare is seen as a means of extending the role of assistive technologies.

Another area of interest includes the identification of events that may signify that the client is in distress and requires either an immediate response or that signifies that a check-up visit by a suitably qualified carer is required. Other possibilities that are being identified include the use of technology to support formal carers who are required to live-in with a client, perhaps during the night, in order to assure their safety. One avenue under consideration by system procurers include technological interventions allowing a carer to sleep and be woken up only if required.

The medical profession are likely to see telecare as a means of discharging clients 'quicker and sicker' into community based intermediate care facilities or their own homes. The ability to perform medical monitoring or to have remote consultations with clients once they return to the community may have advantages to both parties. Conversely, telecare may be seen as a means of delaying admission into institutional care by supporting the client in the community for as long as possible.

Service Providers

Telecare Service Providers (TSP) do not currently exist, per se. A telecare system is likely to consist of infrastructure and services that run on this infrastructure. The infrastructure is essentially the communications link between the client's home and the care providers which make up the response network (including a call centre for emergencies), the equipment used to connect to this communications network, the protocols used to allow devices to communicate and to share information and any compulsory equipment necessary at either end of the link. There are thus several issues that need to be considered in terms of telecare service provision, namely:

1. Telecare infrastructure.
2. Equipment suppliers.
3. Call centre operation.

Possible candidates to run telecare systems and be responsible for providing call-centre services might include those organisations that currently operate Community Alarm services, or alternatively it might be that NHS or Care Direct can be expanded to provide the necessary service provision. The latter would certainly be better placed if medical monitoring were to be employed. Alternatively, telecommunications companies might wish to diversify into telecare in order to generate extra network traffic particularly during periods where capacity is under utilised. As far as equipment manufacturers are concerned, system procurers are eager to escape the current situation with community alarm systems, where the infrastructure dictates which manufacturer's devices it is possible to install. Thus, an open-system rather than a proprietary protocol may reduce the hold that a particular manufacturer might be able to enjoy in the marketplace. To counter this, however, there is great scope for new innovative product ranges offering expansion into unexploited markets with the use of an open protocol serving to stimulate the market.

2.4.4 Policy Makers

Overall healthcare policy in the UK is determined by Government via the Department of Health. Several key UK government policy publications have been referenced as a guide to some of the high-level structures that a telecare system might need to adopt. The healthcare model implemented in the UK is changing – a common theme can be identified throughout all of the governments policies and these themes are of independence, client choice, quality assurance, adaptive and personal care, social inclusion and integrated care. These points have already been considered during the course of this chapter.

2.4.5 Standards & Regulations

Although telecare is a new field, since it is a knowledge-based service, it will be necessary to consider the implications of existing and future standards and regulations in relation to issues such as medical informatics, client and patient privacy, data security and protection, and finally, communications protocols both inside and outside of the home. In addition, because devices will have to be installed into the homes of lay-people and because there may be an element of risk involved with any failures of the system, it will be necessary to conform with any relevant safety standards. In particular, some of the more relevant standards to consider include:

1. Community alarm protocols & standards.
2. Health Coding schemes.
3. Data protection regulations.
4. Medical device regulations.
5. Smart home standards.
6. Safety standards.

2.4.6 Existing Telecare Services

Whilst some of the trials of hospital at home technologies may be considered as telecare, the community alarm (CA) systems that are well established in the UK are the closest to a fully-established telecare system at present. It is logical therefore to consider the role of community alarm (CA) systems which have for many years successfully provided millions of elderly and infirm clients with a 'safety-net' support service, enabling them to retain a certain level of independence. It is important to consider the functionality of CA systems for the following reasons:

- They represent the closest thing to telecare that is currently available.
- The CA market is, at least initially, likely to form the largest sector of the telecare market.
- Telecare systems will have to co-exist with CA systems in the first instance, and eventually succeed them entirely.

CA systems and services represent a significant commitment by local authorities and housing associations in terms of capital investment, running costs and staff training. This investment includes the equipment installed within the homes of their clients and the running costs or contractual costs of 24-hour community alarm control/response centres and the maintenance of the equipment. The CA infrastructure is well established and the technology itself is tried and tested, enjoying a high degree of confidence with both the care providers and the clients themselves.

Community alarm systems, sometimes referred to as social alarms, which Doughty et. al. describe as first generation telecare [15] were first introduced into grouped-housing schemes in the United Kingdom in the late 1960's. Their purpose was to enable the residents of such establishments to communicate with an on-site warden and ask for assistance as and when necessary using what was essentially a local intercom system. The communications between the resident and the warden would be initiated by the client pulling a cord or by the pressing of a button. It took almost a decade to develop similar technology for use in ordinary private housing, so called 'dispersed schemes', where the on-site warden was replaced with an operator in a control centre and the communications path was established over the Public Switched Telephone Network (PSTN).

A conservative estimate of community alarm system users in the UK is 1.3 million people, most of whom are over 60 years old [106]. Many of these alarm systems are pre-installed fixtures in sheltered housing and residential care homes and they employ dedicated wiring within the infrastructure of the building to enable community alarm devices to communicate. There are, however, some 500,000 clients who live outside these schemes in other forms of housing with dispersed alarms that typically use radio-based pendants rather than the hard-wired pull-cord systems to enable the easy retrofit of alarms into existing housing stock. There are 283 control centres, five of which are privately run while the remainder are run by local authorities or housing associations [107].

CA systems in their current form have a limited shelf-life and CA service providers may either see telecare as a threat or as an opportunity. However, they will certainly have an influential role to play in the early adoption of telecare technologies as the CA infrastructure, whilst flawed, has the capability of supporting alarm-based telecare services, and offers a cheap 'entry-level' platform for many care providing organisations who are familiar with and who have invested heavily in CA equipment.

2.5 Summary

A combination of increased life expectancy and decreasing birth-rates has resulted in an ageing population, which is itself ageing. This has resulted in an increase in chronic non-communicable disease which has itself resulted in increased demand for long-term care. Modern times have presented care services with modern problems. The large cash injection promised by the Government must be matched by a reorganisation of care to best match needs to services and hence obtain better quality of care and value for money. Information and communication technologies are seen as a method of using the information available within the system to better effect, targeting services and resources so that the system becomes more effective and efficient. There are many initiatives of this nature targeted within the primary care sector and it seems appropriate to extend the apparent advantages of telemedicine into the community via the principles of telecare. This would represent great progress towards the goal of achieving a comprehensive and integrated care system in the UK.

Chapter Three

Gerontological Foundations of Telecare

In order to identify the care-related needs of system stakeholders and hence the range of services required for next-generation telecare of the elderly, it was necessary to acquire sufficient knowledge relating to aspects of geriatric home-healthcare. This was accomplished by referring to literature on gerontology and through informal conversations with several expert sources, namely: potential clients, carers, care service procurers and community alarm equipment manufacturers. This chapter discusses some of the key aspects of gerontology as they might apply in a telecare setting and also summarises some of the needs and concerns of elderly clients as identified from this discussion and from a consideration of Appendix A. Before proceeding, it is perhaps useful to define what is implied here by the term 'elderly', the meaning of which is highly subjective[1]. By and large, the term 'elderly' is used to describe individuals over the age of 65, although, as the elderly population itself ages, this figure might have to be reconsidered.

3.1 The Process of Care

In order to establish a basis for the consideration of new telecare services, it is logical to examine the nature of the caring process. Figure 3.1 models the typical progression in the caring process that may be followed in a number of care settings during a particular care episode. For example, in a hospital setting the monitoring process may be performed with human expertise aided with data provided by medical instrumentation. The analysis and decision making may be undertaken by a specialist team of health professionals, with appropriate care services being provided by the most appropriate provider, e.g. nursing staff. This closed-loop of care consisting of observation and monitoring, analysis, diagnosis and therapy is a reasonable model on which to base methods of providing telecare solutions for a client who requires care and support in the comfort of their own home.

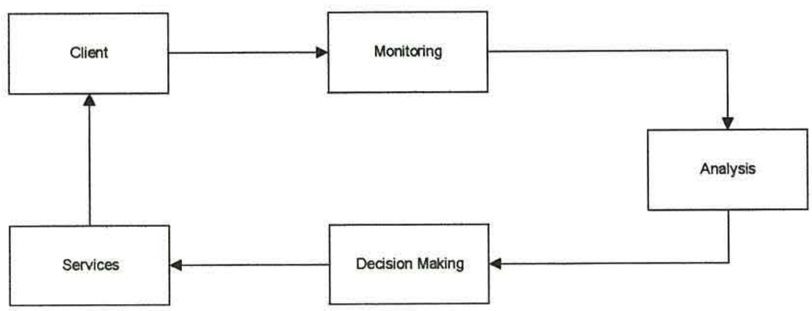

Figure 3.1. The loop of care.

[1] *and is often used to describe someone who is over ten years older than one-self!*

Thus, in order to provide telecare services to a client at home, the system must possess sufficient knowledge about the actual and desired well-being of the client. As the well-being of the client is likely to vary, this must be achieved by analysing both *a-priori* knowledge concerning the health and personal circumstances of the client and up-to-date information describing their current status. Such a 'real-time' model of client well-being will allow responses and other services to be tailored to the changing needs of the client and for external responses to be requested in situations where the client requires such assistance. Furthermore, by storing key elements of this data over a period of time, it may be possible to obtain a history of particular well-being indicators whose analysis may then be used to determine long-term decline or a need for appropriate intervention.

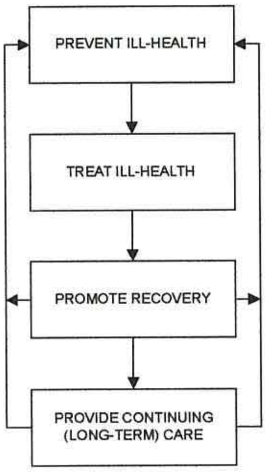

Figure 3.2. The stages of care.

The closed-loop of Figure 3.1 models a low-level process of care. At a higher level, it is possible to identify four classes of care provision: prevention, treatment, rehabilitation, and continuing or 'supportive' care (see Figure 3.2). Prevention is better (and cheaper) than cure; however, ill-health of one form or another is, to a certain degree, inevitable. When ill-health is present, treatment should be prompt and effective and should be followed by as much support and rehabilitation as is necessary in order to promote a speedy recovery. Finally, if chronic symptoms persist, long-term care and support should be provided to allow the individual to live as normal a life as possible and to prevent further complications or unnecessary suffering. Following a particular care episode, the focus of attention should return to prevention.

3.2 Measuring Health & Well-Being

In order for CarerNet to provide a reliable and comprehensive range of services, it must have access to a sufficient portion of the spectrum of parameters that describe client well-being. In order to identify the nature of these parameters, it is necessary to consider in greater detail the concept of well-being.

3.2.1 Quality of Life

The quality of life of an individual is dependent on many inter-related factors as suggested by Table 3.1. These include: physiological and psychological health, the quality of social support networks, perceived levels of safety and security in the home, general happiness and outlook on life, the suitability of the home as a living environment, access to services and level of independence. Many workers have attempted to better define the meaning of the quality of life, quality of health, wellness or well-being of an individual [108, 109]. These qualitative terms, often used interchangeably, are however difficult to quantify due to the complex relationship between the objective and subjective variables that contrive to affect the perceived (or actual) quality of life or well-being of an individual.

Table 3.1. Factors affecting health and quality of life.

Fixed	Socio-Economic	Environmental	Lifestyle		Access to Services	
Genes	Poverty	Air Quality	Diet	Leisure	Education	Information
Gender	Employment	Housing	Physical Activity	Sexual behaviour	NHS	Religion
Ageing	Social exclusion	Water quality	Smoking	Drugs	Social services	Shops
		Social environment	Alcohol		Transport	

Figure 3.3 illustrates the main aspects of an individual's life that impacts on their well-being, derived from [108]. The traditional medical model of health is represented by clinical signs and symptoms. A *sign* is an indication of a particular disorder that is observed by a physician but is not apparent to the client. Clinical signs have physical origins and can usually be monitored using instrumentation. For example, the vital signs include body temperature, pulse rate, blood pressure and respiration. A *symptom* is an indication of a disease or disorder noticed by the client. Some symptoms can be monitored, although many are subjective and cannot. Symptoms can be physiological, e.g. high temperature, palpitations, headache, and breathlessness; or can be behavioural or psychological in nature such as tiredness, depression, moodiness, and loss of appetite.

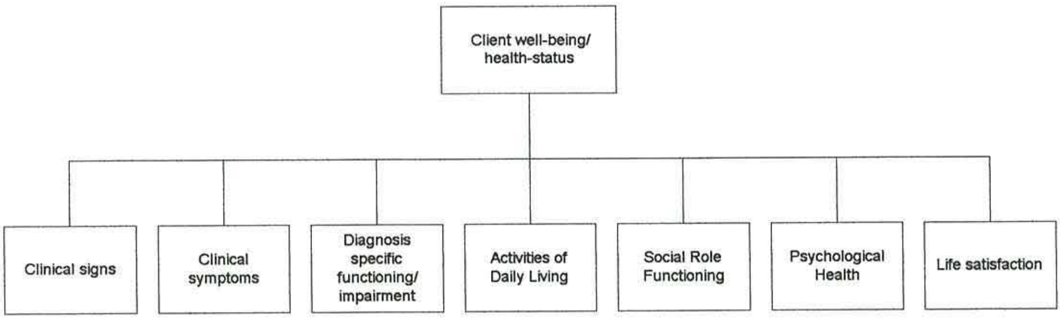

Figure 3.3. Aspects that contribute to the health-status or well-being of an individual.

Diagnosis specific functioning refers to the effects that a particular disease might have in terms of causing an impairment that impacts on the everyday life of the individual. For example, the effect of arthritis on an individual's ability to walk or manipulate objects with their hands, or the effects of various sensory impairments on the individual's ability to navigate or communicate effectively.

Activities of Daily Living (ADL) refer to everyday tasks that must be undertaken routinely in order for an individual to function independently. These include: mobility; toilet management and continence, personal hygiene, grooming, dressing, cooking, shopping and other domestic tasks.

Social role functioning considers an individual's ability to partake in an active and rewarding social life by means of interaction with friends, family and the local community. Social support networks, whether based on work, religion, shopping, sport or other leisure activities, are an important aspect of an individual's lifestyle and contribute towards their *psychological health*, which in turn has a tremendous impact on their perceived quality of life.

Life satisfaction is a measure of an individual's attitude towards all aspects of their life and is essentially a broad measure of their happiness [108].

A brief consideration of these concepts indicates that the nature of the monitoring required in order to build-up a comprehensive picture of client well-being is complex. It is also apparent that some aspects that contribute to an individual's quality of life are more amenable to electronic monitoring techniques than others. In the case of the elderly, however, the picture is complicated still further due to the unique way in which pathology affects the elderly individual.

3.2.2 Multiple Pathology & Aetiology

Just as the perceived quality of life of an individual is determined by the interaction of a number of different factors, the actual health of the client and their resulting ability to perform everyday tasks can be affected by an interaction of physiological and environmental factors. The determination of the underlying cause of presenting symptoms in the case of an elderly individual is complex due to multiple pathology[2] and aetiology[3], which can mean that elderly clients may present with atypical as well as classical symptoms.

In the case of the elderly, the presenting symptom is often heavily influenced by weak elements which are affected first by disruptions in homeostasis. These 'weaknesses' include the brain, the lower urinary tract, the musculoskeletal system and the cardiovascular system [3, 66]. For instance, acute confusion or falling are often the initial presentations of appendicitis or pneumonia in the elderly. Many varied diseases including pneumonia, myocardial infarction, urinary tract infections or drug toxicity may present atypically as one of the so called geriatric giants: falls, confusion, incontinence and immobility (many people now include pressure sores) [3]. These geriatric giants are sometimes referred to as the big 'I's: Intellectual failure, Incontinence, Immobility, Instability and Iatrogenic disease[4]. This is a key characteristic of geriatric medicine – the recurrence of certain clinical conditions (weight loss, fluid and electrolyte abnormalities, heat regulation disorders, syncope, gait disturbance, falls, immobility, confusion, incontinence, pain, sleep abnormalities, and pressure sores) which can all be indicative of different aetiology.

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[2] ***pathology*** *(n.) – the symptoms of a disease [110]*
[3] ***aetiology*** *(n.) – the cause of a specific disease [111]*
[4] ***iatrogenic*** *(adj.) – describing a condition that has resulted from treatment, as either an unforeseen or inevitable side-effect [111].*

As an example, consider the case of an elderly individual, 'Mrs. Jones', who lives alone in a semi-detached bungalow. She suffers from poor vision and has trouble walking due to an arthritic hip. Recently she has had to get up often during the night to urinate due to bladder instability and this has led her to be prescribed a course of nocturnal hypnotics (sleeping pills) to combat her disturbed sleeping pattern. One of the common side effects of these drugs is decreased stability (similar to that experienced by someone suffering with a hangover), which makes her unsure on her feet in the mornings and subsequently leads to an increase in sway when she walks. Considering Figure 3.4 it can be seen that a whole range of factors may combine in order to trigger a sequence of events that may lead to Mrs. Jones suffering some form of acute traumatic episode.

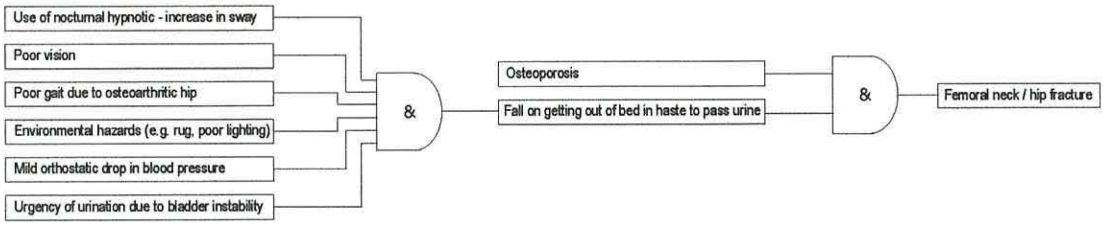

Figure 3.4. Multiple pathology leading to atypical presenting symptoms.

In the early hours of one morning, Mrs. Jones feels the need to urinate urgently and rushes to get out of bed. This action of quickly standing upright after a prolonged period lying down causes Mrs. Jones's blood pressure to drop and become low (orthostatic hypotension) which causes her to feel light-headed. This combined with her 'hangover' effects, her poor vision, unsteady gait, the fact that the curtains are drawn which means the room is still fairly dark coupled with the fact that she is in a hurry to get to the bathroom causes her to trip on the rug in her bedroom, resulting in a fall.

For many, this scenario is already serious and the outcome for the client depends on the extent of the injuries obtained and the speed of response by the appropriate care responders, if required. Clearly, one of the worst-case scenarios for Mrs. Jones is if she were unfortunate enough to fracture either her wrist, hip or the neck of her femur. Such fractures can lead to other complications and often have a direct impact on an individual's likelihood of survival.

Another important factor in the care of the elderly is the speed of response of the care providers after such an acute event. The speed of response is dependant on many factors such as the distance between the care responder and the client, the type and availability of care required and critically, the time between the trauma and the raising of the alarm. In the case of a broken femur, for instance, the outcome of surgery is influenced by a number of factors including how long the client has to wait for an operation following the fall (within 24 hours is preferable) [66].

To illustrate further how time is of the essence reconsider the scenario that Mrs. Jones now finds herself in following her fall. It may be observed from Figure 3.5 that other events and conditions may now conspire against her:

1. It is still the early hours of a cold January morning.
2. The heating is off as she is concerned about whether she can pay the bills (and she had hoped to be asleep at this hour anyway).
3. Her house is old and does not possess good thermal insulation.
4. The window is ajar as she forgot to close it the night before after opening it to air the room.
5. Her ability to perceive falling ambient temperature is not as good as it used to be which means she is only wearing her thin cotton night-gown.

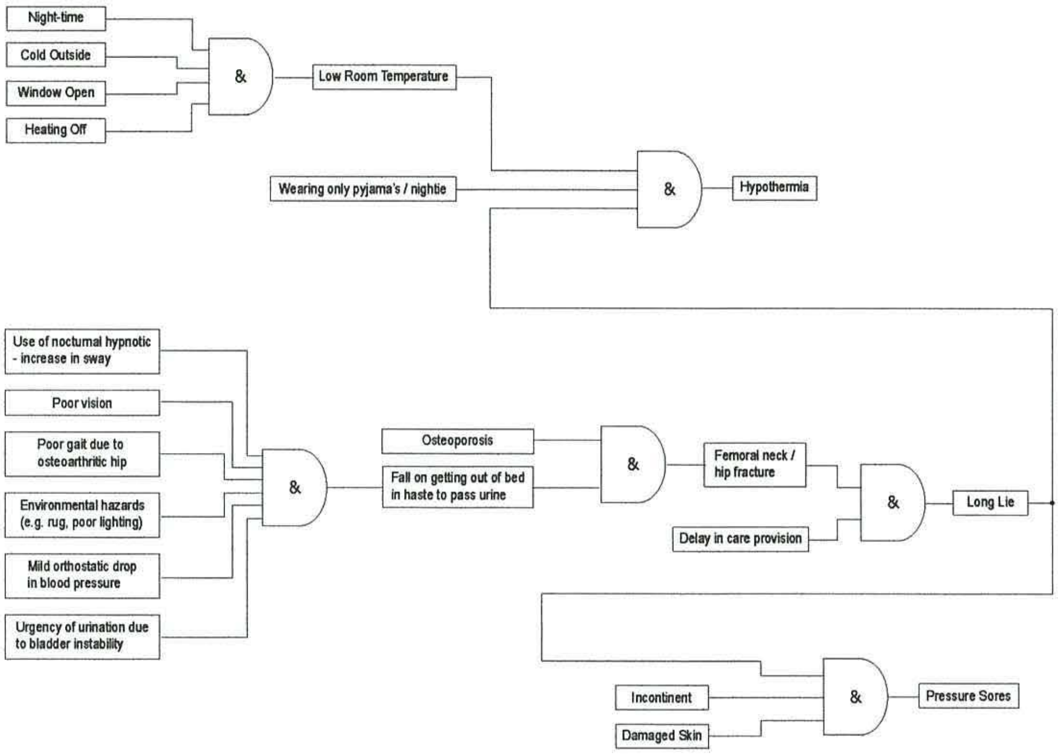

Figure 3.5. The effects of a delay in care after a fall during a cold night for Mrs. Jones.

These events contrive to lower the temperature of her bedroom and expose Mrs. Jones to the cold. This increases her risk of developing hypothermia, which is a real possibility if a significant delay in providing emergency care leads to her experiencing a 'long-lie'. In addition if, after the fall, Mrs. Jones urinated causing her legs to become wet then she is also increasing her risk of developing pressure sores, another undesirable complication.

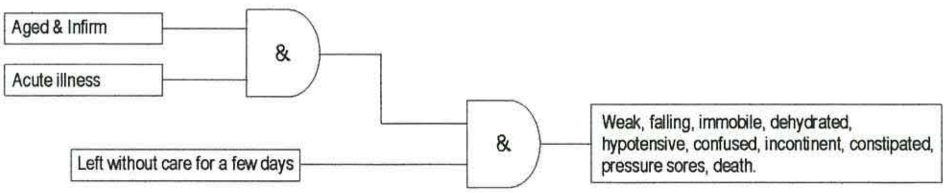

Figure 3.6. General consequences of a delay in care for the elderly after an acute episode.

Thus, in general terms, if an elderly or infirm individual suffering from an acute illness is left without care for a few days then this can lead to a whole manner of complications and presenting symptoms, as suggested by Figure 3.6. In the case of a serious fall, as in the scenario just discussed, the time frame may be even tighter. Fall data suggests that inability to recover from a fall (i.e. to right oneself) resulting in a 'long-lie' has an associated increased risk of death. The problem of a 'long-lie' is not uncommon, one French study found that approximately 20% of elderly patients hospitalised after a fall had been on the ground for more than one hour [112]. A further study found that approximately 50% of those subjects who had fallen and who had remained on the floor for one hour or more had died within the following six months, even if there was no direct physical injury [113].

3.2.3 Comprehensive Geriatric Assessment

An elderly individual's well-being is dependent on a complex mix of parameters and circumstances. It is therefore necessary to assess their well-being using a multi-factorial process, sometimes referred to as Comprehensive Geriatric Assessment (CGA). A study of CGA will identify parameters of relevance describing the care requirements (and hence well-being) of an individual, and typically includes:

1. Functional assessment;
2. Safety assessment;
3. Social support assessment;
4. Psychological assessment;
5. Medication assessment;
6. Nutritional assessment;
7. Physical assessment.

These assessment techniques are likely to assume even greater importance as care packages become increasingly targeted towards the client's individual needs. Care resources will increasingly be allocated based on the results of such assessments (often combined into a single assessment procedure), which identify the type and severity of need. Assessment techniques are particularly important in the case of the elderly where there is often a tendency to blame ill-health on the ageing process. The resulting delay in obtaining help and appropriate care early on in the progression of a disease may lead to a deterioration that could have been averted with earlier intervention. This reluctance to obtain help may be due to poor health awareness, poor health expectations, denial that a problem exists at all, or a general reluctance or embarrassment to 'inconvenience' the care services. While some symptoms experienced by an individual may be attributed to old age, very often there may be an underlying cause that can be treated.

General Health Assessment

There are many instruments that have been designed to measure the general health status of an individual, including: the Sickness Impact Profile (SIP), the Functional Limitations Profile (FLP), the Nottingham Health Profile (NHP), and Short Form 36 (SF-36) [108]. The Sickness Impact Profile[5] was designed to measure the perceived health status of an individual and focuses on the impact of illness on daily activities and behaviour. Although it is designed to be administered in the form of a questionnaire, with yes/no answers, it is a good example of a subjective health measurement scale and provides useful information on the parameters that may be of interest for the purposes of continuous client 'well-being' assessment. The SIP consists of 136 true/false statements which are organised into physical (ambulation, mobility, body care and movement) and psychosocial (social interaction, communication, alertness behaviour, emotional behaviour, sleep and rest, eating, home management, recreation and pastimes, employment). Table 3.2 lists a small selection of these statements with a brief consideration of how the measurements may be automated using telecare.

Table 3.2. Example SIP true/false questions with possible routes to automation.

Statement	Possible route to automation
"I spend much of the day lying down in order to rest"	• Monitor bed/sofa occupancy; • Monitor client activity and orientation
"I sit during much of the day"	• Monitor chair occupancy; • Monitor client activity levels; • Monitor room occupancy profile.
"I am sleeping or dozing most of the time – day and night"	• Bed/sofa/chair occupancy monitoring • Client activity monitoring
"I do work around the house only for short periods of time or rest often"	• Client activity monitoring
"I am going out less to visit people" & "I am doing fewer social activities with groups of people"	• Home occupancy monitoring • Social interaction monitoring

Another assessment instrument is the Minimum Data Set for Home Care (MDS-HC), which enables care providers to assess a client in several key areas, including: function, health, social support, and service use. Some elements of this procedure are set out in Table 3.3. It is intended to be a universal assessment tool that promotes the consistent, comprehensive and holistic assessment of individuals. The screening process of the MDS is used to identify client risk factors and strengths and can be used to trigger the Client Assessment Protocols (CAPS).

Table 3.3. The MDS-HC.

Identification of background information;	Skin condition and foot care;	Activity pursuit patters;
Special treatments, devices, procedures, and supplies;	Vision patterns;	Medication use;
Cognitive patterns;	Disease diagnoses;	Physical functioning/structural problems;
Continence in last 14 days;	Mood and behaviour patterns;	Participation in assessments;
Communication/hearing patterns;	Oral/nutritional status;	Informal support services;
	Psychosocial well-being and social interaction;	Environmental assessment;
	Oral/dental status;	Service utilisation;

The technique is also intended as a method of recording data in such a way that it may be used when auditing the quality of care as well as for monitoring the outcomes of a care process. A selection of screening instruments can be used to trigger a more comprehensive and detailed analysis of particular concerns in order to provide the most appropriate care package for the client.

[5] *© The Johns Hopkins University 1977 - (sometimes used in a modified version known as the Functional Limitations Profile (FLP) in the UK)*

Physiological Assessment

Physiological assessments assesses the status of the body and its organs and organ systems. The key parameters for monitoring purposes are the client's vital signs: pulse/heart-rate, body temperature, respiration and blood pressure. The assessment is an important element in the overall health-assessment of an individual, especially if they are known to possess particular physiological problems. Physiological parameters can give important diagnostic information concerning problems with infection, emotional state & stress, body chemistry as well as various chronic diseases such as asthma, hypertension and heart disease. Figure 3.7 illustrates the main areas for physiological assessment of the elderly client. One of the advantages of physiological monitoring is that the majority of the parameters are quantitative and can be measured absolutely using instrumentation. Figure 3.8 and Figure 3.9 illustrate some problems associated with the heart and with respiration.

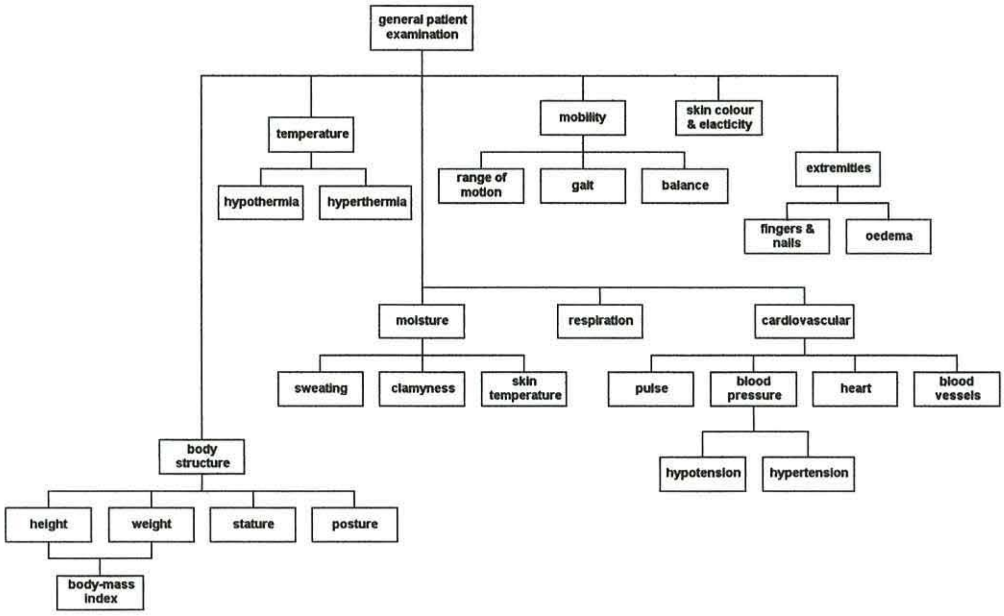

Figure 3.7. Parameters of interest for physiological assessment.

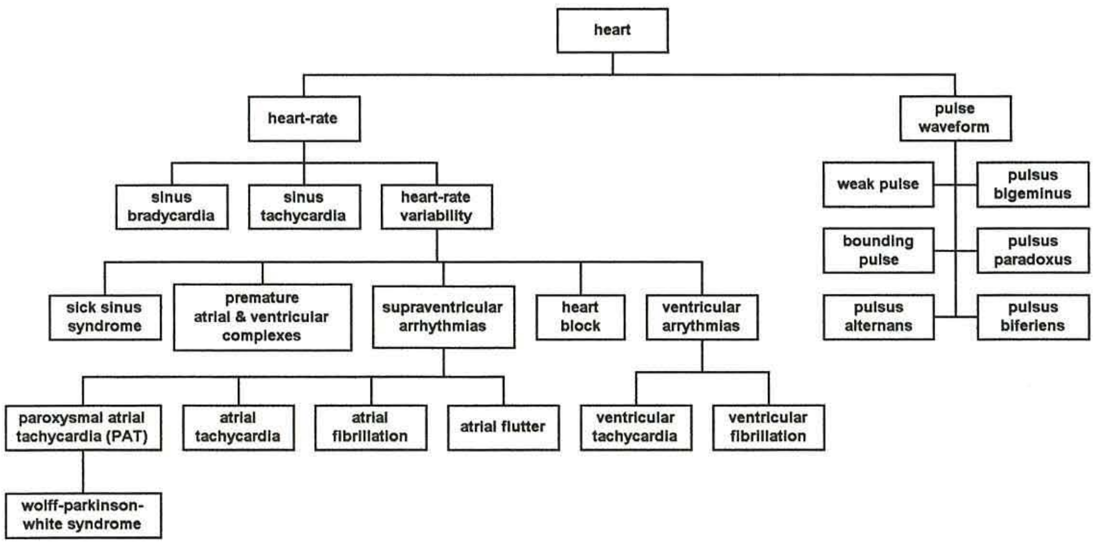

Figure 3.8. Physiological problems associated with the heart.

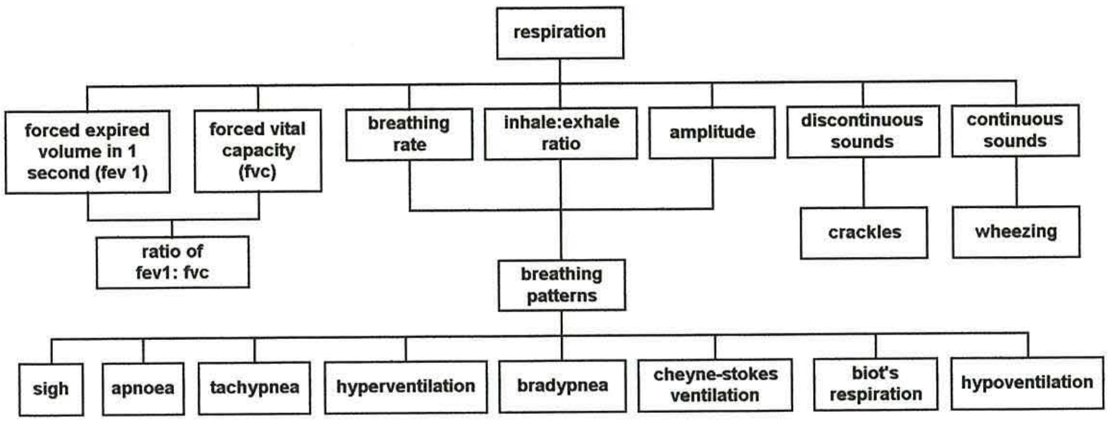

Figure 3.9. Physiological problems associated with respiration.

Functional Assessment Techniques

One of the key factors affecting the quality of life of an elderly individual is independence, which can be threatened by functional or cognitive decline. Figure 3.10 from the World Health Organisation's (WHO) International Classification of Functioning, Disability and Health (ICF)[6] [114] illustrates how the progression of disease can impact on the life of an individual. Pathology (damage or any abnormal process that may occur within an organ or organ system of the body [114]) can result in impairment (a loss or abnormality of psychological, physiological or anatomical structure or function [114]). An impairment caused by disease or the ageing process can eventually lead to disability (any restriction or lack of ability in performing an activity in the manner or within the range considered normal for a human being [114]). A handicap is the effect of disability on the lifestyle of the individual and represents some form of disadvantage introduced by the disease or ageing process. This subsequently leads to varying degrees of functional impairment, which becomes worse with increasing age, and gradually impacts on the ability to perform activities of daily living as suggested by Figure 3.11.

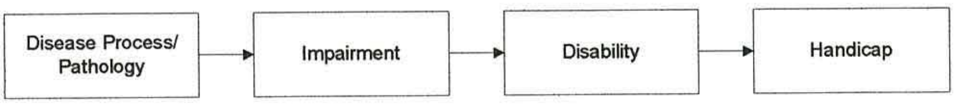

Figure 3.10. The World Health Organisation model of functional impairment.

Many problems associated with the elderly will therefore often generate some form of functional decline long before the classic symptoms present, eventually leading to a reduction in, or loss of, independence. Functional decline generally manifests itself as a failure to get up and about and look after oneself, taking to chair or bed, weight-loss, lethargy, and weakness – which may occur over a period of hours, days, weeks or months.

[6] *ICF is a revision of the International Classification of Impairments, Disabilities and Handicaps (ICIDH).*

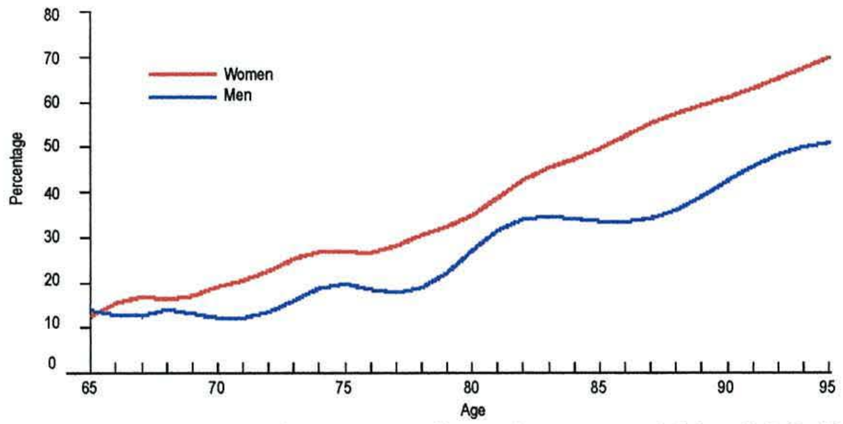

Figure 3.11. Percentage of elderly who find at least two activities of daily living to be either difficult or impossible.

Table 3.4 illustrates some of the problems that elderly individuals experience as functional ability declines, from which it may be surmised that their ability to remain independent is increasingly threatened. Functional impairment can lead to various problems for the individual concerned, from making everyday tasks and activities of daily living more difficult to making the home a more hazardous environment. For example, someone with poor eyesight and arthritis may find it difficult to walk down to the shops and may be more likely to suffer a fall in a cluttered and poorly lit home.

Table 3.4. Handicaps among a sample of elderly individuals aged 75 and over [115].

Function	Percentage
Unable to cook main meals	35
Unable to shop	35
Difficulty getting about home	24
Difficulty with stairs or steps	50
Unable to do stairs/steps at all or only with help	19
Needs help cutting toenails	44
Medium or high dependency due to visual loss	8
Medium to high dependency through hearing loss	7.5
Urinary incontinence	13

In the case of the elderly, there are a number of dedicated functional assessment tools that are based on mobility and gait measurements and also on the Activities of Daily Living (ADL). Table 3.5 lists a small subsection of the assessment scales that have been devised to monitor the functional status of the elderly [108, 116, 117]. It may be apparent that some of the tests used to determine functional capacity are amenable to automation and hence telecare.

Assessment indices based on the Activities of Daily Living (ADL) are used as a measure of the ability of a particular client to live independently with or without assistance. Basic activities of daily living (B-ADL) techniques assess the client under a number of categories such as: mobility (especially transferring), nutrition, toilet management and continence, personal hygiene & grooming, bathing and dressing. Instrumental Activities of Daily Living (I-ADL) include cooking, cleaning, shopping, communication, managing medications, managing finances and other domestic tasks. One of the most popular standardised techniques uses the Barthel Index, which may be applied to any individual with physical disabilities.

Table 3.5. Comparison of functional assessment tools/scales.

	Assessment Tool	Parameters Measured	Comments
Balance, mobility and gait measures	Performance Oriented Mobility Assessment (POMA)	Sitting balance, arising from a chair, immediate standing balance, balance when turning and sitting down; Gait analysis includes step height and length, continuity, symmetry, path deviation, trunk sway and walking stance, etc.	May be appropriate for use with relatively frail older individuals who live in the community or in institutions [118].
	Timed Up and Go (TUG)	Time taken to stand up from a chair, walk 3 meters at a comfortable pace, turn around, walk back to the chair and sit down.	TUG is used to evaluate basic mobility skills in adults.
	Gait Abnormality Rating Scale (GARS)	Gait variability, weaving, waddling, staggering, % time in swing, foot contact, hip range of motion, knee range of motion, elbow and shoulder extension, etc.	Videotape-based analysis
	Ten Metre Walk (TMW)	Walking speed over ten meters.	Measure of client-selected walking speed is a measure of client perceived function and physical ability.
Self-Care Measures	Barthel Index (BI)	Feeding, chair/bed transfers, personal grooming, toilet use, bathing, walking, dressing, continence, and ascending and descending stairs	Several different versions exist. Does not take into consideration the Instrumental ADL parameters.
	Functional Independence Measure (FIM)	6 self-care activities (feeding, grooming, bathing, dressing upper body, dressing lower body, toileting) 2 sphincter control (bladder & bowel management) 2 locomotion (transfers/walking/wheelchair, stairs) 2 communication (comprehension, expression) 3 social cognition (social interaction, problem solving, memory)	FIM is more sensitive than the Barthel Index due to its wider scoring range and is therefore capable of detecting smaller changes in functional ability [119].
	Physical Performance Test (PPT)	Writing a sentence, simulated eating, lifting a book and placing it on a shelf, putting on and removing a coat, picking a penny off the floor, turning 360°, walking 50 feet and climbing stairs.	The use of timed measurements minimises the need for subjective interpretation or judgement and increases the objectivity of the test.
	Nottingham 10-point ADL Index	Drink from cup, eat, wash face and hands, transfer from bed to chair, walk around house, use toilet, dress, undress, make a hot drink, have a bath.	

If functional assessment is performed periodically then it is possible to detect decline and hence address any underlying medical or social problems. The capability to measure and quantify the ability of an elderly individual to perform the activities of daily living (ADL) is therefore highly desirable as any deterioration may indicate some form of untreated illness. By monitoring an individual over time, the deterioration in their functional ability can be used as a trigger, indicating that a more thorough clinical examination might be necessary. Timely intervention at this stage can help identify the root cause of the functional decline and treatment can be instigated to either slow down or reverse any disease process or to compensate for any impairment that might be causing the decline. This early intervention can minimise the impact of any underlying disease or impairment and at the same time improve the quality of life of the individual. However, the effectiveness of such analysis is very much increased if a pre-morbid score is available for baseline comparison. This is not always available (for practical reasons) using traditional 'single-shot' manual assessment techniques.

Habit Assessment

While functional assessment determines whether a client is competent to perform a particular task, it does not necessarily follow that the client is capable of performing such tasks consistently during their regular daily routine. Another technique used by occupational therapists (OT's) is habit assessment, i.e. looking for routine in the lifestyle of the client that shows that they are capable of undertaking the necessary activities to support independence on a continuous basis. OT's look out for maladaptive patterns that are characterised by inconsistency, imbalance, disorganisation, inflexibility, and social inappropriateness. Other simple indicators that an OT will keep an eye out for include: difficulty in 'transfers' in/out from chair; self-neglect - including dirty hands/face/body, dirty clothing, evidence of incontinence, and obesity. It is not always practical to observe the client over a long-term basis and so an assessment must be derived from interviews with the client and with carers. Sometimes it is necessary to observe the client in special assessment units, which clearly places the client in a foreign environment and also under a great deal of pressure, leading to the possibility of misleading results. This is clearly an area where there is potential for telecare to improve the assessment process.

Psycho-Social & Cognitive Assessment

If the client suffers from a psychological or cognitive impairment, then everyday tasks such as housekeeping may pose a threat to their safety, as the client's perception of the risk associated with particular actions may be reduced. In addition, confusion may lead to potentially hazardous situations in which a household appliance is used incorrectly or inappropriately. Furthermore, inappropriate behaviour, e.g. wandering outside in the night may place the client at risk of injury. For telecare applications, conditions that related to client safety and well-being, namely: client delirium/confusion, dementia, and isolation/depression require careful assessment. Client safety will be discussed further in the next section.

The assessment of cognitive ability and dementia is complex and is usually carried out by a trained psychologist. Tests such as the Mini-Mental State examination (MMSE) and the Abbreviated Mental Test (AMT) focus on similar parameters such as: orientation ("What is the day/month/year?"), memory ("Who is the Prime Minister?"), language (comprehension test), and attention (count backwards from 20) [66]. These tests are invariably part of a comprehensive assessment which would include a significant functional assessment, probably based on the activities of daily living. The assessment of depression can be undertaken using the Geriatric Depression Scale (GDS), a reliable and short test, where a series of yes/no questions are asked in order to screen for depressive symptoms in the elderly [117]. If telecare is to be capable of assessing a client for cognitive decline or depression, techniques based on functional assessment and on monitoring the known symptoms and risk factors will be required if the client is not to be aware that a measurement is taking place (see Table's 3.6 & 3.7). Alternatively, a technique of allowing the client to answer suitable questionnaires using a computerised form might be a possibility.

Table 3.6. Risk factors for and symptoms of depression.

Risk Factors	
Bereavement or loss;	Living alone/isolated;
A history of clinical depression;	Visual/hearing impairment leading to communication problems
Chronic, disabling, painful or life-threatening illness;	Dementia
Stroke	Being a full-time carer (e.g. dementia, incontinence) where social isolation brought about through need for constant supervision and a reluctance to mix socially through embarrassment.
Symptoms	
Depressed mood	Impaired concentration;
Diminished interest in most activities	Worrying about memory;
Weight change (plus or minus 5% of body weight in a month) that is not related to any physical problem	Pessimism & suicidal thoughts.
Insomnia, broken sleep or early-morning waking	Unexplained headaches and backaches, digestive upsets, stomach pains and constipation;
Observable restlessness or slowing down	Changes in sleeping pattern, e.g. early morning awakening, sleeping too much, insomnia, chronic fatigue or a general lack of energy;
Fatigue/loss of energy	Withdrawal from family, friends and usual social activities;
Diminished concentration	Irritability;
Excessive sighing	Difficulty in making decisions;
Alcoholism	Few relationships with others;

Table 3.7. Risk factors and symptoms of confusion/dementia.

Risk Factors	Symptoms
Increasing age	Short-term memory loss
Urinary tract infection	Temporal confusion & disorientation, sun-downing
Malnutrition (Vitamin B12 deficiency)	Difficulty in performing everyday routines, e.g. preparing a meal
Anaemia	Decline in personal grooming & hygiene
Stroke	Pacing, repetitiveness of activities
Alcoholism	Wandering and restlessness
Parkinson's disease	Incontinence
	Social withdrawal

3.2.4 Client Safety

Most elderly people wish to live independently in their own home for as long as possible. This can however lead to issues of safety, especially if living alone in property that is not suited to their particular needs. Whether or not an individual is considered to be safe to live entirely independently in their own home depends on a number of factors. Often the process boils down to one of risk management and whether or not the risks associated with the client living at home are considered worthwhile providing they can be managed by the introduction of a suitable care package. A multi-factorial risk assessment typically considers:

- sensory & cognitive impairments;
- general frailty and falls history;
- access to an informal care network;
- physical illness;
- suitability of living environment;
- activities of daily living;
- security;
- financial status;

This is often undertaken following some form of acute episode, whether as a result of an accident or following a period of client illness, and is often part of the hospital discharge process. It is the responsibility of an occupational therapist and a multi-disciplinary case team to ensure that the client's home, in combination with their personal circumstances, poses no threat to the client's safety or welfare. Typical care packages to manage risk might include the provision of meals-on-wheels, a home-help, certain modifications to the home, such as a downstairs toilet or commode, the installation of a community alarm and perhaps other assistive technologies.

Issues of client safety also have an impact on the client's quality of life. For instance, factors such as home and personal security, the ability to easily summon help in an emergency, fear of crime, a comfortable living environment and the availability of various support services will all have a bearing on the perceived quality of life of the client. This is especially the case when the client lives alone and in isolation. It is therefore important to identify the key areas of risk which impact on the client's ability to remain at home and to consider mechanisms to help manage and control these risks to acceptable levels. The following sections describe the key areas of risk that elderly individuals may be subjected to in the home.

Accidents in the Home

There are approximately 2.6 million accidents in UK homes each year that are serious enough for the victim to have to pay a visit to an accident & emergency department, and a similar amount again that require the assistance of a GP [120]. There are almost 4000 accidental domestic deaths, over half of which are a result of a fall [120]. In 1995, home accidents accounted for 37% of all accidents requiring hospital treatment and cost the NHS an estimated £450 million per year [121]. Home Accident Surveillance System (HASS) data from 1997 shows that there are three main categories which together account for nearly three quarters of all home accidents [122]:

1. *Impact Accidents* – These account for approximately 62% of all home accident cases. The most common are falls, which account for about 40% of all home accidents, but also relevant are injuries caused by falling objects and by bumping into objects. The probability of an elderly individual suffering a fall increases with age; with falls accounting for 75% of accidents in the over-75's. The elderly are particularly at risk of fractures and trauma caused by impact accidents.
2. *Burns and Scalds* – Whilst accidents of this type account for only approximately 4% of all home accidents, they can be very serious with long-term psychological and rehabilitation consequences. Examples include the effects of fires but also of stepping into excessively hot bath water or of scalding accidents during cooking.
3. *Poisoning & foreign body accidents* – 6.4% of home accidents involve foreign bodies and poisonous liquids being admitted through the mouth; choking; and objects in the eye, the ear or the nose. Adverse drug reactions are not included in these data, though the dangers posed by such accidents are obvious.

The causes of such accidents are multi-factorial and are often a combination of human and physical factors. Human factors that have an impact on safety include: impatience, absentmindedness, inadequate knowledge or training, sudden illness, ageing, confusion, alcohol, drugs and medicines as well as a general disregard for personal health and safety. Physical factors include: mechanical defects in equipment or the home, faulty appliances, poor design, poor house wiring and gas leaks. A 1997 report by Tunstall Telecom concerning the views of elderly clients who live alone in the community resulted in the following interesting facts that are of relevance to aspects of client safety [123]:

- The majority of people surveyed had received at least one visit during the previous seven days, but the frequency of visits was variable;
- 1 in 3 elderly people had not been visited by relatives during the previous 7 days;
- Nearly half had not been visited by friends in the last week;
- 51% of elderly people surveyed had no relatives living nearby;
- Only 11% had all or most of their relatives close at hand;
- 33% were worried about having an accident.

These results indicate that if an elderly individual were unlucky enough to experience a serious accident, or for whatever reason be unable to request help when required, then in some cases they may be left helpless for a number of days.

Home Accidents and the Elderly

The home can be a hazardous environment, especially for the elderly, who experience a greater risk than any other age group of suffering an accident within the confines of their home, with those living alone being particularly vulnerable[7] [122]. Even though the elderly have less accidents than other age groups, the proportion of accidents amongst the elderly that are classified as serious or very serious is much greater for the elderly, especially amongst the 75 and over age group [120]. Therefore the effects of an accident tend to be more severe, as may be seen from Figure 3.12 [122].

A lack of awareness of risk, either through ignorance or because the client's ability to appreciate risk is impaired by some form of sensory or cognitive problem, e.g. failing vision or dementia, often results in a hazardous situation. By far the most common type of accident amongst the elderly population is a fall. Other accidents mainly involve problems with domestic appliances typically leading to burns or fire. These two broad categories of accident (falling and non-falling) will now be discussed briefly.

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[7] *The likelihood of a person living alone in the community increases with age - in 1992, almost half of all people aged 75 or over lived alone [126].*

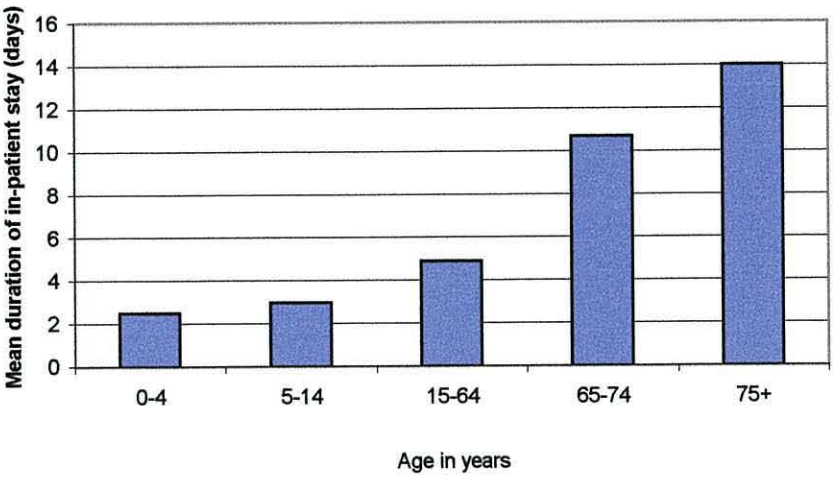

Figure 3.12. Mean duration of in-patient stay following an accident in the home as a function of age group.

Falling Accidents

Falls are a major concern to the elderly and can have a serious effect on the ability of an individual to live alone at home. In particular, the elderly are vulnerable to falling and lying helpless and undetected for lengthy periods. Approximately one third of elderly people over the age of 65 experiences at least one fall every year with two-thirds of these fallers experiencing a further fall within six months [124]. Falls account for approximately 80% of all injuries to the aged and for 90% of all fractures. Fall-related injuries are the fifth most common cause of death amongst the elderly population [125]; with this being a particular concern in the case of the over 75's. Falls present a particular problem when the faller lives alone, and, in particular, if living in isolation. Apart from the obvious risk of broken bones leading to a loss of mobility, the faller may suffer a loss of confidence, which results in a loss of independence and a gradual decline in well-being. This may lead, in turn, to an increased risk of further falls, resulting in a spiral of decline, the outcome of which may ultimately be the need for institutionalisation.

Table 3.8. Factors that predispose the client to an increased risk of falling.

Intrinsic		Extrinsic
Age	Gender (Female)	Slippery floors
Decreased visual accommodation and acuity	Senile gait	Cluttered floors
Decreased adaptation to darkness	Effects of medication, e.g. sleeping pills	Inadequate lighting
Decreased peripheral vision	Postural/Orthostatic hypotension	Insufficient support such as handrails
Decreased glare tolerance and contrast sensitivity	Peripheral and autonomic neuropathies	Stairs
Slower reaction time	Cardiac arrhythmias	The cold
Increased postural sway	Cerebrovascular disease	
Impaired self-righting reflexes	Myopathies	

Falls are invariably of two types: *intrinsic*, caused by dizziness, 'loss of balance', blackouts, medical episodes, syncope etc. and *extrinsic*: caused by trips, slips and other environmentally triggered factors, see Table 3.8 for more detail. Often a person will suffer several minor falls before experiencing a particularly serious one that leads to a major injury or, ultimately, death. In practice, the causes of falls may be multi-factorial and can often imply an underlying problem or illness that requires treatment.

The elderly are predisposed to a greater risk of falling because of physiological changes brought about by the ageing process. They suffer from a reduction in muscle strength as well as being more likely to suffer from some form of visual or hearing impairment. Certain health problems can also lead to an increased risk of falling, these include: stroke, Parkinson's disease, dementia, epilepsy and certain cardiac problems. In addition, temporary or permanent physical disabilities are also responsible for increasing the likelihood of a fall with a lack of general fitness also having some influence. Another factor that can play an important role in falls amongst the elderly is medication. The use of drugs to combat a multitude of ailments that the elderly individual may be suffering from can lead to side effects which may lead to an increased risk of falling.

Environmental factors are more often than not contributory factors rather than the primary reason for a fall; however, they still play a significant role. The elderly population are disproportionately represented in some of the oldest housing stock in the country [104]. This has several effects on their immediate living environment: the house may not have central heating, it will most certainly not have any form of insulation and so will be expensive to keep warm. Secondly, if the house has a stairway then it is likely to be particularly steep. Many old houses still have outside toilets that pose a particular threat, especially if the client needs to go to toilet during the night in the cold winter months. Other environmental factors, which are easier to overcome, include loose mats and rugs, cluttered rooms, slippery floors and poor lighting. The bathroom can be made much more 'elderly-friendly' by installing several assistive aids such as raised toilet seats and safety railings on baths and toilets which help the elderly individual transfer properly. One of the most hazardous areas of the house in terms of falls is the stairs. In the UK, 57,000 elderly individuals suffer a fall on the stairs in their own home each year, with almost 1,000 dying as a consequence [127]. A further 22,000 experience a serious injury resulting in admission to hospital with concussion, a fracture or some other ailment, which requires them to stay in hospital for more than one day.

To summarise, the effects of falls can be devastating and include a reduction in confidence – increasing the risk of further falls; bruising; broken bones – hips, wrists, neck, arms, legs, clavicle, neck of femur; loss of independence/institutionalisation; and death.

Non-Falling Accidents

HASS data from 1986 showed that 0.23% of all domestic accidents involved a gas appliance and that two-thirds of those who suffered such an accident required some form of medical attention after assessment at an Accident & Emergency (A&E) department. Over half of gas-related fatalities were of people aged over 61. The most common non-fatal injuries involving gas appliances are burns – most of which were caused by the person touching the host surface of a gas appliance, rather than by touching a naked flame. The elderly are particularly prone to delayed ignition accidents on gas appliances[8]. These are caused primarily by forgetfulness, as in the case of someone with dementia, and also by restricted movement - causing problems when bending down to ignite the gas, resulting in a delay. Potentially catastrophic incidents involving gas appliances and people with dementia are common enough to be a cause for concern. Tales of dementia sufferers placing plastic electric kettles on a gas hob are not uncommon. There are two major issues - when the client turns on the gas but forgets to ignite it and when inappropriate objects are placed on a lit gas hob, such as a plastic electric kettle.

Accidents can also be due to electric appliances, and can typically be categorised as: tripping hazards caused by trailing electric cables; the overheating of equipment causing scalding & burns; and fire. Some of the older electric blankets, for instance, are notorious for overheating, with the elderly being more likely to own the oldest and least reliable variety of blankets. Confusion as to whether the device can be left on over-night whilst sleeping in bed is also an issue with an uncertainty between the difference in under- and over-blankets[9].

Another scenario, which is sufficiently common to be of concern and that can lead to scalding/burn accidents or hypothermia, is when elderly individuals become stuck in the bath. This may be due to a slip and a fall whilst in the bath or because they are suffering from some form of physical impairment or weakness that makes it difficult to lever themselves out. In one study [128], 1 in 7 elderly patients admitted to a geriatric day hospital were found to have experienced being stuck in their bath at least once, with some having been stuck for several hours and sometimes overnight. Their means of escape were varied, with some managing to get out unaided, and the remainder requiring assistance off a family member, warden, neighbour or ambulance crew. Adverse physical effects were rare but included bruises, pressure sores and myocardial infarction. The psychological impact of the event was however reported to be considerable, with patients describing it as "a terrible experience" and sometimes panicking, with some patients resorting to banging on the wall to try to attract attention. All patients had changed their bathing habits following the incident with some having showers installed, others were awaiting physical aids to be installed in the bathroom whilst some did not now bathe alone, preferring to have a relative present on-hand to assist or by bathing at a local day centre.

Problems with Medication & Polypharmacy

The older one gets, the more medication is consumed. Of people over the age of 75, 80% take at least one prescribed medicine, with 36% taking four or more [129]. Multiple pathology and complex medication regimes may impair a client's ability to effectively manage their own medication regime. Adverse reactions to medication are implicated in 5-17% of hospital admissions. As many as 50% of elderly individuals may not be taking their medications as prescribed and it is estimated that in excess of £100 million of medicines are never consumed once prescribed. Compliance problems with medication and, in particular, polypharmacy, can cause several problems in the elderly, including:

[8] *Additionally, the elderly are, along with people suffering with heart or respiratory problems, particularly susceptible to carbon monoxide poisoning.*
[9] *the former is designed to heat up an empty bed, whilst the latter may be left on all night.*

- Some drugs have a direct effect on the ability of an individual to keep their balance. Such therapies include drugs which lower blood pressure or blood glucose levels, those that affect heart-rhythm, hypnotics, anti-depressants, sedatives, tranquillisers and anti-convulsants.
- The elderly often have an increased sensitivity to certain drugs leading to inappropriate drug ingestion resulting in iatrogenic illness. Adverse drug reactions are twice as likely to occur in people aged between 60 and 70 as in those aged between 30 and 40 years [130] and three times as likely in the over 80's as in the under 50's [131].
- Polypharmacy is a particular problem with the elderly, the oldest 16% of the population receive 40% of all drug prescriptions with the result that interactions increase and compliance decreases, especially with clients who suffer some form of cognitive impairment. In 1981, three quarters of over 75's were taking some form of regular medication with two thirds taking between 1 and 3 different drug therapies whilst the remaining third are estimated to be taking up to 4 or 5 drug therapies at once [132]. Problems also arise when elderly individuals take it upon themselves to purchase additional drugs from their local chemist, hoard medications from repeat prescriptions and also swap medications with their friends.
- Poor compliance increases with the number of medicines prescribed and is also worse with clients who exhibit some form of confusion or dementia or those who live alone and socially isolated. Non-compliance may be due to not taking the medication at all, taking medicines for incorrect reasons, errors in dosage (i.e. incorrect quantity of drug or frequency of taking), and taking additional medication not prescribed by the physician.
- Repeat prescriptions can build up without careful consideration for regular review of the need for the medicine, and monitoring that the medicine is being taken as directed and that the client is benefiting from it.
- Dosage instructions can be vague e.g. "Take as directed" or "Take as required" – individuals need support which may be problematic if there is no easy access to their pharmacy.

Table 3.9. Issues with medication and the elderly.

Indicators of risk with elderly & medication	Problems which hinder medication compliance
Taking 4 or more medicines (polypharmacy is a risk factor for falls).	Problems for client with ordering, picking up repeat prescriptions.
Use of specific medicines, e.g. warfarin, diuretics, digoxin - clients taking hypnotics are more likely to fall during the night.	Problems for client with removing medicines from containers.
Recent discharge from hospital (and change in prescription/medication scheme).	Swallowing tablets.
Inadequate level of home support available.	Reading labels.
Physical impairments such as poor vision and dexterity.	Forgetting to take medicines.
Cognitive impairments such as confusion and dementia which may lead to temporal disorientation, memory and comprehension problems.	Deliberate non-compliance.
Dehydration in clients taking diuretic or laxative medicines can also contribute to falls.	Unpleasant side-effects.

The risk factors associated with elderly individuals taking medicine and some of the problems which may lead to non-compliance are listed in Table 3.9. There is a clear need to monitor compliance (right medications and right quantities at right time) and side-effects of particular medication regimes, e.g. effects on sleeping patterns, falls, and excessive diuresis (increased secretion of urine by the kidneys).

Security

In addition to accidents, the client's perception of their safety is influenced by how secure they feel in their own home. The results of the survey undertaken by Tunstall [123] reported that:

- 25% of elderly people felt unsafe in their home during the day.
- 40% felt unsafe in their homes at night.

Bogus callers and distraction burglary are a serious concern for the elderly; in 1998, there were 16,000 known offences but the figure is likely to be 4 or 5 times higher again due to the manner in which data is recorded [133]. The average age of victims is 81 years and 60% are female, with the majority living alone. Such crimes can lead to heart attacks, stroke and worsened mental stability [133]. Thus, aspects of home security also need to be considered as part of an integrated approach to telecare and the consideration of client safety and well-being. One of the risk factors which contributes to a feeling of insecurity is isolation. A survey conducted by MORI in association with Help the Aged and British Gas [134] concluded that older people who were most vulnerable to isolation included:

1. **The very old**: 26% of people aged 75 and over agree that they are "more or less alone and socialise with very few people";
2. **Pensioners on low income**: are twice as likely to feel trapped in their own homes as those on higher incomes and twice as likely to be acutely isolated;
3. **Older people with a limiting long-term illness**: are more likely to be isolated than those people who are in better health. 14% report that in the last year they have felt like no-one knows they exist, against 3% of those without a limiting illness;
4. **Older women and widowed**: are more than twice as likely to feel trapped in their own homes compared to older men. Nearly half of all widows surveyed said they sometimes felt lonely.

Quality of Care

The quality of the care (QoC) experienced by the client has a significant impact on the overall risk associated with the client remaining at home. Local authorities are generally providing more home care and 'buying-in' more home care than ever before. In 1992, the total number of home care hours provided by local authorities by both internal and external sources was 1.7 million, rising to 2.6 million by 1998. In 1992, 2% of home care (40,000 hours / week) was sourced from an external provider but in 1998 this figure had risen to 46% (1.2 million hours / week) [135]. The QoC provided by such home care services may have a direct safety-related impact on the integrated telecare package supplied to any individual client. If the QoC is poor, then the likelihood is that the risks which this care is designed to manage will spiral upwards leading to increased instability in the client's well-being.

Traditional techniques of monitoring QoC are ineffective as they involve someone accompanying the carer into a client's home to assess the level of service provided, which clearly affects the carer's normal routine. Telecare may offer an indirect method of assessing the QoC provided by the more objective technique of monitoring the nature of care-events.

For instance, it is possible to monitor:

- If the carer is on time for pre-arranged visit.
- The response time, if responding to a traditional alarm call.
- How long the carer stays per visit.
- The total number of visits.
- The type of care provided during each visit (e.g. if the carer is responsible for bathing the client then it is possible to monitor the flow of water into a bath and to detect the length of time for which the bathroom is occupied).

Thus whilst not strictly monitoring the *quality* of the care provided to the client, it does offer a technique of monitoring the *quantity, type* and *punctuality* of care provided which may be of use for auditing purposes, especially where external care agencies are used. This concept may be extended by breaking down a 'care episode' into a number of essential steps which can be compared with an ideal sequence in order to produce a quality approval index.

3.3 Specific Care Needs & Concerns of the Elderly

Having discussed the concept of well-being and considered some of the techniques used to measure it, it is possible to identify potential areas where telecare may be of assistance to clients and care providers alike. When combined with a consideration of the kinds of problems that face the elderly, a range of needs that may be met using telecare can be identified and used to develop ideas for telecare services.

3.3.1 Care Need Classification Methodology

Figure 3.13 illustrates the complex relationship between a client (with associated pathology) and their resulting use of both informal (where available) and formal care resources.

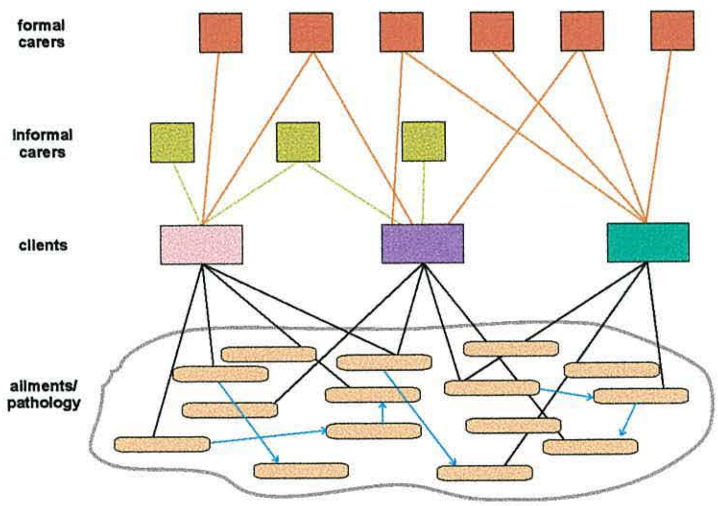

Figure 3.13. The complex relationship between a client's pathology and care requirements.

To complicate matters further, a particular pathology may lead to or imply another (cyan arrows), which may have 'silent' symptoms or remain undiagnosed. The care needs of the client and the care providers will therefore primarily depend on the range and type of pathologies and associated symptoms present. The telecare services required by a client will therefore typically depend on:

1. The ailments and pathologies suffered, and their interactions.
2. The availability and location of informal care.
3. The type and intensity of formal care required.
4. The personal circumstances of the client, including local environmental conditions.

For example, consider the care needs of three individuals: Client A, who has dementia (see Figure 3.14); Client B, who has recently suffered a stroke (see Figure 3.15); and Client C, who is experiencing as yet undefined cardiovascular irregularities (see Figure 3.16).

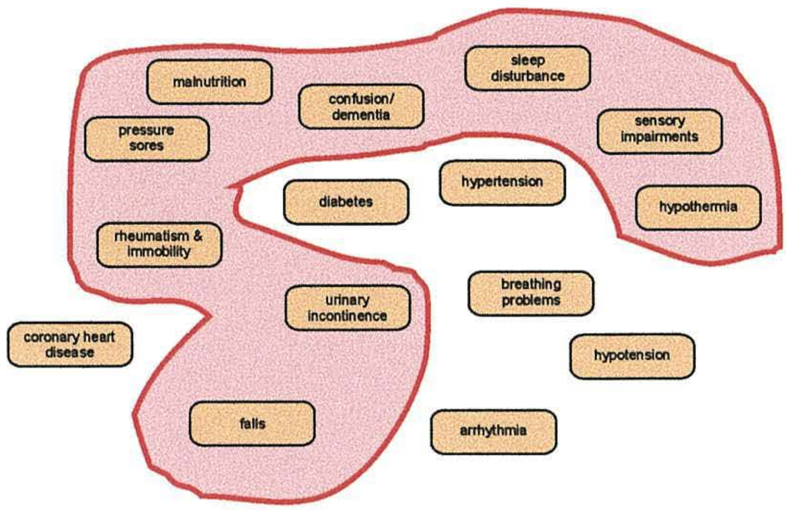

Figure 3.14. Ailments and pathologies suffered by Client A - Dementia.

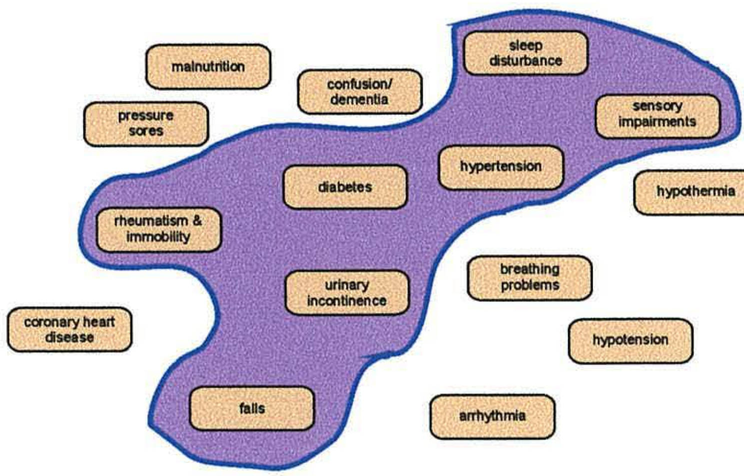

Figure 3.15. Ailments and pathologies suffered by Client B - Stroke.

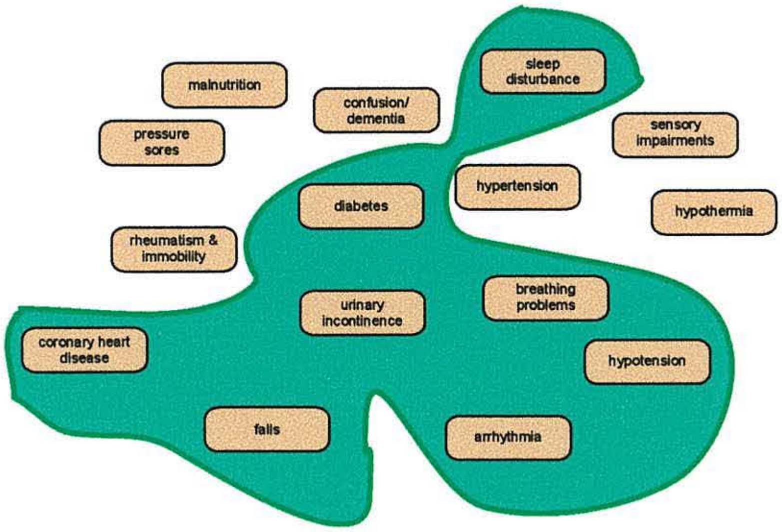

Figure 3.16. Ailments and pathologies suffered by Client C - Cardiac irregularities.

The shaded areas in Figures 3.14 – 3.16 represent the ailments and symptoms suffered by each client, the choice of which was non-arbitrary. However, Client C might just as easily suffer from rheumatism and not be diabetic; and Client B might possess a speech disorder and not suffer from incontinence. Thus, an approach based on the care needs associated with each individual ailment and its associated symptoms will result in individual clients inheriting the care requirements that apply accordingly. Client-oriented services for next-generation telecare may therefore be identified by analysing their needs in relation to a number of key pathologies and their associated symptoms. Those that are most common in the elderly[10], and that have been considered in some detail, are listed in Table 3.10.

Table 3.10. Common pathologies and symptoms used to identify telecare services for the elderly.

General frailty	Urinary incontinence	Hypo-/Hypertension	Depression & isolation
Sensory impairment	Pressure sores	Cardiac irregularities	Sleeping disorders
Physical impairment/immobility	Hypo-/Hyper-thermia	Diabetes	Other miscellaneous
Cognitive impairment	Malnutrition	Respiratory disorders	

3.3.2 Care Needs & Concerns of the Elderly

Table 3.11 summarises a selection of the key concerns and care requirements/needs identified from an analysis of Appendix A and from consideration of stakeholder viewpoints as being potential areas where telecare may be of assistance.

[10] *as established in Appendix A.*

Table 3.11. A selection of care needs & concerns of the elderly and their carers.

Ref.		Stakeholder Needs and Concerns
1		**General Need & General Frailty**
	1	There is a need to provide a safe and secure domestic environment for the client.
	2	The elderly are at a higher than normal risk of falling and would benefit from a method of raising an alarm if unable to recover by themselves in order to prevent the likelihood of suffering a long-lie.
	3	Informal carers want a way of remotely checking-up on the client for re-assurance purposes.
	4	Carers would benefit from being able to perform continuous comprehensive multi-parameter assessments on the client in their home and of being notified if there is a potential issue of concern.
	5	Clients who are exposed to ambient temperatures outside the range considered to be comfortable (approx. 18°C – 24°C) are at increased risk of ill-health or even death (e.g. respiration difficulties, myocardial infarction, stroke, pneumonia).
2		**Sensory Impairment**
	1	Clients with impaired hearing may require assistance with: hearing audible alarms; hearing messages presented in a spoken form; distinguishing between one type of audible alarm and another; locating the source of an audible alarm; hearing a doorbell or knock; hearing the telephone.
	2	Clients with impaired vision may require assistance with: identifying objects; setting dials; operating switches as intended; interacting with system elements; interpreting information provided visually (especially textual or alarm information); reading labels/instructions provided with prescriptions and other medications; identifying visitors/callers.
	3	Clients with a poor sense of smell are less likely to be capable of detecting an unlit source of gas or gas leak, especially if in a different room.[11] This can lead to a risk of suffocation or explosion.
	4	Clients with a poor sense of smell or taste may have difficulty identifying spoiled foods and may also suffer from a loss in appetite. When linked with other problems such as confusion or depression, this may expose the client to an increased risk of food poisoning or malnutrition.
	5	Clients with sensory impairments may have a higher than normal risk of suffering an impact accident or of falling[12]. For example: clients with impaired vision, especially if mobile in the dark, and clients with hearing impairments who may experience problems keeping their balance.
	6	Clients who have problems noticing extremes of temperature (e.g. diabetes), especially at the extremities of the body. This exposes the client to an increased risk of serious burns and scalding.
	7	Clients who fail to perceive ambient temperatures correctly may be placing themselves at risk of developing hypothermia. Temperatures below 12°C can induce transient increases in blood pressure that may be contributory factors towards increased morbidity caused by heart attacks and strokes.
	8	Clients with sensory impairments can become socially withdrawn and isolated preventing them from participating in community life or of carrying out essential activities such as buying their own food.
3		**Physical Impairments/Immobility**
	1	Clients with mobility, range-of-motion and handling problems (e.g. arthritis, hemiplegia, abnormal gait) may be at an increased risk of suffering an impact accident or of falling; and may need assistance with: performing everyday tasks (e.g. ADL); interacting easily with their living environment; responding to a doorbell/knock at the door; and may benefit from alternative methods of activating alarm triggers.
	2	Some clients with severe mobility problems (and who may be virtually housebound) are at risk of becoming socially isolated from the outside world and their local community preventing them from shopping, banking and undertaking other social activities.
	3	Clients who are very immobile (e.g. chair-bound or bed-bound) and frail have a higher risk of developing pressure sores and need appropriate care and support mechanisms to manage their risk.
	4	Clients with mobility problems may find it difficult to warm themselves in the winter months if their house becomes cold, which makes them susceptible to hypothermia.
	5	Clients who are physically frail can find themselves stuck in a chair, in the bath or on the toilet because they are unable to lift themselves up.
	6	Clients suffering with arthritis or severe back pain may benefit from pain-relief systems and e-therapy.
	7	Clients with physical impairments may have difficulty negotiating stairs and need appropriate support.
4		**Cognitive Impairment**
	1	Clients with dementia may require assistance to focus their attention on performing tasks (e.g. washing in the morning, preparing and eating food) or devices (such as those providing information).
	2	Clients with dementia often become disoriented in time and would benefit from temporal re-adjustment/reminder mechanisms.
	3	Clients with dementia often become disoriented in space, and can wander and become lost. This can be a worry for their family, especially if they cannot be located.
	4	Clients with short-term memory problems require assistance with their use of 'post-it' notes for helping to remember important dates and events, e.g. appointment with GP, daughter's birthday. Their use

[11] *This problem is compounded if the client has short-term memory problems (e.g. dementia – where the sense of smell can also be affected) which means there is a higher than normal risk of an unlit gas source being left on for a significant amount of time.*
[12] *These effects are made worse if other symptoms such as impaired motor control, reduced dexterity or cognitive impairment is also present. Stair-use is a particular concern.*

Ref.		Stakeholder Needs and Concerns
		eventually becomes cumbersome and self-defeating as reminders are repeated and multiply.
	5	Some clients need reminding when to take medications, which ones, and how many to take, especially if multiple medications are being taken at once (polypharmacy). Clients with mild to moderate dementia taking cholinesterase inhibitors have been shown to have improved cognitive function and activities of daily living. However compliance must be assured in order for success.
	6	Short-term memory impairment can lead to problems with home-security if the client goes to bed or leaves the home with a ground floor window or front or back door left open.
	7	Clients suffering with general cognitive, sensory or short-term memory problems are prone to leaving household appliances (such as heaters, electric blankets, cookers, irons or gas-hobs) or other household items in an inappropriate state that may be undesired or unsafe.
	8	Clients suffering with cognitive problems may operate household appliances in an unsafe manner (e.g. placing a plastic kettle on top of a gas-hob or placing metal items in a microwave oven).
	9	Clients with dementia sometimes have trouble performing tasks that require sequential co-ordination, e.g. what to do first thing in the morning after waking-up, how to cook a meal, etc. and might benefit from techniques to guide them through such sequential operations.
	10	Clients with dementia and short-term memory impairments repeatedly lose or misplace important items such as door-keys, pension book, and purse/wallet and would benefit from a means of locating them.
	11	Confused individuals are at risk of being conned by bogus-callers and becoming victims of 'distraction burglary' and would benefit from systems to prevent the chances of such a crime being successful.
	12	Clients with dementia can exhibit inappropriate behaviour leading to hazardous situations such as wandering out of the home and becoming disoriented or going outside wearing inappropriate clothing.
	13	Clients with dementia sometimes exhibit anti-social behaviour such as using the vacuum cleaner, playing loud music or phoning relatives at inappropriate times, e.g. 2 AM.
	14	Clients with dementia can sometimes forget to eat.
	15	Clients with cognitive impairments are at an increased risk of falling and may, along with the frail, benefit from the availability of preventative techniques to avoid falling in the first place.
	16	Clients with dementia are at an increased risk of becoming (urinary) incontinent leading to personal discomfort and the potential for unpleasant odours and increased laundry requirements.
	17	Some clients who suffer a stoke (for instance) can have language and communication disorders and may benefit from techniques of supporting them to communicate effectively.
	18	Carers living with clients with dementia need alerting when a client leaves a 'safe' zone (e.g. living room) and enters a 'hazardous' zone (e.g. kitchen) or if a client has changed from being in a stable state (e.g. in bed, sitting down) to a potentially unstable state (e.g. up and about, pacing, wandering).
5		**Urinary Incontinence**
	1	There is a need to provide a mechanism of reminding the client to use the toilet at regular intervals.
	2	The client and carer need to know if the incontinence containment product in use (e.g. incontinence pad, kylie sheet) is soiled and needs replacing (currently have to feel the product with their hands!).
	3	There is a need for a system of helping the client to find the bathroom if they are cognitively impaired.
6		**Pressure Sores**
	1	There is a need to reduce the likelihood of pressure sores occurring or becoming worse. This is a particular concern in the community where it is more difficult to manage the activities of the client.
	2	A client with or at-risk of developing pressure sores should not bathe or shower in hot-water.
	3	A client with or at-risk of developing pressure sores should not bathe or shower for extended periods.
	4	Adverse environmental conditions (low humidity and cold air) can lead to an increased risk of developing pressure sores or of prolonging their occurrence.
7		**Hypothermia & Hyperthermia**
	1	Clients are at risk of developing hypothermia if they are exposed to low temperatures (< 19 deg. c) for extended periods of time leading to a diminished ability to resist respiratory infection (e.g. pneumonia).
	2	Clients risk hypothermia if a bath or shower is too cold or if they stay in the bath/shower for too long.
	3	Clients are at risk of hypothermia if they venture outside in the cold wearing unsuitable clothing.
8		**Malnutrition**
	1	Malnutrition may be caused by cognitive impairment (e.g. dementia) which means that the client simply 'forgets' to eat regularly or does not remember how to prepare food correctly.
	2	Clients who have, for example, recently been diagnosed as diabetic or with high blood pressure or cholesterol or who have been diagnosed as obese and at risk of a serious cardiac event may benefit from readily available and accessible advice on dieting/lifestyle/exercise options.
9		**Hypotension & Hypertension**
	1	Blood pressure must be controlled to minimise risks associated with it being too high or too low. Long-term trends obtained by ambulatory monitoring may provide more meaningful data on which to base suitable therapeutic interventions than measurements performed in an institutional setting.
	2	Clients with hypertension, especially those who have been newly diagnosed, might benefit from supportive advice concerning their exercise and diet regimes.
	3	Clients and carers need to be sure that medication is working correctly, with few adverse conditions.
	4	Low-blood pressure resulting in postural hypotension can increase the risk of falling.
	5	Carers would like to be able to ensure that the client is performing the necessary blood pressure tests.

Ref.		Stakeholder Needs and Concerns
10		**Cardiac Problems**
	1	A cardiologist requires access to cardiac parameters to characterise problems or gauge recovery.
	2	The client may be requested to keep a diary of events, activities and symptoms as an aid to diagnosis.
	3	Clients may feel anxious after returning home following a cardiac event and would greatly appreciate the ability to obtain help in the event of an emergency.
	4	Diagnostic information from cardiac pacemakers will help to manage their maintenance.
11		**Diabetes**
	1	People with diabetes may benefit from support with insulin management, especially those who have only recently been diagnosed or who have been diagnosed along with other conditions simultaneously.
	2	People with diabetes are concerned about the risks of suffering a hypoglycaemic attack, especially during the night when sleeping.
	3	Clients who have recently been diagnosed as diabetic may benefit from readily available and accessible advice on dieting/lifestyle/exercise options.
	4	Carers would like to be able to ensure that the client is performing the necessary blood glucose tests.
12		**Respiratory Disorders**
	1	Clients exposed to low temperatures for extended periods of time have a diminished ability to resist respiratory infection (e.g. pneumonia).
	2	Both low and high relative humidity promote respiratory illness and should be avoided.
	3	Clients who regularly monitor their condition (e.g. spirometry for asthma and COPD) may benefit from automated techniques to store, analyse and display their data.
	4	Clients may benefit from therapeutic services that are linked to their monitoring results.
	5	Carers would like to be able to ensure that the client is performing the necessary respiratory tests.
13		**Depression & Isolation**
	1	Clients who are isolated and at particular risk of falling are particularly vulnerable to suffering a long-lie and might benefit from the confidence that a fall detection system would provide.
	2	Clients may benefit from a means of extending their interaction with the world.
14		**Sleeping Disorders**
	1	In order to diagnose a client suffering from sleep disturbance, it is necessary to obtain a history of their sleeping patterns and to establish the symptoms present.
	2	Clients who suffer with insomnia are often given medication associated with an increased risk of falling.
	3	Clients who suffer with insomnia may be given medication based on antihistamines, these can result in side-effects including: confusion, agitation, orthostatic hypotension, arrhythmias and urinary retention.
	4	Environmental factors (e.g. bedroom temperature that is too high or too low or noise) may be to blame.
	5	The provision of home-based sleep apnoea therapy is desirable.
15		**Other Miscellaneous**
	1	A client with epilepsy who lives alone or who is often left alone in the house may require assistance if they suffer an epileptic seizure.
	2	Geriatricians and other physicians complain of a general problem with non-compliance with the use of hip-protectors in the community.

3.4 The Scope for Telecare

From the preceding discussion of geriatric health care, many services may be identified that will benefit the elderly, and their carers, in a domiciliary setting. The vast majority of these services will rely on the ability of the telecare system to monitor appropriate parameters within the domain of interest, as set out in Figure 3.17. The services provided by telecare can be segregated according to the following classifications:

1. Client Screening & Assessment.
2. Client Support & Assistance.
3. Emergency Monitoring & Response.
4. Client Safety.
5. Care Management.

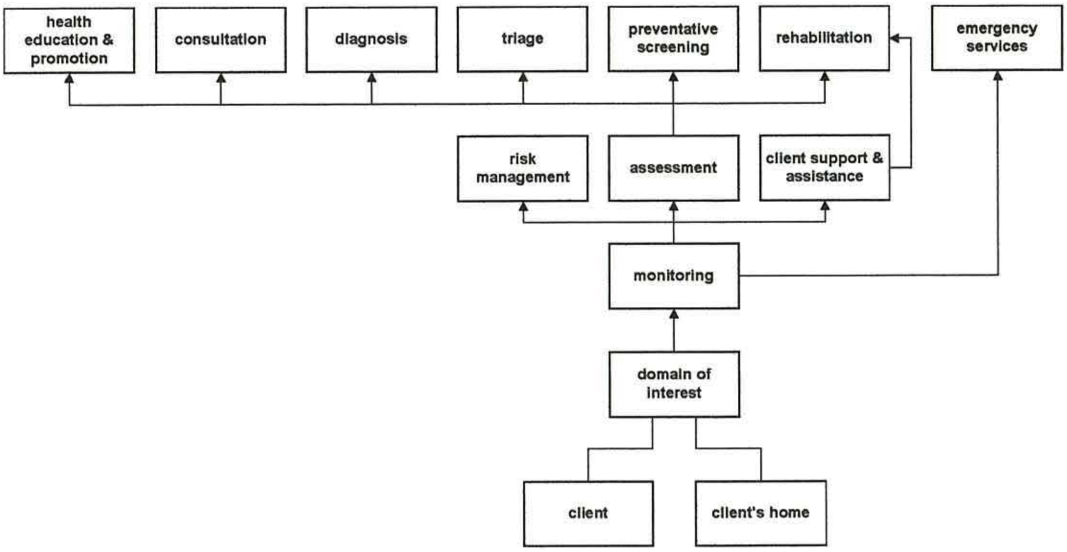

Figure 3.17. Many telecare services will rely on the monitoring of the domain of interest.

3.4.1 Client Screening & Assessment

Occupational or physiotherapists using suitable ability tests are currently responsible for performing functional assessments, usually by interview. The potential of telecare to perform continuous automated *comprehensive* assessments of a client is highly desirable for a number of reasons:

- The assessment would be performed automatically and discreetly thus removing an artificial pressure from the client, resulting in more normal client behaviour and performance and hence resulting in a more accurate assessment score.
- The assessment would be performed in the natural living environment of the client and should also result in more realistic data and hence a more accurate assessment score.
- Automated assessment procedures can be in operation continuously 24-hours a day, 365 days a year, thus providing carers with invaluable trend information that is impossible to obtain using manual assessment procedures.
- An analysis of historical trends can be used along with suitable intervention thresholds and baseline pre-morbid data to screen a client for general or specific problems and used to trigger more specific care assessment protocols, either automated or via a home visit from a carer. This allows a preventative approach and should result in a better allocation of resources.
- It would be possible to monitor the use of assistive devices that had been provided as part of the client's discharge plan. Very often, these are neglected soon after discharge, placing the client under greater risk. If the devices were being used infrequently or incorrectly, then this might indicate that more training is necessary or an alternative, more appropriate, means of providing the support should be sought for that individual client.
- It may be possible to assess the efficacy of individual interventions by monitoring the effect on the client's functional assessment score before and after its introduction.
- By monitoring many parameters at once, it is possible to perform a multi-variable analysis on the available data, which might provide key indicators of particular problems.

3.4.2 Client Support & Assistance

There are many opportunities for telecare to support and assist the client in their wishes to remain independent in their own home and may well be a means of breaking out of the cycle of dependency. Supportive systems are likely to be particularly suitable for clients who suffer from some form of physical or mental incapacity or physiological problem. Examples include devices such as: smart wheelchairs, reminder systems for individuals suffering from dementia, medication delivery and compliance monitoring devices, therapeutic systems such as Transcutaneous Electrical Nerve Stimulator (TENS) unit for individuals with chronic pain, oxygen therapy units, nebulisers and biofeedback systems. In addition, 'smart' home automation services are also of benefit to clients with physical and cognitive impairments and also provide a service of convenience for others. Such services not only allow a more efficient use of environmental control systems, but also enable other services such as risk management and home security.

3.4.3 Emergency Monitoring & Response

There is great potential for telecare to provide an emergency detection and alerting service. There are many situations in which the client may either be unable to raise an alarm or is unaware that an alarm condition is present. In the event of a medical trauma or other emergency, the speed of response is important for client survival. The events that occur during the first hour after a medical trauma significantly impact survival; this period is referred to as the "golden hour". The automatic detection of emergency situations and generation of suitable alarms (with appropriate data describing the incident together with client-specific information) will ensure that individuals receive the best possible care.

3.4.4 Client Safety

Telecare has the potential to be an important enabling technology, empowering individuals to help themselves by retaining a level of independence at home through the use of appropriate monitoring of and response to need. It can provide a 'safety-net' approach to the care of individuals who should be capable of living a healthy and independent life alone at home, provided that the risks associated with them doing so are managed effectively. Telecare technologies can compensate for the lack of immediate and local care expertise by providing care and support in response to identified and established need. In adopting such a technological approach, a compromise must be reached between the client's desire to live at home (at all costs) and the inevitable risks associated with them doing so, particularly as their reliance on technology also increases.

3.4.5 Care Management

Care procurers and providers would benefit from access to (tele)care management and auditing tools in order to help them provide a quality service which fulfil the principles of good practice. In particular:

- Care procurers need to know that the care they are purchasing meets appropriate standards.
- Care providers need to be able to prove that care is/was being provided as intended.
- Care procurers/providers need to be able to prove that the telecare system is/was operating correctly (especially in the event of a client mishap or fatality).

- Care procurers/providers need to know if the client is using system elements as intended, e.g. geriatricians complain of a general problem with non-compliance with the use of hip-protectors in the community.
- Care procurers/providers need to know if the client has manually overridden any system service, i.e. that they have taken responsibility for a situation.
- Stakeholders benefit from outcome measures obtained from particular interventions.

3.5 Conclusions

A wide spectrum of need implies that a wide spectrum of services will be necessary to support the integrated care approach required by CarerNet, illustrated in Figure 3.18. The structure of the spectrum is such that progressing from left to right, the nature of the care service changes from being focussed on the client's medical, social and psychological well-being to the status of the client's local-environment.

Figure 3.18. The spectrum of telecare services.

Table 3.12 provides several examples of clients for whom telecare might be considered and illustrates the diversity of service provision necessary. In general, the range of client-oriented services can be divided into three classes: *responsive*, *supportive* and *preventative*, as in the diagram of Figure 3.19. In practice, some services will span one or more of these classes. Thus the monitoring of activities of daily living will require some form of client activity monitoring system, which might also have a security, energy efficiency or safety role. Solutions in categories A & B have a tendency to be device based, while those in zone C will be more system-based. Responsive services are currently represented by first generation telecare such as community alarms systems. These provide a moderated response to a call for assistance, usually initiated by the client; although a number of *extended first generation systems* such as fall alarms which are compatible with first generation systems and which will autonomously initiate a call for assistance are slowly becoming available [28]. Supportive systems are likely to be particularly suitable for clients who suffer from some form of physical or cognitive incapacity and who require aids to support themselves in an independent lifestyle in their home. Conventional smart home technologies offer some services for individuals with limited mobility or physical or cognitive impairment.

Table 3.12. Example telecare services for a diverse range of clients.

Class	Example Client	Telecare Service Provision
A	A middle-aged individual discharged from hospital following cardiac surgery.	Cardiac monitoring, fall detection, 'emergency' response services.
B	An individual with multiple-sclerosis.	Smart wheelchair, various home automation.
C	Individual being assessed for living alone following a change in personal circumstances.	Comprehensive geriatric assessment (activities of daily living, mobility, safety, cognitive, etc.), 'emergency' response services.
AB	Elderly individual living alone at home.	'Emergency' response services, Video-doorbell, Medication management services, Internet access for e-services, continuous functional assessment.
BC	Elderly person suffering from mild dementia living with spouse (informal carer).	Sequencing systems, Wandering alert systems for informal carer, Medication and appointment reminder services, automatic gas shut-off, continuous safety assessment.
AC	Elderly individual living alone requiring reassurance.	'Emergency response services', fall prevention and detection systems, home security systems (e.g. video doorbell and burglar alarm, telemetered utility meter readings to reduce common form of distraction burglary).
ABC	A individual post stroke.	Blood pressure monitoring, medication support, continuous functional assessment, virtual consultations with neurosurgery department, tele-physiotherapy and speech therapy support, fall prevention and management services (e.g. fall alarm, automated room lighting, etc.).

Preventative telecare relates to situations in which the telecare system is responsible for deriving the current, and possibly future, well-being of the client from the available data as provided by monitoring and supervisory systems. It must also aim to manage the risks associated with various hazards with which the client may be confronted. For instance, by employing predictive indices (derived from a multi-variable analysis of the local domain) it may be possible to predict the likely occurrence of particular events, such as a fall [136]. By setting appropriate intervention thresholds in consultation with the client it may then be possible to target resources to those most in need, leaving others to care for themselves in the knowledge that assistance will be provided should the intervention thresholds be breached. Such preventative systems may well form the basis of a more proactive and interventionist strategy for care in the community. This must however take place in the context of consultation and discussion with clients and be capable of accommodating client choice.

To conclude, consider how telecare might meet the needs of Mrs. Jones (from the vignette in Section 3.2.2), refer to Figure 3.5. A *responsive* system has to deal with the consequences of an acute event, which in this instance is a fall. In particular, it must prevent a long lie and hence reduce the possibility of Mrs. Jones developing hypothermia and/or pressure sores. The obvious way to prevent a long-lie is to detect that Mrs. Jones has fallen and to raise the alarm, requesting help be provided immediately. The chances of hypothermia developing would be minimised if the system were able to monitor the temperature in the room and alert Mrs. Jones and a designated responder that the temperature in her bedroom was too low. However, a much more desirable solution would be if the system were capable of *supporting* Mrs. Jones by attempting to *prevent* undesirable events from occurring in the first place. For example, the fall may have been prevented if, upon detecting that Mrs. Jones was awake and out of bed, the system faded-up the lighting in her room. If the system were regulating the temperature in her room, it could have closed the window to protect her from the outside temperature and ensured that the heating system sustained a comfortable temperature throughout the night.

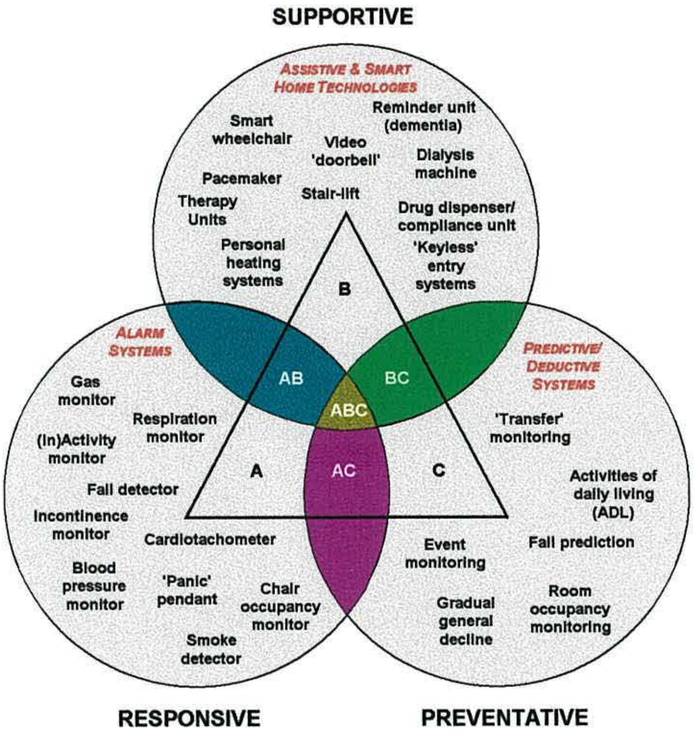

Figure 3.19. Venn diagram of telecare services.

Thus, it may be appreciated that for the case of Mrs. Jones a whole range of services may be necessary to meet her care needs. These services range between fall detection, environmental monitoring, home automation, bed occupancy monitoring and automatic alarm generation. In addition, it may be desirable to be able to assess certain parameters for the purposes of identifying potential hazards before they occur and to ensure that appropriate levels of support are put in place to meet her changing needs. So, for instance, the fact that Mrs. Jones has a fall management system (fall alarm, bed monitor and automated room lighting) and room temperature regulation system in place may be the result of a risk assessment performed by her carers in association with her telecare system.

Chapter Four

An Analysis of First Generation Telecare Technologies

Having considered the gerontological foundations for telecare and identified potential areas of service provision, it is important to consider the capabilities of current (first-generation) telecare technologies. This will establish whether first generation systems are capable of supporting, in any capacity, the types of service anticipated for next-generation telecare. Furthermore, an analysis of their strengths and weaknesses, together with a consideration of their usage, will provide important information concerning the design of CarerNet.

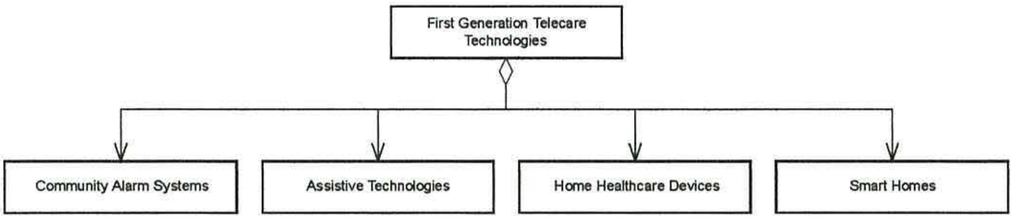

Figure 4.1. The aggregation of systems that constitute first generation telecare technologies.

Figure 4.1 illustrates the four major areas of technology that may be considered to provide or enable elements of telecare in the homes of elderly individuals. Each of these technologies have traditionally been developed and deployed in isolation, each serving specialist markets. Assistive technologies and home healthcare devices provide support and monitoring functionality to many individuals in the community. Smart home technologies provide infrastructure that enables the integration of electronic services within the home, with obvious implications for supporting intelligent care technologies. However, at present, community alarm systems provide the only 'purpose-built' dispersed alarm and response infrastructure and, as such, will be the primary focus of this analysis.

4.1 Community Alarm Systems

Figure 4.2 illustrates the basic functionality of all community alarm systems in place today. The client may use one of several methods to raise an alarm, which is automatically transferred via the public switched telephone network (PSTN) to an alarm response centre (call centre). There the call is dealt with by a human responder, who may then interact with the client to establish care needs and organise such care as appropriate. If the client lives in a sheltered housing scheme with a live-in warden then during office hours the alarm call may be dealt with locally. These systems are simple and popular; however, they suffer from a number of limitations. In order to assess these, it is necessary to analyse the nature of the services provided and the infrastructure upon which they are built. To this end, a model of a community alarm system was conceived.

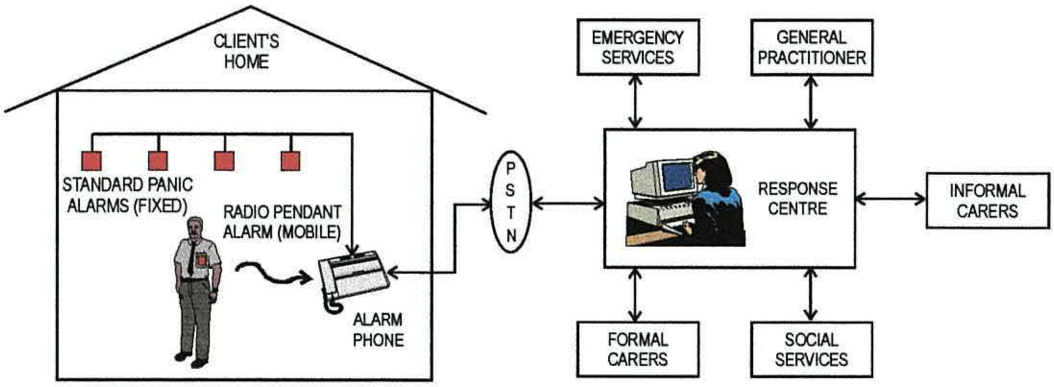

Figure 4.2. Schematic of a standard community alarm system.

4.1.1. Domain Model of a Community Alarm System

The purpose of a community alarm (CA) system is to enable a client to request some form of care-related service on-demand. The CA system may be considered as consisting of technological and human elements, including the equipment in the home of the client and the call-centre as well as the response centre operators themselves. Service providers include the client's GP, pharmacist, informal carers and mobile wardens/health visitors. Figure 4.3 illustrates a selection of use-cases that a CA system might be expected to support[1].

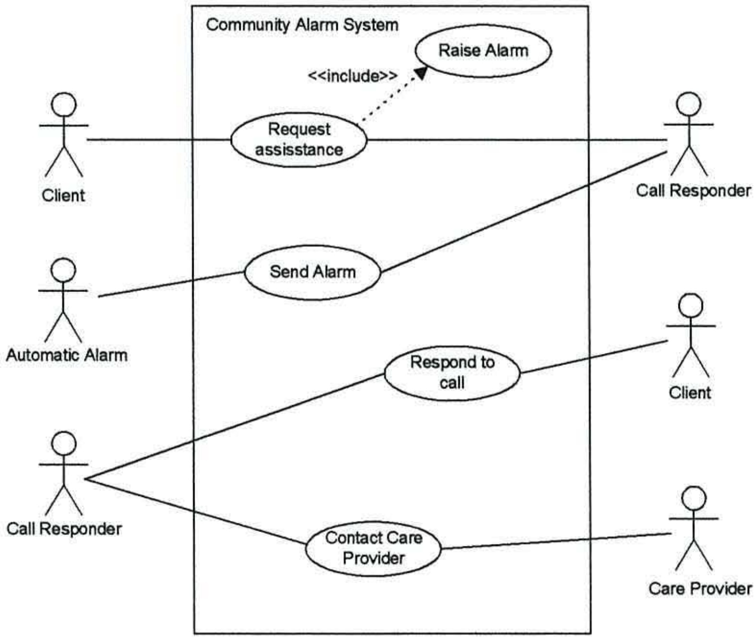

Figure 4.3. A selection of Use Cases for a Community alarm system.

These use-cases are described in detail in Tables 4.1 – 4.4. In Figure 4.3, automatic (or passive) alarms such as smoke alarms are placed outside the domain of the CA system, as have the response operators; this is an arbitrary decision concerning the level of abstraction required to clarify the model. Both of these entities should be thought of as having a need to interact with the CA infrastructure and make use of the relevant services made available.

[1] A use-case essentially shows how 'actors' or stakeholders interact with a system; this helps define the system's boundaries and aspects of its operation.

Table 4.1. "Raise alarm" use case.

USE CASE 1	**Raise Alarm**	
Goal in Context	The client generates an alarm signal in order to establish a connection with the response centre and request help.	
Scope & Level	General high-level.	
Preconditions	The client is able to raise an alarm; the client realizes that assistance is required.	
Successful End Condition	The care-phone receives the alarm signal and establishes a connection with the response centre.	
Failed End Condition	The care-phone does not receive the alarm signal and/or cannot establish a connection with the response centre.	
Primary Actor(s)	Client.	
Secondary Actor(s)	Care-phone, alarm pendant/pull-cord.	
Trigger	Client has a need e.g. has fallen, feels ill, carer has not arrived, etc.	
DESCRIPTION	**Step**	**Action**
	1	Client perceives the need for external care intervention.
	2	Client raises alarm by triggering a device.
	3	Care-phone receives alarm signal, confirms reception to the client and simultaneously dials out in order to establish a connection with the response centre.
	4	When the call is established a response operator enquires as to the purpose of the call.
EXTENSIONS	**Step**	**Branching Action**
	3a	Care-phone is unable to establish connection with response centre: 3a - 1. Care-phone polls through phone numbers in memory until it is successful in establishing a connection.
SUB-VARIATIONS		**Branching Action**
	2	Client may use a panic pendant or a panic pull-cord to raise the alarm; alternatively, they may use the panic button on the care-phone. Client may cancel alarm using the cancel button on the care-phone.

Table 4.2. "Request assistance" use case.

USE CASE 2	**Request assistance**	
Goal in Context	The client requests assistance from the response centre to meet a need.	
Scope & Level	General high-level.	
Preconditions	The client has raised an alarm.	
Successful End Condition	The client is able to obtain the necessary service and/or is left reassured.	
Failed End Condition	The client does not receive the service requested or is not reassured.	
Primary Actor(s)	Client.	
Secondary Actor(s)	Response centre operator, care-phone.	
Trigger	Client has a need e.g. has fallen, feels ill, carer has not arrived, etc.	
DESCRIPTION	**Step**	**Action**
	1	Client describes need to response operator who interacts with client in order to ascertain the most appropriate response.
	2	The response operator provides the most appropriate care and reassurance.
	3	Once the client is reassured then the call is closed.
EXTENSIONS	**Step**	**Branching Action**
	2a	If further external services are required then the response operator acts as advocate on behalf of the client and requests their delivery.
SUB-VARIATIONS		**Branching Action**
	2	After assessing client request/needs, responder either: closes call with no further action; provides advice/reassurance then closes call; passes information on to care services & closes call; forwards call to someone else.

Table 4.3. "Respond to call" use case.

USE CASE 3	Respond to call	
Goal in Context	The response centre operator responds to a call which is made by a client	
Scope & Level	General high-level.	
Preconditions	The call is next in the queue to be answered	
Successful End Condition	The client is able to obtain the necessary service and/or is left reassured.	
Failed End Condition	The client does not receive the service requested or is not reassured.	
Primary Actor(s)	Response centre operator, client.	
Secondary Actor(s)	Care providers.	
Trigger	Client has a need e.g. has fallen, feels ill, carer has not arrived, etc.	
DESCRIPTION	**Step**	**Action**
	1	A call is displayed on the responder's workstation
	2	The responder answers the call and establishes a connection with the client's care-phone.
	3	The responder enquires as to the nature of the call.
	4	Client describes need to response operator who interacts with client in order to ascertain the most appropriate response.
	5	Responder considers client needs/request and provides assistance in the most appropriate manner.
	6	Once client is satisfied then the call is closed.
EXTENSIONS	**Step**	**Branching Action**
	3a	If the alarm has been generated by an automatic triggering device, such as a smoke alarm, then the response operator will act to confirm the status of the alarm with the client. Emergency services will be contacted, as appropriate.
SUB-VARIATIONS		**Branching Action**
	5	After assessing client request/needs, responder either: closes call with no further action; provides advice/reassurance then closes call; passes information on to care services & closes call; forwards call to someone else.

Table 4.4. "Contact care provider" use case.

USE CASE 4	Contact care provider	
Goal in Context	The response centre operator wishes to contact an external care provider on behalf of a client.	
Scope & Level	General high-level.	
Preconditions	Client has called-in requesting assistance of a nature which requires external care/automatic alarm has reported a dangerous situation.	
Successful End Condition	Care providers are contacted and client details & needs are described.	
Failed End Condition	Care providers are not contacted.	
Primary Actor(s)	Response centre operator, care provider/representative.	
Secondary Actor(s)	Client.	
Trigger	Client calls in and is in need of external care.	
DESCRIPTION	**Step**	**Action**
	1	Responder determines from the nature of the call and the available carer list which is the most appropriate to contact.
	2	Responder contacts carer
	3	Responder describes problems to carer and determines best way forward
	4	Responder informs client of situation
	5	Responder closes call
SUB-VARIATIONS		**Branching Action**
	2	Responder is unable to establish contact with preferred carer, in which case the responder tries the next best option.

Figure 4.4 represents a domain analysis of a typical CA system and highlights the main elements, both in the home and in the response centre. The relationships between these elements (or classes) are described semantically in the class association diagrams of Figure 4.5 and Figure 4.6. Figure 4.7 and

Figure 4.8 describe the various activities undertaken during a client-raised alarm and an automatically raised alarm, respectively.

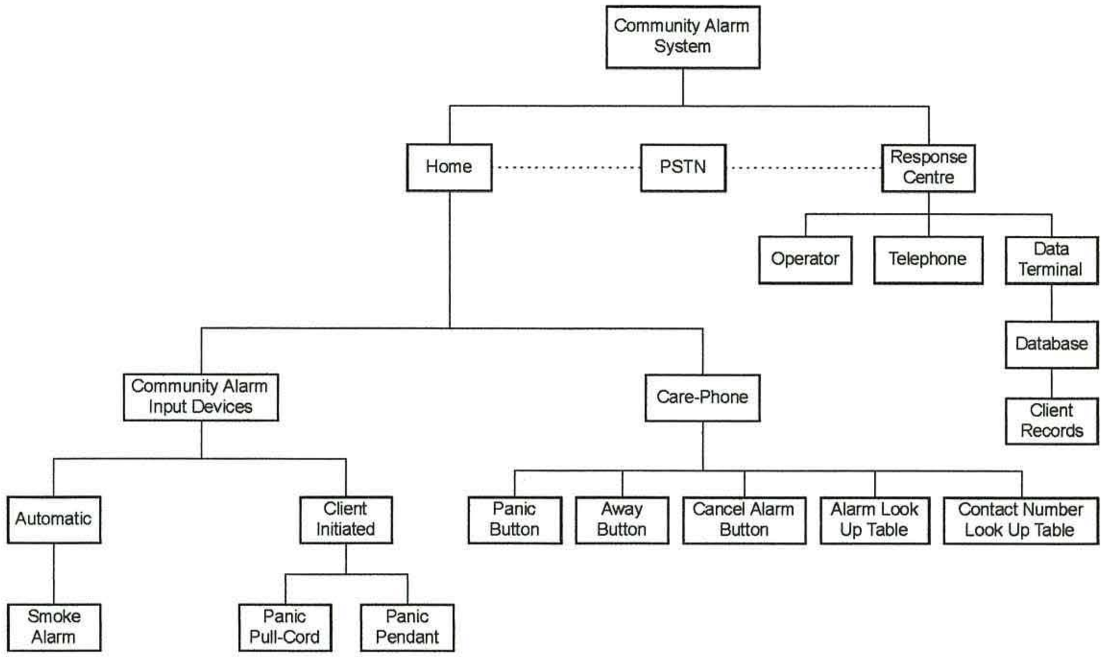

Figure 4.4. Domain Analysis of community alarm system.

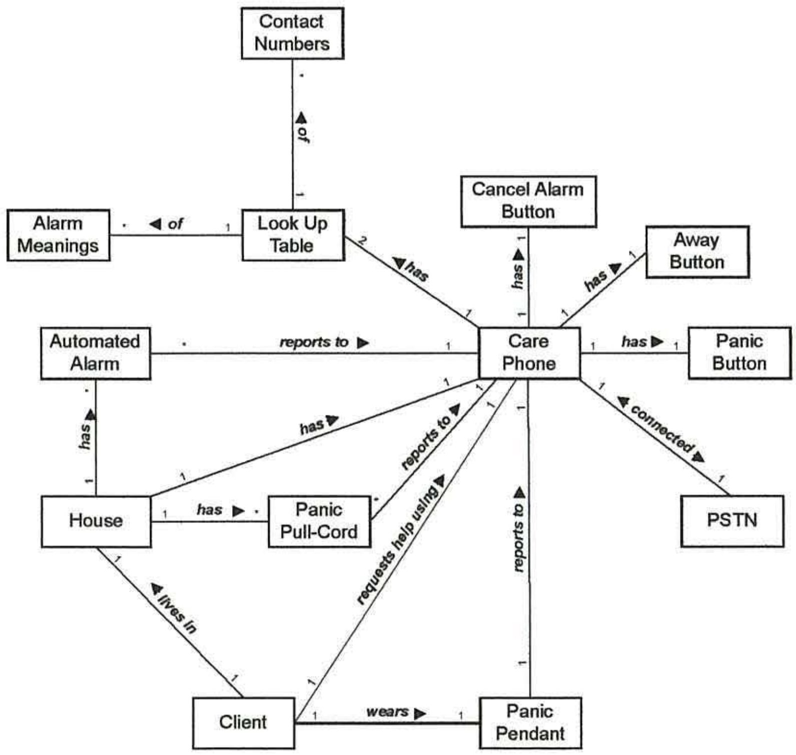

Figure 4.5. Class association diagram for community alarm system in the home.

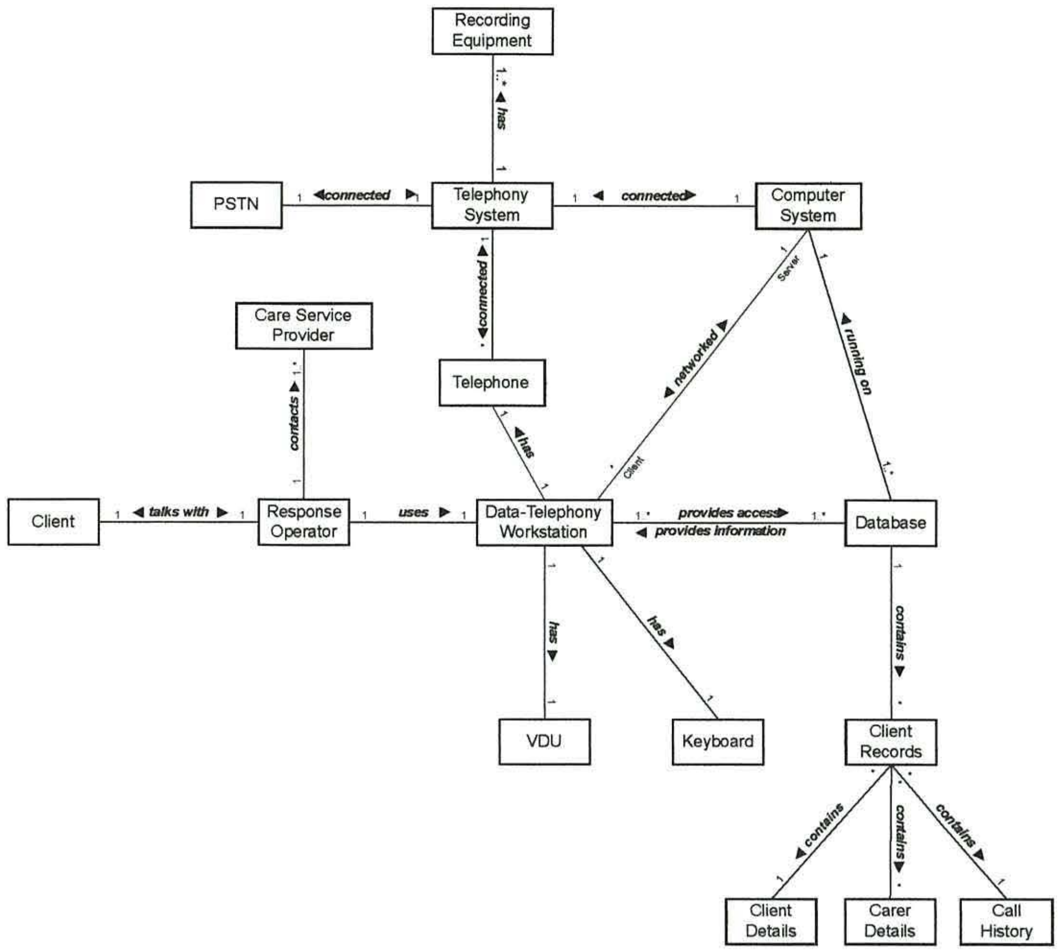

Figure 4.6. Class association diagram for community alarm system in response centre.

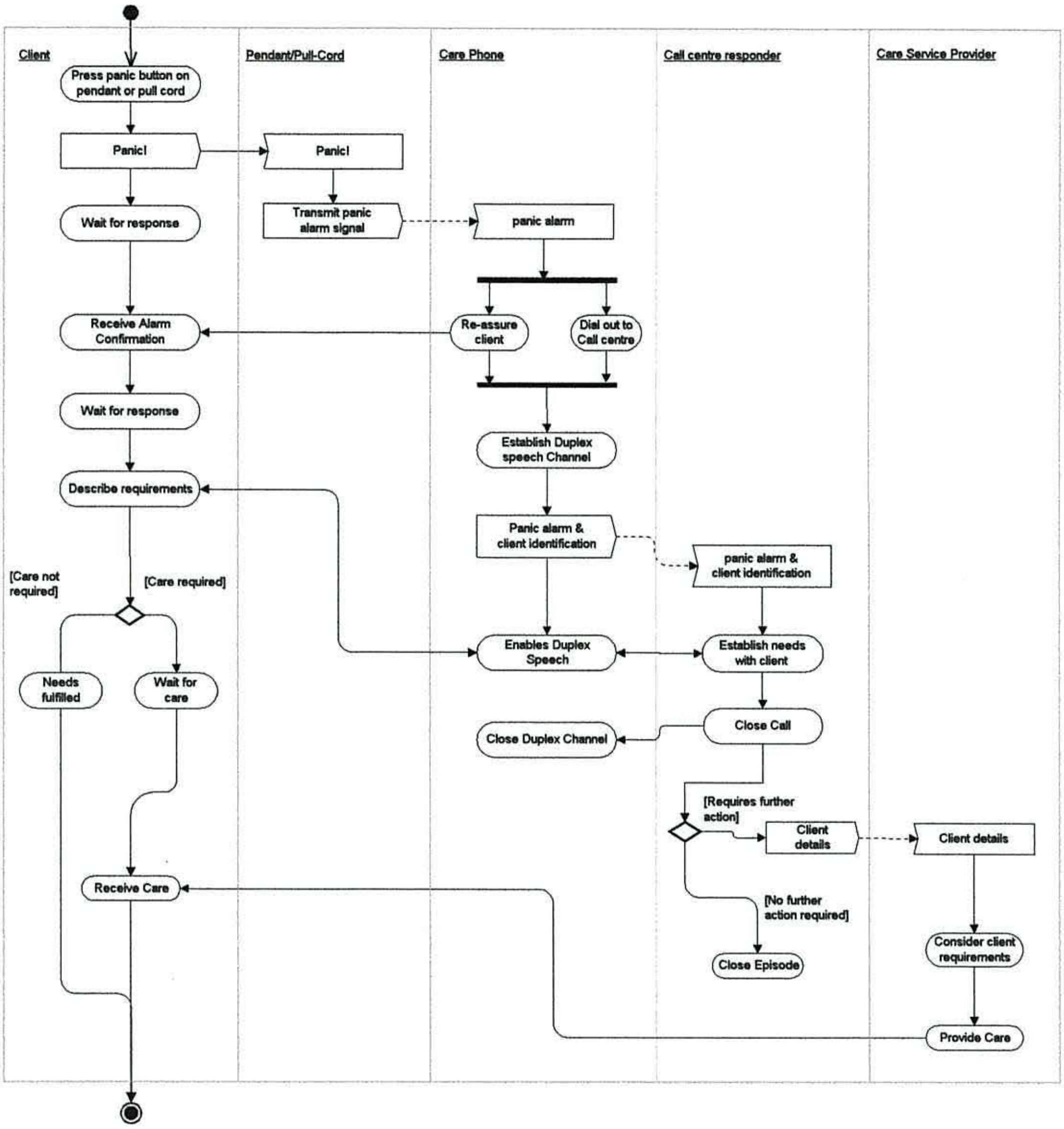

Figure 4.7. Activity diagram for a client-raised alarm.

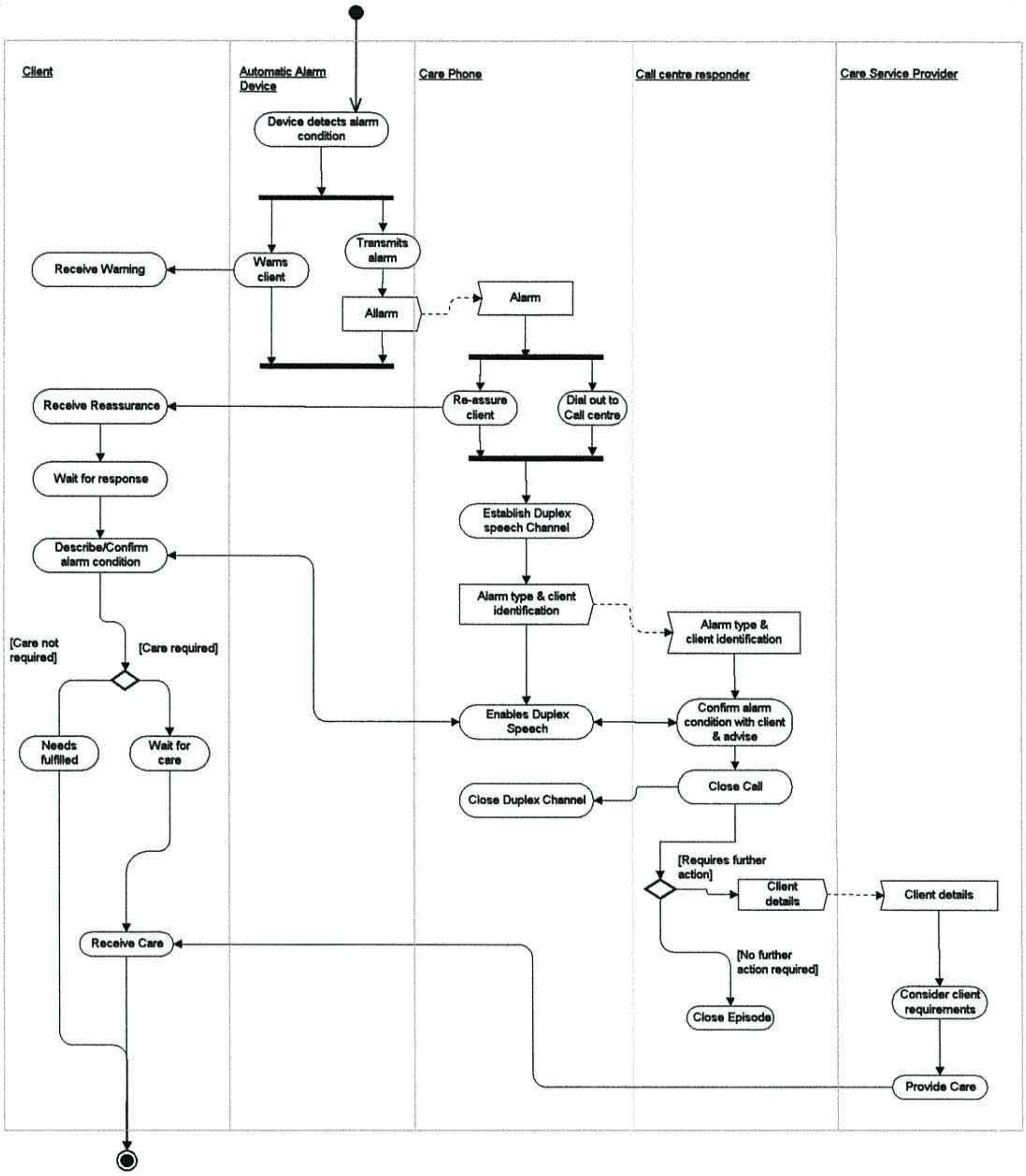

Figure 4.8. Activity diagram for automatic alarm generation.

4.1.2. Client Usage of Community Alarm Systems

Calls to community alarm response centres can be divided into those that are processed by the system and those that are processed by an operator. The former consist of calls informing the centre that a warden has logged on or off for the day, or periodic test transmissions from equipment that has not been activated by the client for more than a significant period of time. [137] contains data, provided to its author during work undertaken under the supervision of Dr. Kevin Doughty in 1997, describing calls received by the Careline CA service run by Birmingham County Council between September 1995 and September 1996. The Birmingham scheme is currently the largest in the UK with over 85,000 'connections'[2]. This information has been re-tabulated according to call category in Table 4.5, overleaf.

[2] *client properties.*

Table 4.5. Breakdown of calls for Birmingham Careline system over a twelve-month period[3].

Call Category	Call Description	Total calls	% Total calls	% calls (operator)
System Calls	▪ System calls indicating that a warden at a sheltered scheme has come on duty or has gone off duty	130,876	49.06	-
	▪ Automatic test signal generated by equipment in the client's home if it is not used by the client within a 25-hour period	76,956	28.85	-
Sub-total		**207,832**	**77.91**	**-**
Emergency Services	▪ An ambulance is called to attend to the client	1011	0.38	1.72
	▪ The fire-brigade is called to attend to the client	619	0.23	1.05
	▪ The local police station has had to be informed of an incident requiring their assistance, e.g. crime or the need to force entry if a client has fallen	496	0.19	0.84
Sub-total		**2126**	**0.80**	**3.61**
Pulled In Error	▪ An erroneous call that has been instigated by mistake or the client was in need of some conversation	24,632	9.23	41.81
Sub-total		**24,632**	**9.23**	**41.81**
Care required	▪ A GP is required to attend to the client	1035	0.39	1.76
	▪ The client is in need of non-urgent assistance and an informal carer is called to provide suitable assistance, perhaps the client has misplaced their spectacles or medication, is feeling under the weather, or just requires some general help	3222	1.21	5.47
	▪ A formal carer is required to attend to the client	1941	0.73	3.29
	▪ Client on floor and needs immediate assistance	1021	0.38	1.73
	▪ Warden wanted by client	4387	1.64	7.45
Sub-total		**11,606**	**4.35**	**19.7**
No answer	▪ An alarm has been generated but there is no answer when the response operator establishes a call. Often due to accidental activation of alarms but more seriously can be due to the client being in a different room to the intercom which is usually part of the care phone and there is typically only one per household. Sometimes care is required, sometimes not	4975	1.87	8.44
	▪ An alarm is received from premises that are believed to be empty	405	0.15	0.69
Sub-total		**5380**	**2.02**	**9.13**
Test & maintenance transmissions	▪ Alarm program/test	8301	3.11	14.09
	▪ A test transmission made to test newly installed equipment	686	0.26	1.16
	▪ Client calls to report that repairs are required to the property	2601	0.98	4.41
	▪ Client calls to report problems with the alarm system that need attention	652	0.24	1.11
	▪ Client calls regarding support services, such as enquiring as to the whereabouts of their meals on-wheels-service	2820	1.06	4.79
	▪ Continuous activation, often caused by faulty equipment, although sometimes due to electrical interference	117	0.04	0.20
Sub-total		**15177**	**5.69**	**25.76**
Total		**266753**		
Recorded calls	▪ All calls that are over 5 minutes long are logged; perhaps the client has been kept in a queue or have been placed on hold whilst the appropriate services have been contacted on their behalf	3118	1.17	5.29

From Table 4.5 it can be seen that almost 78% of calls made to the CA response centre are automatic service calls that are not transferred to the operator. A breakdown of the 22% of calls that do require operator intervention is shown in Figure 4.9, from which it can clearly be seen that the vast majority

[3] *Based on data obtained from [137]*

(77%) are non-urgent and do not result in care being provided to the client. In fact, the largest call category by far is 'pulled in error'. Only 3.61% of calls that do require a response result in emergency services being called out to the client.

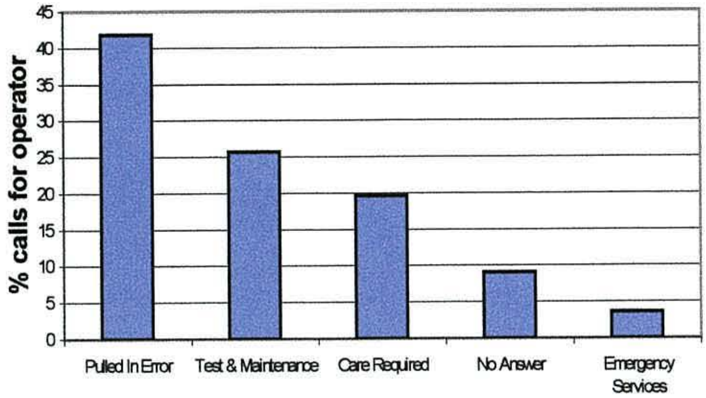

Figure 4.9. Breakdown of call categories handled by response operator.

Figure 4.10 shows the results of a survey of elderly clients by Riseborough of several CA schemes in England who were asked for the circumstances under which they would consider raising an alarm [106]. This response was compared with actual data from logged calls, which placed reasons for alarm use in the following order:

1. Mobile/resident warden.
2. Carer.
3. GP.
4. Crime/Intruder.
5. Falls.
6. Ambulance.
7. Fire.

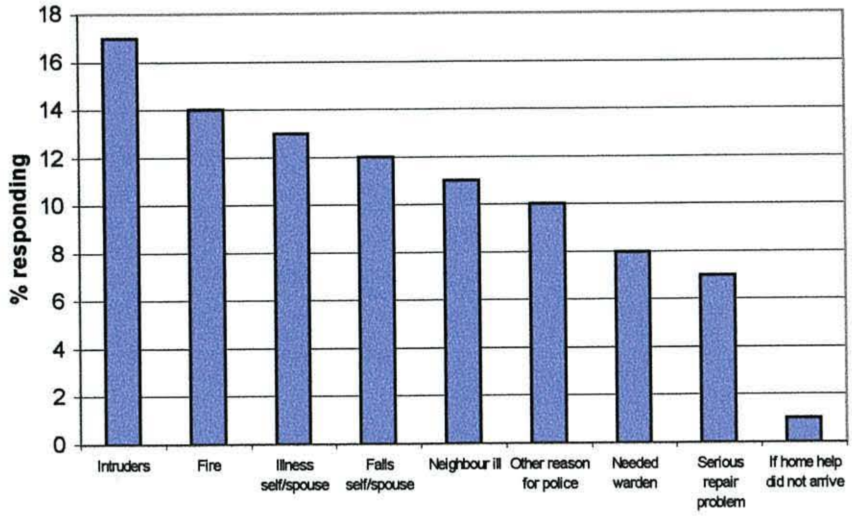

Figure 4.10. Results of a survey of clients who were asked for circumstances under which they would consider using their community alarm system.

The disagreement between the two sets of data may be explained by the clients underestimating the number of times that they call the warden or perhaps by this category being excluded as a bone-fide alarm condition. The reason for emergency service calls being so low down might be accounted for by the fact that nearly half of the respondents claimed they would rather use the telephone for such calls. The issue of what actually constitutes an emergency is clearly an important one and can be very dependent on the personal circumstances of the individual client. For example, [106] describes two instances in which the response centre treated a call from a client as an 'emergency' situation:

- An elderly client had dropped her sandwich on the floor and was unable to bend down to reach it. She was unable to cook and prepare food herself and did not know of anyone else to contact for help.
- An elderly client had locked herself out of her flat, which was part of a sheltered scheme. She did not wish to disturb the resident warden who was off duty and had no relatives living nearby with a spare key.

The nature of calls placed to the response centre are not always emergencies. [106] states that the role of advocate provided by response centre staff was called upon often, with clients asking operators to arrange GP and surgery appointments on their behalf. Clients recognised that the major advantage of a CA system was in its ability to provide prompt access to emergency services and as a backup mechanism for resident wardens. However, 12% of those interviewed also claimed the service provided assurance and gave them someone to talk to.

This tendency of using CA systems to obtain everyday support suggests that they provide an important social support mechanism. In particular, it highlights the fact that clients do not perceive community alarms as merely 'social care' or 'emergency care' systems. Rather, they are perceived as being a single point of access to a range of services providing general care, support, and advice, as well as a means of requesting help in an emergency. However, this comprehensive access to services has serious implications when assigning priority to calls at the response centre. This problem is compounded by the fact that the survey by Riseborough indicated that elderly clients had difficulty in deciding whether a particular situation could be considered an eligible emergency in the first place. Thus, it is entirely feasible to have a situation where one person makes use of the CA service for a non-urgent need, whilst another, faced with an urgent situation does not!

4.1.3. Client Satisfaction with Community Alarm Systems

Client satisfaction with the CA services was mostly determined by response times and the suitability of the alarm equipment [106]. Older people tended to include the actions which followed alerting the response centre in their evaluation of response times, i.e., the *total* delay to receive the actual service requested. Clients perceived the response centre staff as part of a service chain, which is modeled as a UML sequence diagram in Figure 4.11. It describes the process of care service provision using first generation community alarms; the shaded areas illustrate the delays perceived by the client.

In terms of CA equipment, clients generally wanted more pull cords in strategic positions and increased availability of pendants [106]. Clients with physical impairments reported that equipment was often awkward to use, e.g. due to the use of small buttons and stiff switches. Other clients who were hard of hearing reported that they were unable to hear the response operator's voice and that the volume controls were either not present or difficult to operate.

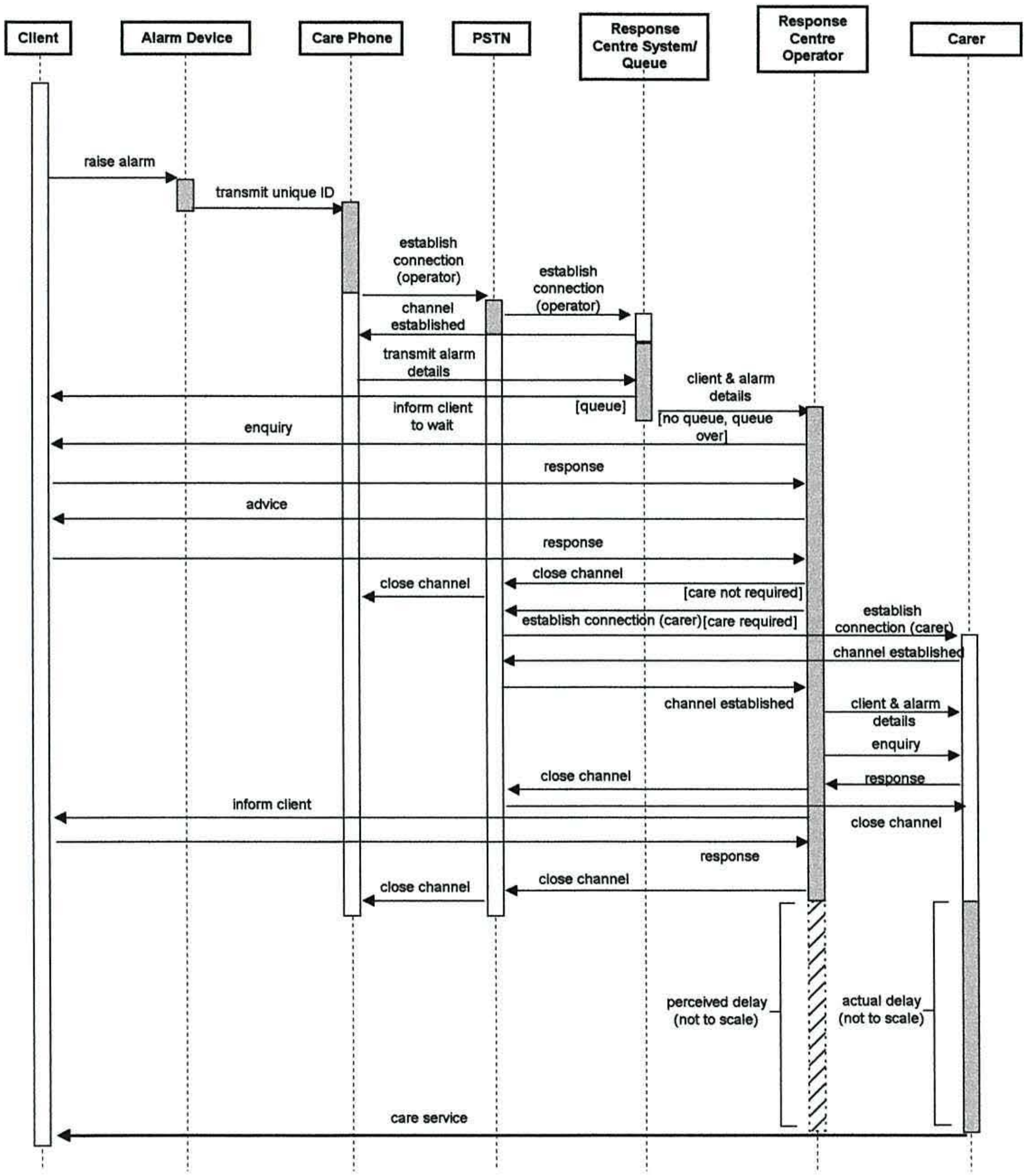

Figure 4.11. Sequence diagram of call to community alarm centre.

4.1.4. An Analysis of Community Alarm Systems

If one considers the functionality of community alarm systems over thirty years after their conception then in essence very little has changed. Whilst the response centre equipment has evolved significantly with the introduction of more sophisticated information and communication technologies (ICT), the functionality of equipment in the home has hardly evolved at all. Minor innovations have occurred, with the introduction of radio pendants allowing the client to 'wear' an alarm trigger providing them with a greater level of confidence in their ability to raise help in the event of an emergency. The most recent development in pendant technology is the introduction of a 'speech pendant' which relays voice to and from the care-phone so that the client does not have to be in the same room as it in order to communicate with the responder[4] [138]. Figure 4.12 illustrates the classification of community alarm devices in common usage today.

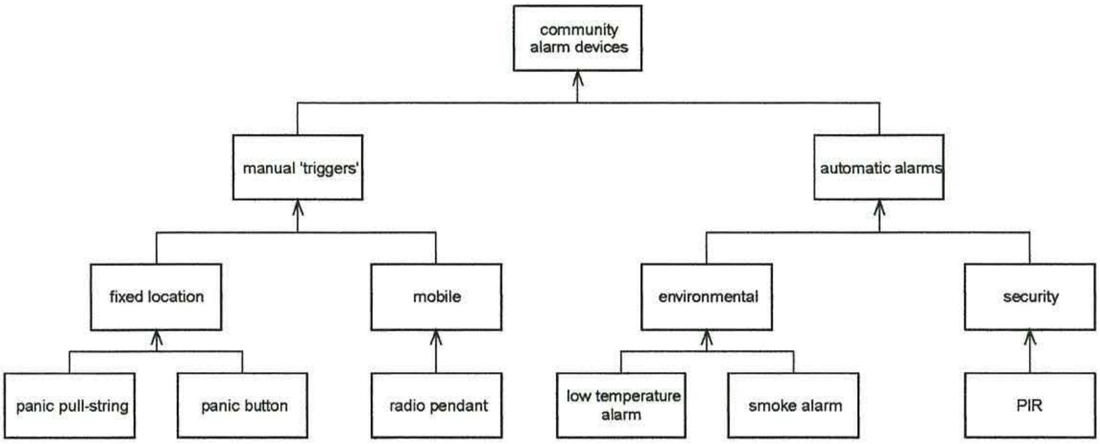

Figure 4.12. Classification of community alarm devices in common usage[5].

In addition to alarm triggers, environmental monitors and techniques of detecting client inactivity (using PIR's) have been considered, although they have not established themselves in the marketplace. This is most likely due to the lack of complementary services that might have encouraged their use. In addition, the ambiguous client activity data obtained meant that it was impossible to distinguish between the large numbers of anomalous situations that could arise with their use.

Advantages and Disadvantages of Community Alarm Systems

Community alarm systems suffer from a number of limitations, which are listed and considered in Table 4.6. While next-generation telecare systems will not be limited to alarm-based services, a consideration of the shortfalls of and improvements to CA systems is a valid exercise, as alarm-based services will still form an integral part of next-generation telecare.

First generation systems are responsive, i.e. they react to a request for help either by the client or from an alarm device only *after* the fact. Because of this, they have very little scope for actively *supporting* the client, for instance by managing the risk associated with a hazardous situation. This is primarily due to the technological limitations of CA systems, which offer little in the way of local intelligence and do not support any practical form of home automation. However, the simple nature of community alarm systems also means that they posses a number of useful properties which should be recognised. These are listed and discussed in Table 4.7.

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[4] *The introduction of a telemedicine monitor by Tunstall is still in a trial phase and does not represent a standard community alarm service.*
[5] *Low temperature alarms are due to become available sometime in the Spring of 2003.*

Table 4.6. The limitations of community alarm systems.

Limitation		Discussion
1	The client has to be aware that an alarm condition exists, which might not always be the case.	For example, consider a client who has begun a course of anti-hypertensive drug therapy. Because there are no obvious symptoms associated with high blood pressure, there is no means of monitoring the client's progress. Furthermore, it is well documented that people who experience symptoms of a heart-attack often delay calling for help for many hours after the event, the so-called denial time, resulting in an increased risk of suffering a more serious attack. This period of client indecision may prove costly. To complicate matters further, the elderly population suffer from declining senses that may affect their ability to detect a hazardous situation.
2	The method of raising an alarm is crude	There are three ways for the client to raise an alarm condition: by pressing the panic button on the care-phone; by pressing the panic button on a radio-pendant; and by pulling an emergency pull-cord. Clearly radio-pendants offer the best means of raising an alarm as the device should be at-hand in the event of an emergency. However, the client will not always have it on their person for a variety of reasons. Often the device will not be 'worn' because either the client has forgotten to wear it or the client did not think to wear it. In addition, the design of the pendants is such that if they are worn in bed then they may be activated by accident. Some people with disabilities may find it difficult to generate sufficient pressure to depress the switch on standard push button pendants. The pull-cord mechanism cannot be lost and offers fixed locations from which to raise an alarm. However, they are responsible for many of the 'pulled-in-error' alarm calls to response centres. Typically, they are pulled by a visitor mistaking them for the light-switch or are caught by the client whilst turning in bed at night. An assumption is made that the client will be able to reach one of the pull-cords in the event of an emergency, which might not always be the case.
3	Client-raised alarms are unreliable.	This can be categorized into four distinct problems: 1. Everyone's definition of an alarm situation is different. Reasons for calling the response centre may range from fancying a chat, to the home-help lady being late, experiencing a fall, or a suspected heart-attack. (There's nothing wrong with any of the above reasons for calling the response centre, but the urgency associated with each category is different). 2. Sometimes the client will refrain from raising an alarm because they do not wish to trouble anybody, or they believe (sometimes mistakenly) that they are not in need of assistance. They may feel that things will improve of their own accord (denial) or they may not be aware that there is a problem that requires assistance. 3. The vast majority of alarm calls received at response centres are 'pulled in error' (perhaps by visitors). 4. Most calls are not emergencies, even those not 'pulled in error'.
4	The client may not always be capable of raising an alarm condition.	This might be the case if, for example, the client has suffered a particularly heavy fall or has had a stroke or a heart attack, and is unable to reach a pull-cord. Even the portable radio-pendant may not prove of assistance; for example in the fall scenario: • The client may have lost or forgotten to carry the device or didn't think it necessary to take it with them. • The client may have fallen awkwardly; be injured in such a way as to prevent the activation of the alarm; or be knocked unconscious, rendering any user-initiated alarm-trigger useless.
5	The client is only able to describe their needs if they are within the range of the speakerphone.	Clearly if the client experienced some form of acute episode outside the range of the speakerphone (i.e. in another room) then the response centre operator would have no way of determining the severity or nature of the problem which caused the client to trigger the alarm in the first place. This often results in the response centre operator erring on the side of caution and calling out the emergency services. Only very recently have speech pendants appeared, but these are significantly more bulky than their regular button-only counterparts and as such are not proving very popular.
6	The response centre operator has no way of prioritising the calls in the queue if they have been raised using pendants.	Because the vast majority of alarm calls to the response centre are client-initiated, there is no information associated with the alarm request other than the time it was initiated, the method used (i.e. a pendant or a pull-cord) and the client's details. All calls may be important to the client but what constitutes an important call might range from reporting that the 'meals-on-wheels' service being 5 minutes late through to reporting a suspected burglary or heart attack. Whilst it is accepted that the community alarm service is more than just an emergency-response service and should provide general support on-demand, the status-quo is not ideal. Currently, the requests for assistance are queued based on the time of the alarm-call, i.e. on a first-come first-served basis. This state of affairs is particularly troubling when one considers limitation 3.

Limitation		Discussion
7	There has been a lack of innovation.	The community alarm marketplace is a conservative one and this has led to this lack of innovation. The range of services that are offered by community alarm systems have not changed much since their inception over thirty years ago. Whilst there has been some improvement in the information technology utilised within the response centres, the technology situated within the client's home seems to have undergone little more than a cosmetic evolution. The most significant advances being the introduction of radio-based pendants and care-phones that provide a speech-based reassurance message upon receiving an alarm signal. This has resulted in alarm pendants being crude and are often considered a 'badge of dependence', which can result in them not being used.
8	CA systems are 'hard' systems that are difficult to modify and whose protocols possess limited scope.	This is a by-product of the lack of innovation. Typically, the radio transmitter placed within devices possesses a unique identification code, which is used as an address in the device look-up table of the care-phone. The most popular system on the market allows 4 different permutations of this address to be transmitted per transmitter. In the main only two are ever used, namely: "alarm" and "alarm & low battery", although meaning is only attributed to these codes at the care-phone itself. Note that in the vast majority of systems currently installed the "low-battery" information is only supplied if the alarm is triggered, although newer systems are slowly addressing this shortfall.
9	CA systems are open loop and cannot control their environment to help manage risk or provide care.	CA systems require alarms to be dealt with by a response operator outside of the home. These operators have no means of remotely controlling parameters within the home and can only help manage the risk associated with a potential hazardous situation by providing advice to the client or by requesting the intervention of a carer.
10	There is no obvious linkage between the community alarm system and the care responders.	The confusion over the services that users of community alarms thought were available bears this out. This might be explained by the fact that CA systems are mostly run by the housing sector.
11	CA systems do not readily support the monitoring and analysis of actual data	The unique ID method of identifying device messages (see 8) does not allow data values to be transmitted, only a finite number of event-message types. Thus data logging is not possible with CA technology as it stands. This negates their use with medical monitors or other monitoring where quantitative data is required, such as for fall prediction indices or environmental monitoring.

Table 4.7. Advantages of community alarm systems.

Advantages		Discussion
1	The user-interface is simple and intuitive.	Client interaction with the system is minimal - alarms are simple to operate. There is widespread familiarity with the telephone, which is hub of home-based equipment.
2	Equipment is tried and tested and has shown to be both reliable and dependable.	The reliability and dependability factor is important and is most likely due to the system's simplicity both in terms of its technological complexity and in terms of usability.
3	Home-based equipment is relatively inexpensive, especially when compared with medical equipment.	Again, this is due to the type of technology currently deployed in the home but is important because the cost of telecare devices will have to be considered in terms of what the market is willing to pay.
4	The response centre operator provides a one-stop point of access for general help & advice as well as access to care services.	A model whereby the client can access a multitude of services by contacting a single operator seems to be popular with clients. They appreciate the role of advocate. Clients seem to believe that their request for help will have a higher priority if made via the response centre. This service model is re-enforced by the government's promotion of NHS Direct in its various guises. The 'call-centre' approach to the provision of tele-services is prevalent in many service industries today and may provide some insight into the future role and logistics of response centres.
5	Response centre infrastructure is well established and available throughout the country	Clients, carers and service providers are all familiar with the community alarm service model.

User-Initiated Alarms

Any system that relies on client-initiated alarms will always be dependent on the client's *subjective* evaluation of a condition, which will be subject to the deficiencies identified in Table 4.6. This reliance on client-initiated alarms is, arguably, the single most obstructive and unreliable stage in the provision of community-alarm-based services at present. Furthermore, the apparent confusion amongst clients as to the correct way of using CA devices and even which services are available highlights the inadequacies of the current approach [106]. The implications for the client are that any delay between the occurrence of an acute event, or the first awareness of symptoms, and the subsequent provision of care may have an adverse effect on speed of recovery, or in some cases, chances of survival.

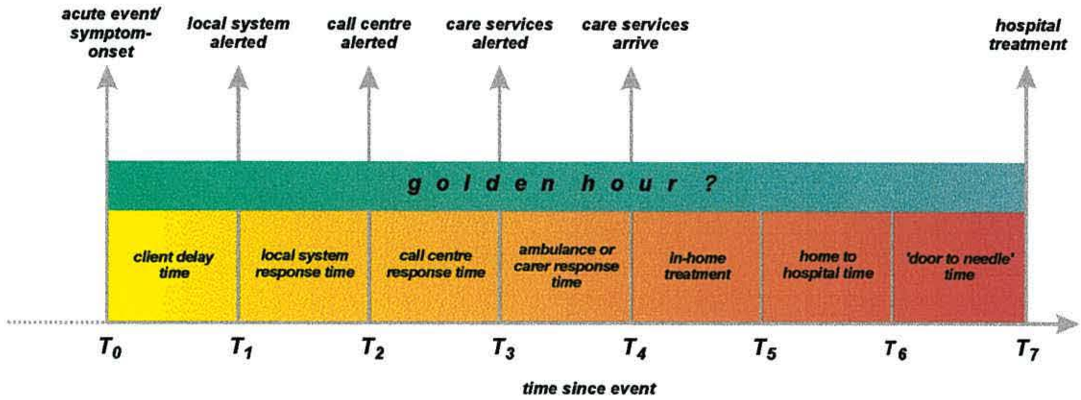

Figure 4.13. Delays in the care response process.

The key period following a medical trauma is the first hour, often referred to as the "golden hour" [139]. This refers to the time between symptom-onset and the administering of suitable therapy. Figure 4.13 shows the series of processes that must occur in order for a client to receive appropriate care following an alarm call. Several factors can affect the total time taken to receive hospital treatment, including:

1. Client delay time[6].
2. The number of alarm signals in the queue/being serviced at the local system.
3. The number of calls in the queue/being serviced at the response centre.
4. The number of calls in the queue/being serviced at the ambulance control centre.
5. The locality of the ambulance station (or carer) in relation to the client's home.
6. The type and amount of first-aid required to be administered in the client's home.
7. The locality of the hospital in relation to the client's home.
8. Local road and traffic conditions.
9. Hospital 'door-to-needle' time.

Client-delay time (T_0 - T_1) will vary between clients and can be divided into a period of client-denial and a period of obtaining guidance from friends or family[7]. The client-denial time will vary according to client-personality, the nature of the symptoms, and the perceived threat. For example, figures available for the case of acute myocardial infarction (AMI) range from between 45 minutes to 3-4 hours [140]. This eats into a significant proportion of the golden hour and inevitably means that the client will not have a symptom-onset-to-needle time of less than one hour. The recommended 'call-to-needle' time ($T_1 - T_7$) for individuals who have suffered an AMI should be no more than 90 minutes, with a 'door-to-needle' time ($T_6 - T_7$) of no more than 30 minutes [141, 142]. This corresponds to a 60 minute 'call-to-hospital' time ($T_1 - T_6$) and emphasises the need to request help as soon as possible following an acute event or following symptom-onset. One of the key properties of next-generation

[6] *If the condition is such that there are few or no symptoms then there may be a significant period of time for which the client is ill without knowing **before** symptoms present, T_{-1}.*

telecare systems will therefore be the ability of the local system to assume a greater responsibility for initiating alarm conditions where appropriate.

Community Alarm Response Centre

The function of the community alarm response centre plays a pivotal role in the provision of support and care to the client. A simplified activity diagram detailing the essential roles of the response centre operator is illustrated in Figure 4.14.

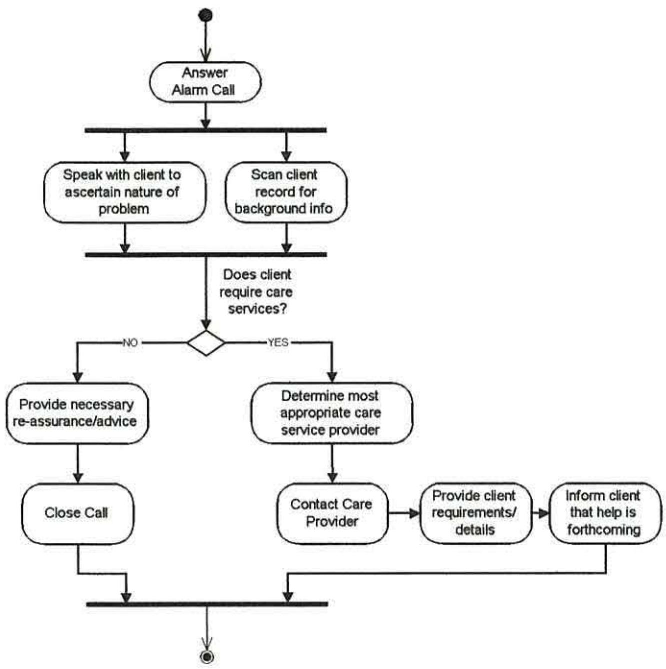

Figure 4.14. A simplified activity diagram for response centre operator.

It is apparent that the role of the response centre staff is to enquire as to the nature of the call, analyse the data presented and contact which care services, if any, are most appropriate. It is often necessary for the care responder to comfort the client and act as a friend who is available at the touch of a button. It is suggested therefore that the role of the response centre staff is therefore three-fold:

1. A remote but always available carer who provides general advice, comfort and support to the client and who acts as their advocate where appropriate.
2. A filter assessing the severity of each call and determining whether to proceed with alerting the care services.
3. An intelligent switch, distributing requests for assistance and information from a data source (the client) to the most appropriate data sink (care provider) based on rules linking the nature of the call to the services provided by the care providers.

The combination of automated and client-initiated alarms will result in a two-track alarm interpretation system, shown in Figure 4.15. Telecare response centres may have to evolve to cope with the shift towards well-being monitoring, with a team of better qualified call-responders[8]. NHS and Care Direct

[7] *including instances where the client is reassured to such an extent so as to delay or completely abandon the call for help.*
[8] *Operators who do not possess suitable care qualifications are likely to always adopt a 'safe' approach and pass-on requests for help, thus defeating their role as a filter.*

are already staffed by fully trained nurses and may end up as the single-point of entry into the primary care system. If telecare services are to be commissioned by Primary Care Trusts, then there may be a real desire for their operation to be under their control, as part of a bone-fide primary care service.

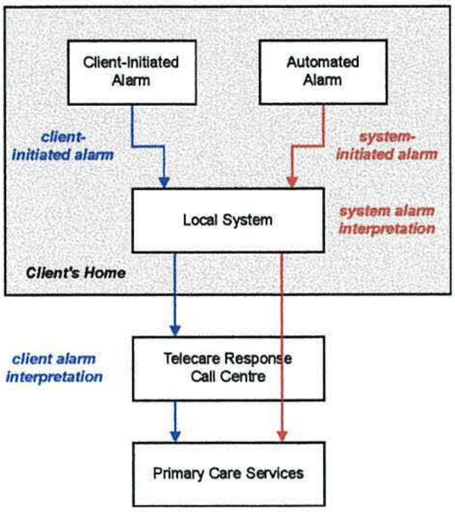

Figure 4.15. 'Two-track' alarm interpretation system.

Community Alarm Protocols & Architecture

Even though a British Standard exists for CA coding systems, the UK market is dominated by TT92, a comprehensive proprietary protocol developed by Tunstall Telecom, the market leaders. The protocol enables the meaning and location of an alarm to be transferred to the response centre. CA devices within the home are not 'aware' of their functionality and the unique ID that they provide on activation does not convey any meaning other than to uniquely identify a particular unit. One of the limitations of this approach is that it becomes difficult to employ devices that have several output messages. The meaning associated with a particular device is assigned by the installer and stored in the care phone using a look-up table, see Figure 4.16.

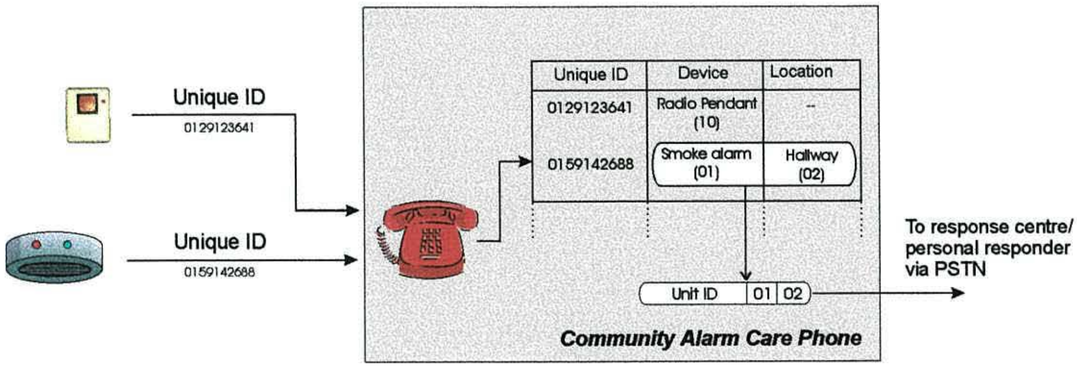

Figure 4.16. An example of how community alarm protocols work in the home.

CA coding schemes are enumerative and work by attempting to predict all of the terms that are likely to be required in advance, assigning each a code. They typically contain several unused values that have been reserved in anticipation of new devices so that meaning can be assigned as and when the need arises. However, the protocol implemented *within the home* leaves very little scope for assessment services[9] or for the transmission of data-streams. Because of this, significant events associated with these parameters need to be identified and used to trigger alarms, e.g. 'heart-rate high' or 'client-activity low'. This does not lend itself to the historical or long-term trend analyses of the underlying data-sets that might yield valuable information.

Another major limitation of CA systems is their inability to instigate feedback locally within the home. This is because care phones possess insufficient output capabilities and are in any case restricted by the need to have a human in the loop of care (i.e. no local intelligence). This problem is compounded by the fact that the human in question is typically situated at a remote location.

There are certain situations when it is desirable for an action to be performed immediately or information and advice to be provided to the client without the need for external intervention. For example, if an overflowing bath causes a flood then ideally the local system should automatically turn off the water supply to the bath and inform the client. Likewise, if the front door is accidentally left open, then the client should be alerted to this fact and be given the opportunity of closing the door *before* a carer is called out unnecessarily. In order to achieve this level of local control, it is necessary to remove the need for the human intelligence in the care feedback loop. This involves closing the loop of care within the home by using *local* intelligence to control *local* parameters. It also requires an improved client-system interface within the home in order to convey appropriate messages to the client.

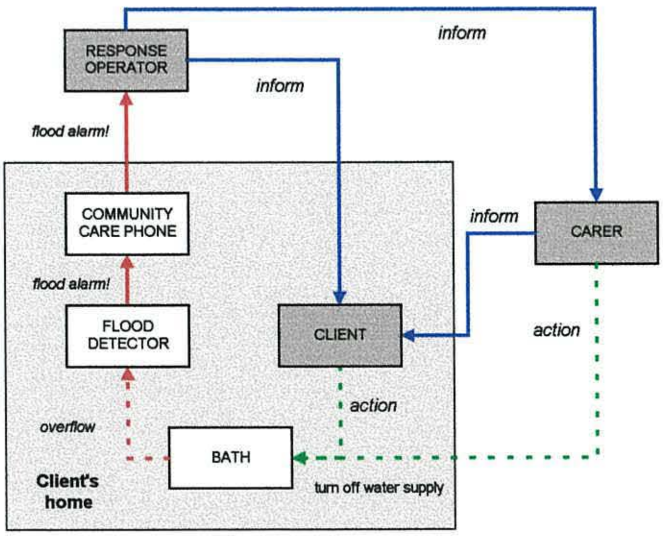

Figure 4.17. 'Human in the loop' control.

Figure 4.17 illustrates the control loop required to control the flow of water into a bath using CA systems. The human operator in the loop, introduces an unnecessary delay as they are unable to directly control the flow of water into the bath; hence, all that they are able to do is inform the client that the bath is overflowing. The hazardous situation may then be rectified, providing of course that the client is able to turn off the bath-water (but why is it overflowing in the first place?). Alternatively, if the response operator is unable to contact the client or the client is unable to turn off the water supply, then

[9] *data transmission is uni-directional – towards the care phone*

a carer must be called out, which could take several minutes or several ten's of minutes, depending on the carer's location in relation to the client's premises.

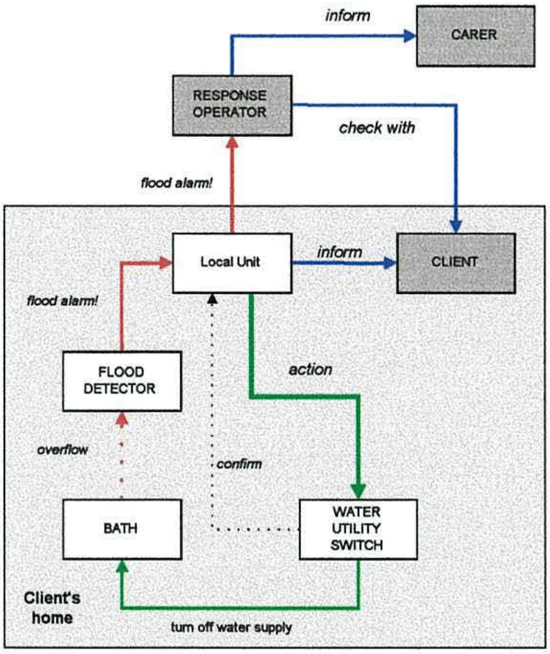

Figure 4.18. Closed-loop local control.

A much better solution involves the arrangement of Figure 4.18, which illustrates that for certain events, the local unit can take responsibility for performing the critical action. It can still inform the response centre who may request a carer to call if necessary. However, by automatically performing the critical action, in this case, turning off the water supply, it has limited the damage and hence controlled a potentially hazardous situation much faster than if a carer had to come round to turn it off. There are many other situations where the control of local parameters by the local unit may be required. Such control capabilities could be extended throughout the home for other parameters providing many advantages over the present system. For instance, it would:

- Close the loop of care within the home, speeding up response times (because there is no need to dial out and wait for a responder), reducing the risk associated with some events, e.g. gas alarms where a long response time may prove fatal. In particular, the response time of the alarm itself must be taken into consideration.
- Support a preventative methodology that would enable risk to be managed *before* an alarm condition arose, reducing the burden of calls to response centres. In the previous example, the system could prevent the bath from overflowing in the first place by monitoring the volume of the bath water. In many instances, automatic alarms could be dealt with locally within the home and merely logged at the response centre for auditing or analysis.
- Local intelligence and control capabilities have positive safety implications because of improved response times and enhanced system performance, maintenance and reliability checks. Furthermore, it ensures that some level of service provision is maintained in the unlikely event that the PSTN connection with the response centre fails.

- Client-sensitive information may be processed and contained within the home, thus increasing the client's privacy – this will become increasingly important if monitoring in the home is to be increased.
- The reduced quantity of data and frequency of their transmission from the home also implies a greater level of data security. This also has benefits for the response centre as the local unit will effectively operate as a filter, only passing on data on a need-to-know basis and thus reducing the burden of processing at the response centre.

4.1.5. Discussion

It may be apparent that the nature of the services provided by CA systems are currently very much constrained by the capabilities of its infrastructure. The reliance on a 'simple' communications gateway[10] into and out of the home, coupled with a crude unidirectional addressing system within the home limits the possibilities for interoperability, closed-loop care and co-operation between devices. Care phones generally have little processing capabilities and hence cannot provide intelligent services. However, they can accommodate the introduction of new, alarm-based services by placing any necessary intelligence into the sensors themselves, which may then trigger the required alarms. Spare CA codes may then be assigned to provide unambiguous interpretation of these alarms at the response centre, enabling rapid and appropriate responses and interventions to be made.

It may be concluded that the CA platform, as it stands, is not capable of supporting telecare type services in a fully integrated and intelligent fashion as advocated by CarerNet. Although it may offer a short-term means of extending alarm services by injecting intelligence into the front-end sensors, and/or by improving the specification of the care phone platform. This is a desirable goal in the short term because of the well established CA response network, which is reliable, and well understood by care providers and clients alike. This may offer the best route to market for new alarm-based telecare services but does not represent a viable means of introducing more advanced, data-intensive services.

4.2 Assistive Technology & Home Healthcare Devices

The spectrum of telecare, presented in Chapter 3, implies that services currently available to enable or support home healthcare and independent living will have an important role to play as part of an integrated telecare strategy. A short discussion of assistive technologies and home healthcare devices is therefore relevant in order to assess their suitability for telecare.

4.2.1. Assistive Technology

The purpose of assistive technology (AT) is to maintain the functional independence of individuals with some form of physical, sensory or cognitive impairment, or any combination thereof. The independence of such individuals may be supported in any number of ways, such as by:

- Introducing into the client's living environment a specialised piece of equipment.
- Modifying the living environment.

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[10] *i.e. the care phone.*

- Modifying existing equipment.
- Providing the client with a personal assistive device.

Services offered by AT include home automation, sensory augmentation, mobility enhancement, and mechanisms for communication and social interaction, see Table 4.8. Assistive technologies are typically stand-alone solutions that meet a specific need, and can range in sophistication from a pair of spectacles to a smart wheelchair. In many instances, the solution implemented may not have been designed with AT in mind (e.g. Internet connectivity). The key difference is that to one group the device or service may represent a convenience, whilst for the functionally impaired, it is likely to represent a necessity. Individuals that might consider the use of assistive technologies include:

1. Informal carers for whom the availability of AT may decrease the burden of care.
2. Elderly clients for whom AT may promote safety or reduce the risk of injury.
3. Clients who experience age-related changes or functional decline and for whom AT would enable independent living.
4. Clients with a first-time disability or with multiple chronic conditions and who may require numerous assistive devices to perform personal care activities.

Table 4.8. Examples of assistive technologies.

tap/dial turners	spectacles	bath-lift
bath/stair rails	ramps	stair lift
kettle tipper	video camera	pill box with timer clock
sculpted foam-grip cutlery	power socket controller	motorised wheelchair
bed hoist	Internet connectivity	specialist user interfaces
chair/bed raisers	remote-control light switch	automatic ground-level lighting
incontinence bed mattress	internal/external door opener	videophone & video-doorbell
commode	page turner (for books)	community alarm care phone
shower-seat/walk-in bathtub	voice-activation units	hearing aid
day-of-the-week pill box	chair/bed occupancy monitor	panic pendant/trigger
smart wheelchair	remote control of home appliances	local alert pager (for live-in carers)
motorised kitchen work-surfaces and cupboards (to alter level)	remote-control motorised door/window/curtain opener	large-button telephone with picture-cue direct-dial numbers
epilepsy seizure alarm	memory jogger for dementia	dementia wandering alarm

Despite the clear benefits of AT, there can be a reluctance on the part of some individuals to accept it as a solution to their particular needs. There are many barriers to acceptance and use, which are important to consider within the context of telecare, and which must be offset against the perceived advantages. Some of these barriers to use are identified in Table 4.9 [143].

Table 4.9. Barriers to acceptance and use of assistive technologies.

The cost of assistive technologies can be prohibitively high	Poor fit with environment or client's need
Can be seen as a 'badge of dependence'	Device lost, forgotten or broken
Client's functional ability improves	Preference for personal assistance
Use of one device reliant on use of another	Feelings of embarrassment
Lack of knowledge/training about how to use device	Denial of need

The use of over-engineered solutions, often ported from institutional settings, can be a turn-off for individuals as well as being expensive and unwieldy for service providers. Poor aesthetics (which are not as important in a hospital setting) can result in an unwillingness to accept a particular solution due to the associated stigma. Furthermore, inadequate training and client support, coupled with a mismatch of device to client need can leave AT being under utilised once installed. Unfortunately, care providers are often unaware of the solutions that are available to meet the needs of particular clients. Indeed, even when they are, they can be lacking understanding of technological capabilities, which can lead to confusion over how to best match the needs of the client to a particular solution. This often results in inappropriate technology being offered, which then does not perform as expected, resulting in both client and care provider losing confidence in the product and in AT as a whole. Thus, the use of AT has not been as widespread as might have been hoped. This may have serious repercussions for telecare, where there may be an even greater plethora of solutions available. If the client is reliant on a particular solution to manage risk, then the consequences of the incorrect provision or use of equipment may have serious consequences. Setbacks caused by the miss-allocation or misuse of telecare services may damage its reputation and hence delay its roll-out as part of mainstream home-care.

At present, the majority of AT has been developed and introduced into the domestic environment in relative isolation. Clients who require multiple assistive technologies are therefore likely to benefit the most from an integrated care and support system in the home, such as that advocated by CarerNet. Encouragingly, studies have shown that it is these people who are more likely to regularly use AT, once it is provided [143].

4.2.2. Home Healthcare Devices

Home healthcare devices are typically used to monitor physiological parameters or provide therapy in the comfort of the home. There is a wide and growing range of medical equipment that may be used in the home, see Table 4.10. These range from standard home-based equipment (e.g. a thermometer for measuring body temperature) through to 'hospital-at-home' equipment (e.g. an oxygen concentrator for oxygen therapy). Home healthcare devices can be 'prescribed' by a physician or purchased privately.

Table 4.10. Home healthcare devices.

Monitoring	Therapy
Thermometer	Transcutaneous Electrical Nerve Stimulators (TENS)
Sphygmomanometer	Continuous Ambulatory Peritoneal Dialysis (CAPD)
Cardio-tachometer/ECG monitor	Functional Electrical Nerve Stimulation (FES)
Glucometer	Ventilator
Pulse oximeter	Nebuliser
Spirometer	Portable infusion pumps
Sleep apnoea monitor	Implantable drug pumps
Incontinence alarm	Implantable Pacemaker
Weight-scales	Incontinence trainer
Stethoscope	Oxygen concentrator

Monitoring equipment found in the home can include: a sphygmomanometer for measuring blood pressure; a cardio-tachometer for measuring heart-rate; a glucometer for measuring blood glucose levels in diabetics; and spirometers for measuring respiratory function. In addition, therapeutic equipment that can be found in the home includes: nebulisers and inhalers for asthmatics, electronic pumps for infusion therapy, Transcutaneous Electrical Nerve Stimulators (TENS) for pain relief, and Continuous Ambulatory Peritoneal Dialysis (CAPD) for renal disease management.

The majority of medical devices for use in the home are stand-alone solutions. However, some have been developed with telemedicine in mind, e.g. an electrocardiogram (ECG) monitor that can be used to continuously monitor a client's ECG and upon detection of an abnormal event, upload data via the Public Switched Telephone Network (PSTN) through to a call centre for analysis [44]. Another recent innovation has been the integration of several vital-signs monitors into a single home-based unit in order that a multi-parameter assessment of a client's physiological status may be performed. One such commercially available device is the AVIVA 1010 from American Telecare. This unit includes as standard a blood pressure monitor, stethoscope, pulse-rate meter, and a teleconferencing link with a physician. In addition, a glucose meter, pulse oximeter and a client weighing scale can be added to the unit, if required. Agilent Technologies use a wireless link between a separate blood-pressure monitor, heart-rate monitor, client weighing scales and base unit connected to the PSTN in order to enable electronic house calls for the home-management of coronary heart disease [34].

4.2.3. Discussion

Varying degrees of 'technological literacy' together with an increasing use of AT and home-based medical devices, is likely to present challenging human factors issues. The major concern is to ensure that client safety is not in any way affected by their use. In practice this means that the devices must be reliable, safe, and easy to use. In the case of a periodic medical assessment, mechanisms must be put in place to remind the client to perform the measurements if they are missed. Additionally, suitable support must be made available to guide the client through the measurement process in order to ensure that results are as accurate as possible. Furthermore, it is desirable to be able to monitor the use of assistive and home-healthcare technologies, especially when these technologies have been allocated based on the result of a risk assessment. If the client has been allocated a care package based on the use of a number of technologies, which are not being used effectively, then it is essentially as if the systems are not present. Thus, the client is at a greater risk than intended.

The monitoring of medical parameters using home-healthcare devices is, in the main, on-demand rather than continuous availability (unless the device is body-worn 24 hours a day). This is fine for general assessment but not ideal for somebody suffering from cardiac arrhythmia, where the attack may occur intermittently. Thus, under certain circumstances, it may be desirable to increase the availability of physiological data in the home. This may be achieved through the use of smart-clothes with embedded medical sensors. For instance, the Vivometrics LifeShirt (under development) is a lightweight (8 oz.), machine washable, comfortable, easy-to-use physiological monitoring shirt with embedded sensors. To measure respiratory function, sensors are woven into the shirt around the patient's chest and abdomen. A three-lead, single channel ECG measures heart rate, and a two-axis accelerometer records patient posture and activity level. Optional peripheral devices measure blood pressure and blood oxygen saturation [29]. Alternatively sensors may be embedded in other locations where client occupancy is high, such as in the client's favourite armchair, bed [e.g.25, 26], bath [22], or toilet [27].

In order to avoid inappropriate solutions being offered to clients, a structured telecare assessment process performed by approved assessors would be necessary. This process of assessment, where the best combination of services is derived from an analysis of client need, may be amenable to computer-aided techniques (e.g. questionnaire/database or expert system). In order to maximise the number of people who may benefit from telecare, it is essential that system elements are wide-ranging and affordable. This presents a particular design concern when one considers the diversity of telecare users. Ideally, all elements of a telecare system, including the physical environment, should be capable of evolving with an individual over their lifetime and of adapting, or of being adapted, to their changing needs with minimum disruption and modification. This is the principle of universal design[11]. The concepts of which are summarised by Table 4.11 and represent a set of goals against which any system may be evaluated.

Table 4.11. The principles of universal design [144].

Design Principle		Description
1	Equitable use	Allows users to operate device or system with ease without stigmatising them.
2	Flexibility in use	Ensures that the product or system can be used by individuals with varying abilities, preferences and skills.
3	Simple and intuitive use	Employ a consistent user interface. Provide suitable prompting and feedback during and after task completion. Above all keep it simple.
4	Perceptible information	Multi-sensory approach to the presentation of information supporting user definition. Keep messages simple and clear.
5	Tolerant of error	Fail-safe approach with suitable and appropriate warnings and checks. Minimise adverse consequences of accidental or unintended actions.
6	Low physical effort	Easy to use and ergonomically effective design.
7	Size and space for approach and use	Access must be suitable for all users irrespective of personal circumstances.

This plug-and-play approach may cause problems with the provision of user-control functionality throughout the house, whether it be mobile, distributed, or fixed at a convenient location. A method of updating the user interface to add or remove functionality in line with current services is required. This implies a graphical user interface capable of adapting its control options as new devices are installed and removed. This feature is now readily realisable by using the myriad of LCD-based touch-sensitive universal remote controls now available or alternatively the use of web-tablets/tablet PC's [145, 146]. The move to interconnected devices throughout the home offering integrated services implies the availability of a suitable communications network with protocols capable of supporting such services. One technology that may offer such connectivity is smart home systems.

4.3 Smart Homes

A 'smart' home is one in which appliances can communicate with each other over a network, sharing information and services in order to facilitate intelligent modes of operation that offer improved system functionality than those available when devices are used in isolation. The intelligent functionality of smart-homes is achieved via the linkage of sensors, user interfaces and actuators married together using machine intelligence. In addition, because devices can transmit data and receive commands over the smart home network, it is possible to centralise the user interface for control of home-based systems at several convenient locations within the home. Consequently, a smart home may be defined as:

[11] *c.f. 'design for all', 'barrier-free', 'lifetime homes'.*

"a home that contains an abundance of sensor, actuator, control, communication, information and machine intelligence technologies to facilitate user, remote, or autonomous control or enhancement of appliances or the home environment in order to improve and support the lifestyle and well-being of its inhabitant."

4.3.1. Smart Homes – A Technology of the Future?

The concept of a smart home is one which has been in existence for many decades, and yet they are still considered a technology of the future. Lessons must be learnt from their slow adoption, due, in part, to market uncertainty over which competing protocol to adopt and compounded by the lack of a 'killer application'. In addition, the user groups most regularly associated with smart home technologies are too small to promote mass adoption, i.e. the traditional early adopters of new technologies (technophiles) and people with severe functional impairments.

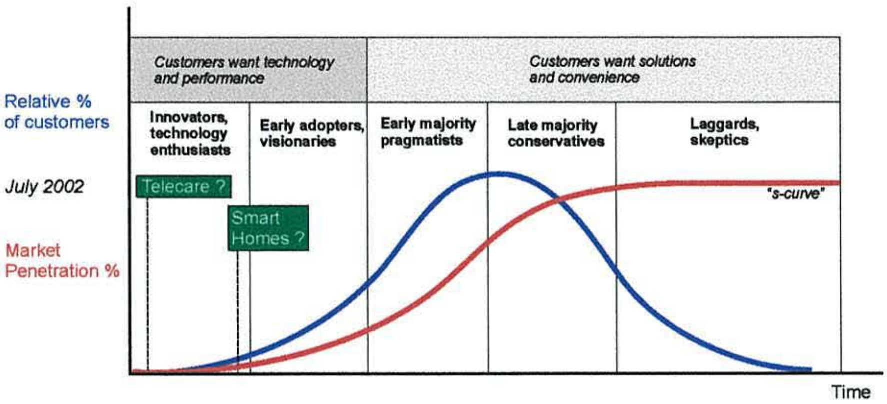

Figure 4.19. The adoption of new technology in the marketplace.

The rate at which new technology is adopted in the market place often tends to follow a characteristic S-curve, shown in Figure 4.19, and modified from [147], which describes a slow initial take-up mostly by technophiles and other early adopters, which gradually gathers momentum as the technology develops mass market appeal. Finally, the rate slows down again as the technology approaches its saturation level with only a small number of potential customers remaining. Figure 4.19 offers a guesstimate of the current penetration of both smart home technology and telecare in the marketplace.

The result of poor market penetration is a lack in mass production which means that system costs remain high. In terms of their use in an assistive role, smart home system purchasers have little flexibility of choice and have not in any real sense been able to develop a means of matching provision to the needs of their clients or of growing the provision as need develops. The danger with such an approach is that both the purchaser of the technology and the client group for which it is intended lose confidence in the ability of the technology to meet their needs, further delaying its introduction. Thus, both the assistive and mass-market adoption of smart homes has been hindered by a number of inter-related factors, including:

1. **A lack of standardisation** – There are a multitude of competing standards and protocols. This usually ties a particular smart home installation to a particular set of manufacturers, which results in a lack of choice for the consumer. The ability to mix and match best-of-breed

products from different manufacturers is not always possible. More recently, there has been some effort in producing new open-standards for smart homes, however, there are still competing standards. Work is underway to converge several of the more popular standards into a single common open protocol, although this still may be some years away.

2. **Difficulties with installation** – In order for devices to communicate with each other, it is necessary for a suitable network infrastructure to be available in the home. In order to keep costs down, it has been necessary to rely heavily on guided media, such as existing power-line infrastructure or by installing twisted-pair or coaxial cabling throughout the house. This may be achieved for relatively low cost in new-build projects, but results in much inconvenience when installing in existing housing in a retro-fit fashion. The availability of low-cost unguided (wireless) networking, such as Bluetooth [148], will make retro-fit installations much easier, although the cost of such links is prohibitive presently. Furthermore, plug-and-play technologies will allow devices to auto configure themselves within the network should increase the ease of installation and improve the usability and reputation of such technology.
3. **A lack of a killer-application** – Smart home protocols have, in the main, been developed to provide services that typically fall into one of five categories:

    a. Climate monitoring and control (Heating, Ventilation & Air Conditioning – HVAC).
    b. Home security (burglar alarms, occupancy simulation, etc.).
    c. Energy management (e.g. controlling HVAC & lighting).
    d. Safety (smoke & gas detectors, video-doorbell, bath-flood & scald prevention).
    e. Home 'infotainment' (distributed hi-fi, home cinema, computer networking).

    However, neither of these application areas have proven popular enough to kick-start the mass adoption of such technologies.
4. **Cost** - The lack of a mass-market for smart home functionality has resulted in low-volume sales and a sales distribution service that is fairly non-mainstream which has thus kept the costs associated with smart home technology prohibitively high.

4.3.2. Smart Home Services & Protocols

The services offered by smart homes to date mainly focus on enabling user or automated control of the living environment. It may be observed that the data requirements involved in smart home applications are highly variable. For example, data rates range from several bits per second for a single measurement of room temperature to many megabits per second for moving images. Furthermore, event-based services (commands, discrete data or alarms) characterised by short asynchronous transmissions between devices/applications may only require a connectionless communications channel (with or without acknowledgements), whilst others (file transfer, video, speech) may require a connection-oriented channel with a guaranteed quality of service. These communication requirements have implications not only for the complexity of the network protocols implemented, but also on the demands of the physical medium required throughout the network. Subsequently, there are a profusion of smart home protocols currently available, both proprietary and open, many biased towards the particular requirements of their own application domain (home entertainment, security, HVAC, etc.).

Table 4.12. Smart home protocols & related control network/interoperability technologies.

Shared Wireless Access Protocol (SWAP)	Home Bus System (HBS)	Open Service Gateway Initiative (OSGi)
BatiBus	Home Electronic System (HES)	BACNet
Bluetooth	Home Plug Alliance	TCP/IP
Controller Area Network (CAN Bus)	Home Plug and Play	Wireless Access Protocol (WAP)
Consumer Electronics Bus (CEBus)	HomeAPI	VESA Home Network
Wireless Ethernet Compatibility Alliance	Home Audio Visual Interoperability	LonMark Interoperability Association
HomeRF	HomePNA	HomeConnex
European Home System (EHS)	Wireless LAN / IEEE 802.11	X-10
European Installation Bus (EIB)	IrDA	No New Wires
FieldBus	Jini	CORBA
Firewire (IEEE 1394)	Lonworks	SOAP/XML

Table 4.12 provides a non-exhaustive selection of connectivity and distributed application technologies that are currently competing/collaborating in the field of smart homes and which span various levels of the ISO-OSI seven layer reference model, Figure 4.20. Table 4.13 presents a selection of the various smart home protocols currently available.

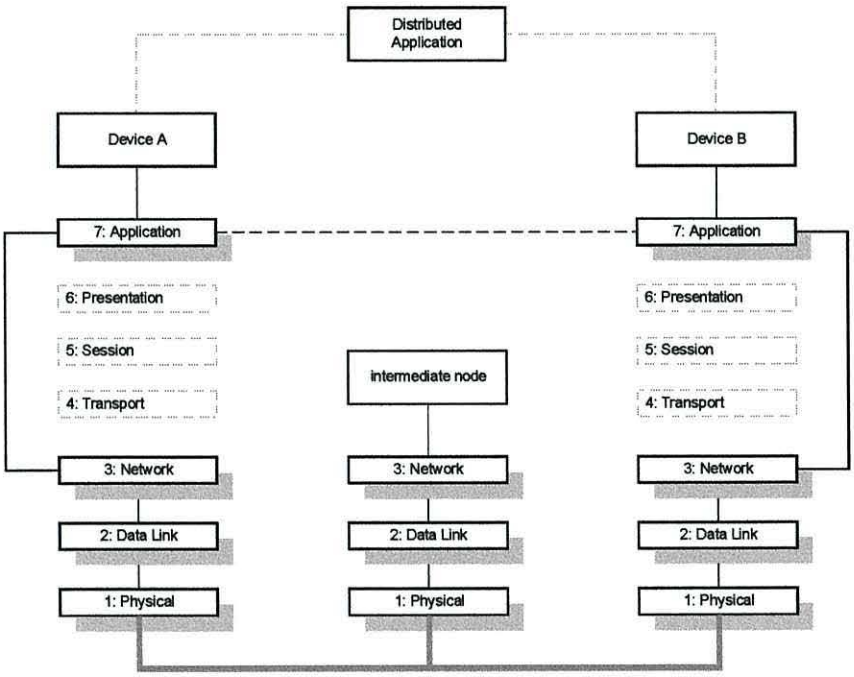

Figure 4.20. A protocol architecture for smart homes, mapped on ISO-OSI model[12].

It is immediately apparent that interoperability or inter-changeability between a smart home temperature sensor and heater controller picked up at random is unlikely to result in a successful marriage of functionality. Ultimately, it is fundamental that a truly common applications language (CAL) is developed in order to enable devices to communicate with each other at a high-level peer-to-peer. This would enable distributed devices to share services and information irrespective of their manufacturer, or of which lower level protocols are being used for network connectivity.

[12] *In Figure 4.20 the presentation, session, and transport layers have been bypassed because the heavy dominance of connectionless 'datagram' services in smart home implementations renders them largely unnecessary, with services being shifted (typically) to the application layer.*

Table 4.13. A selection of common smart home protocols.

Protocol	Media	Comments
X-10	PL	X-10 was developed as a means to control mains powered equipment such as lights, heaters and other household appliances using the existing mains wiring in the house as a communications medium. Its low cost and complexity has established itself as one of the most popular home automation protocols.
CEBus	PL, TP, CX, RF, IR, FO.	The CEBus Standard is a protocol specification developed by the Electronic Industries Association (EIA) to support the interconnection and interoperation of consumer products in a home. CEBus is an open architecture which defines protocols for how to make products communicate through various media. The standard also offers a defined language of many object oriented controls which include commands such as 'volume up', 'fast forward', 'rewind', 'pause', etc.
EIB	TP	The European Installation Bus (EIB) links sensors and actuators to building systems that control HVAC, security, access, and life safety. Scheduled to converge with BatiBus and EHS.
EHS	PL, TP, CX, RF, IR	A European industry and government collaboration on home automation. Among the objectives of European Home Systems Association are accelerating the process of standardisation and encouraging international harmonisation. Scheduled to converge with BatiBus and EIB.
LonWorks/ LonMark	PL, TP, CX, RF, IR	The LonMark Association's mission is to enable the easy integration of multi-vendor systems based on LonWorks networks using standard tools and components. LonWorks is widely accepted to be one of the leading protocols in use in intelligent buildings. Uses intelligent nodes built around a 'neuron' chip that supports all the communication protocols as well as providing microcontroller functionality.

There has been a great effort of late to produce an all-embracing universal and open standard for smart home networking, unfortunately several groups are competing to produce it, thus defeating the point somewhat. However, there are now significant efforts between the working groups of several of the major European protocols to produce a single common standard, for instance the EHS, EIB and BatiBus standards are in the (slow) process of converging. While smart home technology may eventually offer a useful method of providing connectivity throughout the home, the application level protocols do not currently extend across the spectrum of services anticipated for telecare.

4.3.3. Discussion

Although it has always been considered that the elderly would benefit greatly from smart home technology, efforts to provide smart homes have mostly centred on one-off new-build 'showcase' installations that focus on home automation [e.g. see 149]. Because these are new-build schemes rather than retro-fitted into existing dispersed housing the availability of an (often expensive) cabling infrastructure is assumed which is not practicable for dispersed housing. An immediate flaw of such schemes is that most older people would describe themselves as generally well (though suffering from various chronic but medically controlled conditions) and so it might be difficult for them to justify relocating into a purpose-built smart house. Indeed this clearly defeats the key theme of telecare – that of empowering the individual to remain in their own home. Relocating to a smart home or extra-sheltered scheme may be preferable to moving to a residential care home, however, a means of retro-fitting telecare services into existing homes of individuals is much more desirable.

While the initial customers of telecare might be housing associations, care trusts, social services departments and other care organisations, the client themselves might in future be inclined to invest in telecare technologies for their home if the related smart home technologies become commonplace. This is an important point to consider, for if homes of the future are to become 'smart' then telecare devices may be considered as merely providing another range of services and would plug-in to the same network infrastructure. Thus, smart home systems should be considered as an *enabling technology* that offer a means of *connectivity* and which can support any number of intelligent services that are required within a particular home, including telecare.

4.4 Conclusions

An analysis of first generation telecare technologies can be made on two levels, firstly in terms of service provision and secondly in terms of system infrastructure, both internally and externally to the home. Within the home, care service provision may be provided by assistive technology, home-healthcare devices and community alarm systems. External to the home, community alarm (CA) systems can provide access to a care-response network based on client requests for help or on automatic alarm-based messages. More recently, NHS Direct has provided health-related support over the telephone or World Wide Web and soon Care Direct will offer specialised services for the elderly.

Traditionally, first-generation technologies have been used in relative isolation partly because of the absence of the necessary infrastructure within the home to enable integrated services. CA systems offer a primitive integration of alarm based devices using a common point of access to an external response network (i.e. the care phone). Several one-off show-homes have experimented with the more flexible and comprehensive connectivity solutions available with smart home (SH) systems. However, due to the bias of SH devices towards environmental monitoring and control, these have all invariably required the adaptation of existing AT to help support telecare. In general, SH systems have been self-contained within the home and have not been capable of directly communicating with a dedicated care response system (without interfacing with a CA care phone first).

CA systems provide a reactive response to an acute event, while SH systems may provide supportive and preventative services, for instance, by means of home automation. One of the goals for next-generation telecare will be to integrate the supportive services of AT, the environmental, security, and interconnectivity capabilities of SH systems and the alarm services and response network of CA systems. By achieving this, the dependency on reactive services will diminish with supportive and preventative services taking on more of the care burden. In addition, there is a need to support *new additional services* that may be enabled by the integration of these services.

Chapter Five

Stakeholder Requirements Elicitation

The combination of a diverse group of stakeholders, a comprehensive spectrum of anticipated telecare services, and an integrated approach to the provision of care implies that a *needs*-led *systems*-based methodology is best suited for establishing system requirements. A systems approach (i.e. one that takes into account the viewpoints of all stakeholders and the inter-dependencies and relationships between system elements) will help to identify the necessary collaboration between stakeholders and services to enable an *integrated* telecare system.

A viewpoint-based methodology was adopted to consider the needs of each of the principal stakeholders which were gathered during the course of this research by:

1. A consideration of UK Government policies and publications concerning community and primary care.
2. Referring to academic and professional literature describing various aspects of gerontology, with particular emphasis on community and home-care settings.
3. An analysis of existing home-care and community alarm services and technologies.
4. Personal communication with a number of 'domain experts' including: potential clients, carers, service procurers, community alarm service providers and equipment manufacturers.

In addition, these needs were considered in relation to a number of 'use-case' scenarios as part of an iterative process of telecare service identification and refinement. Vignettes (or scenarios) were also used to compensate for the inability of certain stakeholders to comprehend the potential of a particular telecare service. Their use allowed new concepts to be conveyed within the context of familiar circumstances[1]. This design approach, refer to Figure 5.1, allowed earlier work to focus on system *requirements* rather than on issues of technology and system *implementation*. This ensured that the services identified were truly user-centred rather than being focussed, and in some instances constrained, by current technological capabilities (i.e. needs-led rather than technology-driven). The resulting identified requirements can be divided into two categories:

1. *General high-level system requirements* which can be applied to all telecare implementations. These are based on generic user and stakeholder need, government policy, and current health and social care thinking.
2. *Service-level requirements* that meet the specific needs and wants of the client (and their carers) and which must be implemented based on a comprehensive assessment of client need.

[1] *Often, it was necessary to suggest possible telecare services (which had been derived from analysing the literature) in order to obtain opinion on its efficacy. This was necessary, in part, because of the limitations of current technologies and a corresponding lack of understanding by stakeholders of what might be feasible, both at present and in the future.*

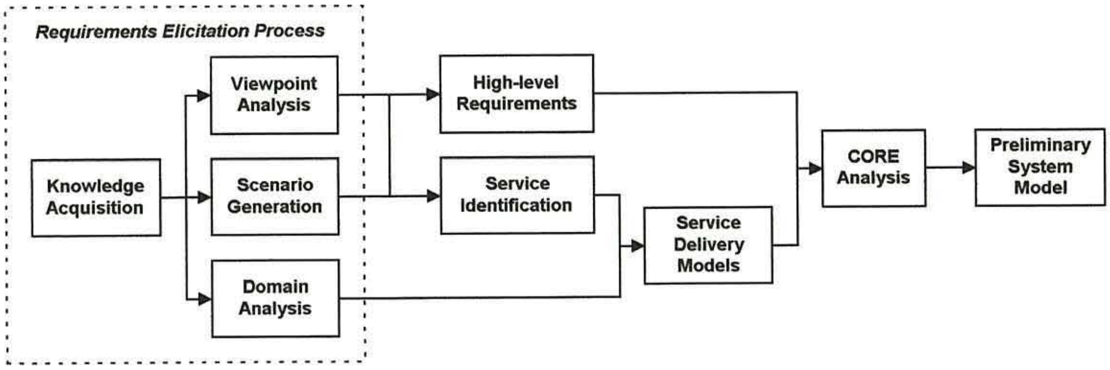

Figure 5.1. The systems methodology applied.

An analysis of CarerNet service requirements together with a consideration of the scenarios resulted in the development of various generic service-delivery models for next-generation telecare. The classification of system elements required within the home was achieved by considering the identified service requirements alongside the results of a domain analysis of the home. The requirements and information processing responsibilities of each viewpoint were tabulated in accordance with the Controlled Requirements Expression (CORE) format [150]. This helped to identify missing viewpoints as well as clarifying the flow of information throughout the system and establish the pathways of connectivity between stakeholders. The high-level model for next-generation telecare that was subsequently developed could be used as the basis of a detailed system architecture for CarerNet.

5.1 High-Level Stakeholder Requirements

The principal stakeholders for telecare were introduced in Chapter 2 and are described once more in Table 5.1 and are represented in the form of a viewpoint hierarchy diagram (VHD) in Figure 5.2[2]. A selection of high-level requirements are listed in Table 5.2.

Table 5.1. Stakeholder descriptions.

	Stakeholder	Description
1	*Clients*	The recipients of remote care services.
2	*Carers*	A team of formal (statutory) and/or informal (voluntary) carers working together.
3	*System procurers*	Commission and pay for the installation of telecare equipment and services. They may also perform the role of the telecare service provider, described below.
4	*Service providers*	Telecare Service Providers (TSP) should run the day-to-day operation of telecare systems such as data storage and processing, and call-centre responsibilities.
5	*Policy makers*	UK Government departments responsible for shaping healthcare policy as it applies in a primary/community setting, and devolved further in Scotland, Wales and Northern Ireland.
6	*Standard & regulatory bodies*	Since telecare may be safety-critical and involve the transfer of personal information (medical & social), it is likely to be impacted by a range of regulatory standards, recommendations and protocols.
7	*Existing 'telecare' technology manufacturers*	Manufacturers of community alarm systems, assistive technologies designed for the home, home-healthcare devices and smart home devices and systems.

[2] *The root of the VHD represents the viewpoint of a generic stakeholder, with subsequent branches representing stakeholders with increasingly specialised requirements.*

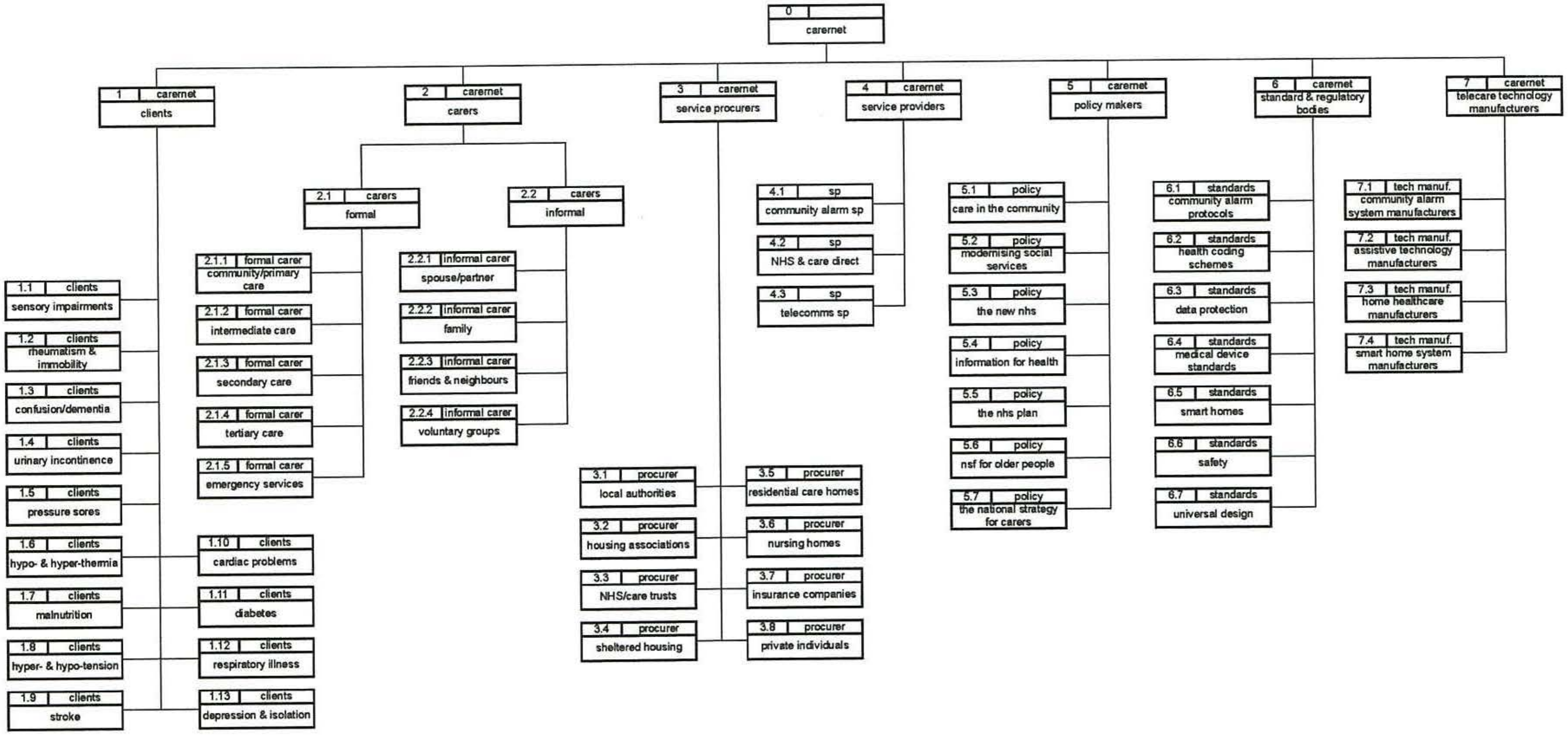

Figure 5.2. Viewpoint hierarchy diagram of CarerNet stakeholders viewpoints.

Table 5.2. A selection of stakeholder requirements for CarerNet.

Ref	Requirement (The system should ...)
1	Help to enable a wide range of clients with diverse care needs to live independently in their own home.
2	Enable available care resources to be employed more efficiently by identifying need and targeting resources accordingly.
3	Complement conventional care services.
4	Support services that enable individuals to be discharged sooner from hospital/institutional care.
5	Support services that prevent or delay admission into hospital/institutional care.
6	Integrate seamlessly with primary and community care information systems.
7	Employ appropriate technical and organisational measures to prevent accidental loss or destruction of, or damage to, client data. It should also guard against unauthorised access to client data.
8	Be compatible with smart home standards and protocols, where this is practicable and/or applicable.
9	Help the client to maintain social inclusion and a sense of community.
10	Ensure that there are a range of care options available to meet a wide variety of needs.
11	Support informal carers in their role.
12	Reduce levels of anxiety associated with issues of safety, security, and isolation.
13	Respond to client-need as quickly as possible.
14	Empower and not intimidate or constrain the client, i.e. the client should remain in control of telecare services in the home, rather than the other way around.
15	Offer a 'transparent' and non-obtrusive solution, i.e. system elements should not be seen as a 'badge of dependence'
16	Intervene no more than is necessary to foster independence, e.g. services should not be provided that perform functions which the client is perfectly capable of performing by themselves. (i.e. the introduction of technology should not result in an increase in the dependency of the client).
17	Reliable, dependable and safe. It should be fault-tolerant, should fail-safe and should degrade 'gracefully'.
18	Easy to install, setup, use, and maintain.
19	Continue to provide essential services in the event of a power outage for as long as possible.
20	Identify if a client is in distress and raise an alarm to the most appropriate responder.
21	Still provide methods of allowing the client easy access to a response centre operator.
22	Filter client-initiated requests for help to ensure that they are prioritised according to the severity of need.
23	Flexible and adaptable to meet diverse client needs.
24	Service infrastructure should be future-proof in order to protect capital investments.
25	Employ an open architecture with multi-vendor interoperability so that service procurers can obtain 'best of breed' products from the most suitable vendor and at competitive prices.
26	Filter information so as to not overload the carer or responder – only key information should be presented in the first instance, with the ability to request and analyse more detailed data, if necessary.
27	Allow the efficacy of particular care packages and interventions to be assessed. For example, this might include the ability to monitor the effect of a particular medication regime or monitor the use of a particular assistive device provided to the client in order to assess its effect on their activities of daily living.
28	Provide care audit information (especially by third-party care providers) – e.g. punctuality, response time, time spent with client and type and quality of care provided, etc.

5.2 Telecare Service Requirements

CarerNet will support its users, namely the client, their carers, and other responders and service providers by providing suitable services to meet their needs, some of which were identified and summarised in Chapter 3. These services must be provided within the constraints and guidelines identified from a consideration of the high-level system requirements.

This section identifies key service requirements for CarerNet, the definition of which will help to characterise the devices necessary to provide sufficient knowledge of, and access to, the local domain. Due to the focus of this research, the services considered will mainly consist of passive second generation services that are provided within the client's home. Table 5.3 summarises the main services identified from an analysis of the stakeholder needs discussed in Chapter 3 and Appendix A.

Table 5.3. A selection of telecare service requirements.

Service Type			**Service Requirement** (The system should ….)
1	**Safety**		
	1	*General*	
		1	Automatically unlock/open external doors in an emergency requiring the client to exit the home or to provide access to emergency services upon receipt of appropriate access code.
		2	Be able to wake-up the client, if sleeping.
		3	Be able to obtain the attention of a client in order to draw their attention to a message/alert.
		4	Inform a responder if system intervened on behalf of the client to manage/control a hazard.
		5	Enable the client to cancel erroneous alarm conditions.
		6	Register whether the client has acknowledged receipt of a reminder/message.
		7	Warn client that an appliance is approaching an unsafe state.
		8	Automatically switch off any appliances either in or approaching a potentially unsafe state, e.g. stove, hob, oven, microwave, iron, kettle, heater, electric blanket, etc.
		9	Enable appliances to be re-activated only through the use of appropriate key or code where appropriate (e.g. gas supplies/cooker).
		10	Detect if the client is in distress and notify a designated responder.
		11	Raise an alarm to the client if they step into a bath/shower and the water is too hot or cold.
		12	Raise an alarm to a responder if the client steps into a bath/shower and the water is too cold.
		13	Warn the client if the temperature of their bath/shower is too low.
		14	Ensure that bath/shower temperature in never too low.
		15	Raise an alarm to a designated responder if the client fails to eat.
		16	Have a selection of alternative responders in case of a problem.
		17	Contact the responder most appropriate to meet client needs.
		18	Provide sensory substitution techniques wherever possible and integrate with sensory augmentation devices wherever possible.
		19	Automatically disable power from electrical sockets when unused.
		20	Automatically disable power to a device from an electrical socket if device connected to it fails.
		21	Support the remote control of home appliances.
		22	Automatically close windows if it is raining outside.
	2	*Fire*	
		1	Raise an alarm to the client upon detecting a fire.
		2	Raise an alarm to the emergency services upon detecting a fire.
		3	Identify location of fire within the home and inform client of the location of the fire.
		4	Inform emergency services of location of the fire within the home.
		5	Extinguish the fire.
		6	Turn on emergency lighting to help visibility.
		7	Suggest an exit route for the client (e.g. "Fire in Kitchen, exit via front door.")
		8	Guide the client to the recommended exit by highlighting the best possible route of escape.
		9	Attempt to suffocate the fire by controlling sources of oxygen (windows, doors and vents) into the area where the fire is located providing that the area is unoccupied.
		10	Disperse smoke in order to improve the client's chances of escape and survival (e.g. by opening doors, windows and by turning on extractor fans.)
	3	*Flood*	
		1	Raise an alarm to the client upon detecting a flood.
		2	Raise an alarm to a designated responder upon detecting a flood
		3	Minimise the potential damage by automatically turning off the water supply causing the flood.
		4	Warn the client if a bath/sink is close to overflowing.
		5	Prevent accidental flooding by ensuring that the bath or sink does not overflow by controlling the flow of water into them.
	4	*Carbon Monoxide*	
		1	Raise an alarm to the client upon detecting dangerously high levels of Carbon Monoxide (CO).
		2	Provide advice to the client in the event of a CO alarm. (e.g. "Exit home immediately and do not return until it is safe to do so").
		3	Raise an alarm to the designated responder(s) upon detecting dangerously high levels of CO.
		4	Identify the location of the high concentration of CO and switch off potential sources of CO in the identified location.
		5	Improve ventilation in home by opening doors, windows and by turning on extractor fans.
	5	*Combustible Gas*	
		1	Raise an alarm (if appropriate) to the client upon detecting higher than normal levels of combustible gas (CG).

Service Type		Service Requirement (The system should ....)
	2	Raise an alarm to designated responder(s) (including the emergency services) upon detecting abnormal levels of CG.
	3	Switch off potential sources of CG in the location of the alarm.
6	Climate Control	
	1	Maintain room temperature (and if necessary) room humidity at a comfortable and safe user-defined level between permitted minimum and maximum values.
	2	Raise an alert to the client if they are exposed to a room temperature/humidity that is too high or too low for an extended period.
	3	Raise an alarm to a designated responder if the client is exposed to a room temperature/ humidity that is too high or too low for an extended period.
	4	Raise an alarm to a designated responder if the temperature in the house is so cold that it poses a threat of water pipes bursting.
	5	Switch on short-term infra-red heating in order to warm the client up quickly and efficiently if the client occupies a room that is too cold (e.g. bathroom).
	6	Control air-conditioning in order to cool the client if the client occupies a room that is too warm.
7	Scalding/Burns	
	1	Ensure that water temperature at the point of delivery to the client is regulated to ensure that it is incapable of exceeding $44^{\circ}C$ for bathwater and $41^{\circ}C$ for washbasin and shower applications ($47^{\circ}C$ for kitchen sink).
	2	Warn the client if the temperature of their bath/shower/sink is too high.
	3	Remind the client not to have the bath/shower/sink water too high.
	4	Raise an alarm to the client if they step into a bath or shower and the water is too hot.
	5	Raise an alarm to a responder if the client steps into a bath or shower and the water is too hot.
	6	Enable client/carer to set desired water temperature electronically.
8	Home Security	
	1	Raise a standard or 'silent' alarm to the client if an unlawful entry is suspected.
	2	Raise a 'silent' alarm to a designated responder if an unlawful entry is suspected.
	3	Enable the client to discreetly trigger a silent alarm.
	4	Simulate occupancy of the home if empty.
	5	Display the image of a house-caller to the client and designated responder.
	6	Enable client to converse with the caller without opening the door.
	7	Enable a designated responder to converse with the caller.
	8	Provide a means of verifying the authenticity and identification of 'official' visitors.
	9	Enable the client & designated responder to open an external door remotely.
	10	Remind the client that an external door/window has been left open. Automatically close doors/windows to secure house if necessary.
	11	Raise an alert to the client if there is a security problem and the client is about to leave the home, go to bed or go for a shower/bath.
	12	Raise an alarm to a designated responder if the client is about to leave the home in an unsafe state (e.g. cooker on).
9	Falls	
	1	Enable the client to easily request help in the event of a fall.
	2	Automatically raise an alarm to a designated responder if the client has fallen and is unable to recover by themselves.
	3	Remind the client to wear their hip-protector.
	4	Inform the appropriate care provider if the client persistently fails to wear their hip-protector.
	5	Fade-up light level in room if client gets out of bed/chair and it is dark.
	6	Fade-up lighting in room if client is up and about and it is dark.
	7	Generate a fall-prediction index capable of predicting the likelihood of a fall and raise an alarm to a responder if the likelihood of a fall exceeds a pre-determined threshold.
	8	Warn the client if they are approaching a hazardous area and should take care (e.g. a spoken message "You are approaching the top of the stairs Mr. Jones, please take care").
	9	Automatically highlight the edges of stairs in order to help define each step when the client approaches either end of the stairs, especially in the dark.
	10	Raise an alert to a designated responder if the client gets out of bed at night and does not return within a specified amount of time.
	11	Provide back-up lighting (e.g. battery-powered) that automatically comes on if it is dark and the main lighting has failed (e.g. power-cut or bulb-fail).
10	Memory/Confusion	
	1	Switch off the power to a microwave oven if a metallic object has been inserted into it.
	2	Warn the client if an appliance has been placed in an unsafe or potentially unsafe state.
	3	Remind the client if an appliance has been in a potentially 'unsafe' state for a period of time.
	4	Identify when food has 'turned' and warn the client/designated responder.

Service Type			Service Requirement (The system should ....)
		5	Remind client about important appointments/events (e.g." Gas man is visiting at 3PM today")
		6	Inform a designated responder if the client has a visitor.
	11	Dexterity/Mobility	
		1	Provide the client with a means of negotiating the stairs.
		2	Where necessary provide various methods of assisting the client in to and out of the bed/chair/bath/shower/toilet.
		3	Raise an alarm to a responder if client appears to be stuck in a bed, chair, bath, shower or toilet.
	12	Pressure Sores	
		1	Warn the client if they remain in a single position for too long.
		2	Warn the client if they adopt a position which has been 'forbidden' due to the presence of an existing pressure sore.
		3	Warn the client if they return to a position too soon.
		4	Monitor compliance with recommended activity/sitting/lying plans.
		5	Raise an alert to a designated responder if the client repeatedly fails to comply with recommended activity/sitting/lying plans.
		6	Ensure that environmental conditions are optimised (avoid low humidity and cold air).
		7	Time how long the client is in the bath or shower and inform them if they have been in the bath/shower for an extended period of time and remind them not to stay in much longer.
	13	Epilepsy	
		1	Raise an alarm to a responder upon detecting that the client is experiencing an epileptic seizure.
		2	Warn client (and carer) of an impending seizure so that they can prepare for it in advance.
2	**Screening/Assessment**		
	1	Comprehensive Geriatric Assessment	
		1	Perform a functional (including physical & sensory) assessment of the client.
		2	Perform a safety assessment of the client and the home.
		3	Perform a social support assessment of the client.
		4	Perform a nutritional assessment of the client.
		5	Perform a medication assessment of the client.
		6	Perform a psychological/cognitive assessment of the client.
		7	Trigger assessment notification alerts to designated responder(s) if assessment scores exceed pre-determined intervention thresholds.
		8	Generate a fall-prediction-index
		9	Generate an overall well-being index.
		10	Generate a risk-of-living-alone index.
3	**Client Support**		
	1	General	
		1	Provide a visual signal when the doorbell is activated.
		2	Provide a visual indication when the telephone rings.
		3	Provide remote access to home-based services provided that access codes are provided.
		4	Provide positive information to the client informing them that all is well.
		5	Provide the client with a 'digital assistant' capable of supporting them in their everyday activities. (e.g. ordering a taxi, reminding of appointments & important dates, recording of symptoms, etc.)
		6	Automatically dispense the correct dose of medication to the client.
		7	Provide a means of allowing the client to trigger sequences of events (macros) using a single method of activation (e.g. switch). For instance a "Hello" switch to turn off security system (some form of code or biometric technique would be required), turn on lights (if dark) and heating (if cold) in the house. Similarly a "Goodbye" switch could ensure that all appliances were in a suitable state (e.g. cooker off), close windows, remind client if fridge door was open and enable security system.
		8	Provide a means of automatically running event-macros based on client activity and location (e.g. automatically performing the services mentioned in 3.3.9 using house occupancy information).
		9	Provide a means of allowing the client or a suitable carer to define the sequence of events that make up the required macros.
		10	Provide biofeedback systems to help support incontinence, high blood pressure, relaxation etc.
	2	External access to services	
		1	Provide remote access to external services to enable the client to interact with the outside world from their home (e.g. www, e-mail)
		2	Provide remote access to external services to enable the client to manage their shopping and financial needs remotely. (e.g. e-shopping, e-banking, e-commerce).
		3	Support remote consultations with physicians.
		4	Provide e-entertainment to clients including virtual community services (e.g. card games, etc)

Service Type		Service Requirement (The system should ....)
3	Exercise & Nutrition	
	1	Help clients to better manage the consumption & storage of perishable foods.
	2	Provide appropriate diet and recipe information to clients with special dietary needs. (e.g. low-sodium, low cholesterol, low sugar, low saturated fats, low calorie, high fibre). Can be linked in to bar-code scanning of available foodstuffs.
	3	Enable a client to undertake a managed level of exercise in their own home.
	4	Enable e-shopping list creation by scanning bar-codes.
	5	Provide nutritional characteristics of food to client on-request.
	6	Provide assistance to the client to communicate with others.
4	Incontinence	
	1	Inform client if absorption-based incontinence pad is close to saturation and needs replacing.
	2	Predict when client is due to go to the toilet and remind them to go to (esp. dementia).
	3	Train a client to stop nocturnal enuresis by waking them up.
	4	Highlight the path to the bathroom/W.C. for clients who have difficulty finding their way.
5	Diabetes	
	1	Monitor blood glucose levels and record them for historical analysis by the client (and/or a carer) so that the level of insulin in the blood, and hence diet, can be managed effectively.
	2	Warn the client if their glucose levels are too high or too low.
	3	Raise an alarm to an appropriate carer if the client's blood sugar levels are repeatedly outside 'normal' levels (for the client).
	4	Be capable of delivering insulin into the bloodstream/body in a controlled, monitored fashion.
	5	Remind the client/carer to perform blood glucose measurements.
	6	Warn the client if they repeatedly fail to monitor their blood-sugar levels.
	7	Inform the most appropriate carer if the client persistently fails to perform measurements.
	8	Wake-up a client if there is a suspicion that they are about to go hypoglycaemic.
	9	Raise an alarm to a responder if the client suffers a hypoglycaemic attack (a 'hypo').
	10	Provide a mechanism for the client to record their dietary intake in an electronic form.
6	Medication	
	1	Remind the client of when to take their medication.
	2	Ensure that the client takes the correct medication
	3	Warn the client if they have not taken their medication.
	4	Monitor client's compliance with prescribed medication regimen.
	5	Inform a formal carer (e.g. GP, pharmacist, community nurse) if the client's compliance is consistently poor or if they have missed a particularly important medication.
7	Memory/Confusion	
	1	Raise an alert to the client if they have left the fridge/freezer door open for an extended period.
	2	Raise an alert to a designated responder if the client has left the fridge/freezer door open for an extended period.
	3	Raise an alert to the client if they have left an external door open for an extended period.
	4	Automatically close an external door if it has been open for an extended period (and the client has not responded to an alert).
	5	Automatically lock external doors if they are unlocked when the client has gone to bed.
	6	Provide supportive cue's/instructions to help enable a client to perform sequential tasks (e.g. making a cup of tea).
	7	Help a client (or carer) to locate misplaced items.
	8	Provide temporal re-orientation information to the client in the form of time, date, day of week, and a simple means of day-time/night–time differentiation.
	9	Advise the client not to step outside if it is inappropriate – such as during inappropriate times (e.g. it is 2AM) or during inappropriate weather conditions (e.g. it is cold, windy and raining)
	10	Advise a client on appropriate clothing, based on current weather conditions, if they are going out. (e.g. "It is raining out – wear your raincoat and take your umbrella").
	11	Remind/encourage a client to eat.
	12	Disable certain out-going phone calls during unsociable hours.
	13	Divert certain out-going phone calls to an appropriate responder/carer.
	14	Filter incoming phone calls and divert to an appropriate responder/carer.
8	Dexterity/Mobility	
	1	Enable 'keyless' entry into home (using electronic rather than mechanical keys, or some other biometric technique such as finger-print or voice).
	2	Adjust height of work surfaces and cupboards according to need.
	3	Automatically open/close doors & windows (if necessary).
	4	Open/Close doors/windows on-demand.

Service Type			**Service Requirement** (The system should ....)
	9 Behavioural problems		
		1	Remind the client of the time and of advising them to alter their behaviour accordingly.
		2	Automatically return volume settings to acceptable levels if they are too loud/too loud for the time of day.
		3	Automatically turn off source of high volume.
		4	Prevent appliances being miss-used during inappropriate hours.
	10 Energy Efficiency		
		1	Automatically turn off lighting in rooms that have been unoccupied for a period of time.
		2	Automatically turn down/off heating in rooms that have been unoccupied for a period of time.
4 Carer Support			(see also safety section)
	1 Incontinence		
		1	Inform an appropriate responder if a client's absorption-based incontinence pad is close to saturation and needs replacing.
		2	Predict when a client is due to urinate and inform a carer.
	2 Memory/Confusion		
		1	Immediately inform a designated responder if the client wanders from (i.e. leaves) the home under particular circumstances (e.g. inappropriate time, weather, when unwell, or always).
		2	Inform a designated responder if the client wanders from the home and fails to return within a specified amount of time.
		3	Provide a means of locating the client if they have wandered away from the home.
		4	Warn a live-in carer if the client has changed from a 'stable state' to an 'unstable state' (e.g. if a client has or is *about* to get out of a chair or bed).
		5	Warn a live-in carer if the client has left a 'safe zone' or entered an 'unsafe zone'. (e.g. if a client has or is *about* to leave or enter a particular room [e.g. kitchen] or exit the home).
		6	Inform designated responder if the client seems agitated, e.g. if there is an increase in client wandering and pacing and inform a carer as appropriate.
		7	Provide access to data on-demand for reassurance purposes.
	3 Medical		
		1	Monitor client's physiological parameters e.g. blood pressure, breathing characteristics, pulse/ heart-rate and strength. etc.
		2	Identify and record abnormal patterns of ECG activity and transmit to a specialist.
		3	Monitor palpitations and identify abnormal heart-rate variability (arrhythmia's) and record such sequences for later analysis.
		4	Remind/assist the client to keep an up-to-date diary of symptoms and activities.
		5	Assist the client to provide relevant information concerning symptoms experienced.
5 Care Management			
	Human Care Audit		
		1	Monitor the provision of care by human responders.
		2	Monitor the quality of care by human responders
	2 System Care Audit		
		1	Monitor and log the operational status of the system.
		2	Monitor the provision of care by the telecare system.
		3	Monitor the quality of care provided by the telecare system.
		4	Monitor client usage and interaction with the system.
	3 Care Plan Audit		
		1	Monitor the progress of the client following particular interventions and provision of care and care equipment.
	4 Outcomes Monitoring		
		1	Assess whether a client is using and benefiting from any assistive technology provided to see if it is suitable for the client's needs.

5.3 Domain Analysis

The domain of CarerNet spans the client's home, the telecare response centre, and that of the various responders. For the purposes of the present work, it is sufficient to focus on the home (or domestic/local domain), which consists of the client (and other inhabitants of the house, if present) and the living environment, see Figure 5.3.

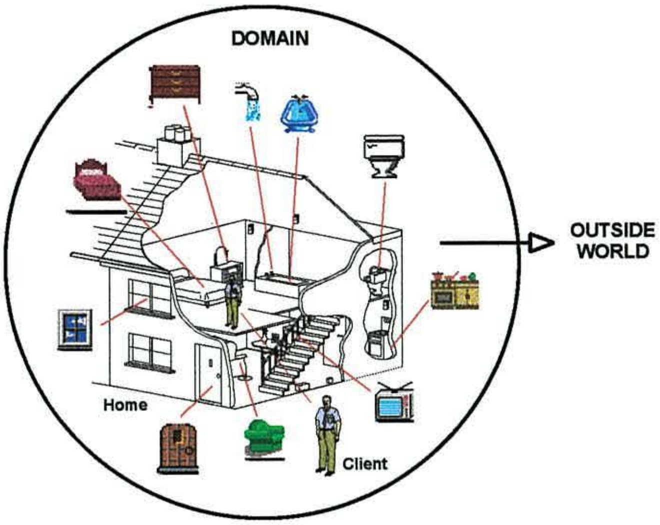

Figure 5.3. The local CarerNet domain.

This is represented more formally as a UML aggregation in Figure 5.4, which further highlights the boundaries of the domestic system [151, 152]. A more detailed examination of these entities will help to identify the types of primary data-source that are likely to be available and will also enable the creation of a high-level model capable of representing the status of the local domain in software.

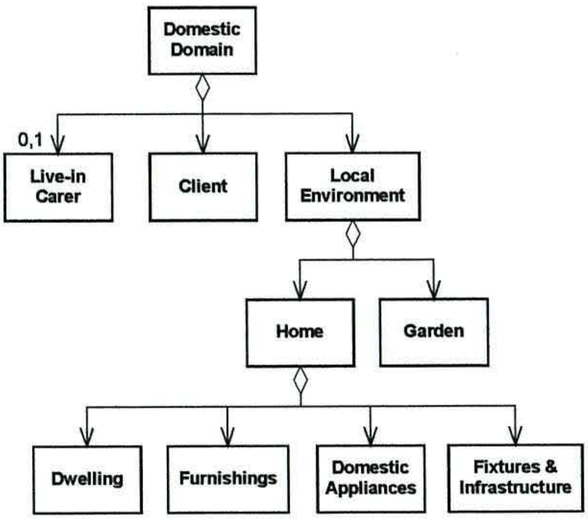

Figure 5.4. An aggregation of the elements that constitute the local CarerNet domain.

5.3.1 The Client

Figure 5.5 illustrates a partial conceptual decomposition of the structure and function of a client. Each of these may be further decomposed into more precise systems or structures. For example, a client's physiology can be categorised into various sub-systems including: respiratory, cardiovascular, locomotive, sensory and nervous systems. Likewise, cognition may be sub-divided further into sensory perception, attention, memory, language and thinking, etc.

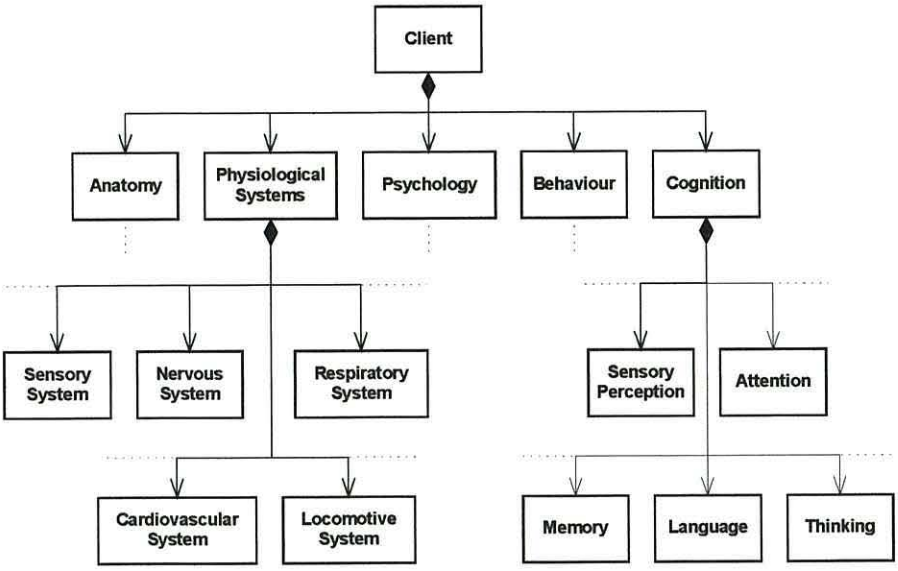

Figure 5.5. A partial conceptual decomposition of a client.

For the purposes of telecare, it is sufficient to realise that an electronic monitoring system will only be able to automatically 'perceive' the client in terms of monitoring physiological and behavioural parameters. It may subsequently be possible to derive or infer cognitive and psychological parameters by careful interpretation of physiological, behavioural, and related data caused by so-called 'sentic-modulation'[3]. For example, physiological signals which can be modulated by state-of-mind include: sighing, client activity levels, facial expression, vocal intonation, heart-rate, respiration profile, blood flow, muscle activity, and level of perspiration [153]. Although it then becomes important to discount other causes of physiological trends, e.g. an increased heart-rate might be due to feelings of excitement or increased levels of stress, or, it may be caused by walking quickly up the stairs (or it could be all three!). In addition, it is also possible to monitor if the client performs repetitive activities, the frequency of erroneous or dangerous events, and the level of interaction with outside world. If a more accurate representation of a client's state of mind were necessary, then it may be necessary to provide the client with some form of structured (electronic) diary that could allow them to easily record their feelings throughout the day in a convenient form for analysis. The latter is, however, likely to be an unreliable means of obtaining psychological and cognitive data because firstly: it depends on the client remembering to regularly and reliably record diary entries, which they don't always do [154]; and secondly: they must be capable of expressing their feelings in a suitable form.

Table 5.4. A selection of relevant client details.

Name	GP details	Chronic conditions	Care Plan
Age	Informal Carers	Allergies	Care Assessment Scores
Address	Key-holders	Known side-effects with drugs	Blood group
Date Of Birth	Pharmacist details	Service Charge details	Special Emergency Instructions
Gender	Prescription(s)	Service Plan	Next-of-kin contact details

[3] *For a discussion of such concepts see [153].*

In addition to the physical status and behaviour of a client, it is necessary to be aware of a whole host of other personal information. This includes client identification details as well as other relevant items from the client's medical and care history, see Table 5.4.

5.3.2 The Local Environment

The local environment must provide a comfortable and safe habitat in which the client can thrive. A knowledge of the way in which the client interacts with the local environment can provide functional and behavioural parameters that may help to establish an indication of client well-being. In order to obtain an overall feel for a typical home, refer to Figure 5.6 and Figure 5.7, which represent floor-plans of a typical two-storey, three bedroom, semi-detached house.

Figure 5.6. Representation of a typical floor-plan (ground floor).

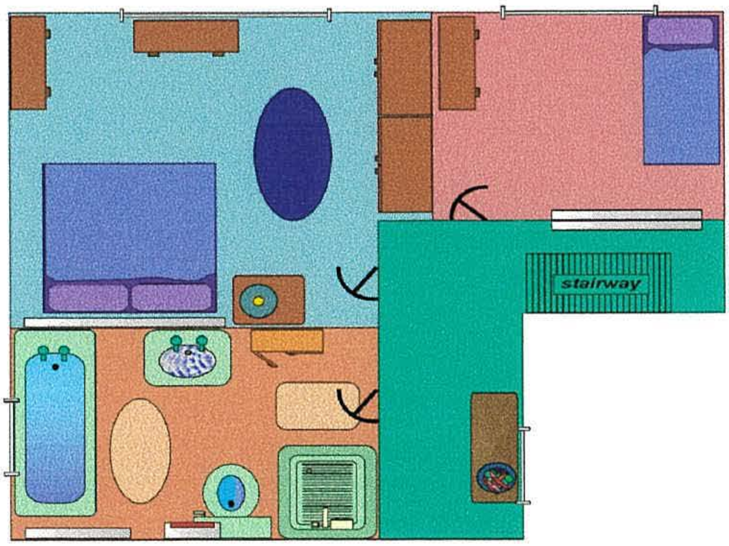

Figure 5.7. Representation of a typical floor-plan (first floor).

The following diagrams represent this domain in a more structured format using the graphical notation of the Unified Modelling Language (UML) [151, 152]. The actual dwelling itself has both form (e.g. Figure 5.8 and Figure 5.9) and function (e.g. Figure 5.10). Figure 5.11 to Figure 5.18 represent various other domain entities with relevance for telecare.

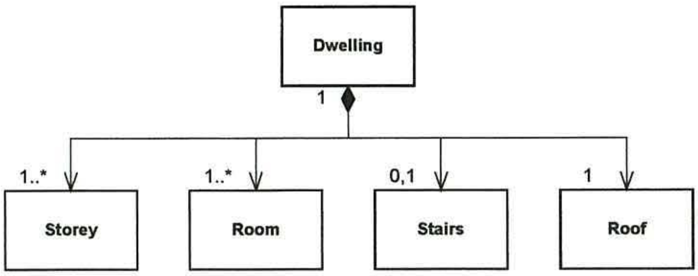

Figure 5.8. The composition of a typical dwelling.

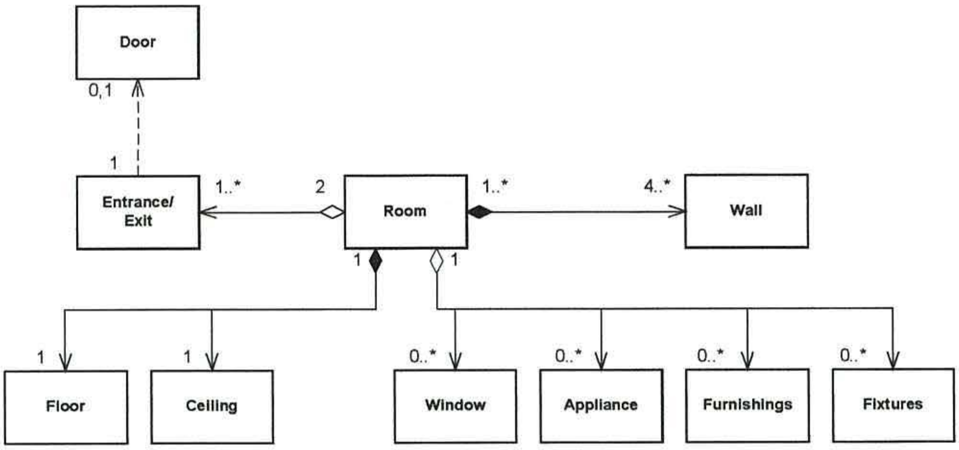

Figure 5.9. The composition of a typical room.

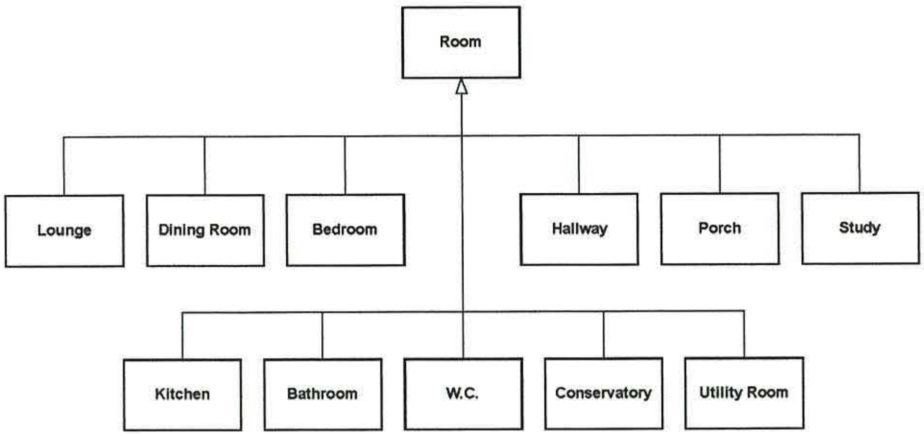

Figure 5.10. The various 'functions' of a room.

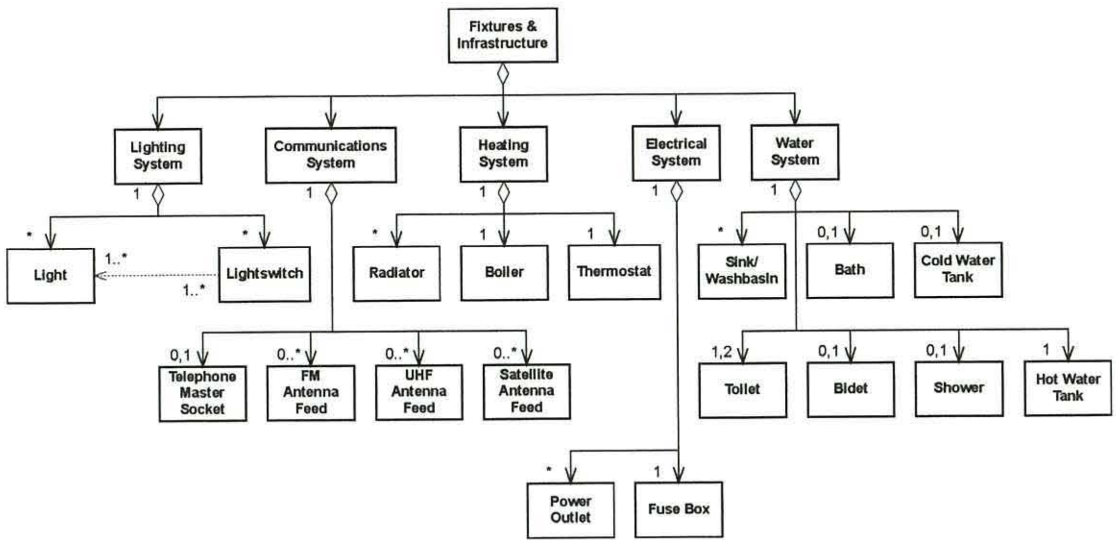

Figure 5.11. Key fixtures and infrastructure within the home.

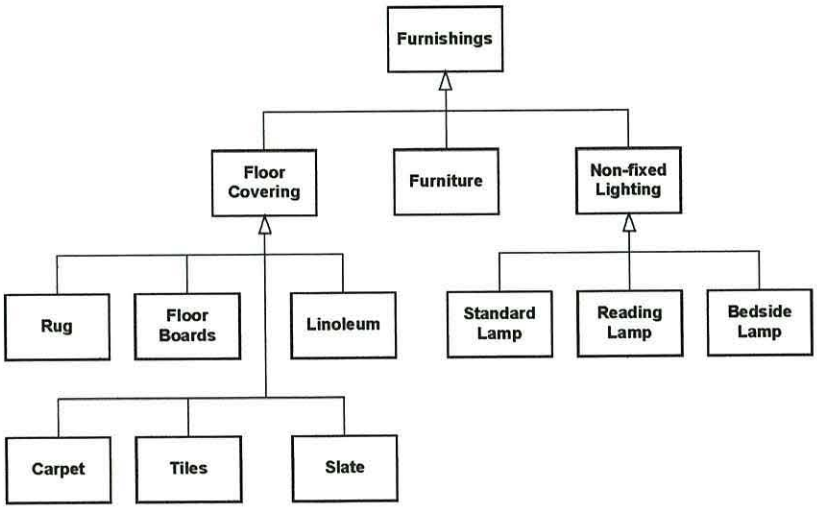

Figure 5.12. Key furnishings within the home.

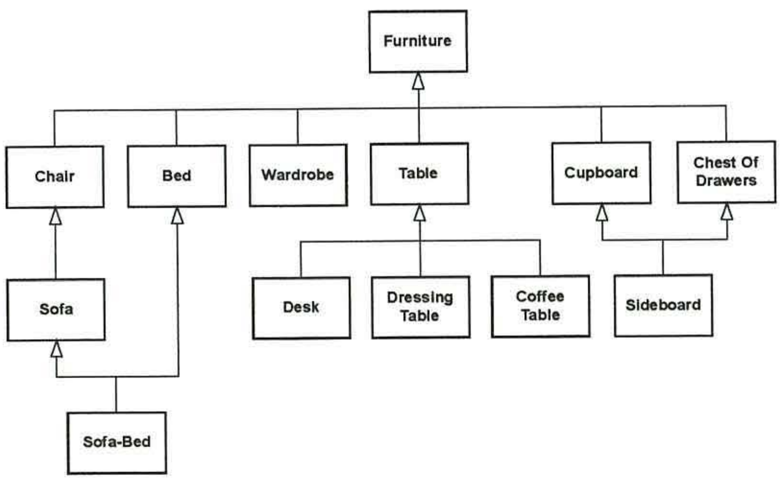

Figure 5.13. Types of furniture within the home.

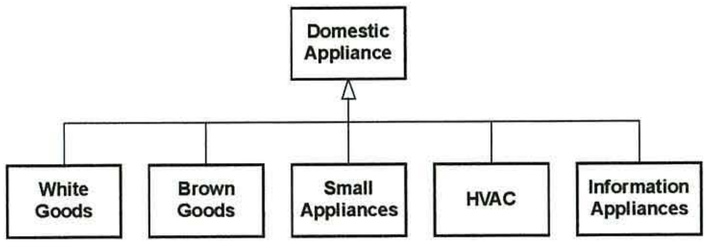

Figure 5.14. Key domestic appliances found within the home.

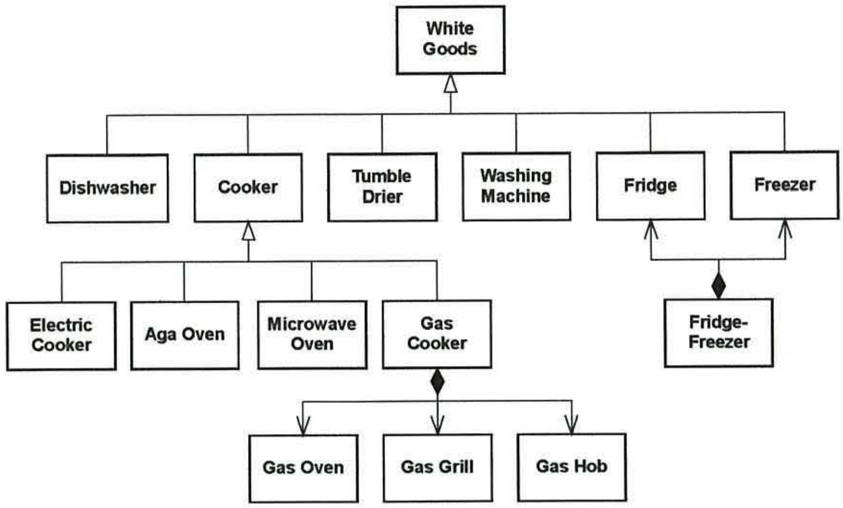

Figure 5.15. Typical white goods found in the home.

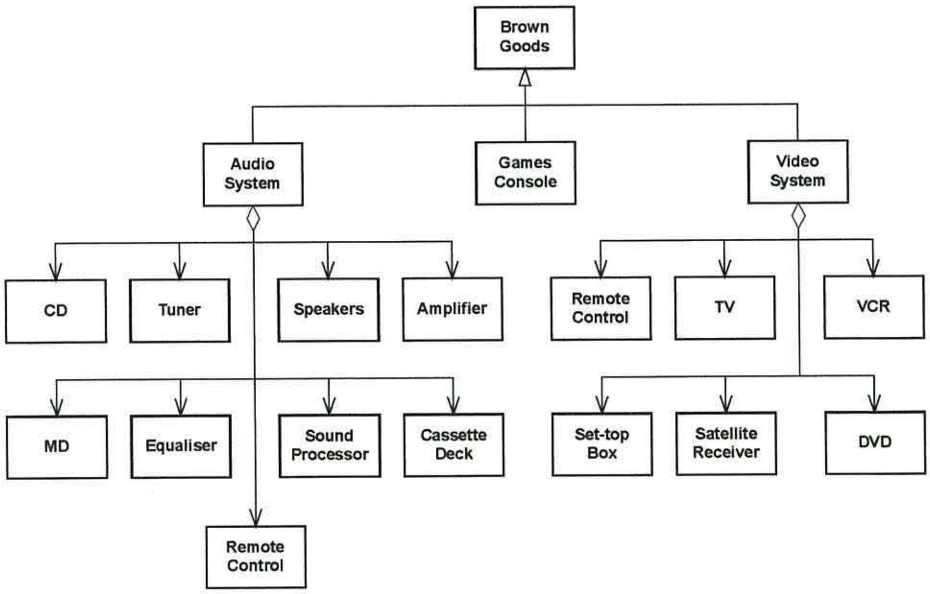

Figure 5.16. Typical brown goods found in the home.

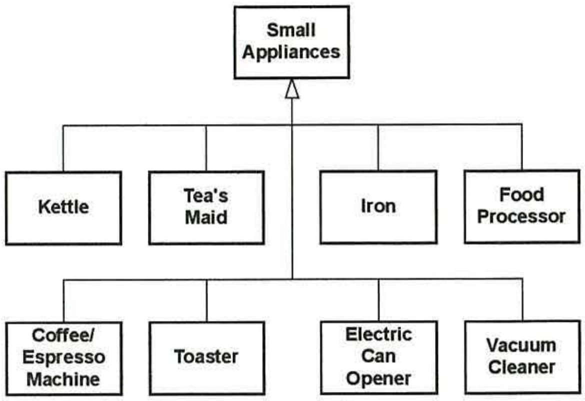

Figure 5.17. A selection of common 'small appliances'.

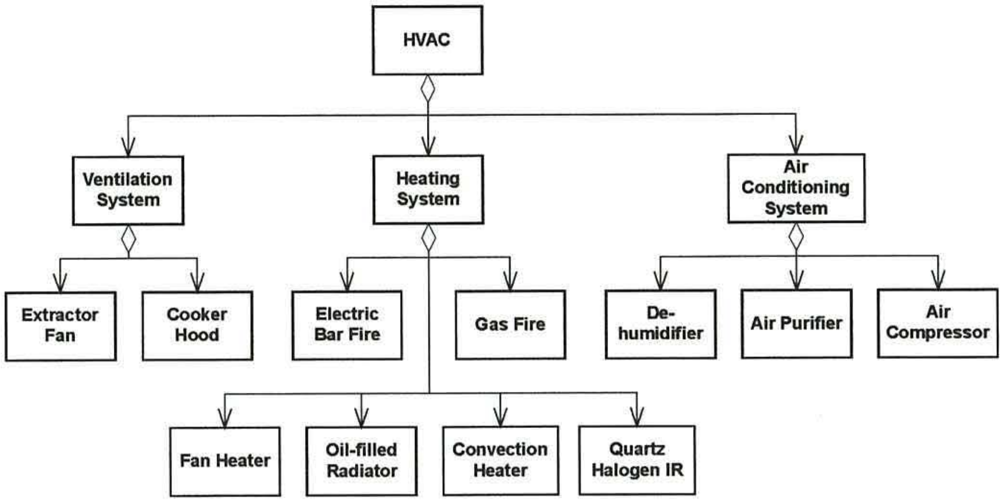

Figure 5.18. Heating, Ventilation and Air-Conditioning elements within the home.

5.3.3 Discussion

In terms of *physically* monitoring or controlling the local domain of interest, telecare services must have access to five basic data-classes:

1. Client physiology.
2. Client 'lifestyle' and behaviour.
3. The state of use of domestic appliances & utilities.
4. The state of use of domestic furnishings.
5. Local environmental conditions.

In order to realise these services, various system elements will have to be conceived in order to perform the necessary monitoring, control and intelligent functionality required, see Figure 5.19. This diagram illustrates how the system intelligence must accept data from a battery of monitors (and corresponding sensors) in order to provide it with the necessary information about its local domain. It can then make decisions based on this, and other data, and act on them, sometimes using a matching range of effectors in order to close the loop of care within the home and provide the necessary telecare services.

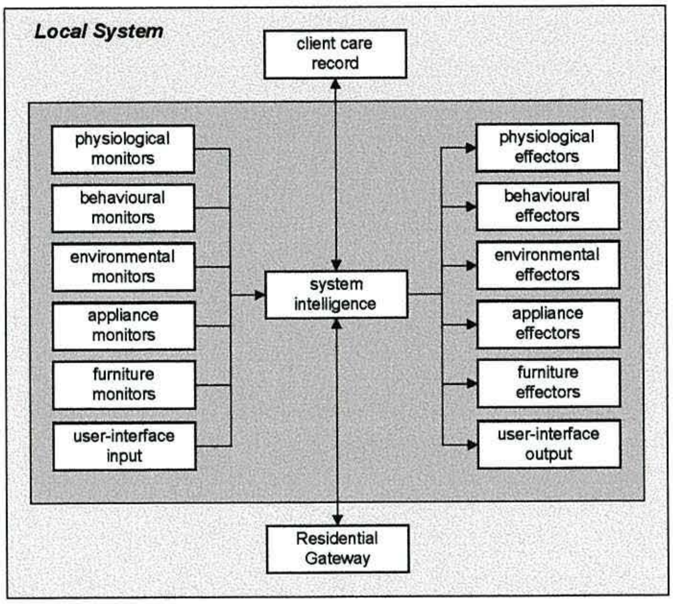

Figure 5.19. Module-level system diagram for the local CarerNet system.

5.4 Scenario Analysis & Service Delivery Models

Part of the requirements elicitation process involved developing use-cases based on potential real-life scenarios (or vignettes) in which the use of telecare might be considered. By analysing these scenarios it was possible to refine ideas for potential telecare services and to consider how they could be implemented and how clients and carers might interact with them. Moreover, the combined scenario and viewpoint analyses enabled generic methods of telecare service delivery to be classified which subsequently aided the development of an architectural model for CarerNet.

The analysis shows that CarerNet must possess flexibility, extending from the range of services that it can offer to the manner in which these services are provided (and even paid for). For instance, telecare services might first be instigated by the client or a relative for personal reassurance following a distressing event such as a fall, or a visit by a bogus caller. The needs of the client may, in due course, increase to such an extent that telecare is actually prescribed in order to perform an assessment, provide support to improve the quality of life of the client, or to facilitate early discharge from (or prevent admission to) institutional care. Moreover, the needs of clients who live with an informal carer will differ from those who live alone; similarly clients who live in a city-centre sheltered housing scheme will have different needs to clients living in dispersed housing in the countryside.

There is clearly then a great deal of scope for various service delivery and funding models within these different scenarios. Funding models are outside the scope of this work and, hence, only the logistics of care provision will be discussed further. Figure 5.20 shows the various care and support options available for a client living in their own home.

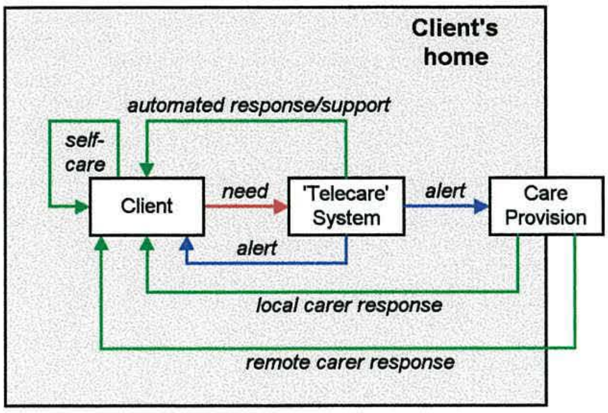

Figure 5.20. Care delivery options.

These are:

1. Self care.
2. Assisted care.
3. Local care.
    a. Local informal carer.
    b. Local formal carer.
4. External care.
    a. External informal carer.
    b. External formal carer.

An analysis of stakeholder viewpoints, telecare service requirements, and various use cases for telecare has resulted in the development of three general models of service delivery. These are necessary to accommodate the wide ranging options for the delivery of care and support, which will vary according to a number of factors, including:

- The care requirements, personal circumstances, and dependency of the client.
- The type, condition, and location of the housing in which the client lives.
- Whether the client lives alone or with a carer.
- The ability of an informal carer to support the needs of the client.
- Whether or not the client requires formal care provision.
- The location of the carer in relation to the client.
- Whether or not the client has a (good) informal/voluntary/social support network.
- Who requests the service.

5.4.1 Type 1 Service Delivery Model

The Type 1 Service Delivery Model (SDM-1) is intended to meet the needs of clients who live alone and who require some assistance to live independently but do not necessarily have need of external intervention. SDM-1 may also be suitable for clients who receive the support of a live-in carer. Thus, SDM-1 represents a solution totally independent of external care agencies, Figure 5.21. This is similar to the present situation where a client is provided with various items of assistive or home-healthcare technology which do not possess the capability of communicating with the 'outside world'. The difference being that CarerNet services must interoperate (where applicable) and thus may be considered similar to a smart home in that respect.

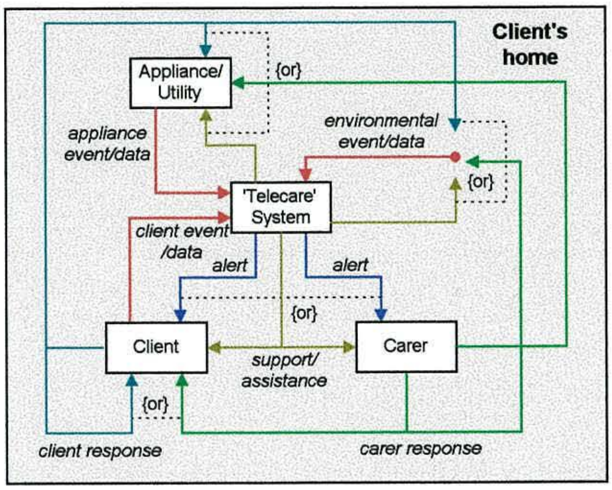

Figure 5.21. Type 1 Service delivery model for telecare.

Any alert or alarm that is generated either automatically or manually by the system is for the sole attention of the client or the live-in carer, who must respond appropriately. Alternatively, the telecare system may itself provide a response to a perceived need, such as by automatically switching off the water to a bath if it is in danger of overflowing and nobody has responded to its warning.

Vignette 5.1. An example scenario for Type 1 services.

Mrs. Ferguson is finding it difficult to sleep as she is worried about her husband who suffers from dementia and has developed a tendency to wander. Mrs. Ferguson is concerned that he might fall down the stairs or step outside in the cold without her knowing, in particular during the night. She would feel much more relaxed if a simple alerting mechanism would inform her if Mr. Ferguson:

a) got out of bed and did not return for more than 15 minutes;

b) opened the front (or any other external) door;

c) fell.

In addition, there should be a means of waking her up if any of these events were to occur during the night. Furthermore, Mr. Ferguson's short-term memory is failing and he has developed an irritating habit of leaving the freezer door open. Several times the contents of the freezer have had to be thrown away. A means of providing a warning that the door has been left open would be extremely beneficial.

In fact, whether SDM-1 may be regarded as *tele*care in the strictest sense of the word is open to debate. Although in the case where there is a live-in carer, the function of the system remains to either request assistance from or provide information to a 'remote' carer. Alternatively, automated care and support services compensate for care that would otherwise require external intervention. An example where SDM-1 might be appropriate is provided in Vignette 5.1, which describes the case of a client who lives with a spouse who also performs the role of the primary informal carer.

SDM-1 can offer a basic solution in the way of a simple alarm mechanism or it can be fairly sophisticated with integrated and intelligent autonomous services. SDM-1 does not require external communications but still represents a highly relevant means of supporting care at home and is sufficient to provide many individuals with a simple technological solution to meet their particular requirements. SDM-1 may offer an entry-route into telecare with basic support and/or alert/alarm services being provided in the first instance, and may, in time, lead to the 'adding-on' of more sophisticated telecare services.

Another application for SDM-1 might include care service procurers who have to provide round-the-clock or night-time care for home-based 'at-risk' individuals, e.g. a nurse supervising home-based intra-venous drug therapy. There may also be some advantages for carers who are only required to perform on-demand non-care-intensive services, e.g. ensuring that a piece of equipment is functioning correctly.

5.4.2 Type 2 Service Delivery Model

The Type 2 Service Delivery Model (SDM-2) is based on clients for which the necessary level of service provision may be provided informally by friends, relatives or other informal carers. An example scenario for which a type 2 SDM may be appropriate is described for the case of an individual suffering from epilepsy in Vignette 5.2.

Vignette 5.2. An example scenario for Type 2 services.

Mrs. Neville suffers from epilepsy and can be prone to quite vicious seizures. Her husband works locally in town during the day whilst Mrs. Neville stays at home as she has retired through ill-health. Mr. Neville is anxious that he be kept informed of any epileptic seizures that his wife may suffer so that he can return home to take care of her. It is for this reason that he purchased a mobile phone so that he can always be contacted in case of emergencies. Both Mr. and Mrs. Neville would appreciate some means of automatically generating an alarm message on the mobile phone either when a seizure is taking place or soon after. This message might be generated either by Mrs. Neville pushing an alarm button or by the use of a smart sensor, capable of detecting that an epileptic seizure is occurring and of automatically raising the alarm.

This enables information or alarms to be transmitted to an informal carer who might be situated at another location within the community. This level of service may be supported by a number of means, including telephony, paging, e-mail, text-messaging, or via voicemail. There is still no external care agency involved directly with care provision. SDM-2 thus describe services which extend SDM-1 in the sense that communications capabilities external to the home are now supported, see Figure 5.22.

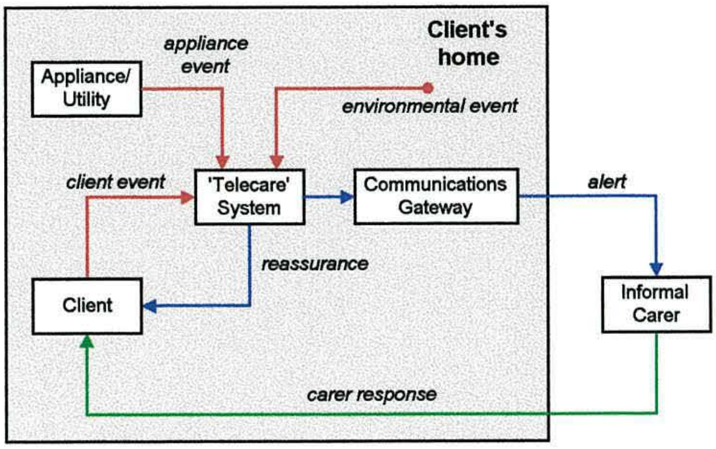

Figure 5.22. Type 2 service delivery model.

5.4.3 Type 3 Service Delivery Model

The Type 3 service delivery model (SDM-3) has been segregated into two levels (A and B). SDM-3A represents an intervention-on-demand approach as in the current generation of community alarm systems. SDM-3B represents a more pro-active approach, where external care providers are able to perform more detailed assessments with greater control over the quantity and level of information that is made available and which can be transmitted onward from the home.

Type 3-A

The Type 3A service delivery model (SDM-3A) might be considered when external care agencies are required to handle exceptional situations in which an informal carer is either unable to help, has failed to be contacted, or is not available. It might typically support medium- to low-risk clients, especially if living alone, who are by and large in good health and enjoying a good quality of life. Such clients would not normally consider themselves to be so frail as to warrant continuous active intervention by external care agencies, but would nevertheless enjoy the piece of mind provided by a 'safety-net'. Thus, any intervention by the external care network is almost always in response to a request for help.

Type 3A services allow only alarm-based information to leave the local environment, allowing little or no access to the underlying data-sets. SDM-3A therefore resembles the model of service delivery employed with community alarm systems where the hub of the system is the telecare response centre, which processes the calls received from the various clients that are connected to it, see Figure 5.23. In the main, external care provision is not provided via the telecare system other than by the TSP responder service. An example scenario for which SDM-3A may be appropriate is described for the case of an individual who is generally well but also concerned about the implications of falling, having fallen badly recently, Vignette 5.3.

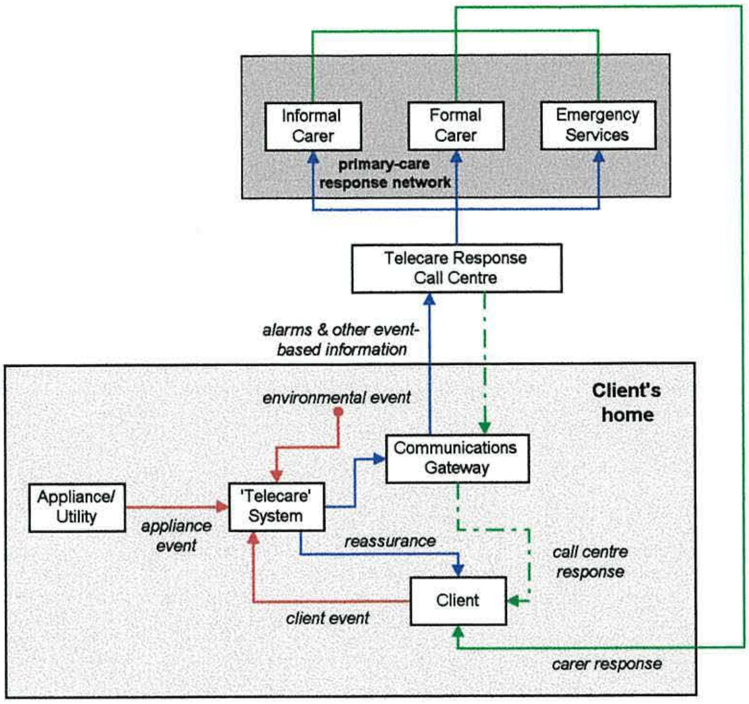

Figure 5.23. Type 3-A Service delivery model for telecare.

Vignette 5.3. An example scenario for Type 3-A services

Mr. Pritchard, 72, lives alone in a very old terraced house with an outside toilet and no central heating. He is generally in good health but has some pain in his hip and wears spectacles to correct his myopia. He has been in and out of residential care homes during periods of illness, but always returns to his home once recovered because he likes to be amongst his possessions. His niece, visits him once or twice a week and performs some chores for him such as doing the laundry, changing the beds and some shopping. Mr. Pritchard has a home-help to prepare meals for him some days of the week.

One day, Mr. Pritchard suffered a fall and was unable to right himself for several hours. It was only by chance that help happened to arrive later the same day when his niece visited on her way home from work. Whilst Mr. Pritchard was unhurt, both he and his niece were concerned as to what might happen if the same thing happened another time. Because his niece lived only 10 minutes away from where her uncle lived, she could provide a fast response to any acute event such as a fall, if only there was a way of letting her know. However, his niece worked part-time in a shop in a neighbouring town and would not always be available.

SDM-3B

The Type 3B service delivery model (SDM-3B) enables external carers to obtain low-level data from the local system and perform detailed assessments, i.e. data is permitted to leave the home and carers may alter operating parameters or control home-based appliances/devices from afar. It is for clients who are actively undergoing therapy or assessment or care and for which the care providers require greater access to client data and well-being. It might be considered suitable under circumstances where the client is undergoing some form of assessment procedure, either to establish variations in long-term trends so that a preventative/interventionist approach may be employed or to perform short-term monitoring of physiological parameters or the effect of a medication regime following some acute medical episode.

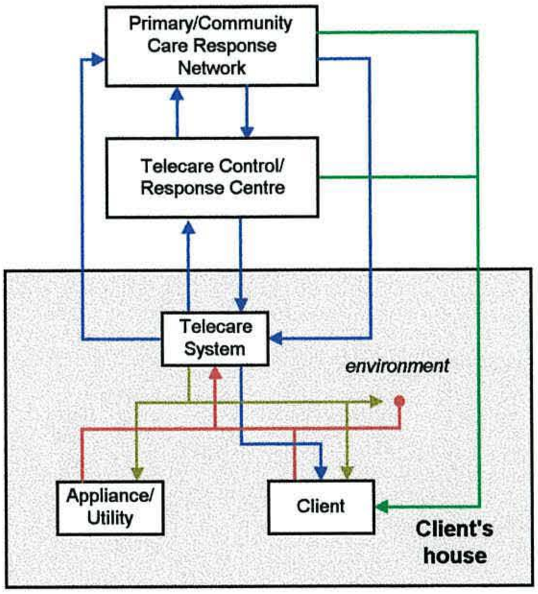

Figure 5.24. Type 3-B Service Delivery Model.

Vignette 5.4. An example scenario for Type 3-B services

Mr. Smith (aged 65) recently suffered a stroke on the left-side of his brain and had to undergo emergency neurosurgery. As a result, he acquired a mild form of dysphasia and sometimes finds it difficult to communicate effectively. He also has a weakened right-hand-side and impaired mobility, including an uneven gait which combined with his general weakness following his discharge has led to a fear of falling. Mr. Smith has been prescribed a host of medications, including:

1. *Pain killers for his headache;*
2. *Antihypertensive drugs to control his hypertension;*
3. *Oral medication to control his type 2 diabetes.*

He lives with his wife and so has the luxury of a live-in informal carer who can respond to his immediate care requirements and help him with the task of readjusting to life at home and to the process of recovery. He will shortly be undergoing a course of speech therapy and physiotherapy and the GP is anxious to ensure that the course of medications that he is taking is having the desired effect.

5.4.4 Discussion

The development of the service delivery models helped to discover the mechanisms by which telecare can be provided as well as identifying the high-level flows of information necessary between various system stakeholders. The knowledge gained from their development can be used to help construct a high-level model for CarerNet.

5.5 Viewpoint Analysis

A modified CORE methodology was used to help formalise the roles, responsibilities, and information requirements of stakeholders and system elements [150]. This process involves the consideration of each viewpoint in terms of the data required with its source, any processing performed, and output data generated, with its destination. This permitted the relationships between them to be confirmed and any omissions in the system identified. A selection of viewpoint diagrams are included here for illustrative purposes[4], see Figure 5.25 to Figure 5.27; an explanation of the client viewpoint is discussed in Box 5.1.

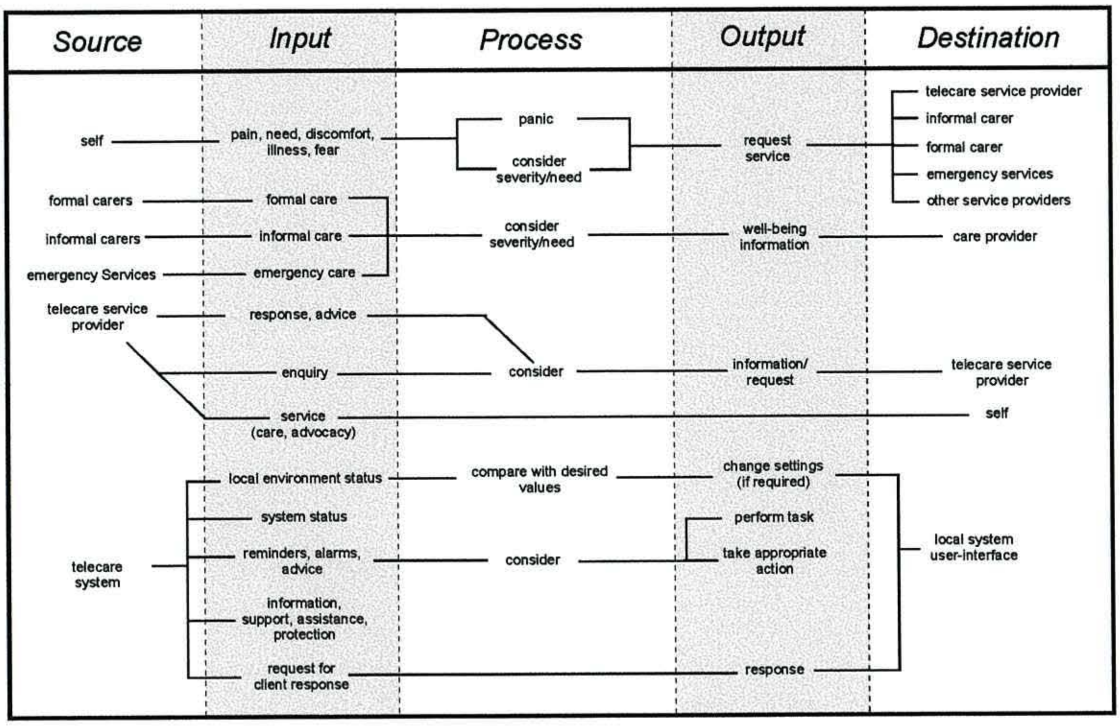

Figure 5.25. Client viewpoint diagram.

[4] *This exercise was performed early on in the requirements elicitation process to help formalise knowledge of the domain in terms of the responsibilities of, and flow of information between, stakeholders and system elements.*

Box 5.1. Client Viewpoint.

Consider the viewpoint of a generic client, shown using the CORE notation in Figure 5.25. This illustrates how a client might interact with other key stakeholders and system elements. A client will be subjected to various situations and stimuli which may result in feelings of distress, discomfort, isolation, anxiety, and fear. In addition, any illnesses suffered will result in increased frailty and will invariably impair the functional capacity of the individual. The client will continuously assess a particular combination of symptoms, feelings and circumstances and any resulting needs which arise as a result. If the client requires help of some form, then they have at their disposal the support of a wide variety of care service providers who will provide the appropriate type and level of care required. The care providers will require feedback describing the well-being of the client in order that the client's response to care can be monitored and care packages optimised accordingly.

Depending on the nature of the client's needs, care providers may be contacted directly or use may be made of a care-response call centre. The most likely requests for help/service will involve informal carers (spouse, sibling, friends & neighbours); formal carers (including the GP, community nurse and local pharmacy); and emergency services (police, ambulance, fire-brigade). Other non-care related services might include: utility suppliers such as gas, electricity, water or telecommunications; or various e-commerce services such as e-shopping or e-banking. The client may also require the support of the response centre operator in their own right who may offer advice on a particular problem, attempt to match client need to service provider (by enquiring as to the nature of the call) and organise the most appropriate response on behalf of the client.

The client will receive care from a range of formal and informal care service providers as well as other ancillary services. This service will be provided on-request (from the client), periodically as part of an on-going care package, or on-demand (e.g. if the system raises an alert). A formal carer may provide a care service to the client if one has been requested or if the well-being data-set to which he/she has subscribed has indicated that some form of intervention may be appropriate. An informal carer may provide a care service to the client if one has been requested or if the client has suffered some form of acute event such as a fall for which the informal carer is one of the primary responders, perhaps due to the fact that they live with the client or close by.

Locally, the telecare system may provide a multitude of services to the client to support their independence and assist in the activities of daily living. The local system must possess several user-interface stations to provide information regarding the operating status of the system; on local environmental conditions; the status of home appliances or doors/windows, and will provide a mechanism to allow the client to alter these parameters as required. The system may also provide information and advice to the client for instance by reminding them to perform certain actions. The system may also raise alarms to warn the client of any potential hazards or emergency conditions that may be present. Sometimes the system may require a response from the client to a particular event in order to ascertain the well-being of the client or to confirm a particular course of action.

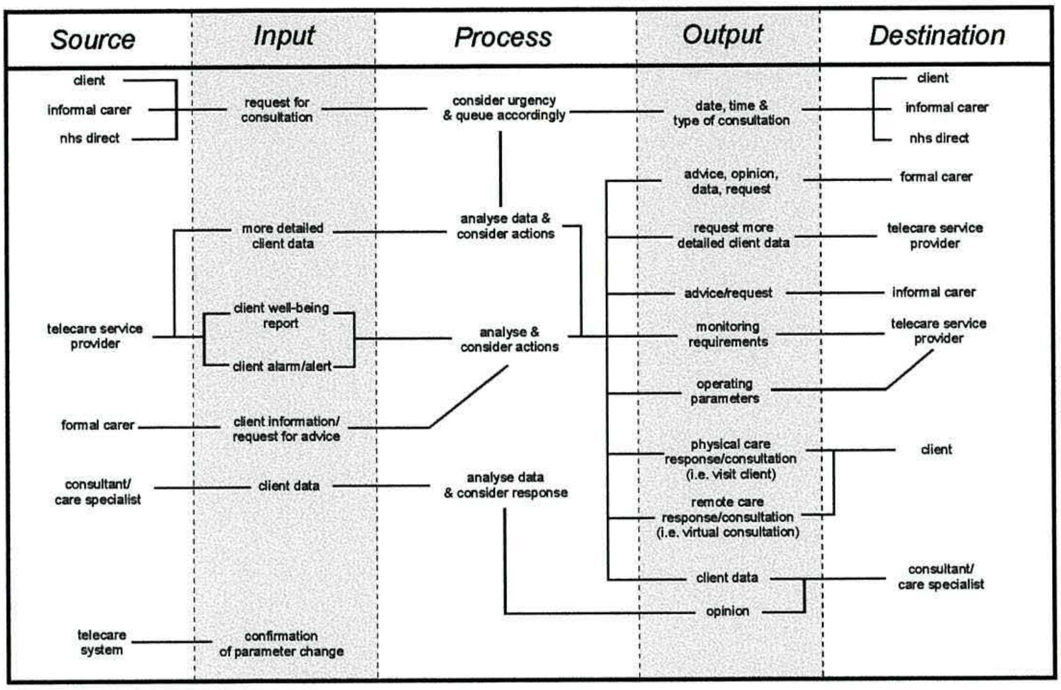

Figure 5.26. Formal carer viewpoint diagram.

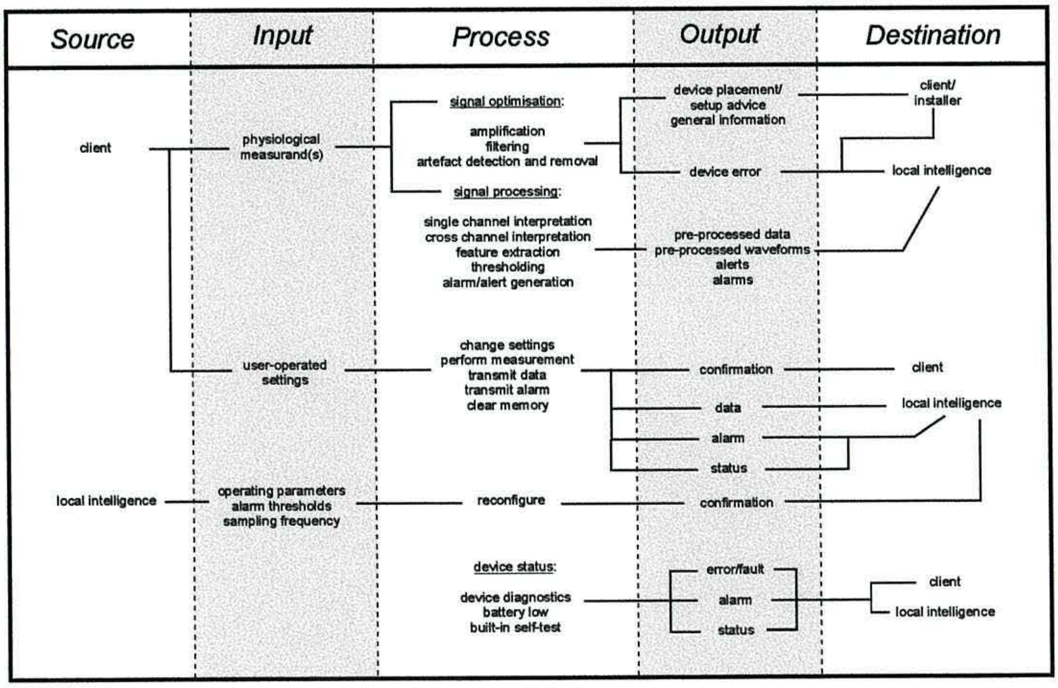

Figure 5.27. Physiological monitoring.

By relating system stakeholders according to the flow of information between them (i.e. by linking the *source* and *destination* fields of the CORE viewpoint diagrams) it was possible to construct a crude representation of the CarerNet system which could be used as the basis of a high-level system architecture. The preceding analysis has resulted in a preliminary viewpoint relationship diagram, shown in Figure 5.28 which illustrates the relationship between viewpoints in terms of the flow information between them, the key to which is given in Table 5.5. This may be used as the basis of a high-level architecture for CarerNet.

Table 5.5. Key to information flows in Figure 5.28.

Information Flow	Description
	Home-based communications
	Client-based communications
	System-initiated external communications
	Client-initiated (voice-based) external communications
	Client-system interaction
	Logical connection

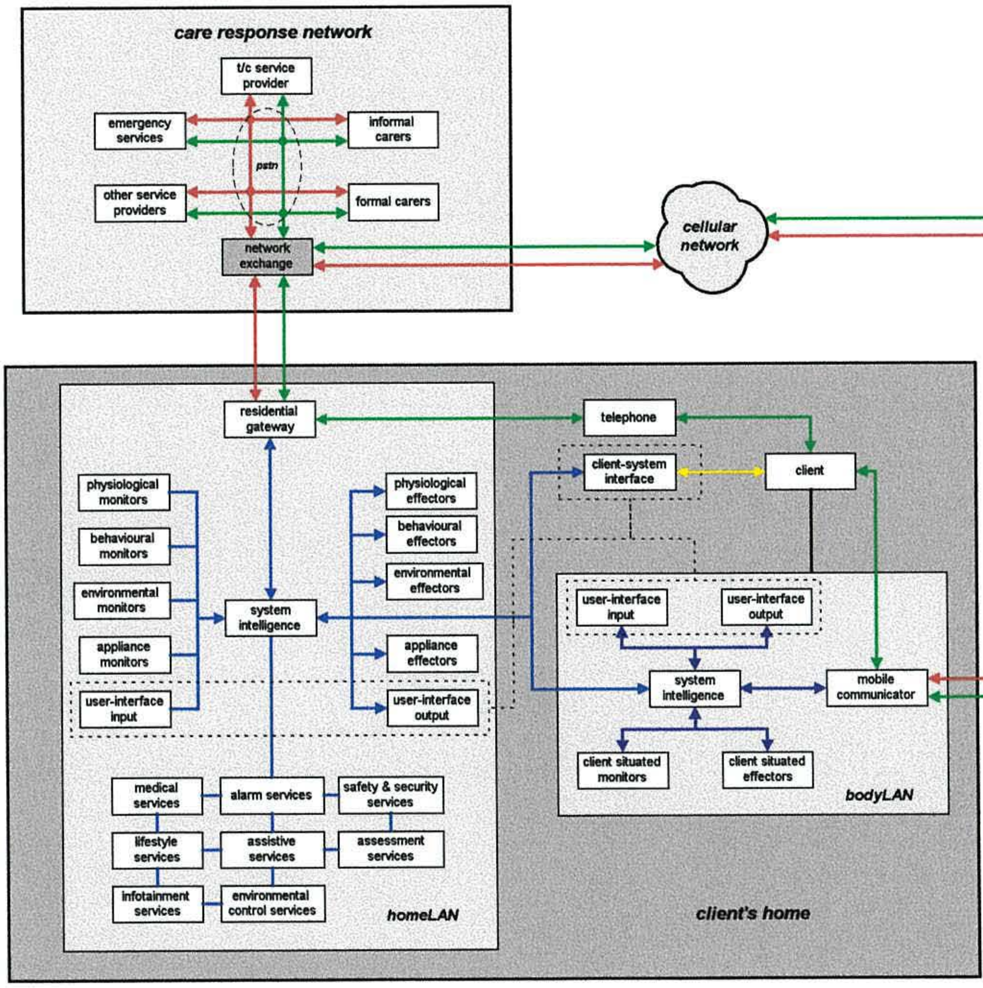

Figure 5.28. High-level model for CarerNet (based on viewpoint relationship diagram).

The preliminary model of Figure 5.28 has been built upon a knowledge of the overall system requirements, the nature of the services to be supported, the mechanism of service delivery and the composition of the local domain. The next chapter will analyse this knowledge to develop a more detailed model for next-generation telecare, and CarerNet, by:

- Analysing the services in a formal fashion to identify the local intelligence requirements.
- Identifying the domain properties with significance for telecare services.
- Identifying & resolving conflicting stakeholder requirements.
- Developing a more detailed system model capable of accommodating all of the above.

Chapter Six

System Requirements Analysis

Before the 'idealistic' functional requirements of Chapter 5 can be implemented, it is necessary to impose upon them several 'real-world' constraints (i.e. non-functional requirements). Many of these constraints will be the result of compromise between conflicting stakeholder viewpoints. It is also necessary to identify the domain-properties to which the local system will require access in order to establish the range of sensors and actuators required in the home. The output of this work will be a high-level system architecture for CarerNet within the home.

6.1 Telecare Service Requirements Analysis

The range of services that might conceivably be implemented using telecare were identified in Section 3.4 (Chapter 3), following a consideration of stakeholder needs. It was recognised that in order to implement these services, the local system would be required to monitor (or effect) entities within the local domain that might have influence over the well-being of the client (or the suitability of their living environment) and respond appropriately.

6.1.1 Adaptive Services

The interpretation of information obtained from the local domain is unlikely to be straightforward as the domain itself represents a highly non-deterministic environment, with each dwelling likely to have its own distinctive layout and physical characteristics. Furthermore, the manner in which the client interacts with their local environment will be determined by his/her personal abilities, routine, and idiosyncrasies. Consequently, many services will have to adapt to the characteristics of the home and the routine of the client. Another complication arises from the impracticalities of being able to monitor every property of the local domain, resulting in data having to be obtained from a well defined but finite set of sensors. Taken together, this implies that the system be capable of deriving useful information from a partial data set, and also that it should be capable of 'learning' from 'experience'.

6.1.2 Pre-Determined and Primitive Services

Any service that relies on experience will not be able to function reliably during the initial period of operation. This period may be weeks or even months, depending on the likely frequency of events. However, some services may be so vital that a non-optimal implementation may be necessary. For instance, one service might raise an alert if the client spends significantly more time in the bath than is normal (and fails to respond to a request to confirm that they are alright). In the initial stages, it is possible to employ a service with a *pre-determined* time-threshold. This may be very short, e.g. 15 minutes, which may lead to false alarms. Alternatively, a worst-case value such as 1 hour may be chosen, which will result in a long delay between the occurrence of a problem and in help arriving. The threshold used in the first instance may subsequently be modified as knowledge about the routine of the client is gained. In addition, some scenarios will require only modest interpretation and a well-defined response, resulting in services whose behaviour must always be *pre-determined* (and guaranteed). An example of such behaviour concerns issues of safety, where a particular action must be accomplished within a specified amount of time following the detection of a particular hazard (e.g. the automatic shut-off of gas to an unlit hob.)

Finally, *primitive* services are required which provide basic functionality such as user control capabilities and data-logging. The former ensure that at the very least, the system is capable of responding to commands issued by the client and the latter provide the data upon which the more sophisticated services will operate on.

6.1.3 Monitoring Techniques

When a service refers to a property such as room temperature or heart-rate that can be monitored directly, then the resultant sensor requirements are evident. However, for services that are concerned with more abstract concepts, such as client lifestyle or activity, the sensor requirements are not straightforward. In such cases, it will be necessary to infer the required information from more readily available data sources, see Figure 6.1.

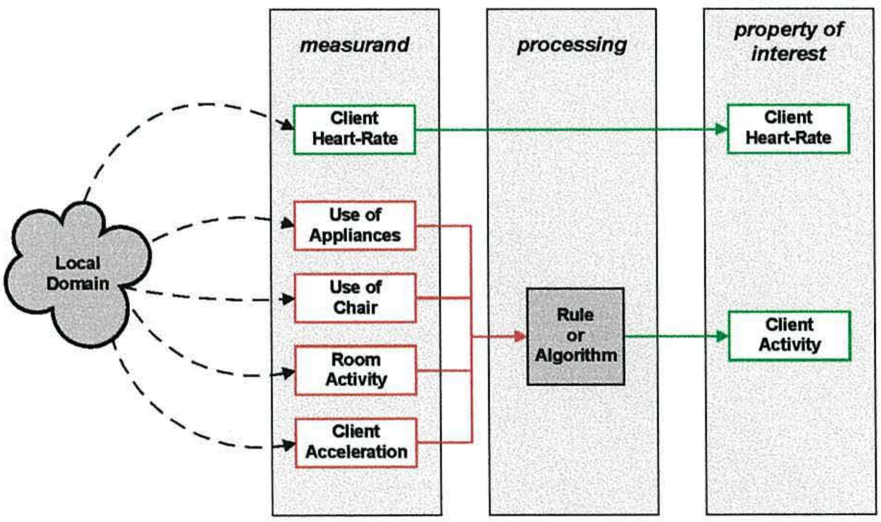

Figure 6.1. *Direct* and *Indirect* means of monitoring parameters.

It may also be possible to derive the same information using different techniques and even data sources. In such cases, one technique would usually be considered as the *primary* method, with any *secondary* methods being called upon as backup if the primary source fails, or as an alternative if the primary method is not installed. The use of multiple sensing techniques can help in determining the validity of a particular reading or event - effectively a form of cross-checking.

6.1.4 Service Classification

A classification of telecare services was presented in Section 3.4 (Chapter 3), which identified five main service areas. From a consideration of these service categories, it is believed that the provision of telecare services for supporting client-independence at home should be considered in the following sequence[1]:

1. **Services that support the safety of the client** – *in the first instance it is necessary to manage the immediate risks associated with the client living at home. Preventative safety and security measures can help to ensure that the client is, at the very least, considered to be safe and secure in their own home.*
2. **Services that provide an external (emergency) response** – *if the client were to have an accident, be subject to a security breach, or suffer from acute ill-health, reactive services should be capable of automatically requesting external assistance, especially if the client is unable to do so.*
3. **Services that help to support the client (and their carer) in their own home** – *once safely in their home, the client may require or benefit from a range of services conceived to assist their everyday activities. These services may be considered as a means of increasing their independence by providing an alternative to requesting external assistance.*
4. **Services that help to monitor and assess the well-being of the client** – *the well-being of the client will need to be re-assessed continuously to ensure that the care package provided best matches their changing care needs. It may be possible to identify previously unknown risks associated with the client living at home. Long-term trends may also screen for chronic conditions as well as the likelihood of a particular acute episode occurring and may therefore be used in a preventative fashion.*
5. **Services that help manage the process of care** – *these services can be used to perform a variety of support functions, including: performing an audit of care provision; logging response times; monitoring the usage of care equipment supplied as part of a care package; and monitoring intervention outcomes in order to improve future care plans, etc.*

This classification may be generalised further by grouping telecare services according to whether they are 'active' (i.e. client interaction is required) or 'passive' (i.e. no client interaction is required). Active services include panic-pendants, user-interfaces and personal digital care assistants (PDCA's)[2]. Passive services typically manage risk; identify emergency and abnormal situations; and provide support, assessment, and some care management functionality.

It is possible to classify passive services further by considering the time-span over which the data that they use is collected. This will have an influence over the data-processing requirements of the local intelligence. Three time-spans have been considered:

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[1] It should be noted that the first two service categories are very closely related and are likely to be considered in parallel.
[2] PDCA's consist of services that provide reminders to the client; provide a means of electronically recording daily symptoms; and provide support to a client when performing self-administered monitoring programmes (e.g. the discrete monitoring of physiological parameters such as blood pressure, heart-rate, or blood glucose level).

1. *'Real-time' event-based scenario-detection (and reaction)* – where certain events, conditions, and facts established about the local domain are used to determine client activities and sometimes trigger an appropriate 'real-time' response or assessment from the system over a period of seconds/minutes;
2. *Intermediate habit & trend assessment* – Performed over a period of hours, days, or weeks for monitoring purposes, such as lifestyle monitoring; medical observation; or mobility assessment;
3. *Longitudinal trend analysis* – Data collection (and mining) for assessments performed over a period of months or years (and may be performed off the client's premises).

6.1.5 Lifestyle Monitoring

Lifestyle monitoring assesses the long-term functional well-being of the client, and can also help identify abnormal behaviour which may signify client-distress. It deserves special consideration, as it often depends on indirect monitoring, and an heuristic interpretation of events to derive meaningful 'activity-episodes'. It is also a relatively new 'telecare-specific' service and is likely to require the development of specialised sensors.

Lifestyle monitoring may be provided using devices worn by the client or 'passively' where devices are situated in the local environment. Worn activity monitors measure acceleration or movement at various points of the body (wrist, ankle, waist) to determine the level of activity and/or energy expenditure [40, 41]. The problem with such devices is the need for the client to have to wear a monitor, which might not always be convenient. In addition, such techniques do not provide an indication of a client's interaction with their environment, which is essential for determining the activities of daily living (ADL) and Instrumental activities of daily living (I-ADL). Therefore, passive techniques are also required, even if the client also 'wears' lifestyle monitoring devices.

Previous attempts at passive lifestyle monitoring have included attempts at generic data analysis in order to match domain events with actual client activities, the performing of ADL assessments, and alarm-based systems [37, 59]. The latter have suffered from a lack of data due to an insufficient number of sensors [62]. This can result in a high number of false alarms, or, if these are to be avoided, in response times that are unacceptably long [155]. Conversely, there are also potential pit-falls if the system obtains too much domain data, resulting in 'data-smog', which may hamper the analysis process [60] and results in a more complex and expensive system.

False alarms result when scenarios are inferred from incomplete or misunderstood domain data. If client activity and room occupancy are derived solely from the number of PIR activations then uncertainty will result. The results of an experiment undertaken to determine the number of PIR activations associated with various everyday activities illustrates that PIR events cannot be relied upon in isolation, Table 6.1. For instance, there is little discernable difference between someone who has collapsed on the floor and someone who may be sleeping in an armchair. The results also show that the number of PIR activations produced by similar activities are greatly variable, depending as they do on the level of activity and the relative position of the PIR.

Table 6.1. Results of PIR activation experiment for various simulated activities over 10 minutes.

Activity	Mean PIR Activations/minute	Standard deviation	Range
Reading newspaper/magazine	7.8	9.3	0 - 26
Moving around in room (e.g. tidying up)	33.3	10.3	18 - 52
Watching TV	3.2	2.6	0 - 9
Sitting (almost) motionless in chair	0.1	0.3	0 - 1
Lying (almost) motionless on floor	0.2	0.4	0 - 1
Standing still & cleaning teeth	19.1	5.4	11 - 29
	PIR Activations		
Walking towards PIR (slowly)	9.5	1.6	7 – 12
Walking towards PIR (briskly)	2.5	1.1	1 - 4

Furthermore, there is not a clear relationship between the number of PIR activations and the mobility of the client. A high activation count may just as easily be caused by a client moving energetically around the room or due to a client with poor mobility moving slowly across the field of vision of the PIR. Finally, it is impossible to distinguish between the activities of two or more people in the same room, resulting in erroneous data when the client has visitors.

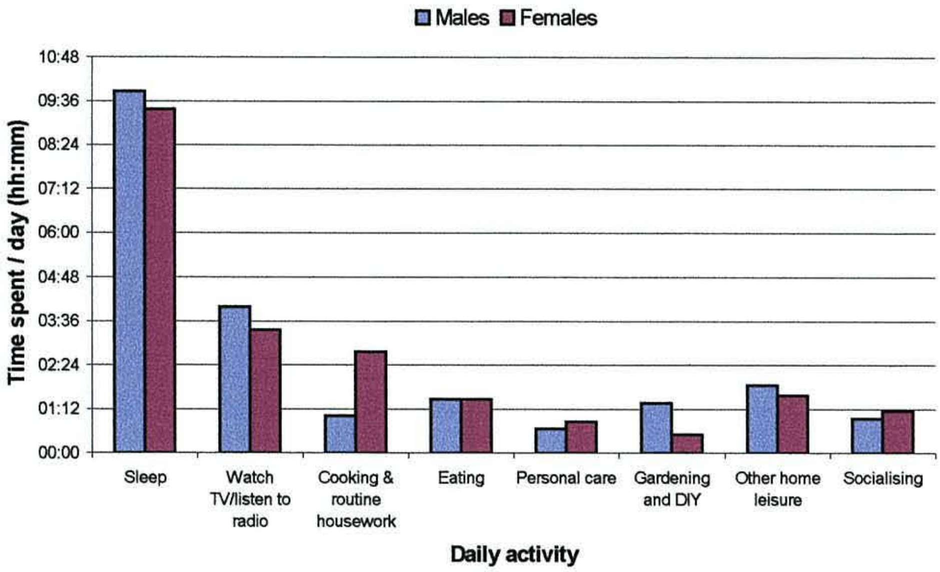

Figure 6.2. Time use in the home in GB by activity and gender for people of retirement age, 1995.

In order to conceive of improved methods of reliably monitoring client lifestyle, everyday activities of the client were sub-divided into discrete 'activity-episodes' characterised by specific sequences of events. Though each individual will have a unique 'lifestyle-signature', the activity-episodes that contribute are likely to be common for all, but with varied frequency and duration (with one or two exceptions). Consider, for instance, the daily activities of people of retirement age and over[3] in Great Britain during 1995, Figure 6.2 [156] which provides a basis for the consideration of lifestyle-

[3] *≥ 65 years for male; ≥ 60 years for female.*

indicators. Thus, the lifestyle profile of an individual is likely to consist of islands of well-defined and purposeful activity, for example: 'watching television', 'cooking dinner', 'having a bath', 'reading a book', 'getting dressed', 'using the toilet', 'answering the front-door', etc. These are likely to be intermingled with (usually shorter) periods that represent the transfer from one state to the next.

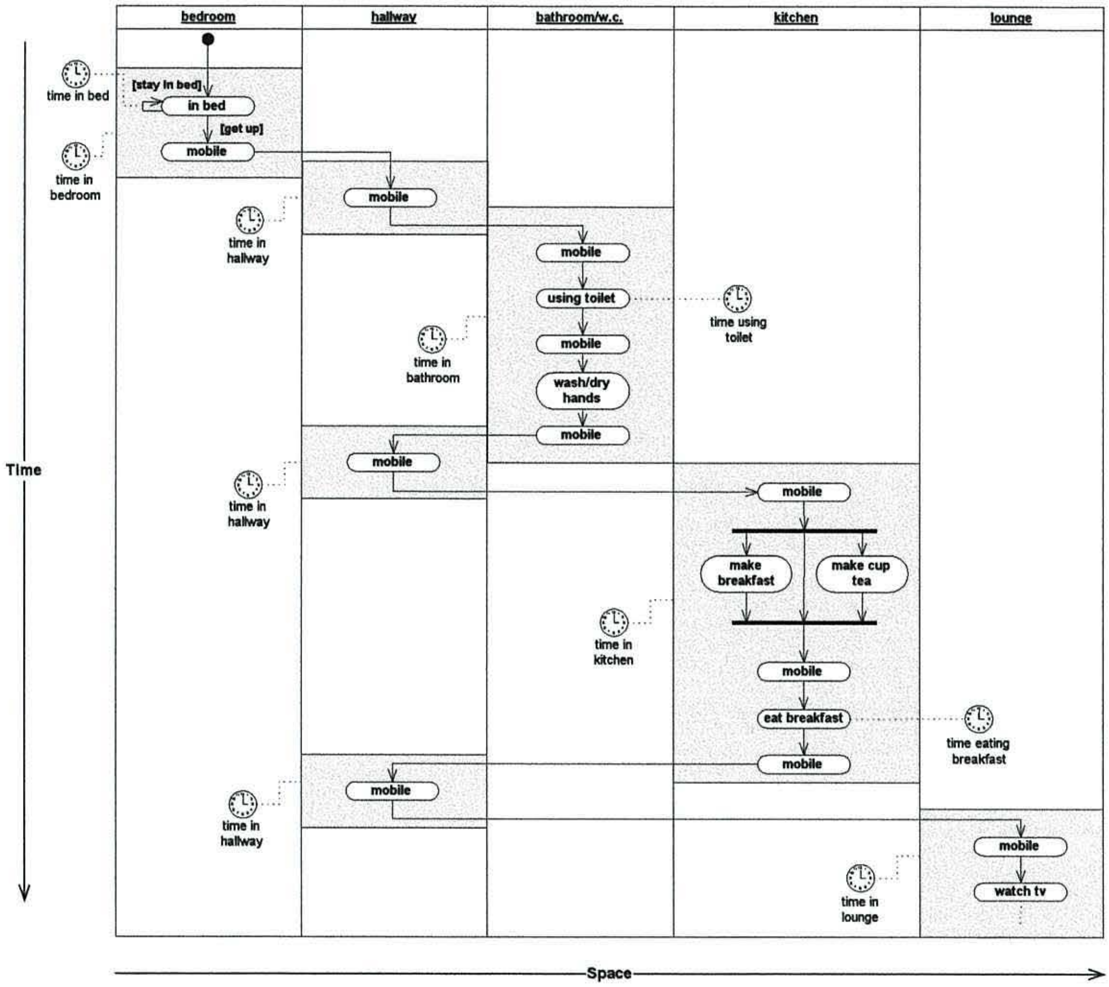

Figure 6.3. Client gets up in the morning (simplified).

It is imperative therefore that a telecare system should be capable of identifying as many of these purposeful activities as possible so that it may always be capable of inferring, with confidence, the activity of the client. In terms of the ability of the system to successfully interpret activities, this can be considered as long-periods of 'stability', with intermittent periods of 'instability' in between. Each of these 'stable-states' can usually be associated with a particular location within the home and will have a typical time, duration, and frequency of occurrence, see Figure 6.3.

Table 6.2 considers a range of activities, decomposing them into smaller sub-activities and ultimately single events that are more conducive to monitoring techniques.

Table 6.2. Typical activities undertaken in the home on a per-room basis.

Room	Activity[4]	Sub-Activities	Associated Events[5]
General	Clean	Use vacuum cleaner/polish/duster/mop/wipe surfaces.	Vacuum cleaner on Motion in room Sound level change
	Turn light on/off	Flip switch.	Light switch change Light level change
	Transfer	Get up from chair/bed; sit down in chair or lie down in bed.	Chair occupancy change Bed occupancy change Change in mobility Client mobility change
	Entering/Leaving room	Open door (if closed), walk through door, move into or out of room, close door (optional)	Door status change, Motion through door; Motion in room; Client mobility.
Lounge	**Lounge/Relax**	Sit/lie down on chair/sofa; Watch TV/listen to radio; Read newspaper/book/magazine; Perform hobby (e.g. knitting, cross-stitch, crosswords)/sleep in chair.	Chair occupied Activity in chair TV/Radio switched on Infra-red remote control use
	Use the phone	Lift receiver; Dial number (out-going); Respond to ringing (in-coming); replace receiver.	Phone ringing, Phone off-hook, Phone on-hook
Kitchen	Prepare/cook food, prepare drink	Use fridge/freezer; Open cupboards, drawers, etc.; Use cooker, microwave, hob, grill; Use kitchen appliances (e.g. can opener, kettle); Obtain water from taps; Place rubbish in bin.	Fridge/cupboard/drawer status change; Cooker/ microwave use; Water flow
	Eat food & drink[6]	Use cutlery, mugs/glasses, plates/bowls; Sit at dining table to eat.	Cutlery drawer use Kitchen chair occupied
	Washing-up	Obtain hot water; Use kitchen sink.	Water flow; Client vicinity to sink
Bathroom	**Go to the toilet**	Use the toilet standing up (male); Use the toilet sitting down (male & female); Flush toilet.	Client vicinity to toilet Client sitting down Use of flush
	Have a bath	Run the bath; Get in bath & wash; Get out of bath; Empty bath; Dry-off.	Water flow; Bath water level & temperature; Bath occupancy status
	Take a shower	Turn on shower; Get in shower & wash; Turn off shower; Get out of shower; Dry-off.	Water flow Client vicinity to shower
	Wash face/ freshen-up/shave	Stand in front of washbasin; Fill wash-basin; Wash/shave/freshen-up; Empty washbasin.	Client vicinity to washbasin Water flow & level
	Clean your teeth	Stand in front of washbasin; Run cold water tap; Clean teeth.	Client vicinity to washbasin Water flow & level
	Weighing themselves	Stand on bathroom scales.	Client vicinity to scales. Scales auto turn on.
Bedroom	**Dressing & Undressing**	Use wardrobe & drawers & dress mirror; Put clothes on/off; Move around; Sit on chair/bed.	Wardrobe/drawer status change
	Sleep	Get in bed; Sleep; Get out of bed.	Bed occupancy change
Hallway	Enter home	Open front door from outside & enter; Close front door from inside.	Front door status change Person vicinity inside door Person vicinity outside door
	Exit home	Open front door from inside & exit; Close front door from outside.	Front door status change Person vicinity inside door Person vicinity outside door
	Answer external door	Open front door from inside & close front door from inside.	Front door status change Person vicinity inside door Person vicinity outside door
	Walk through.		Motion in room

[4] *Activities in **bold** represent key activities that would normally be expected every day.*
[5] *Non-exhaustive.*
[6] *Not exclusive to the kitchen, but placed here to simplify table.*

In addition to the detection of abnormal deviations in client behaviour over a period of weeks or months, which might be performed using statistical analysis, it may also be possible to infer potential problems over a shorter '*real-time*' period. For instance, if the client remains in a 'stable' or 'unstable' state for too long, which would occur during the scenario where a client gets out of a chair, and falls heavily onto the floor, and is unable to recover, Figure 6.4

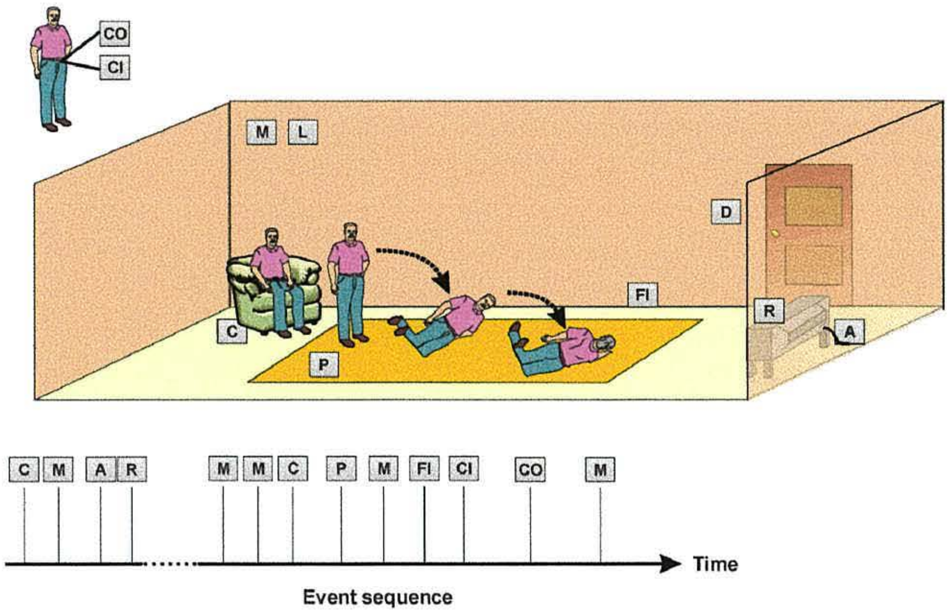

Figure 6.4. Fall detection example[7].

Table 6.3 lists the sequence of events that the system might conceivably receive, resulting in the raising of an alert[8]. This mechanism may be described as event-based scenario detection. The recognition of certain event-sequences or '*client distress indicators*' will be employed by CarerNet in order to infer whether the client may be in need of external assistance. It may be apparent that the detection of client distress indicators relies on the system's ability to reliably monitor as many of a client's everyday activities as possible.

[7] *A = appliance monitor; C = chair occupancy monitor; D = door status monitor; FI = floor impact monitor; CO = client orientation monitor; R = remote control use monitor; P = client presence monitor; M = PIR; CI = client impact monitor.*
[8] *Figure 6.4 also illustrates other possible domain properties of interest including impact detection and client orientation.*

Table 6.3. Event sequence for hypothetical client fall scenario (basic installation).

Event ID	Event	Client Status	Stable Timer	Unstable Timer
1	Client in chair	**Stable**	**Enabled** (0)	**Disabled**
2	PIR activity	**Stable**	+ 5 seconds	....
3	Infra-red remote control use	**Stable**	+ 10 seconds	....
4	TV switched on	**Stable**	+ 11 seconds	....
5	Infra-red remote control use	**Stable**	+ 21 seconds	....
6	PIR activity	**Stable**	+ 30 seconds	....
34	Client gets out of chair (C)	**Unstable**	**Disabled**	**Enabled** (0)
35	PIR activity (P)	**Unstable**	......	+ 15 seconds
36	PIR activity (P)	**Unstable**	......	+ 30 seconds
51	PIR activity (P)	**Raise Alert!**	......	+15 minutes
52	PIR activity (P)	**Unstable**	......	+ 15 min 15 sec.
53	PIR activity (P)	**Unstable**	......	+ 15 min 30 sec.

<u>**Rationale**</u>

1 The system knows that the client is in the room as the chair is occupied, the PIR has been registering activity, the door is closed, and it is known that the client is alone in the house.

2 When the client gets up out of the chair, the system begins the 'unstable-state' timer.

3 The system knows that the client is still in the lounge as there may be (depending on the severity of the fall) some PIR activity, there has been no movement in the hallway (i.e. the adjacent room) and furthermore, the lounge door has not been opened.

4 The interpretation of subsequent events will depend on the level of client activity and on a knowledge of the client's well-being:

a) If client activity is low, the client may have fallen; an alert may be raised after 10 minutes.
b) If client activity is high and the client is known to suffer from dementia, then the client may be pacing (wandering in one room); an alert might be appropriate after 10 minutes.
c) If client activity is high and the client is known to suffer from epilepsy, then the client may be suffering a seizure. Knowledge of the client's orientation would be useful here.
d) If client activity is normal, then an alert may be raised after 30 minutes.

5 The additional information provided from P, FI, CO and CI monitors will also improve the accuracy of fall detection and hence the speed of response.

6.1.6 Knowledge Requirements

It may be observed that many telecare services are event-based and can be implemented using a combination of software timers and inference rules, the associated operating parameters of which may be adapted according to experience (e.g. using statistical methods). The advantage of rule-based systems over others such as neural networks, for prototyping, include:

- They represent knowledge in a simple manner, similar to human reasoning, and as such can be prototyped fairly quickly;
- Rules are modular and can be altered easily without affecting the rest of the system;
- There is flexibility in the sense that hybrid operation with procedural routines and databases is possible (if not always straightforward);
- They do not require large data sets in order to 'learn';
- They can cope to some extent with issues of uncertainty;
- The conclusions drawn by a rule-based system can be easily explained/understood.

By considering the services of Table 5.3 (Chapter 5) it was possible to conceive of high-level rules, built around knowledge of the system-domain, which can be classified into three categories:

1. **Domain knowledge** - e.g. *if* the lounge is occupied *then* the house must be occupied; you have to walk through the hallway to get from the lounge to the kitchen; the bedroom is upstairs; the client has hypertension, diabetes, and is prone to falling.
2. **Procedural knowledge** - e.g. *if* room temperature is less than 17°C *then* raise an alert *and/or* increase the thermostat setting for the room; *if* the client is up and about and it is dark and the lights are switched off *then* switch on the lights.
3. **Heuristic knowledge** - e.g. *if* the client is in the bathroom for more than one hour *then* there may be a problem; *if* the client is in the bath for 75% more time than normal *then* there may be a problem; *if* the client is still in bed by mid-day *and* they went to bed at their normal time, *then* the client may require assistance.

Figure 6.6 to Figure 6.7 show the decomposition of several of these rules[9], with their associated input and output dependencies[10] (where appropriate). These rules were checked for consistency using the CLIPS expert system tool [157], a forward-chaining rule-based expert system. The CLIPS environment allowed rules to be implemented quickly at a conceptual level and tested with the assertion of facts that corresponded to various domain events[11]. The analysis helped characterise the behaviour of the services in terms of key events and activities which helped to identify domain properties of relevance.

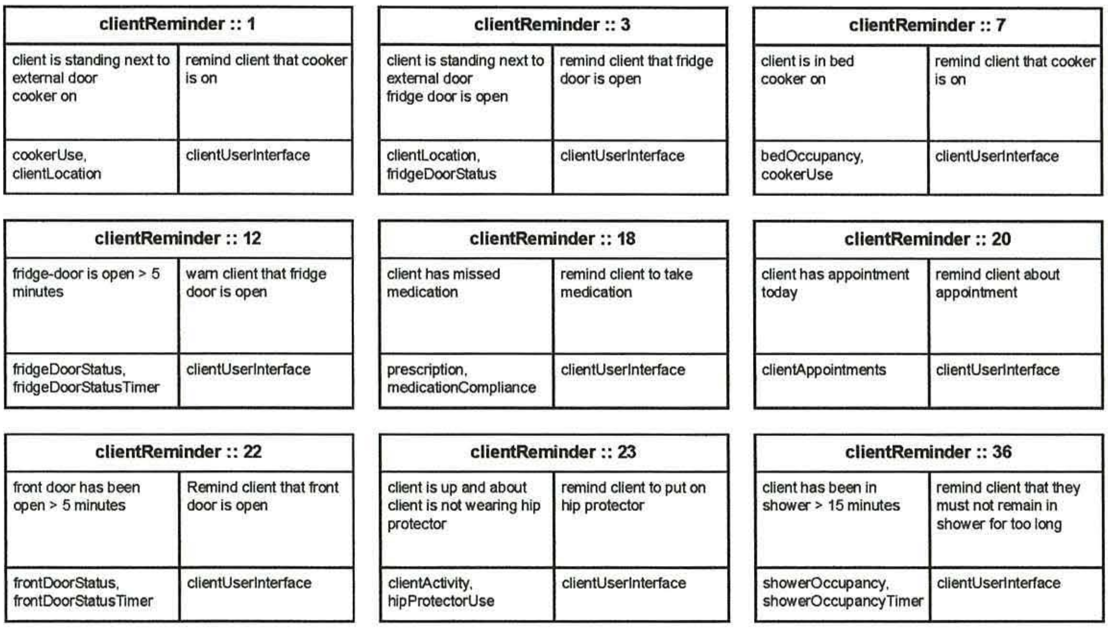

Figure 6.5. A selection of client reminder rules.

[9] *Certainty factors associated with these statements are not relevant at this point.*
[10] *The rule-element graphic (from top-down and left to right) depicts: the rule's class and identifier; the if-part; the then-part; and the rule's relationship/connectivity with other rules (input and output dependencies).*
[11] *Only a very basic implementation was undertaken using CLIPS.*

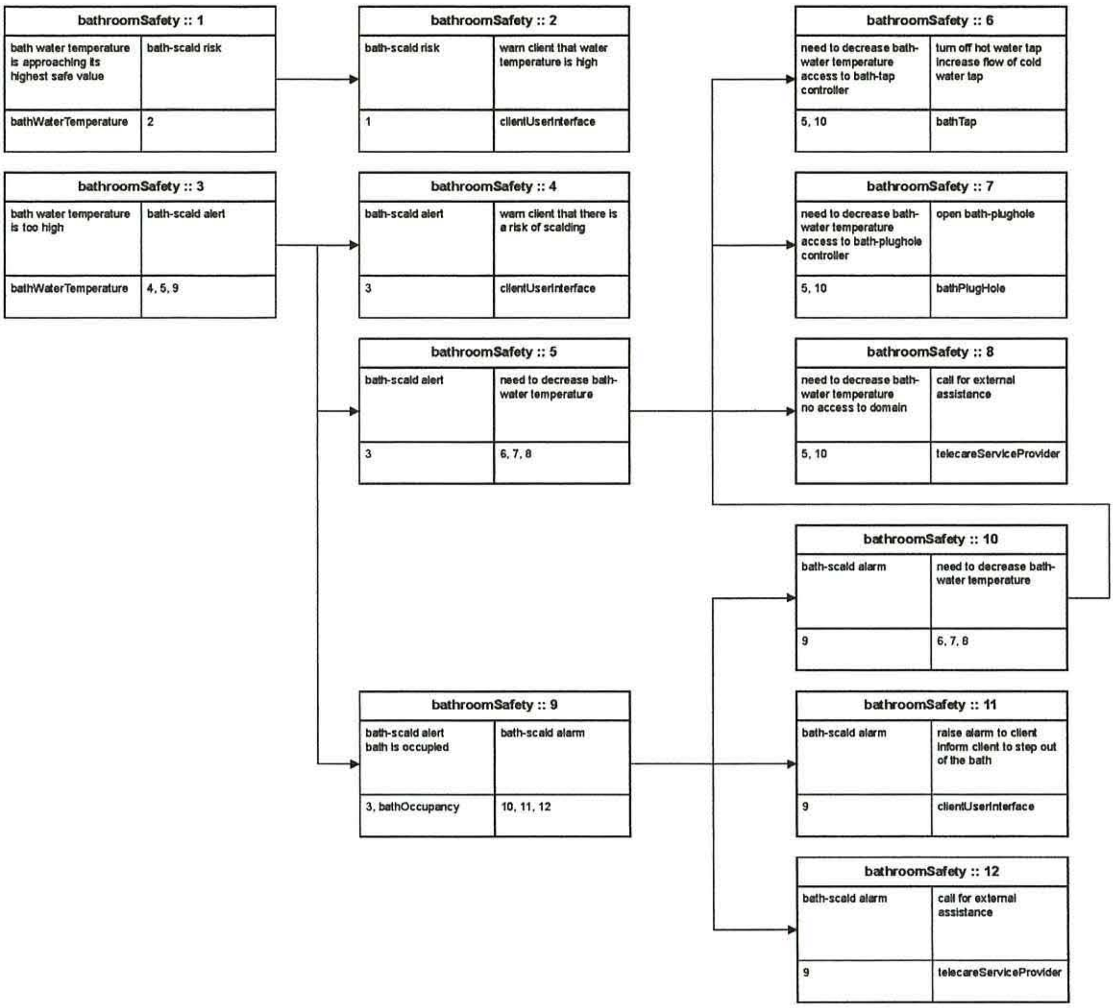

Figure 6.6. Bathroom safety [1-12].

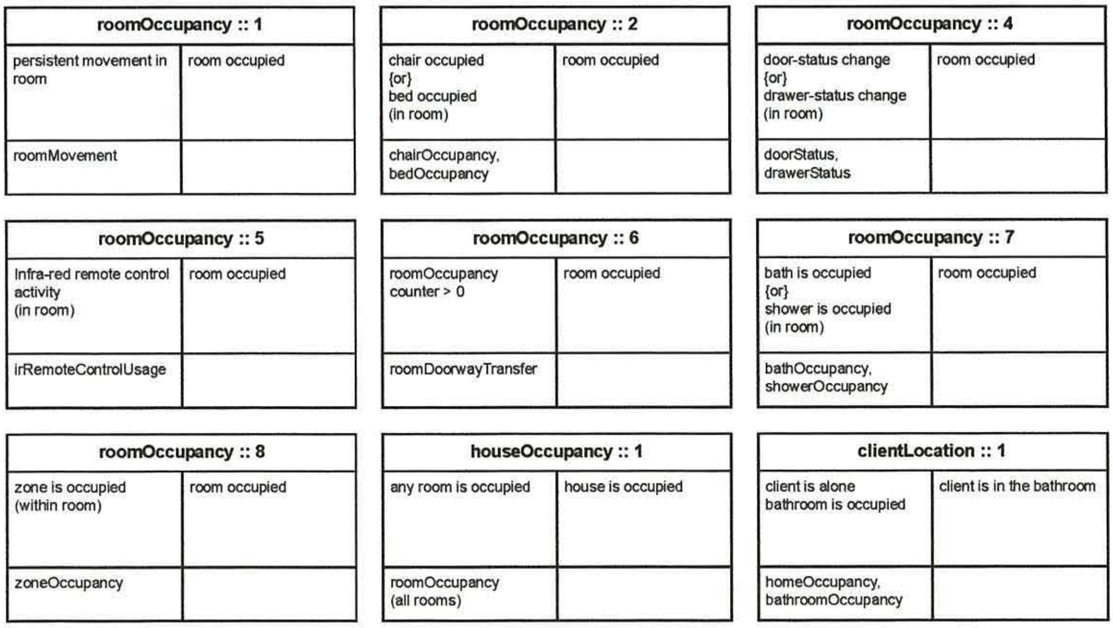

Figure 6.7. A selection of rules associated with room/house occupancy & client location.

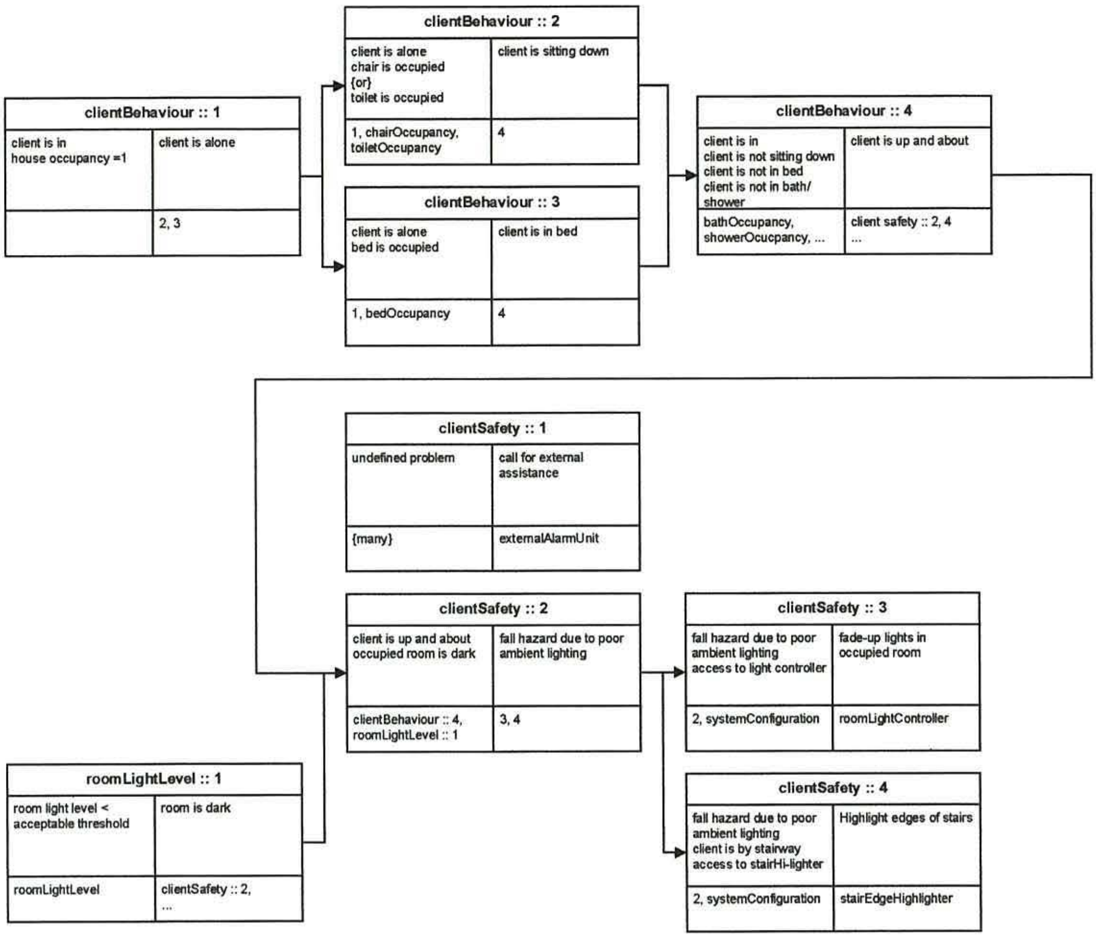

Figure 6.8. Hybrid collaboration between rules for fall prevention services.

A selection of the domain properties identified as having potential significance for telecare are listed in Table 6.4 for *constant* properties and Table 6.5 for *variable* properties. These properties help to define the sensing and actuating devices necessary to implement telecare services in the home.

Table 6.4. A selection of *constant* (known *a-priori*) domain properties of relevance to telecare.

Domain Property	Potential Significance for Telecare
Room name	• A room's name defines its function, which affects how the client interacts with it. For example, during the course of a day you would expect a client to spend more time in the lounge than in the hallway. Likewise, you would not be concerned if the client were in the kitchen for over an hour at tea-time, but you may be concerned if the client were in the bathroom for this length of time during any period of the day.
Room neighbour(s)	• The neighbour(s) of a room establish the connectivity between rooms, and define the layout of the home. This can be useful in clarifying the movements of the client as well as helping to determine if there is more than one person in the home. It also provides an indication of the length of time it might take to get from one room to another. • A knowledge of the connectivity between rooms provides a mechanism for identifying unlawful entry when considered alongside house and room occupancy information, window tamper devices, and the use of entry/exit routes.
Client Age	• This provides some indications of the range of pathologies that an individual is likely to be susceptible to and thus has a bearing on predictive risk indices including: heart-disease, diabetes, stroke and falling.
Client Gender	• Gender can be of relevance for predictive indices such as fall prediction. • It may help with the interpretation of monitored indications (men and women can use things differently, e.g. toilet).

Table 6.5. A selection of *variable* domain properties of relevance to telecare.

Domain Property	Potential Significance for Telecare
	Client Physiological Parameters
Body-weight	• Needed for measurement of Body Mass Index (BMI) and subsequently to ensure that client is not malnourished. • Some patterns of weight loss may indicate malnutrition, diabetes, anaemia, or an overactive thyroid gland. • The ability to control body weight is important if client suffers with type II diabetes. • Gradual weight loss may indicate pacing or wandering in a client with dementia (i.e. burning a significant amount of Calories). • Low body-weight is a risk factor associated with hypothermia.
Gait/sway & balance	• Client sway upon getting out of a chair may indicate postural hypotension. • An irregular gait may render the client more likely to suffer a fall. May have application in the calculation of fall prediction indices. • May be an indication of a sprain or even stroke (if sudden onset) or some other chronic condition such as arthritis (if slow-onset).
Blood pressure	• Important to monitor people with hypertension, as well as those at risk, e.g. people with diabetes and some stroke sufferers, etc. • Provides an indication of stress/anxiety.
Body Temperature	• Chest infection/pneumonia causes body temperature to increase. • Indication of hypo and hyperthermia.
Blood oxygen saturation	• Used as part of home-based respiratory therapy, e.g. COPD, asthma. • SpO2 drops significantly during asthma attack. • Used in home-based sleep assessments.
Blood glucose	• Important to monitor and control for diabetics.
Sweat	• Varies with stress, anxiety, ambient/body temperature, level of exercise, fever, hypoglycaemic attack, hyperthyroidism, asthma attack, and urinary tract infection.
Sighs	• Indication of mood/anxiety/depression.
ECG, heart-rate & heart-rate variability	• Is a general indication of health status, e.g. can be indicative of fever or of infection. • Used to identify and assess tachycardia (approx. > 100 b.p.m.) and bradycardia (approx. < 50 b.p.m.). • Look for arrhythmias/palpitations, e.g. extra/missing beats, QRS duration & RR-interval. May be the cause of unexplained falls or syncope; may be due to too much caffeine intake or some form of heart disease. • Useful to gauge body's response to exercise (e.g. climbing stairs). For example, it can indicate the level of exertion (e.g. b.p.m of > 120-130 might be indicative of over exertion or under-fitness or a combination of the two.) • An asthma attack is often accompanied by a rapid pulse. • Increased heart-rate may be an indication of stress/anxiety. • Heart-rate rises by approx. 10 b.p.m. per 0.5°C rise in body temperature. • Used in characterisation of sleep states (heart-rate drops during sleep).
Breathing rate, amplitude, & patterns	• Related to stress, asthma, indication of respiratory dysfunction. Variability can help differentiate between REM and NREM sleep. • Used to discount sinus arrhythmia with heart/pulse rate monitoring. • Breathlessness on modest exertion indicative of heart failure as is breathlessness while lying flat. • Rapid onset breathlessness may indicate asthma, chest infection heart failure, acute or chronic bronchitis. • Gradual onset of breathlessness could indicate anaemia. • Identification of sighs (and hence possible depression). • Analysis of body's response to exercise. • Identification of sleep apnoea. • Identification of tachypnoea, hyperventilation, bradypnoea, hypoventilation, Cheyne-Stokes respiration, Biot's respiration.
Acceleration	• Can be used to determine client activity levels and energy expenditure
	Client Behaviour
Location	• See Room Name in Table 6.4
Orientation	• Important for determining whether the client has fallen or collapsed and also for identifying when the client is lying down.
Response time	• This may be used as part of a cognitive as well as a mobility assessment. It is important to be able to detect long-term as well as abrupt changes in a client's levels of responsiveness. (related to mobility)
Repetition	• Persistent repetitive actions performed by the client may be indicative of some form of cognitive/memory impairment or dementia.
Mobility	• Provides data for an ADL assessment. • Acute changes in a client's mobility may indicate some form of distress.
Activity	• This includes everyday actions performed by the client that provide an indication of interaction with their environment e.g. moving about, operating appliances, performing

Domain Property	Potential Significance for Telecare
	household chores, opening doors, go to bed, sit down, eat, watch TV, go to the toilet, etc. Significant variations in habitual activities may indicate a problem that requires assistance. • Abrupt weakness with fever may indicate pneumonia in elderly. • Restlessness/weakness may be caused by a hyper-active thyroid gland.
Food & fluid intake	• Increased food intake may indicate hyperthyroidism, diabetes. • Monitoring of nutrition. • Correlation with increased urination, e.g. tea is a diuretic. • High fluid intake may indicate intense thirst - a symptom of diabetic ketoacidosis. • Lifestyle monitoring/habit assessment – eating & drinking are one of the key activities that people undertake every day, and their absence is likely to be indicative of some form of illness or problem.
Stair use	• Stair transition time will provide an indication of mobility • Helps to determine location of client (i.e. upstairs or downstairs) • Detection of client at either end of stairs may be used to remind client to be careful, and/or to light-up edges of stairs at night.
	Exterior Local Domain Properties
Weather (temperature, rain, wind, pressure)	• Clients with dementia may require advice on their choice of clothing when venturing outside or even whether it is appropriate to do so at all. • It can also be used to warn the client if the ground outside is icy, representing a fall hazard. • Wind indication can be useful for clients who are particularly frail and who are frightened of falling outside. • Mortality has been shown to increase by approximately 2% per °C fall in outdoor temperature below 19°C and is greater in homes to have comparatively low indoor temperatures. • There is a correlation between variations in the occurrence of asthma attacks and weather conditions such as hot and humid air; cold air; and electrical storms. • There is some evidence of a correlation between weather conditions (temperature and pressure variations) and the incidents of heart attack, hypertension and stroke.
Outside light level	• Used alongside motion detectors to switch on security lighting. • Can be used to compare with inside light level to determine status of curtains and as a means of determining when to simulate house occupancy (along with knowledge of the date and time).
Outside air quality	• Can be used for identifying potential aggravators of allergies and may be of particular use for people with respiratory problems.
	Interior Local Domain Properties (General)
House occupancy	• Knowledge of house occupancy ensures that client inactivity and other external alarm conditions do not trigger if the home is empty. • It can be used to switch the system into security mode. • It can be used to set environmental parameters to an economy setting. • Knowledge of house occupancy can be used to monitor social interaction. • Knowledge of the number of people in the home can be used to identify the presence of visitors/carers. The presence of another person may alter the responsibilities of the system and change its method of response.
Water temperature	• Need to ensure that client does not scald/burn themselves when taking a bath, shower, or when using a washbasin. Conversely, water temperature should not be too low for bath/shower to avoid risking hypothermia. • Need to prevent clients who are prone to pressure sores from aggravating their condition by using water that is too hot. • Can provide a warning if water pipes are close to freezing in the winter, resulting in a serious flood hazard (useful when property is vacated).
Water use/flow	• Provides lifestyle data, with the possibility of differentiating between differing water-use events, such as: having a bath or shower, boiling a kettle, flushing the toilet, etc. Thus, if there is no (or abnormal) water-use in the home then there may be a problem.
Room occupancy	• Knowledge of room occupancy can indicate client location. • Provides house occupancy information. • A profile of room occupancy can be used to identify abnormal situations, e.g. the client staying in a particular room for an abnormal length of time. • A profile of client location may be established. Abnormal patterns e.g. wandering, pacing or a gradual decline in mobility (i.e. number and frequency of transfers) can be used to flag potential problems. • Room occupancy information can be used to trigger various home automation services, e.g. for energy efficiency.

Domain Property	Potential Significance for Telecare
Room temperature & humidity	• The ability to monitor and control ambient temperature is important in order to maintain a safe and comfortable living environment. • The rate of change of room temperature may be used to detect a fire. • Can also be used as a method of confirming that the heating in the room is performing as required (i.e. closed-loop control). • Room humidity will affect the perceived warmth of the room (heat index) and can also provide an indirect indication of bath/shower use. The dampness of a room may also be of relevance for clients with pressure sores or respiratory difficulties.
Room light level	• For implementing safety measures that help prevent client accidents in the dark, such as by reducing the risk of falls by automating room lighting. • Confirmation of a request to turn on a light source. • It can be used to monitor client-initiated actions within the home (e.g. client turning on room lighting or opening curtains). • Used as part of a sleep assessment study to identify causes of insomnia.
Room sound level	• Can be used to detect if the a television is on (continuous sound in room) • Can be used to detect if the vacuum cleaner is being used.
Room combustible gas level	• It is important to identify unlit sources of natural gas such as a gas hob/oven or fire and also gas leaks. • Especially useful for clients suffering with mild cognitive impairments such as memory loss or Alzheimer's. • It is desirable to be able to switch such appliances on and off as required.
Room air quality	• Can be used for identifying a range of problems from a lack of personal hygiene, smoking, potential aggravators of allergies, and may be of particular use for people with respiratory problems. • It may be desirable for clients suffering with incontinence.
Chair occupancy/use	• Provides absolute room occupancy information. • Can also be used in conjunction with other data to perform a variety of automated assessments, e.g. using the client getting out of the chair as a reference point to measure how long it takes to answer the front-door, following a knock or doorbell. • Provides an indication of client activity, which may be useful if the client is prone to developing pressure sores or is attempting to lose weight. Likewise, it may be possible to assess the 'sitting-balance' of the client in a chair to ensure that they do not place undue pressure on their sore. • The way in which the client 'uses' the chair may provide important assessment information for OT's. For instance, does the client use the arm-rests when getting in or out? Or does the client *drop* into the chair when sitting down? How much effort is involved for the client to be able to get into or out of the chair? • Can be used to detect abnormal situations, e.g. client appears to be 'stuck' in the chair.
Wardrobe/ cupboard use	• Provides transient information on room occupancy. • Provides information about the everyday activities of the client. For example, if in the kitchen, it may provide information regarding eating habits; if in the bedroom, it may provide information concerning dressing. • It may be used to assess cognitive decline if excessive levels of rummaging is detected (i.e. persistent, repetitive searching through drawers & cupboards).
TV/Remote control use	• Provides transient information on room occupancy. • Gives an indication of client activity. • TV/HiFi may be used as a user-interface.
Door & Window status	• Information pertinent to regulation of room temperature. • Security implications. • Door status provides transient information on room occupancy.
Letterbox use	• Lets system know that mail has been delivered. This can be used in association with a client presence monitor by the letterbox (i.e. front-door) to determine if the client has picked up their mail.
	<u>*Interior Local Domain Properties (Kitchen)*</u>
Kettle use	• Provides transient information on room occupancy. • Provides information about the everyday activities of the client, such as the amount of hot drinks being consumed, and can be used as part of an automated ADL assessment. • The ability to make a cup of tea is generally considered a good indicator of client independence.
Fridge/Freezer use	• Provides transient information on room occupancy. • Provides information about the everyday activities of the client and, in particular, whether the client is eating fresh food (and using items such as milk for making cups of tea) which can be used as part of an automated ADL assessment. • Research has indicated that elderly individuals with empty or poorly stocked fridges are more likely to fall ill than those whose fridges were well stocked. Thus, monitoring the actual use of the fridge is likely to have some sort of equivalence.

Domain Property	Potential Significance for Telecare
Cooker/ microwave use	• Provides transient information on room occupancy. • Provides information about the everyday activities of the client and, in particular, whether the client is eating cooked (i.e. warm) food. This can be used as part of an ADL assessment.
Bread-bin use	• Provides transient information on room occupancy.
Kitchen bin-use	• Provides information about the cooking/eating habits of the client.
Can opener use	• Provides an indication of what and how often the client may be eating.
	<u>Interior Local Domain Properties (Bedroom)</u>
Bed occupancy/use	• Provides absolute room occupancy information • Can be used in conjunction with other data to perform a variety of assessments, e.g. for sleep disturbance assessment, it is important to be able to determine when the client goes to bed and for how long. How much effort is involved for the client to be able to get into or out of the bed? • Useful for performing habit assessments and for identifying if the client stays in bed for an abnormal amount of time (which may indicate illness) • Can be used to identify potential alarm conditions, such as if the client fails to return to bed during the night. • A change in bed occupancy status can be used to trigger various events such as: warning the client if they have left an appliance on or window open; turning on lights if the client gets out of bed in the dark; or reminding them as they get out of bed of the date ("Good morning, today is Thursday. Your home-help will be visiting later.").
	<u>Interior Local Domain Properties (Bathroom)</u>
Bath & shower occupancy/use	• Provides absolute room occupancy information • Can be used in conjunction with other data to perform a variety of automated ADL assessments (e.g. washing/self-care). • Used to ensure that client does not remain in the bath/shower for too long. • Provides an indication of how long the client may be in the bathroom. • Can be used to identify if the client has suffered a fall or is for some other reason unable to get out of the bath or shower. • Can be used to provide care provision audit assessment information.
Toilet occupancy/use	• Provides absolute room occupancy information. • Is a key parameter that would be expected to occur every day, without fail. • Provides information for ADL assessment (toileting). • May provide information on nutrition, e.g. too much tea/coffee (diuretics) will result in increased frequency of urination. • May indicate incontinence or another urinary problem such as kidney failure, kidney stone or pharmacological side-effect (e.g. client is in but doesn't visit loo as often as they used to). May also indicate constipation. • May provide a mechanism of identifying the onset of type II diabetes i.e. by identifying an increase in the incidence of nocturia (night-time urination). • Provides information concerning the length of time a client might be expected to spend in the bathroom (useful for discounting a fall).
Washbasin use	• Provides information on room occupancy. • Provides information about the everyday activities of the client. For instance, in the bathroom, it shows that the client is performing an important function (of hygiene). • It provides extra information concerning the length of time for which the client may be expected to remain in the bathroom in order to assess whether the client is ok. • May be indicative of the amount of time spent grooming (e.g. if a mirror is on the wall above the washbasin) and could therefore be used as part of the ADL assessment. • It also has potential as a means of triggering a reminder to the client to perform a certain action (e.g. if the medicine cabinet is in bathroom, then it could be used to trigger a reminder for the client).
	<u>Temporal Properties of Relevance</u>
Day & Date	• Client may perform certain tasks on certain days and will thus exhibit different patterns of activity accordingly (e.g. weekday activity patterns may differ significantly from weekend activity patterns). • Client may require reminders as to events or appointments for a particular date, or even what the day's date actually is.
Time (of day)	• Client activity will vary according to the time of day (for example due to circadian rhythms) – thus their interaction with their environment will vary accordingly. • Client may require reminders as to events or appointments for a particular time, or a reminder of the time. • Certain actions performed by a client suffering with dementia may be inappropriate or unadvisable at certain times of the day. • Provides a reference for monitoring key events that occur frequently more or less at specified times, e.g. going to bed, having tea, eating lunch, etc. • Is required for certain alarms that are sensitive to the time of day, e.g. client failing to return to bed during the night, client with dementia opening front-door at 3 AM, etc.

6.2 Conflict Discovery & Analysis

A diverse group of system stakeholders, each with multiple needs and differing priorities, has resulted in a significant number of conflicting system requirements. Suitable compromises must therefore be engineered in order to accommodate these conflicts without adversely affecting the system's ability to provide the required services. These compromises are likely to place significant design constraints upon the structure and operation of CarerNet. The root cause of many of the conflicting requirements may be found in Table 6.6, which details a number of benefits and drawbacks associated with telecare as perceived by the key stakeholder groups. In order for telecare to be adopted en-masse, it is essential that the perceived benefits outweigh the perceived drawbacks [158].

Table 6.6. Summary of benefits and drawbacks of telecare for major stakeholders.

Stakeholder	Benefits	Drawbacks
Client	• May prevent the need to be admitted into institutional care. • May enable earlier discharge from institutional care. • Increased access to remote services. • Equity of access to services and resources. • Reassurance that care will be forthcoming in the event of an emergency. • The possibility of preventative services and support within the home. • Management and reduction of risk.	• Need to accept a significant level of technology into the home. • Possible feelings of 'intrusion' & degradation in level of privacy due to the need for monitoring systems (the 'Big Brother' effect). • The threat of technology replacing care staff. • Potential for increased social isolation caused by a possible reduction in the number of informal & formal care visits. • Concern about a computer taking control over the living environment. • Concern over who pays for telecare. • Misgivings about who has access to personal data.
Informal Carers	• Provides peace of mind. • Allows carer to take a break. • If living with client then it may reduce the burden of care. • Assists by supporting the care-process. • Can provide 'snapshots' of client well-being on-demand for piece of mind.	• The continuous availability of access to the carer by the client may prove to be a problem if client uses or abuses the system. • If living remotely from client then it may increase the responsibility of care. • May become a 'slave' to the system.
Formal Carers	• Allows resources to be allocated and prioritised according to need. • Enables more realistic assessments due to client being in own home. • Provides opportunity to monitor continuously with more accurate data. • Allows the effect of a particular care regime or intervention to be assessed. • Removes the need for staff to perform degrading tasks (e.g. feeling the state of an incontinence pad with their hand). • Promotes and enables integrated care.	• May result in poorer rates of pay for some staff. • The threat of technology replacing (low-skilled) care staff. • Time and effort taken to re-train in new skills. • How much extra work will be generated through its use, e.g. responding to alerts, considering data? • Are there appropriate response mechanisms in place to cope with new types of alerts (e.g. gas alarm)?
System Procurers	• More efficient allocation of resources. • Potential of savings in medium to long-term (although may only be justified if integrated care is being funded using a pooled budget). • Kudos of being perceived as being a forward-looking authority.	• High initial outlay in capital expenditure. • Staff training costs. • Higher qualified response centre staff with more responsibilities will require higher wages. • Short-term gamble using new technology. • Legal liability if system fails to detect a client in distress or decline.
Telecare Service Provider	• Allows automated calls to be prioritised according to need. • Provides background data to help deal with manual requests. • Improved technology should result in fewer false alarms.	• Move to integrated care with medical services is likely to result in the need for more skilled staff at response centres. • Will NHS Direct take over the function of privately run call centres? • Legal liability – who is responsible if system fails to detect a client in distress or decline?

Stakeholder	Benefits	Drawbacks
Service Infrastructure	• Telecommunications Service Providers may witness an increase in traffic, especially at low-volume time slots. • Potential to expand into new markets.	• Might put extra pressure on 'local-loop'. • May ultimately need to invest in roll-out of better access technologies to home (e.g. Asymmetrical Digital Subscriber Line).
System Manufacturer	• Opportunity to diversify into new markets. • Potential for sale of multiple-units per household. • Large customer-base that is likely to grow in number.	• The lack of an established market may constitute a risk. • Research investment required to identify, develop, and trial new services. • The lack of identified budgets to pay for services may hinder the take-up of telecare and hence limit sales. • Legal liability if system fails to detect a client in distress or decline.
Policy Makers	• Potential for auditing of care provision. • Better epidemiological information. • Increased health awareness, improved access to information, and assessment & screening programmes may result in reduced costs for long-term care.	• Cost of funding research into telecare. • Cost of implementing pilot schemes.

In order to identify conflict between system requirements, they were compared using a conflict analysis matrix. Table 6.7 is a fragment of the matrix used to identify the extent of conflict between key requirements[12]. An explanation of the scoring system used is provided in Table 6.8, and a discussion of some of the issues raised by the conflicts identified is provided in Table 6.9.

Table 6.7. A selection of conflicts identified from the CarerNet stakeholder requirements.

	Client privacy & empowerment	Client Safety	High Reliability	System Autonomy	Affordability	Fast Response	Comp. Service Provision
Client privacy & empowerment	-						
Client safety	+2 (A)	-					
High Reliability	+2 (B)	-1 (C)	-				
System Autonomy	+2 (D)	-1 (E)	+1 (F)	-			
Affordability	0 (G)	+2 (H)	+2 (I)	+3 (J)	-		
Fast Response	+2 (K)	-1 (L)	+2 (M)	-1 (N)	+2 (O)	-	
Comp. Service Provision	+3 (P)	+1 (Q)	+2 (R)	0 (S)	+2 (T)	+1 (U)	-

Table 6.8. Key to the requirement conflict analysis matrix of Table 6.7.

Score	Meaning	Description
-1	*Re-enforcing*	The requirements are in agreement and complement each other.
0	*Independent/No conflict*	The requirements may be considered in relative isolation.
+1	*Potential for conflict*	Certain circumstances may generate a conflict between requirements.
+2	*Probable conflict*	There is a strong likelihood of conflict between these requirements.
+3	*Definite conflict*	Opposing requirements requiring definite compromise.

The main areas of conflict that impact on the acceptability or operation of telecare systems involve issues of client privacy and control, system affordability, and issues concerning safety and reliability (highlighted in Table 6.7). Furthermore, there are a number of informatics issues that need resolving. In

[12] *It highlights the main issues of contention that require resolution.*

particular, information should be presented to care providers in an efficient manner[13], allowing them to concentrate on the *human* aspects of their work. Otherwise, the amount of data likely to be generated will give rise to carers becoming overwhelmed, resulting in telecare hindering their ability to care.

Table 6.9. A discussion of potential conflicts from Table 6.7.

A	Client safety depends on the ability of the system to manage hazards in the local environment. In order to achieve this reliably, it is necessary for the system to be able to effect various domain entities. This may be perceived as being intrusive and of taking control away from the client and presenting it to the 'system'.
B	In order for the system to perform reliably it requires an accurate representation of the local domain, which is commensurate to the quality and quantity of information available. There is likely to be a point at which the client will feel that their whole lifestyle is being scrutinised. Likewise, the desire to ensure that the client has the right to turn off certain monitoring and alarm functionality may have implications for the ability of the system to operate reliably in the event of an emergency. There may also be implications for service reliability if a client-initiated action is relied upon or can affect system operation in any way.
D	An autonomous system must not result in the client feeling as though they are no longer in control of their own living environment. Furthermore, excessive home automation may result in the client becoming less independent as they rely more and more on the technology to perform various tasks. Privacy issues are also of concern when the local system is capable of automatically transmitting data out of the home.
F	Autonomous control of the local domain is realised via the use of actuators. These contain moving parts and are subsequently liable to mechanical failure, thus affecting the reliability of the system as a whole.
H O	Safety often depends on speed of response, which depends on the system's ability to control its domain, using the relevant actuators. These are often expensive and, as such, place a constraint on the number that can be installed with a finite budget. If service provision is cut-back to limit costs then this may place the client at-risk. Safety may also depend on the reliability of the system, which can be affected by issues of quality and levels of redundancy, etc., both of which have cost implications.
I	In order to increase reliability and dependability, there is a need to employ good engineering practice, components, and materials. Additionally, there may be a need for multiple or redundant units and techniques such as Built-In Self-Test (BIST) and auto-recalibration. All of these options are likely to increase system complexity and hence costs, thus making a solution less affordable.
J	System autonomy implies bi-directional communications and the use of actuators; both of which have an associated cost. Radio transceivers are typically more than twice the price of a single transmitter or receiver unit. Wired implementations will, however, offer low-cost bi-directional capabilities.
K M	The desire to achieve a fast response may result in an increase in the number of false alarms. For instance, the use of heuristic rules with 'fuzzy' data may result in incorrect decisions being taken. False alarms result in unnecessary intrusion. Furthermore, certain situations, whilst of concern, may be rectified by the client themselves, given an appropriate amount of time and support.
P	An increasing number of services implies an increasing data-set requirement resulting in a more intrusive system. This may also result in a more obtrusive system if more technology is subsequently required.
Q R U	As the number of services increases, so does the complexity of the system. Increasing complexity implies increasing numbers of devices or software elements. This results in a greater likelihood of failure and hence a reduction in reliability, which may adversely affect overall safety. There is also the possibility of the system being impaired by data-smog, which *may* slow down the response time of the system.
T	As the number of supported services increases, so does system complexity, and hence system cost. It is plausible that the cost involved may exceed the budget available, resulting in the ideal telecare solution being unaffordable. In particular, if a client requires medical devices or actuators, then the cost to implement telecare is likely to be considerably more than if just monitoring devices and alarms were required.

6.2.1 Intrusion, Privacy & Control

The relationship between 'patient' and 'carer' will be significantly different in a domestic setting compared with an institutional setting. In the latter, a 'patient' will accept significant amounts of physiological monitoring, almost without question. Whereas, in the former, a 'client' may be disinclined to accept the more intrusive lifestyle-based monitoring. Of particular concern, is the knowledge-based nature of telecare, relying as it does on ubiquitous monitoring and control and the distribution of this knowledge to entities outside of the home. This is contrary with the desire to minimise intrusion and maximise the privacy and autonomy of the client. As a result, the successful implementation of a care plan that includes elements of telecare may prove to be difficult or contentious.

[13] *i.e. carers should not be required to analyse or process large amounts of data.*

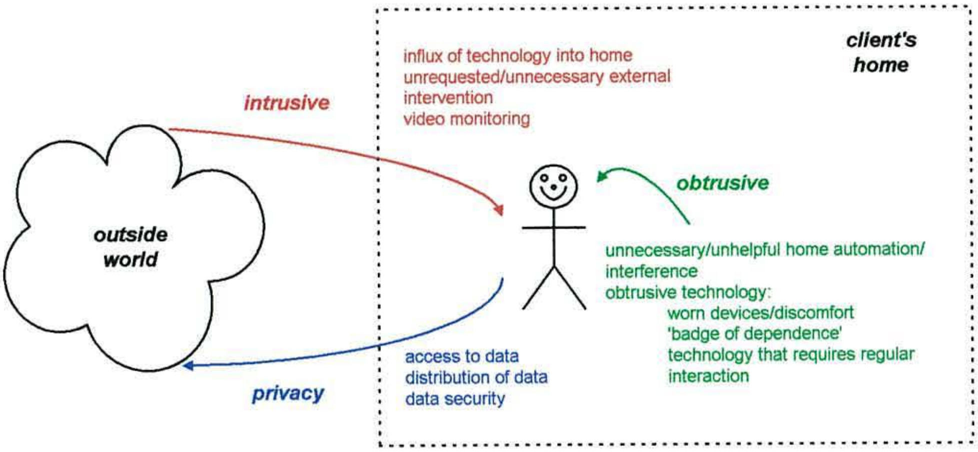

Figure 6.9. Issues that affect client privacy and empowerment.

In order to resolve this conflict, it is necessary to arrive at a suitable compromise on the methods by which telecare services are realised. In order to conceive of such a compromise, this complex issue has been modelled as three distinct but nevertheless inter-related problems, illustrated in Figure 6.9.[14] The methods considered to manage these concerns are invariably design constraints, which are placed upon the system and are discussed below.

Enable client override

A client should be able to override or turn off particular services if they so wish, providing that the overall safety of the client and their community is not adversely affected by them doing so.

Discourage image-based monitoring

Even though image-based devices can, potentially, provide a wealth of data, they are distrusted by clients and many carers. The use of videophones and intercoms under the control of the client are permitted.

Minimise the amount of time required to specify and install telecare services

An automated assessment tool will help to determine a client's telecare service requirements. Wireless devices will enable a quick and easy system installation (and removal) especially when retro-fitting into existing housing stock. Devices should be plug and play (i.e. auto set-up, test, and calibration) and provide sufficient diagnostic information to the installer to ensure a successful installation.

Minimise the need for on-site system maintenance and reconfiguration

Enable 'in-service' access for remote system reconfiguration. Ensure that battery-powered devices have a battery life in excess of 12 months. Built-In Self-Test (BIST) facilitates self-diagnosis of the system, allowing problems to be reported automatically, thus reducing the mean-time-to-repair [159].

[14] ***intrude*** *(v.) – come uninvited or unwanted; force on a person;* ***obtrusive*** *(v.) – unpleasantly or unduly noticeable;* ***privacy*** *(n.) – the state of being private and undisturbed;* ***private*** *(adj.) – belonging to an individual; confidential; not open to the public [110].*

Information flow away from the home should be controlled

The local CarerNet system (and, in particular, its response infrastructure) may be modelled as a series of 'knowledge zones' that surround the client, as depicted in Figure 6.10. As information is passed outwards through successive zones, the level of privacy afforded to the client is decreased. Each zone is separated by a 'knowledge boundary' which represents the interface between care providers. In order to manage the flow and control of information, it is necessary to define precisely the decision-making processes required at each boundary.

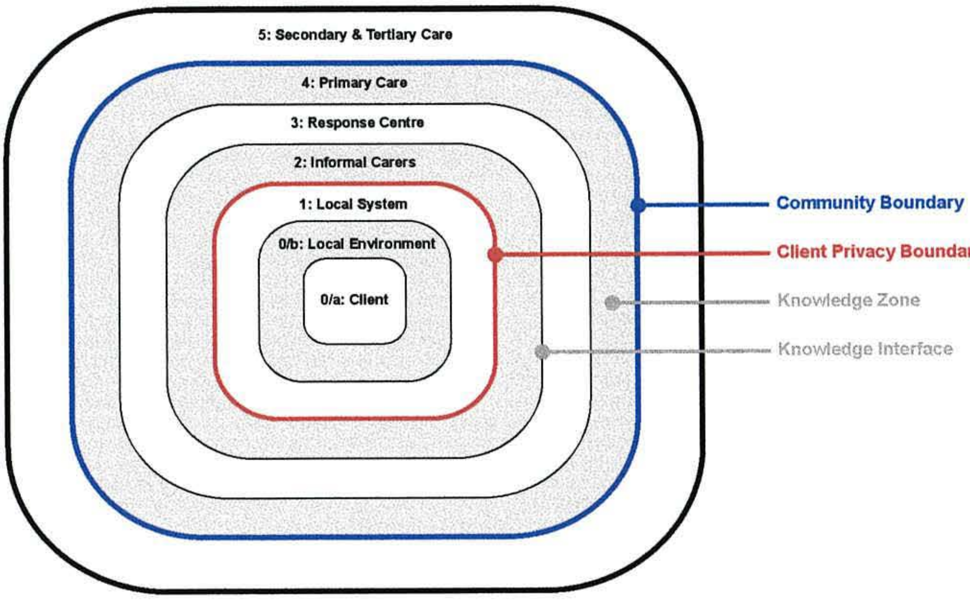

Figure 6.10. CarerNet knowledge zones.

It may be observed in Figure 6.10 that there exists a 'client-privacy boundary', whereby data contained within the client's home may be considered as private. The level of intelligence required to process information increases as it is passed outwards through the zones, resulting in an increase in human rather than machine intelligence. Thus, the perceived level of intrusion and the subsequent invasion of privacy may be minimised by containing data within the home. Every effort should be made to provide an appropriate response from the closest level to the client, refer to Table 6.10[15]. In the first instance, local resources within the home should be considered as part of a telecare supported self-care solution. Secondly, if a local carer is present, then they may be capable of providing a suitable response; if not, then perhaps an informal carer living nearby may be capable of providing assistance, and so forth.[16] The response centre may be used as the source for an alarm message if there is some uncertainty as to the nature of the alarm or as to the most appropriate responder.

[15] *An exception to this rule is likely to be when medically-related information, which may be confidential between the client and their GP/physician, is involved.*

[16] *Informal carers should have the option to decline responsibility for a call. In which case, the call should be passed on to the next informal carer, and so on, until either an informal carer accepts responsibility, or the response centre is notified instead.*

Table 6.10. A selection of example 'vertical' CarerNet information flows.

Information flow	Example service
domain to local system	• System-initiated (passive) monitoring based on client (and carer) need and as per the client's telecare prescription. • Client-initiated (active) monitoring and alarm generation, and other system-client interaction (e.g. manually-raised panic alarm, manually set room thermostat).
local system to domain	• System-client interaction (via user interface) e.g. medication reminder, fridge door open alarm, temporal re-orientation, alert confirming client status, etc.
local system to local informal carer	• A local carer may act as the primary responder to many alert or alarm events. • Several services may be provided for the primary benefit of a local carer, such as notification of a change in state of a client with dementia, e.g. client out of chair/bed alert, wandering alert, front-door open alert, etc.
local system to remote informal carer	• Some alert conditions may be transferred directly to a remote informal carer without involving any third-party care organisations. This may be accomplished using various means, e.g. phone call, text messaging, pager, e-mail, etc.
remote informal carer to local system	• Responding to alerts, for example by conversing with the client. The remote carer may also wish to reassure themselves by checking the client's local system in order to confirm that all is well.
local system to telecare service provider (TSP)	• Alarms may be transferred to the TSP if no appropriate alternative responder is available or if the nature of the alarm call is undetermined (e.g. client-initiated panic alarm), or if the client wishes to use the TSP to request a service.
TSP to local system	• Setting operating parameters, acknowledging alerts, etc.
TSP to remote inf. carer	• Request response to an alarm (e.g. nominated key-holder to open door)
local system to primary carers.	• An alarm message to an appropriate emergency responder. • An alert (on request) to a formal carer (e.g. GP, pharmacist, occupational therapist) informing them that the notification thresholds set up had been reached, e.g. diabetic client has not monitored their blood glucose levels for over a week; or client has forgotten to take their medication more than 3 times in a week. • Assessment scores provided as requested, e.g. download of monthly ADL score for review; a plot of a client's blood pressure readings for analysis, etc. • Measurements obtained as part of a video-consultation by client using monitoring equipment in home, as directed by physician.
primary carers to local system	• Setting-up operating parameters, acknowledging alerts, performing virtual check-up on client, video-consultation.

Convert low-level data into high-level information using local system intelligence and export data out of the home on a 'need-to-know' basis only

By adopting local intelligence within the home, it is possible to pre-process much of the low-level 'intrusive' data into more meaningful information locally so as to reduce the quantity[17] of data required to leave the home, Figure 6.11. This may reduce the perceived level of intrusion experienced by the client and will filter large data sets into more manageable items of knowledge. In addition, the use of client assessment scores can 'summarise' historical trends and identify when intervention may be necessary.

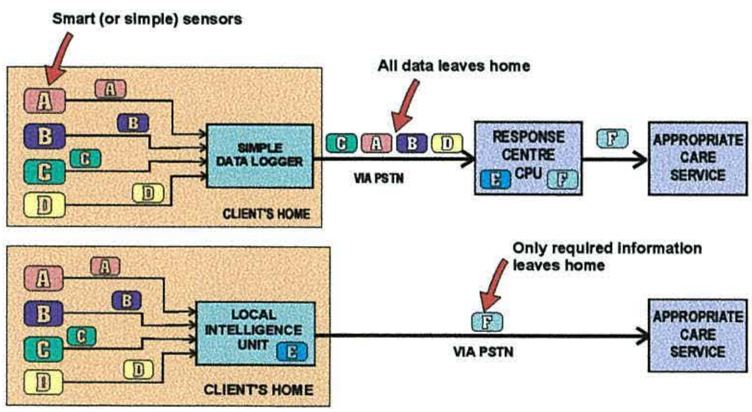

Figure 6.11. Conversion of low-level data into high-level information within the home.

[17] *both the amount of data and the frequency of transmissions.*

Minimise unnecessary external interventions & unnecessary home automation

This is of particular concern where a decision based on heuristic intelligence using fuzzy or incomplete data may err on the side of caution (i.e. fail-safe) and notify external carers, ultimately resulting in a high number of false alarms. In order to establish whether external intervention is necessary, alerts should be raised to verify with the client before raising an alarm, see Figure 6.12. This may still cause some irritation to the client, but is likely to be preferable to unnecessary contact from external care agencies.[18]

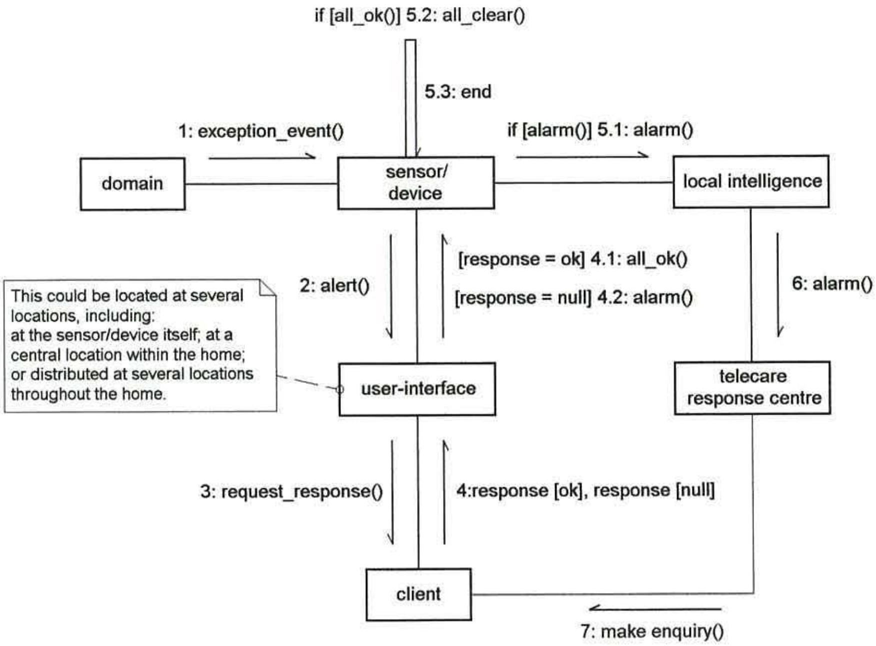

Figure 6.12. Proposed local alarm sequence for CarerNet.

Another technique may be the remote 'passive' enquiry mechanism (i.e. a 'virtual check-up') that provides information regarding the client's status and well-being as well as that of the living environment. This should be conveyed using just enough information to reassure a concerned carer that the client is ok and that the system is operational (this does affect client privacy).[19]

Minimise the number and visibility of devices in the home

A high number of highly visible devices in the home will be obtrusive. Multi-function devices should be conceived in order to minimise the number of 'boxes' required in the home with devices sharing common functionality between services to avoid excessive duplication. Ideally, the system should be data-efficient, i.e. provide the maximum amount of information with the minimum amount of data (and hence technology).

[18] *However by providing the client with the ability to cancel alerts, it is necessary to ensure that all of the safety implications of doing so have been considered. For instance, the options presented to the client are likely to be based on the nature of the alert and on the ability of the client to respond accordingly (with particular attention made to clients suffering with forms of dementia).*

[19] *For instance, consider the case where a client is not answering the phone in the morning, causing undue concern for a carer, then they would be able to perform a virtual check-up that could inform them if the client were in the loo/bath or in bed.*

Devices may be blended into the local environment by incorporating them into everyday items such as appliances and furniture; or embedding them into clothing. A more understated system will interfere less with the everyday activities of the client and is likely to be more reliable as it will be interfered with less[20]. Placement issues are of concern for monitoring equipment where location might be important for correct operation, for instance when monitoring client-originated parameters, see Figure 6.13. It is anticipated that a wide variety of installation options will be necessary to provide the required data-coverage and the mix will vary according to whether telecare was considered as part of a new-build or retro-fit solution.

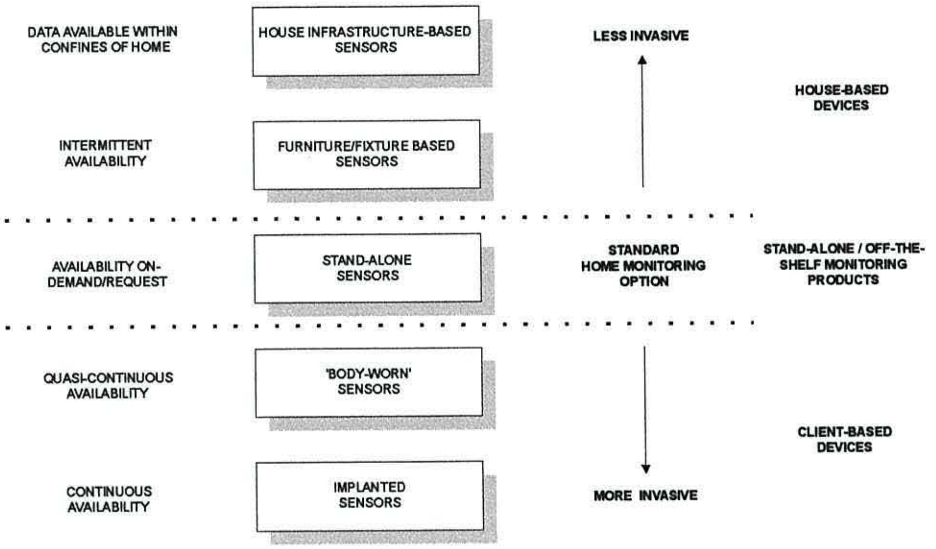

Figure 6.13. Location of devices.

6.2.2 Safety, Reliability & Affordability

Safety and Risk Management

Telecare relies on the successful deployment of care technologies into the homes of clients with varying degrees of technical proficiency. Some of these technologies are concerned with the management of risk and involve the prevention or management of various hazards, refer to Table 6.11. If the system were to consistently generate false-alarms, then this would inconvenience both the client and the response network. Worse still, it may result in the system being 'switched-off' and/or in genuine alarm conditions being ignored. Similarly, if genuine alarm-situations were missed then it would lead to a lack of confidence in the system and may give rise to tragic consequences. It is apparent that if a client is considered safe at home on the basis that they are in receipt of an integrated care package that includes elements of telecare, then it is essential that these elements are considered to be reliable and safe. In order to ensure this, several measures must be undertaken:

1. A comprehensive client assessment is required in order to ensure that it is safe for a client to remain at home with an appropriate care package and that the most appropriate telecare services and technologies are prescribed;

[20] *Individuals with dementia in particular are renowned for 'playing' with new or strange items of equipment.*

2. System services should minimise the occurrence or consequences of unsafe circumstances or actions. They should not themselves be responsible for injury either due to inappropriate client behaviour, incorrect use or failure of devices, system upgrades, or by the introduction or removal of telecare equipment.
3. System services and elements should be reliable, fail-safe, and degrade gracefully such that failures may be tolerated for a period of time long enough for repair to be undertaken.

Table 6.11. An example of some hazards and various risk management techniques.

Hazard	Risk of	Conventional Approach	Telecare Approach
Poor gait, hemianopia, loose rug or cabling, steep stairs	Falling	Walking frame, physiotherapy, remove rug/cabling or fix down, remove need to go upstairs, install a stair-lift.	Employ integrated fall management care package – fall prevention and detection.
Poor vision	Falling, taking the wrong medication.	Correct vision using spectacles or corrective surgery.	Fall management services, remind client to wear spectacles, medication management.
Administering incorrect medication	Illness, weakness, injury, death	Use alternative sensory info to convey tablet type & quantity. Use pill-mill device, have a care worker call to administer drugs, explain importance and action of drugs, label bottles with clear instructions, avoid blister packs.	Medication management systems to remind client and monitor compliance and dispense medication if necessary.
Poor lighting	Trip, slip, fall, impact hazard	Install better lighting	Use automated 'smart' lighting systems; Use floor level lighting;
Over spilling bath/sink	Flooding	Overflow outlet pipe	Flood detection; Bath-water volume monitor; Electronic taps.
Scalding hot water in bath	Burn/scald.	Test water temperature with hand; Thermostatic valve	Monitor and control bath-water temperature.
Gas taps left on / gas leak	Explosion Suffocation Fire	Gas alarm; Smoke alarm Heat alarm	Automatic gas shut-off systems; Gas appliance status display/ reminder systems by bed & exits.
Poor heating	Hypothermia Infection Stroke	Install insulation measures Close windows	Use smart technologies to regulate temperature throughout the home; Quartz halogen heaters can provide 'personal' heating zones;

Cost Implications

The quality of a telecare system will be proportional, to some degree, on the investment made. For instance, many services associated with safety require closed-loop control using actuators such as gas valves; window and door openers; and medication dispensers. Unfortunately, these are often expensive in comparison to non-mechanical sensor technologies[21]. User interfaces can also be expensive if large screens or other special requirements (e.g. voice-recognition, speech output, or wireless connectivity) are required. Furthermore, services that infer client well-being from diverse data sources are likely to be more reliable (up to a point) as their access to the domain is increased (i.e. more sensors).

Thus, given a finite budget, there is potential for conflict between on the one hand, the need to manage risk and ensure a safe environment for each client; and, on the other, the ability to pay for these services. These conflicting requirements can be considered at two levels:

1. *Service level* - the ability to purchase the necessary services, given a finite budget. This is compounded in the case of safety-related services due to their reliance on expensive actuators.

[21] *and also present further issues of reliability due to their moving parts.*

2. *Technical level* - the need to achieve a reliable system with adequate levels of functional safety (such as with redundancy and Built-In Self-Test), but which nearly always introduce additional overheads due to the need for more devices, or more complex devices.

Service Level Considerations

The first point may be addressed partly by rationing services according to need. For instance, if a client's risk assessment score is below a pre-defined threshold, then a lower-cost alternative to actuators might be considered, such as warning and reminder systems. Another solution is to minimise the cost of the technology. Consider Figure 6.14, which illustrates the conceptual mapping of requirements onto matching telecare services, domain parameters and associated devices, each of which may be implemented using specific sensing or actuating technologies (implementation-space).

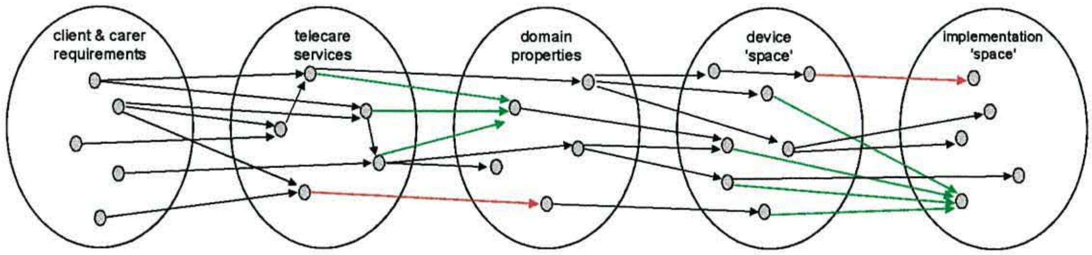

Figure 6.14. Many-to-one mappings are desirable (from left to right).

The cost of telecare devices may be reduced to some extent, without compromising on quality, through an economy of scale, requiring that a many-to-one relationship exists between individual devices and their method of implementation (green arrows). Devices that take advantage of a common hardware platform (in particular one that includes a common and better still, low-cost, sensor[22] technology) are therefore ideal. Costs may be reduced further if it were possible to increase the size of the potential market for devices capable of supporting non-telecare-specific smart home services. This would require that devices be capable of integrating and interoperating with other generic smart home systems.

The cost-effectiveness of telecare services can be further improved by conceiving of a device-set that is 'data-efficient' (in a systems-context). Accordingly, it is desirable for a single device to map on to multiple services, with the ideal solution comprising a core set of devices that, between them, are capable of supporting a large range of (the most commonly required) services.

The many-to-one mapping required between telecare services and domain properties implies that devices should be capable of sharing their services (e.g. access to data) across the local network. This should result in lower implementation costs due to the reduction in duplicated functionality at various points throughout the system[23]. Finally, telecare equipment should, where possible, be easy to remove from a client's home if it becomes surplus to requirements so that it may be reused elsewhere.

[22] *There are always likely to be more sensors than actuators.*
[23] *although a certain amount of redundancy may be desirable for reliability issues*

Technical Considerations

A compromise is required between the safety integrity of a service and its associated cost[24]. In order to develop a safety-case for a particular service or device, the potential hazards which might result due to its failure (or absence) must be established. It is necessary to ensure that the level of safety measures put in place will achieve a satisfactory level of safety integrity given the identified hazards and risks. In order to accomplish this there is a need to apply a framework for the allocation of safety integrity levels to telecare services. No such framework currently exists and it was therefore necessary to generate one based on a knowledge of services and devices currently under development, undergoing user trials in pilot studies or that have been developed as part of this work (see Chapter 8 and 9).

Aspects of safety as it applies to telecare at both human and technological levels is presented in Appendix B including a detailed discussion of functional safety for telecare devices. A framework for the allocation of safety integrity levels is presented based on an extension of IEC 61508, an international standard concerning the *functional safety*[25] of electrical, electronic, and programmable electronic safety-related systems [160]. The standard offers a common approach to functional safety across multiple application areas but is also intended as a foundation for the development of application-specific standards. This work is summarised in [161].

6.2.3 Information Management

The pervasive nature of telecare monitoring will result in large quantities of data being generated. However, human data-clients (mostly carers) will not have sufficient time to analyse this data in order to derive useful information about the well-being of each of their (many) clients. Therefore, there is a need for intermediate machine-based data clients that are capable of restructuring and filtering the low level data into more concise high-level knowledge. This is likely to involve:

- Data processing - to derive meaningful information from large volume, low-level, data sets.
- Data 'compression', such as the use of event-monitoring and well-being indices that provide a concise indication of various parameters in order to assist the investigation of long-term trends.
- Automated assessments with auto-alerting thresholds, i.e. assessment techniques that raise exceptions when scores exceed carer-defined norms or exhibit particular trends.
- Data visualisation techniques that process information into a form suitable for presentation to a carer (e.g. a histogram of client activity over time, or a 'real-time' display of client status.)
- Automatic notification that requested data is available for viewing (e.g. a plot of a client's blood pressure or blood glucose profile over the last month.)
- A familiar user-interface for accessing & manipulating data (e.g. web browser.)

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[24] *There is little point in developing the 'safest possible' system if the resulting cost is so prohibitively high that nobody can afford to purchase it!*

[25] *the ability of a system to carry out the actions necessary to achieve and maintain an appropriate level of safety both under normal conditions and when a fault or hazard occurs [160].*

Information Coding

Ideally, information generated by a telecare system should be represented using a universal coding/classification system. This may prove difficult due to the varied nature of the care professionals likely to participate in telecare who are likely to have different information requirements and very often will have their own terminology and methods of classification. This would suggest therefore that information transfer should be implemented using a generic technique, suitable for conversion into the most appropriate coding schema. The use of the eXtensible Markup Language (XML) to represent such data might therefore prove to be of benefit in this respect. It may be possible to represent large portions of such information using the *International Classification of Functioning, Disability and Health* [114].

Data Compression with Event Logging

Many of the domain properties to be monitored will vary slowly over time (e.g. room temperature) and will not require frequent logging. The information of interest is often contained within significant changes to the signal, e.g. where a value exceeds a threshold (e.g. blood pressure high event) or varies abnormally in a short space of time (e.g. rate of change of room light level). If the property concerned is discrete, then it is enough to log the occurrence of the event describing the feature (e.g. room temperature low alarm). If the property is required for long-term trend analysis then it is normally sufficient to obtain a high, low, and mean value over a given monitoring interval (e.g. room humidity sampled once per minute, but logged in 15 minute intervals, i.e. 4 mean readings per hour). Where the property is continuous and has a significant time-varying component, it may be useful to log a segment of the signal either side of the episode of interest (e.g. capture of ECG trace during arrhythmia).

6.3 Implications for System Architecture

6.3.1 An Object-based Approach

It is proposed that an object-oriented based approach be adopted for the development of the system architecture in the home. This is because:

1. It is ideal for modelling complex 'real-world' systems. The modelling of domain objects rather than the system functionality should, in principle, result in a more robust architecture as the objects in the domain are more likely to remain constant compared to system functionality, which may be required to change. It should also map onto the domain analysis of Chapter 5.
2. It promotes modularity by minimising the number of inter-component dependencies (i.e. there is loose coupling between components). This is achieved by encapsulating the internal structure of system elements and employing a well-defined interface to external elements.
3. It helps to separate a service from the detail of its implementation. For example, there are many ways of determining bed occupancy (e.g. monitoring weight, movement, temperature, and even different methods of implementing each of these). However, the information required is always the same. Providing system vendors implement a common interface and protocol, then devices will be capable of interoperating with each other.

4. It should help to identify the potential re-use of system elements in order to assist in the development of a low-cost and reliable implementation.
5. It will improve the chances of compatibility with emerging smart home systems and protocols which are increasingly modelled and implemented using object-oriented principles [162].
6. It should provide a structured method of representing knowledge of the domain in a form suitable for an open and universal data description and messaging protocol for telecare.

6.3.2 Distributed Intelligence

The distribution of intelligence throughout the system can be considered on a number of levels. Clearly, as the information moves upwards through the system and becomes more structured and knowledge-based, the system intelligence will rely more and more on human-based reasoning and analysis. Lower down the system where large quantities of data processing is necessary, the system intelligence will be predominantly machine-based.

The analysis of Chapter 4 identified the need for machine-intelligence in the home of the client in order to enable closed-loop control of domain properties. This also protects the privacy of the client by reducing the quantity of data required to leave the home and reduces the processing and data-storage requirements at the response centre as well as the cost involved with data transmission. The distribution of intelligence also has positive safety and reliability implications in terms of response times and quality of service (improved tolerance to individual failures compared with a centralised approach).

The distributed approach is also recommended within the home itself for similar reasons to those mentioned above. In addition, the use of many low-cost microcontrollers to distribute the burden of rule processing may result in a solution that is easier and cheaper to implement.

Smart Sensors

A smart sensor is one that is context-aware (i.e. it possesses self-knowledge of its capabilities and operating domain and can represent this information in the form of an 'electronic data sheet'); it can apply algorithms and rules locally in order to convert low-level measurements into high-level information (in the required scientific units) or into knowledge, e.g. see Table 6.12; and is capable of communicating this information in a format suitable for its host-system.

Table 6.12. Various data abstractions for smart sensors.

Abstraction	Description	Example: Temperature Monitor
Measurand	The physical property that is monitored using a sensor in order to determine the value of a domain property.	Voltage signal proportional to temperature.
Measured Property	The parameter of interest, which may be obtained directly or may have to be derived from the measurand.	Temperature.
Derived Property	Extra properties of interest that may be obtained by simple pre-processing of the measured property	Mean temperature.
Events	A notification that a pre-defined condition has been met; typically used to confer the condition of a Boolean state.	Temperature High Event. Temperature Low Event.
Alerts	Events or sequences of events that may require closer analysis or a suitable response.	Temperature Low Alert (e.g. temperature trend too steep).
Alarms	Events or sequences of events which pose a serious threat to the client or to the system and which require an immediate response.	Fire alarm. Hypothermia alarm.

It can also possess several other features, including: local memory, a real-time clock, advanced power management, and Built-In Self-Test (BIST). The advantages of smart sensors are numerous and are summarised in Table 6.13.

Table 6.13. Advantages of smart sensors.

1	Signals are exposed to less noise prior to processing and interpretation.	**6**	Signals are not band limited by restrictive low-cost communications channels.
2	A smart sensor converts the measurand into a form suitable for the local bus and allows operating parameters such as alarm thresholds and sampling rates to be tailored to the individual client.	**7**	Because the signal processing occurs at the data source, it is possible that a single device can be used to provide multiple information by processing the sensor signal in different ways and presenting appropriate messages to the system.
3	Information concerning device location or attachment may be available for verifying that the device is in use or being used correctly.	**8**	The device's immediate local environment may be monitored if necessary to provide useful self-checking capabilities.
4	There may be useful information available at the sensor-end which can give diagnostic information as to the 'health' of the device itself. For instance, changes in the noise signature might give an indication of sensor status. The sensor may also provide an indication of the quality of the data available [163].	**9**	Signals may be processed at source, hence only the required information need be transmitted onwards - leading to a reduction in the amount of data transmitted (both the number and length of transmissions) – i.e. it can perform the function of an information filter. This results in a subsequent reduction in the required data capacity of the network. Less transmissions also reduces the chances of message collisions, especially with simplex radio links.
5	It can be self calibrating, minimising the amount of interaction with the client or with service personnel, especially at installation time.	**10**	A smart sensor is capable of optimising its performance by controlling appropriate parameters such as signal gain, measurement bandwidth, measurement frequency, etc.

CareWare Components

The term 'CareWare' has been coined to describe the machine-intelligence distributed throughout the local system in the form of modular rule-elements and algorithms, which together enable the provision of telecare services within the home. CareWare may reside at any point in the local network, e.g. as part of a smart sensor, a smart hub, or at the Local Intelligence Unit (LIU) itself. In cases where all the necessary data are available at a single location, the CareWare associated with that data may be located at the point of data capture. However, there are numerous services that require data from sources that are distributed throughout the home. In this instance, CareWare may be considered (at a conceptual level at least) to be the execution of a 'virtual' smart sensor, implemented in software, and behaving as if it were a real sensor with access to all the necessary information. Alternatively, some CareWare components may modelled as an 'agent', charged with a responsibility to provide a service, which it performs autonomously by gathering all the necessary data and performing the required actions.

If devices are to be capable of supporting multiple services, then it is necessary to be able to control which services are implemented at any one time. The tailoring of service provision to a client's individual need should be possible without having to pay a visit to the client's home (in order to minimise the level of intrusion and so as not to needlessly burden formal care resources). This implies an ability to remotely re-configure system CareWare in software, allowing the hardware and communications infrastructure to remain intact. This makes the system more attractive, especially in sheltered or extra-care housing schemes, as it means that a given hardware platform possesses an ability to adapt to provide varying levels of support, as required.

6.3.3 System Architecture

The architecture of Figure 6.15 is proposed for the CarerNet local environment and is based on the premise that the local domain consists of a client and a dwelling, and that the 'atomic unit' of a dwelling is a room. In order to reduce the burden of processing at the local intelligence unit (LIU) and to minimise the number of transmissions (and hence chances of collisions) on the inter-room message bus, each room has its own (intra-room) message bus and corresponding 'smart room hub'. Information at the room level may be contained within the room by using the hub as a smart filter and event processor, passing data onwards onto the inter-room message bus as required. In addition to the smart room hub, it is proposed that multiple body-situated devices should be arranged in a similar fashion via the use of a body-hub. This would permit lower-power transmission in the vicinity of the client and the sharing of common resources as part of a Client Local Area Network (ClientLAN) [164].

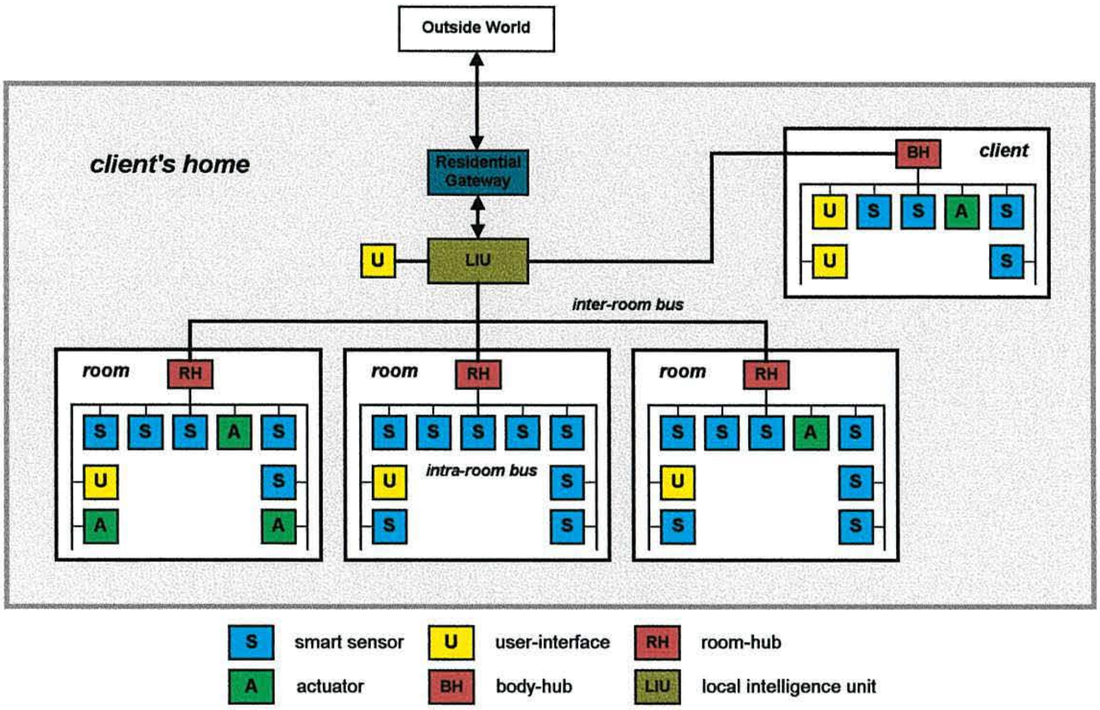

Figure 6.15. CarerNet – Local system architecture.

The LIU needs to co-ordinate CareWare throughout the local system. It (along with other smart devices) must be capable of processing events in 'real-time', but uniquely, it should contain a database of events, which can be interrogated periodically (and/or as scheduled by a carer) in order to perform various assessments. The LIU must also bridge the local network with the outside world (although not necessarily directly) and furthermore be responsible for raising external alarm and data transmissions. It must also handle incoming requests for data or system re-configuration.

6.4 Conclusions

This chapter has considered the characteristics of the services defined in Chapter 5 with a view to developing a suitable architecture for the home. A particular emphasis was placed on lifestyle monitoring, resulting in a strategy based on the principle of client 'stability' to overcome the flaws and limitations of previous attempts at lifestyle monitoring. This requires that sufficient knowledge of client activity is made available to the local system so that the local intelligence may determine the well-being of the client using a scenario-based activity classification approach. An analysis of this and other monitoring classifications, together with a high-level consideration of the rules required to implement the various services, enabled the identification of domain properties with significance in the provision of telecare services. These properties will enable the identification of the appropriate devices required in the home (i.e. sensors and actuators), which will be described in the next chapter.

Various compromises in the form of system design constraints are required in order to accommodate the conflicting requirements of system stakeholders. One of the outcomes of this work was a framework for the allocation of safety-integrity levels for telecare services and devices. A selection of self-imposed design constraints placed upon the local system architecture include:

- Telecare services should be prescribed as part of a *package* of care defined by a comprehensive assessment procedure.
- Local intelligence is required to create a client-privacy boundary around the home so that information is transmitted onwards on a need-to-know basis only.
- Services that raise external alarms using lifestyle monitoring should raise an alert with the client in the first instance in order to empower the client and hopefully minimising the number of false alarms in the process.
- A response to need should originate from a service provider as close as possible to the client with tele-assisted self- and local-care considered in the first instance.
- Distributed intelligence is required throughout the home in order to improve the quality of information input to the system; reduce the number of data transmissions; and improve the tolerance of the system to individual failures.
- Local system intelligence in the form of CareWare components should offer a flexible means of enabling/disabling services and of altering their operating parameters according to the needs of the client.
- The system architecture should be object-based in order to enable a modular design capable of supporting interoperability between devices. This will also ensure that devices offer an implementation-independent interface to other system components.

Chapter 7 will proceed to identify the devices required in the home of the client in order to provide the system with sufficient knowledge of the local domain. The CareWare components required in order to manipulate this domain knowledge into intelligent behaviour will be characterised and discussed within the context of several example services.

Chapter Seven

Local System Architecture

The preceding chapters have laid the foundations from which it is possible to construct a detailed architecture for the implementation of CarerNet services in the home. Knowledge of potential services coupled with their corresponding domain properties allows the identification and characterisation of system-elements within the home. These elements, which must be tailored to the individual needs of the client and their carers consist of: sensors, actuators, user-interfaces, and CareWare modules.

This chapter identifies the devices required within the home of the client and also characterises the necessary system intelligence, in the form of CareWare, required to 'glue' the various domain properties into a form capable of providing telecare services. The methodology followed during this section of the work will be introduced by way of a discussion involving several examples. This will provide context to the results of the analysis which may then be presented in a more concise format.

7.1 Methodology

7.1.1 Device Identification

The methodology followed in determining the design of CarerNet devices and associated CareWare was based upon object-oriented principles for the reasons discussed in Chapter 6 and can be described by the following tasks [165, 166]:

1. Identify system classes.
2. Specify the responsibilities of each class.
3. Identify collaborators for each class.
4. Refine class responsibilities with use-cases.
5. Identify relationships between classes.
6. Refine classes into hierarchies.
7. Factorise responsibilities.
8. Identify re-usable design patterns/frameworks.

Table 6.5 in Chapter 6 detailed a selection of domain properties with significance for telecare. When this information is coupled with the domain analysis of Chapter 5, it enables the identification of the devices required to help realise telecare services in the home. For example, consider Figure 7.1, which illustrates a modular decomposition of the components of a bath (*grey*) and their respective attributes (*yellow*) with significance to the provision of telecare services.

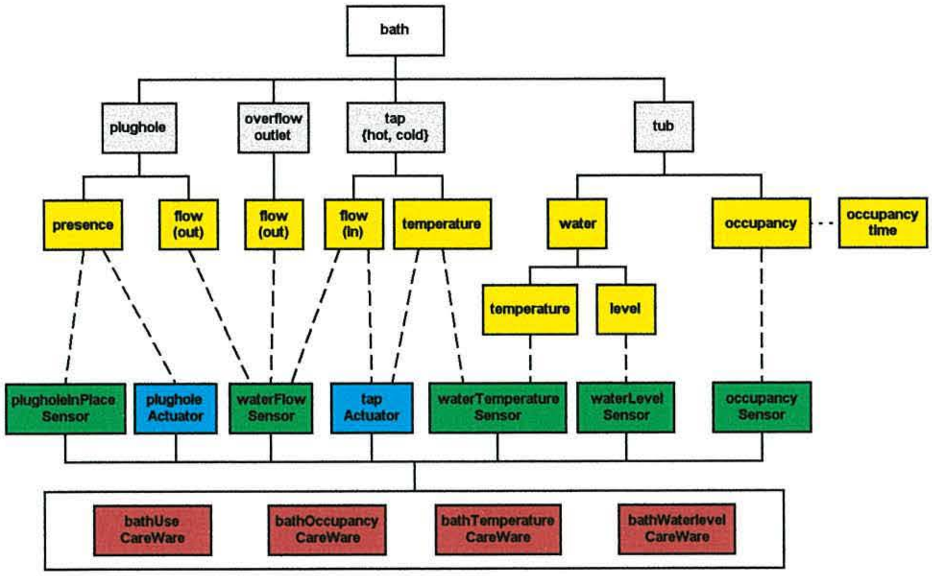

Figure 7.1. Bath-related domain properties, devices and services.

Using this technique, physical devices such as sensors (*green*) and actuators (*cyan*) which provide meaningful access to the local domain for CareWare (*red*) may be identified. In this instance, the CareWare components associated with the client's use of the bath must support:

- Services that determine use of the bath for characterising the activity of the client[1] and which can be logged for assessment purposes;
- Services that ensure that the client does not remain in the bath for too long or that raise an alert if the client appears to be in distress – e.g. appears to be stuck in the bath;
- Services that prevent the client from having a bath in water that is too hot or cold; and
- Services that help to prevent the bath from overflowing and hence the bathroom from flooding.

By a similar process to that indicated in Figure 7.1, it is possible to systematically identify a comprehensive range of devices for the home with potential application towards the provision of telecare services, see Table 7.1.

[1] It should be noted that other non-bath related domain properties may also be useful in the determination of bath use, for instance, the bathroom's relative humidity is likely to increase significantly when a hot bath is run.

Table 7.1. A non-exhaustive list of home-based devices for telecare.

Sensors		
Environmental		
Temperature sensor	Sound-level sensor	Flood alarm
Humidity sensor	Light-level sensor	Carbon monoxide alarm
Air-quality sensor	Rain sensor	Smoke/fire alarm
Frost sensor	Pollen sensor	Wind velocity sensor
Fixtures & Furnishings		
Curtain-status sensor	Drawer-status sensor	Bed-occupancy sensor
Window-status sensor	Cupboard-status[2] sensor	Chair-occupancy sensor
Window tamper alarm	Door-status sensor	Shower occupancy sensor
Fridge-door status sensor	External-door tamper alarm	Toilet-seat occupancy sensor
Bath occupancy sensor	Toilet-flush sensor	Letterbox-use sensor
Bin-use sensor	Water-level sensor	Water-flow sensor
Appliances		
Television-status sensor	Phone-use sensor	Cooker status sensor
Kettle status sensor	Microwave status sensor	Sitting up in bed sensor
Freezer-door status sensor	Microwave misuse alarm	
Client – Lifestyle/Behaviour		
Client presence floor-mat	Doorway-transfer sensor	Sleep disturbance sensor
House caller sensor	Room motion/activity sensor	Doorbell-use sensor
Hip-protector use sensor	Activity monitor	External front-door presence mat
Client - Physiological		
Client-weight sensor	Body temperature sensor	Tremor sensor
Heart-rate sensor	Spirometer	Bed-epilepsy alarm
ECG sensor	Breathing sensor	Blood pressure sensor
Blood glucose sensor	Skin conductivity sensor	Pulse oximeter
Skin colour/pallor sensor	Gait sensor	Impact sensor
Orientation sensor	Incontinence sensor	Pedometer
User-Interface		
Speaker-pillow	Fixed alarm trigger	Client-system interface
Mobile pendant alarm	Intercom (video)	Universal Remote Control/PDA
Intercom (audio)	Watch-based communicator	
Actuators/Effectors		
Environmental		
Door-status actuator	Room temperature controller	Room light-level controller
Window-status actuator	Room humidity controller	Room sound-level controller
Curtain-status actuator	Water-tap valve	Water-temperature controller
Light/Lamp controller	External-door lock controller	Audible alarm
Fan-controller	Room perfume dispenser	Air-purifier
Fire extinguisher (sprinklers)	External light controller	Stair-edge highlighter
Appliance		
Cooker status controller	Gas-tap valve	Microwave status controller
Heater status controller	TV/Hi-Fi Volume controller	
Medical/Client-located		
Medication dispenser	Cardiac pacemaker	Insulin delivery device
Vibration attention grabber	Intra venous pump	Home dialysis machine

7.1.2 CareWare Identification

Having established the potential range of access to local domain properties, the rule-based intelligence required to realise telecare services in the form of CareWare components can be defined. The concept of CareWare was introduced briefly towards the end of Chapter 6. 'CareWare' has been coined as a generic term to describe the modular rule-elements and algorithms used for enabling 'intelligent' system behaviour. CareWare components must offer flexibility, allowing telecare services to be tailored to the individual needs of the client and their carers. Thus, individual CareWare components must be capable of being enabled or disabled as required, and their associated operating parameters should be modified to suit the needs of their particular domain. Table 7.2 lists a selection of the CareWare components identified, some of which will be considered further later in the chapter.

Table 7.2. A selection of 'CareWare' system components.

CareWare Package/Component	Responsibilities
Preventative	
bedroomFallPrevention	Ensures that the bedroom light fades up automatically when the client gets out of (or sits up in) bed when the room is dark. Automatically switches off again once they have returned to bed (or if the room becomes sufficiently light).
bathOverflowPrevention	Ensures that the water in the bath does not overflow.
autoGasAutoShutOff	Automatically disconnects the mains gas supply to an appliance if there is an abnormally high level of gas monitored in its vicinity.
Supportive	
medicationReminder	Reminds the client to take their medication at the appropriate times. Can be set to be a pre-emptive service or only to activate a certain time after the client has forgotten to take it by themselves.
measurementReminder	Reminds the client to perform physiological measurements such as blood glucose, blood pressure, peak expiratory flow, weight, etc. Can be integrated with compliance monitoring services, see below.
externalDoorAlert	Used to remind a client if they have left an external door open and unattended.
safetyReminder	Warns client if they have left an appliance (e.g. cooker, iron, electric blanket, electric fire, fridge-door open, etc.), tap, or a door/window in an unsafe or unsecured state if they are about to go to bed or leave the home.
misplacedItemLocator	Helps client to locate a tagged item within the home (e.g. house keys, wallet).
temporalReorientation	Reminds a client of the time of day, especially if they are about to perform an action that may be considered to be inappropriate. For example: if they are about to leave the house after 10PM or if they get out of bed at 4AM or if they are about to use the phone very early in the morning.
Reactive	
primaryFallDetection	A worn fall detector based upon client impacts, orientation and activity levels.
secondaryFallDetection	A virtual detector that attempts to identify a possible fall situation by interpreting client activity/inactivity patterns.
medicationComplianceMonitor	Monitors and logs client's compliance with prescription. If compliance is persistently poor, it can raise an external alarm.
measurementComplianceMonitor	Monitors and logs client's compliance with a monitoring regime. If compliance is persistently poor, it can raise an external alarm.
externalDoorAlarm	Raises an alarm if the client has left an external door open and unattended for an excessive period (as defined by the care team). An alert is usually raised in the first instance (see above). If the system is in security mode, it will raise an alarm if the external door is opened and the client is not in the hallway (if the house is occupied) and/or if the burglar alarm code is not entered within a certain time limit.
intruderDetector	Monitors the sequence of room occupancy and raises an alarm if there is an irregular pattern, based on a knowledge of the house layout and on the status of entry/exit points and windows Will also raise an alarm if it believed that there has been tampering with windows or external doors, e.g. if a window is opened (manually) in a room that is unoccupied..
floodAlarm	Will raise an alarm if there is a flood on the floor.
clientElopementMonitor	Will raise an alert/alarm if the client either leaves the home (at any time or during a pre-determined period) or if the client leaves the home but does not return within a pre-determined period. (used for people with dementia who are prone to wandering out of the home and getting lost).
clientDistressAlert	Used in conjunction with roomOccupancyMonitor to determine if the client is in a 'stable' or 'unstable' state.
Hybrid	
bedOccupancyMonitor/ (chairOccupancyMonitor)	Alerts/alarm settings can be generated if the client spends too long in bed (i.e. may be unwell) or if they do not go to bed within a certain time (could be in distress, e.g. a fall). Other services on the same theme might include raising an

[2] *includes wardrobes & kitchen units, etc.*

CareWare Package/Component	Responsibilities
	alert if the client were to get out of bed during the night and not return within a particular time. Alternatively, an alert may be required the instant a client gets up in the night to warn a live-in carer. A similar set of services is also available for chair occupancy monitoring.
bathOccupancyMonitor/ (showerOccupancyMonitor)	Raises a alert if the client occupies the bath for an excessive amount of time and, if the client does not respond with an "all-clear", will raise an alarm. The alert process may then re-trigger up to a maximum number of times. A similar set of services is also available for shower occupancy monitoring.
incontinenceAlarm	Raises an alarm if the client wets their incontinence pad (client or bed/chair based).
bedEpilepsyMonitor	Raises an alarm if the client suffers an epileptic seizure during the night (whilst in bed).
bathOverflowMonitoring	Warns the client if the bath water level is too high by raising an alert. It will raise an alarm if the client does not respond (i.e. by turning off taps).
Domain/System	
deviceTamperAlert	Raises an alert if it is believed that a device has been tampered with, e.g. if the client moves their flood alarm unit to a non-ideal location.
deviceUseMonitor	Monitors whether client is using a device, e.g. whether they are 'wearing' their body-worn primary fall detector, or whether they are ever using the Zimmer-frame supplied as part of their care package. Can also be extended to assist the client in ensuring that they have installed a device in the correct fashion.
roomOccupancyMonitor	Monitors the state of client activity in the room (movement and actions such as opening doors, using appliances, interaction with furniture, etc.) in order to determine room occupancy and hence client location. Can optionally raise an alert/alarm if the room is occupied (or unoccupied) for more than a pre-determined period.
washbasinUseMonitor	Monitors flow of water into and presence of client in front of washbasin in order to determine if it is in use or not.

7.1.3 Class Identification & Analysis

This entire process enables candidate system classes to be identified in the 'solution-space' of Figure 1.3 (refer back to Chapter 1). Class-Responsibility-Collaboration (CRC) cards [167], like the one featured in Figure 7.2, were used as a method of refining the responsibility and composition of system classes, helping to establish the scope for collaboration with other system entities. Use-cases, in the form of real-life and 'contrived' client-scenarios, were used to further refine the responsibilities and interactions required between the identified *classes*.

bedroomFallPreventionCareWare	
Responsibility	**Collaboration**
• Ensure that the bedroom light fades up if the client gets out of bed and the room is dark. • Ensure that the bedroom light turns off after a short delay if the client returns to bed. • Raise a system error if the room does not become brighter after the light has been instructed to turn on.	• bedOccupancyMonitor • bedroomLightLevelMonitor • bedroomLightLevelController • systemErrorHandler

Figure 7.2. CRC 'card' for *bedroomFallPreventionCareWare* class.

It should be noted that this entire process was highly iterative, with modifications having to be made as service requirements or ideas for their implementation changed. For example, consider the real-life client-scenario presented in Box 7.1.

Box 7.1. A real-life scenario.

Mr. X, an 83 year old bachelor, lives alone in a small terraced house. The house has no central heating, a coal fire and an outside toilet. He has a small kitchen with a hard tiled floor, which leads to the back garden where the toilet is situated. One evening Mr. X went outside to get some coal in to make up the fire for the evening. On his way back into the kitchen he fell and was unable to get up. Mr. X was stuck on the floor for over 2 hours, during which time he had urinated. The fire was out and it was a cold evening. During the time that Mr. X was on the floor, the paper boy had delivered the local paper. Mr. X. was eventually found by a relative who happened to be a key-holder and who had decided to pay a visit to Mr. X after being told that someone had seen him in some distress earlier in the day.

Mr. X hardly ever spends more than 15 minutes at a time in the kitchen. Certainly, his continuous presence in the kitchen for more than half an hour would be atypical and, coupled with a lack of activity (i.e. physical movement as well as use of drawers, cupboards, fridge, etc.)[3], would suggest potential client-distress. Further to this information, the fact that Mr. X had failed to collect the paper upon its delivery (he always looked forward to reading the local paper) implied that there may be some merit in using information provided by a letterbox use monitor and external doorway presence sensor to trigger an alert, especially if the client was known to be in an 'unstable state'. The alert might take the form of a client-user interface requesting the client to "press the green 'OK' button" if they were alright. If the room temperature of the kitchen or lounge fell below the threshold set for Mr. X, then this would also raise an alert. In all likelihood, this would be the slowest indicator of client-distress in this scenario.

After candidate system classes had been established, it was possible to assign to them their necessary state (or attributes/properties) and behaviour (methods, services, or functionality). In addition, the messages and events used to communicate with other components of the system could also be assigned. This process was formalised using a graphical notation based upon that of the Unified Modelling Language (UML) [151]. Consider Figure 7.3, the *bedOccupancySensor* class by way of an example[4].

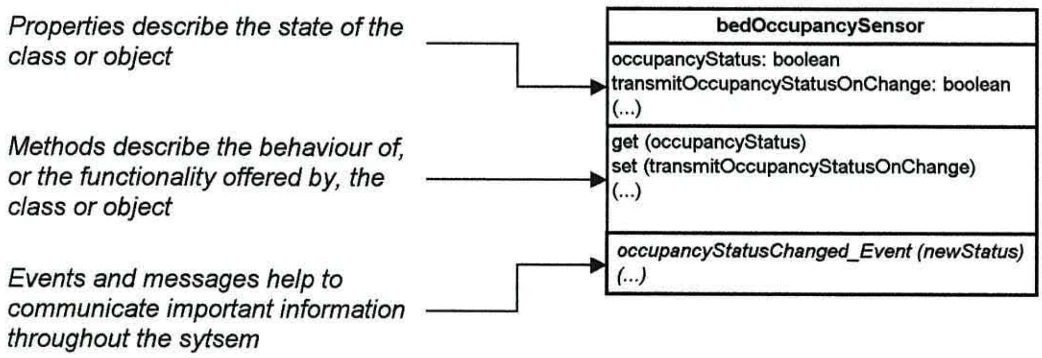

Figure 7.3. *bedOccupancySensor* class diagram.

[3] *A sequence of events described in Chapter 6 as an 'unstable' state.*
[4] *(...) indicates an abridged list of properties, services or messages.*

Note how the class diagram essentially defines a state and a set of system services which any CarerNet compatible *bedOccupancySensor* must realise, irrespective of the method of implementation[5]. The methods and messages supported by a class may also be considered in terms of a guaranteed *interface* that the device must present to the system.

The bed occupancy information afforded by the *bedOccupancySensor* may be used in the following telecare services:

- Monitoring client activity status – i.e. determining a client's bed occupancy status to establish whether they are in a 'stable' or 'unstable' state in the bedroom;
- Raising an alert if the client remains in bed for an abnormally long time after they would normally get up;
- Raising an alert if the client gets up during the night and fails to return to bed within a certain time period;
- Raising an alert immediately if the client gets up out of bed during the night;
- Monitoring the number of times the client gets up in the night;
- Monitoring the length of time for which the client stays out of bed during the night;

Other bed-related services that are not directly concerned with occupancy per se, but which might conceivably be provided using the same sensor-set include:

- Establishing levels of sleep disturbance;
- Detection of epileptic seizures;
- Monitoring the client's weight;
- Monitoring client's breathing and heart rate.

In order to provide these services, it is necessary to enable the relevant CareWare components. These may reside on individual devices or operate at a conceptually higher level, accepting data from a variety of often distributed sources in order to derive knowledge concerning some aspect of the local domain. Finally, some CareWare components will operate solely at the Local Intelligence Unit.

Figure 7.4 illustrates an example of sensor-resident CareWare in the form of a smart bed occupancy monitor, rendering the device 'smart' enough to provide the desired services in isolation[6].

---

[5] *A class is a template for an object. An object is any real-life entity and can be described in terms of its state and function. Thus the bedOccupancySensor* ***class*** *describes the state of, and functions provided by, a generic bed monitor. A bedOccupancySensor* ***object*** *refers to the status of a particular instance of a bed monitor.*

[6] *If desired, some CareWare modules may alternatively be ported to other system nodes. For instance, instead of generating bed occupancy alerts and alarms locally, simple bed occupancy information could be transmitted onwards where it could be processed as required.*

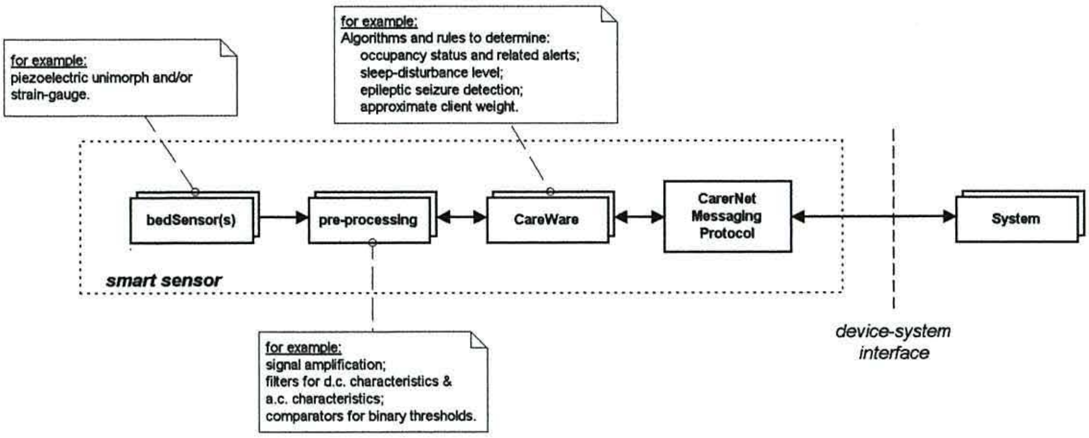

Figure 7.4. Example smart bed occupancy monitor.

Figure 7.5 illustrates the example of a *bedOccupancyMonitor* which consists of a *bedOccupancySensor* with on-board CareWare. The services offered by the *bedOccupancyMonitor* are provided by a collection of CareWare components capable of raising events associated with a client's bed occupancy status (obtained from the *bedOccupancySensor*). In this example, two other standard system classes are used: an *absoluteTimer* and a *realTimeClock*. These are classes in their own right as they represent common functionality that is repeated throughout the system.

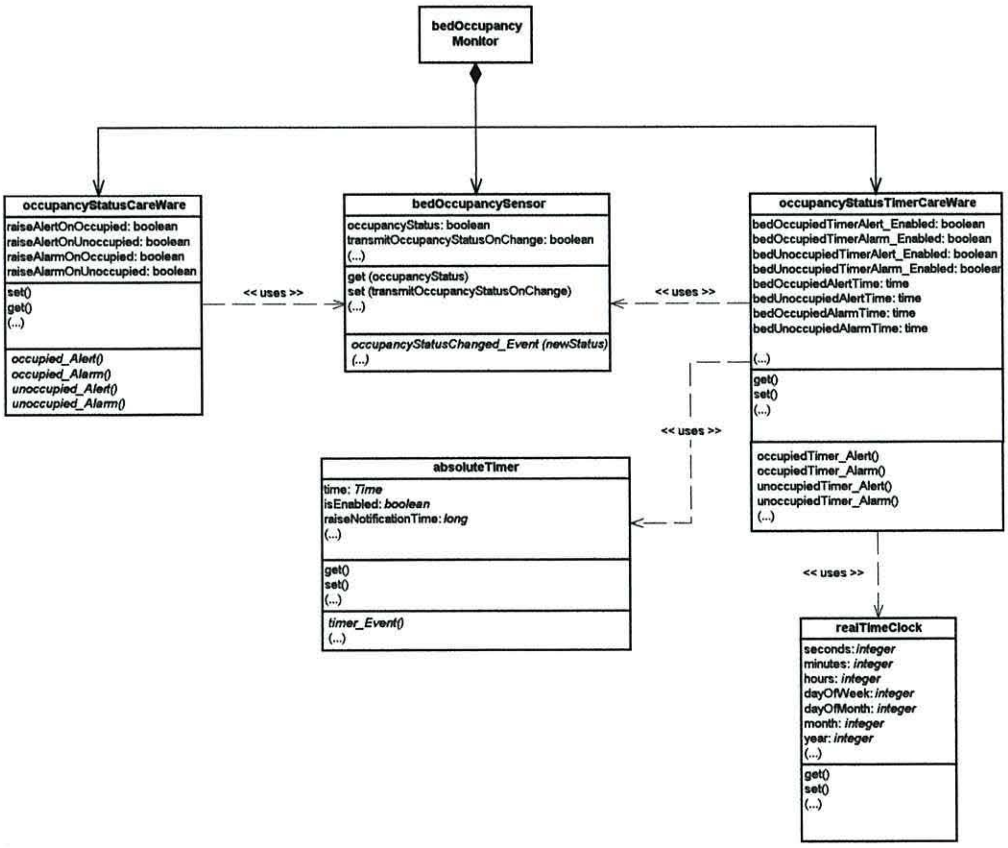

Figure 7.5. The *bedOccupancyMonitor* as an aggregation of other system classes.

The CareWare components that operate across multiple devices rely on message passing and data flow between system elements. It is more intuitive to model their behaviour using techniques based on the more dynamic UML interaction and collaboration diagrams. For example, consider Figure 7.6, which illustrates the operation of the *intruderDetectorCareWare*, responsible for monitoring the patterns of room occupancy in the home (and other related parameters) to monitor for the presence of an intruder.

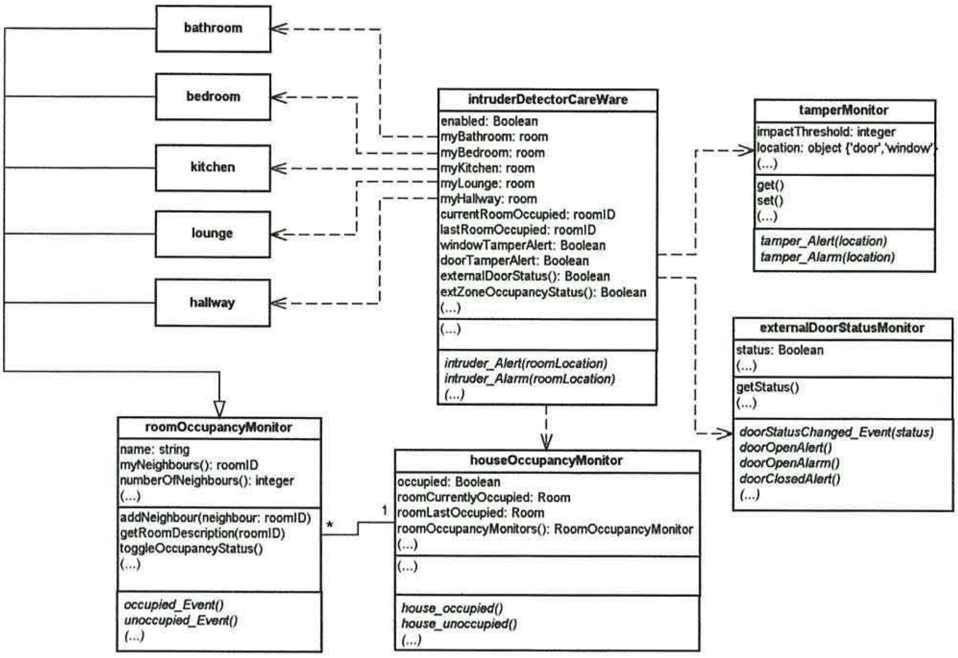

Figure 7.6. ***intruderDetectorCareWare class diagram.***

The *intruderDetectorCareWare* works on the principle that the client lives alone and that therefore the norm is that only one room may be occupied at any one time. Figure 7.7 is a diagram illustrating a particular sequence of room occupancy within the client's home. It shows the client moving about, getting ready for bed, and the detection of an intruder in the lounge[7]. The diagrams illustrate how the *intruderDetectorCareWare* relies on knowledge of the layout of the home. This is obtained by linking it in with each room's *roomOccupancyMonitor* which contains a list of all of the room's neighbours. The *intruderDetectorCareWare* receives notification of room occupancy status from each of the room occupancy monitors. By determining whether there is a valid path between consecutively occupied rooms and by knowing that no external doors have been opened, then it is possible to raise an *intruderAlert or intruderAlarm* for the room in question. The *intruderDetectorCareWare* also monitors windows and external doors for signs of tampering and also monitors for movement outside the home.

Finally, some CareWare components will operate upon data and events stored at the LIU. Services might include periodically applying algorithms and rules for determining various assessment scores and also for re-calculating CareWare operating parameters. For instance, the length of time for which the client is expected to remain in bed before raising an alert can be updated by calculating the mean bed occupancy time from historical data and feeding a suitable value back into the bed occupancy monitor, see Figure 7.8.

[7] *See Figure 8.2 in Chapter 8 for a room-layout of the home.*

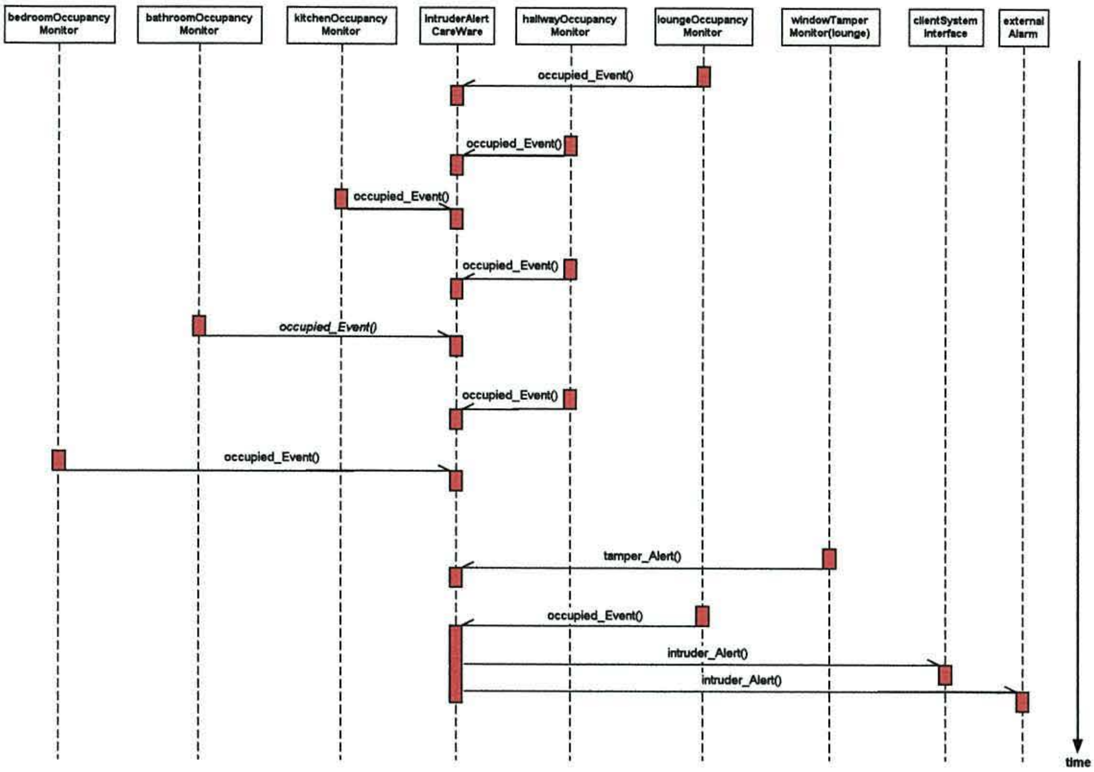

Figure 7.7. ***intruderDetectorCareWare*** **sequence diagram.**

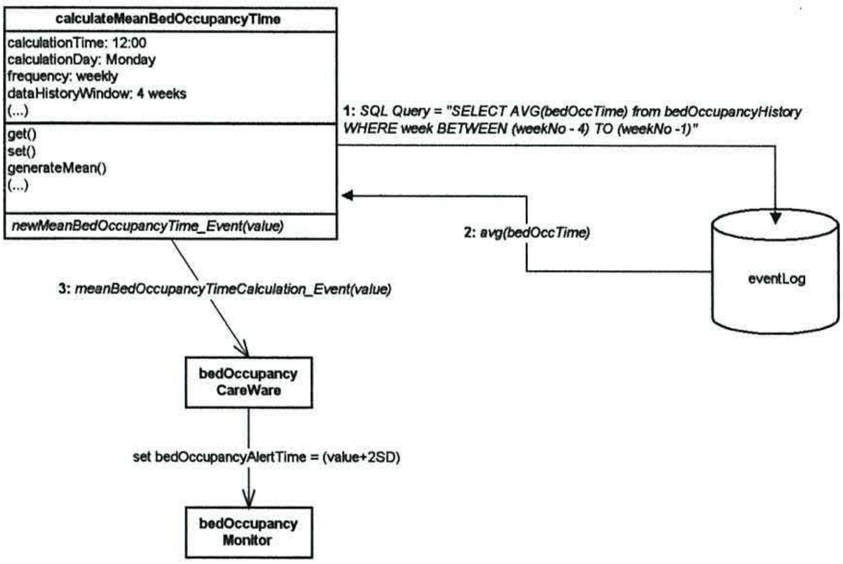

Figure 7.8. Example of ***calculateMeanBedOccupancyTime*** **CareWare.**

7.1.4 Conclusions

A similar class identification and characterisation process has been performed for a range of candidate devices and associated CareWare. As part of the object-oriented analysis process, these classes were rationalised in order to identify classes with similar responsibilities or behaviour. This helped to establish a structure capable of ensuring modularisation, promoting reuse, and hence obtaining a system with low coupling between system components. Not all system elements can be rationalised in this manner, however, many will possess some of the common functionality but will extend it in some fashion. By allowing each individual CareWare component to be enabled or disabled and its operating parameters to be altered in-situ, it is possible to modify the level of service provided by the system in accordance with the current needs of the client.

In order to present information efficiently, the results of this analysis will be used in Section 7.2 to present the characteristics of a selection of key devices for the provision of telecare services. The functionality of many of these devices at a system-level is best considered in terms of the device-level CareWare required. A further discussion of the system-wide CareWare components will be the subject of Section 7.3.2.

7.2 Device Classification

An analysis of the identified system classes was performed in order to help identify generalisation, specialisation, and aggregation hierarchies with the intention of improving system modularisation. This work involved defining the necessary functionality required for a range of devices without necessarily relying on a particular means of implementation. This resulted in the definition of the system-device interface required to support telecare services. Section 7.2 will consider the base classes which describes the sensor inputs. Section 7.3 will discuss the additional device-level CareWare components required to convert these into useful 'smart' monitors.

7.2.1 System Management

All CarerNet devices will require a common set of properties and functionality in order to ensure that they are capable of operating across a network with other system elements (e.g. a network address). As well as a basic description of the device type and its capabilities, there are other features such as Built-In Self Test and power management services that might also be required. Furthermore, knowledge of the device location is also required as much information will be location specific and may be required to determine room occupancy. The local network may use the unique identification of the device (a combination of its *vendorID*, *productID* and *deviceID* – effectively a serial number) to assign a local network address when the device first registers with the local system. Passwords may be required for some devices to ensure that only authorised users are permitted to alter operating parameters or enable or disable on-board CareWare components. Many of the key requirements of a generic CarerNet device are represented in the class diagram of Figure 7.9.

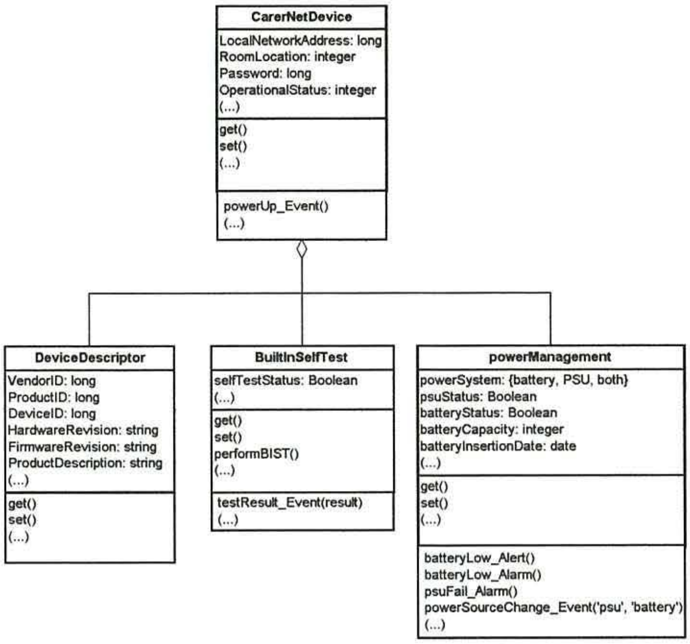

Figure 7.9. An indication of a device' generic characteristics.

7.2.2 System Inputs

The nature of CarerNet system inputs may be summarised by the diagram of Figure 7.10. Devices may either be considered as event-based or analogue in nature. Event-based devices generate event messages asynchronously that directly represent the status of, or an alert or alarm associated with, a domain entity. They are used to monitor domain properties that possess a finite number of possible states, usually two (i.e. Boolean). Analogue devices on the other hand are used to monitor physical properties. They can also generate event-based messages, but these must be derived from a physical measurement of the local domain, which is sampled at an appropriate rate. Analogue devices usually (but not always) provide data to the system, either as a series of discrete samples or, where the time-varying nature of the signal is important, as a 'real-time' continuous waveform.

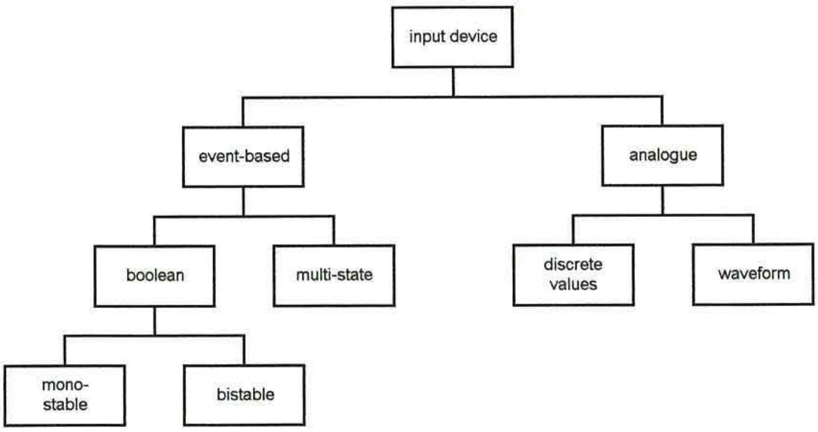

Figure 7.10. The range of system inputs for CarerNet.

Boolean and Multi-state Event Inputs

Many of the domain properties of significance to telecare are discrete, event-based, properties. They may possess at any one time only one of a number of discrete states. For example, a *toiletUseStatus* property will at any moment in time possess one of only *three* possible states: 'not in use'; 'in use [sitting]'; and 'in use [standing]'. There may also exist two 'after-use' states: 'flushed' and 'unflushed'. Figure 7.11 illustrates the state and behaviour of a generic *multiStateSensor* class.

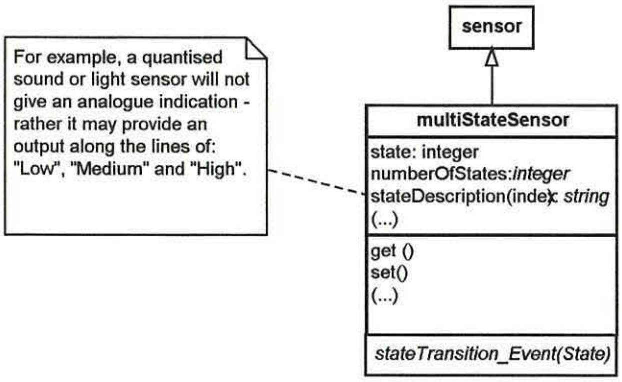

Figure 7.11. The *multistateSensor* class.

The majority of discrete-state properties are Boolean, that is, at any one time they can possess one of two possible states. They may be considered as a special case of multi-state sensor with the number of states equal to two. Boolean properties can be categorised further as being either mono-stable (or transient) or bi-stable. The former describes properties possessing a single, stable, 'default' state, with occasional momentary transitions into an unstable state, e.g. doorbell activation and letterbox use[8]. Useful information is associated only with the brief *transition* from one state to the other. The latter describes properties possessing two equally stable states, e.g. bed occupancy status (occupied or unoccupied) and door status (open or closed). Both states are generally of significance to the overall status of the domain, *in addition* to the transition, which is also of importance.

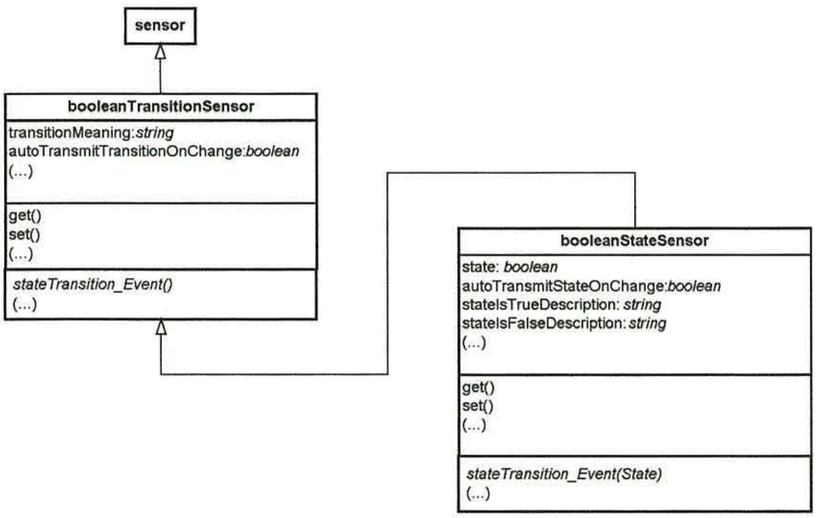

Figure 7.12. *booleanTransitionSensor* and *booleanStateSensor* class hierarchy.

[8] *although, in theory, both examples may possess a 'stuck' state.*

Figure 7.12 illustrates the *booleanTransitionSensor* and *booleanStateSensor* CarerNet classes, and illustrates that a *booleanStateSensor* is a type of *booleanTransitionSensor*, which is itself a type of *sensor*. The diagram illustrates the progression in 'sophistication' provided by a 'bistable' device, most notably in the absolute knowledge concerning the current status of the property. Figure 7.13 illustrates the CarerNet devices identified as *inheriting* the characteristics and behaviour of Boolean transition sensors. Figure 7.14 lists those devices identified as being Boolean state sensors, where knowledge of the state is attainable and meaningful.

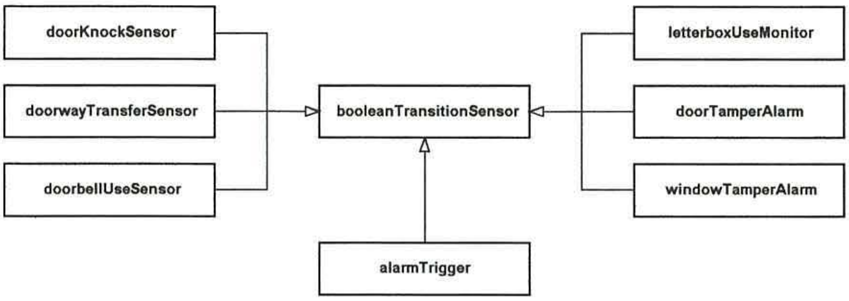

Figure 7.13. Examples of the *booleanTransitionSensor* class.

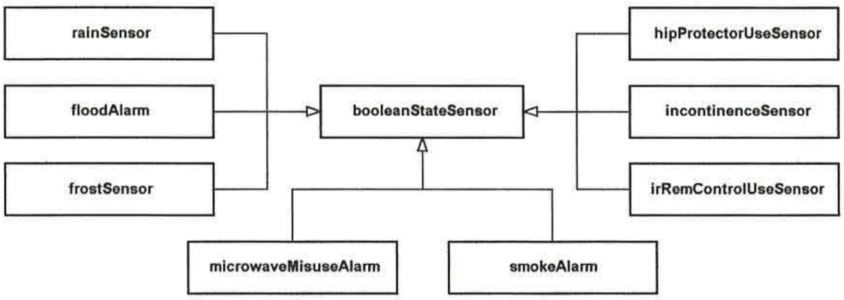

Figure 7.14. Examples of the *booleanStateSensor* class.

Analogue Sensors

Many of the physical properties of the local domain are not event-based but are, rather, analogue (or continuous) in nature. Examples include: temperature, humidity, light-level, water-level, respiratory sounds, electrocardiogram (E.C.G.), and expiratory flow. Analogue signals can be separated into those containing a significant time-varying component, i.e. where the waveform itself contains useful information (e.g. 'real-time' signals such as an E.C.G. or respiratory waveforms); and those that possess a very long time-constant, where discrete snapshots or samples of the physical property is sufficient (e.g. temperature = 22°C; blood glucose level = 7.6 mmol/l; relative humidity = 56%; or systolic blood pressure = 16 kPa or 120 mmHg). Analogue properties will be sampled at various rates in order to establish a profile of their value at the appropriate level of detail. Figure 7.15 illustrates some of the characteristics of the *analogueSensor* class.

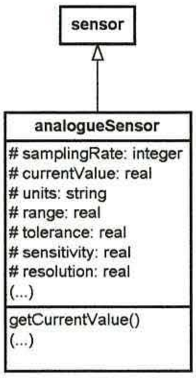

Figure 7.15. The *analogueSensor* class.

7.2.3 System Outputs

Whilst the main focus of this work was concerned with the gathering and processing of suitable data in order to realise telecare services, it was also necessary to consider how the system was to be able to respond in terms of effecting its local domain. Relatively less effort was afforded to the definition of system actuators as they represent standard components in various smart home initiatives. The nature of CarerNet outputs are summarised in Figure 7.16.

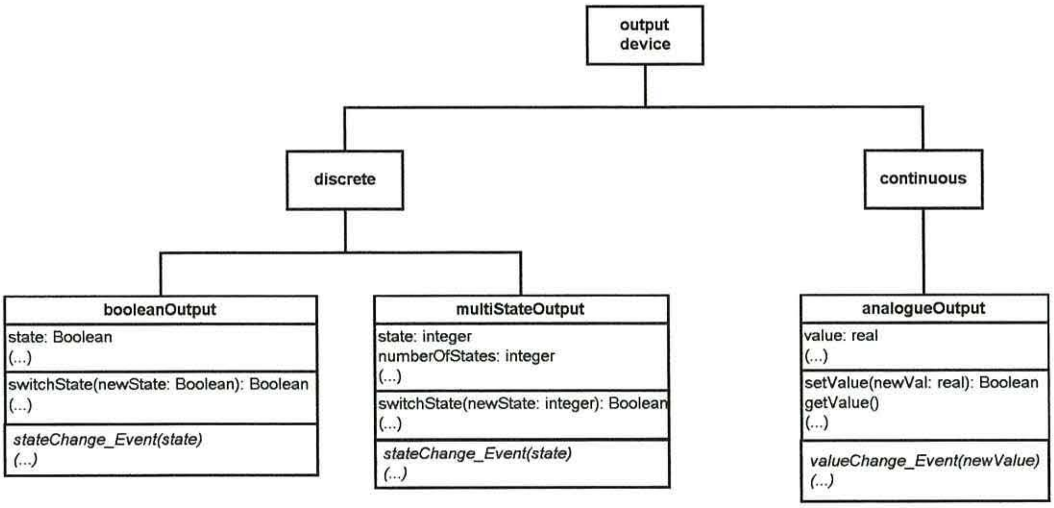

Figure 7.16. The range of system outputs for CarerNet.

Boolean & Multi-state Outputs

These represent outputs that can either be turned 'on' or 'off' in the case of Boolean outputs, or, can be set to one of a finite number of discrete states in the case of multi-state. Figure 7.17 and Figure 7.18 illustrate examples of the *booleanOutputs* class and the *multistateOutputs* class respectively.

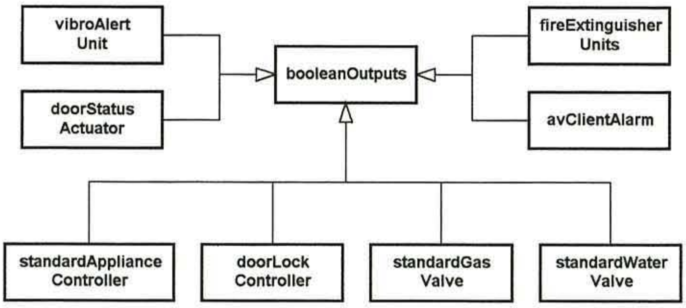

Figure 7.17. Examples of the *booleanOutputs* class.

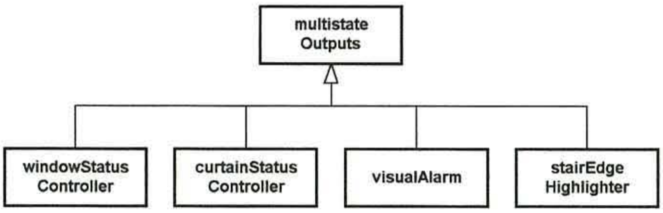

Figure 7.18. Examples of the *multistateOutputs* class.

Analogue Controllers

Analogue controllers are a class of analogue output usually responsible for controlling the properties of physical domain values. Examples of which are shown in Figure 7.19.

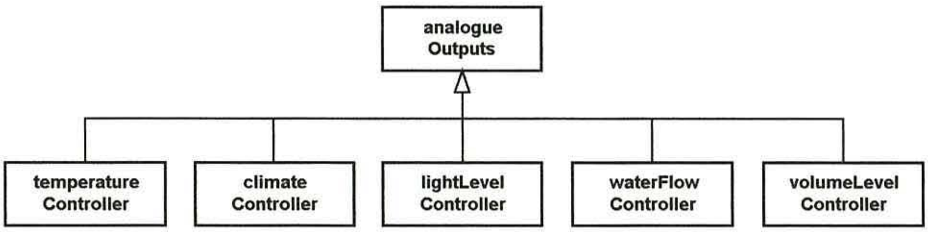

Figure 7.19. Examples of the *analogueOutputs* class.

Alarm Output

In addition to the physical devices discussed thus far, CarerNet may also output event-based information in the form of external alerts and alarms. Figure 7.20 illustrates the characteristics of the *carerNetAlarm* class. Note how the alarm can be set to be a 'one-shot' alarm or re-triggerable. Furthermore, the alarm (or alert) has a manual cancel feature, which can be enabled or disabled as required (according to the nature of the alarm). This feature may be constrained by limiting the maximum number of cancellations that can be performed beyond which the alarm will not be able to be cancelled manually.

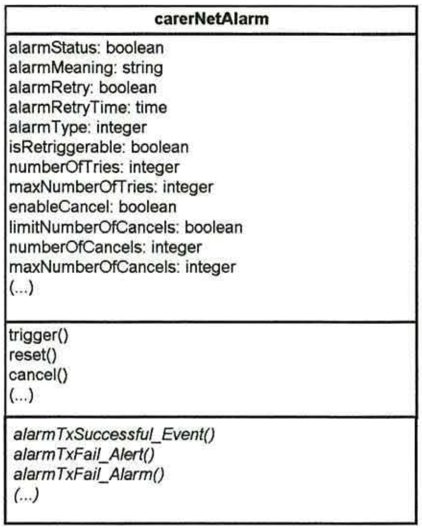

Figure 7.20. Example of the alarm class (also similar to an alert).

Each CarerNet alarm will be assigned a preferred recipient and a list of backup recipients if the primary source is unavailable or rejects the call (an informal carer may be unable or unwilling to respond to particular alerts/alarms).

7.2.4 Client-System Interface

The final classification to be considered is the *userInterface* class, which will be mentioned briefly for completeness. User interface requirements may range from a simple press-button/light-emitting diode (LED)/buzzer approach through to a more sophisticated device such as a handheld personal digital assistant (PDA) or smart display unit (e.g. mobile touch-screen 'tablet-PC'/Smart display device such as Microsoft's Mira technology [168]) which may also include speech recognition and/or generation. One thing in common for each user interface apart from the need to convey information and/or accept commands is that there will be a need to gain the attention of the client to a particular piece of information, in particular alerts that require a response from the client.

7.3 CareWare Classification

The rules and algorithms that together comprise the CareWare components distributed throughout the system are responsible for enabling the 'intelligent' operation of CarerNet. An attempt has been made at grouping CareWare components into categories according to their place within the system hierarchy; the data-types upon which they operate; and their overall function or responsibilities. Whilst not all will fall neatly into these categories, the vast majority of CareWare may be fitted into the types identified in Figure 7.21. Other, more complex or unusual components can, more often than not, be considered as a hybrid of these categories.

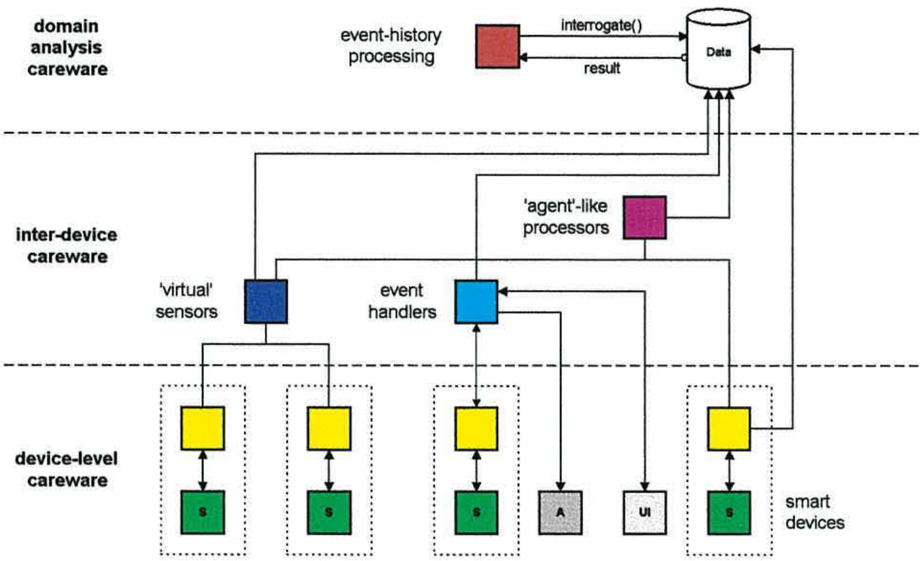

Figure 7.21. CareWare types.

Figure 7.21 illustrates three *major* classifications of CareWare components:

1. **Device-level CareWare** - *CareWare components that operate solely upon localised data sources (i.e. CareWare that resides upon the actual sensor).*
2. **Inter-device CareWare** - *CareWare components that operate across many devices, accepting data from various distributed and ubiquitous data generators and generating knowledge or actions based on these data.*
3. **Domain analysis CareWare** – *CareWare components that are responsible for analysing a database of domain events and data in order to perform client assessments and/or to generate appropriate operating thresholds for the lower-level CareWare.*

It is not inconceivable for inter-device CareWare to reside at the device level, but for the purposes of the demonstrator system it will mostly operate on intermediate nodes. Each of these CareWare categories will now be examined in greater detail.

7.3.1 Device Level CareWare Classification

This section will discuss issues concerning device-level CareWare components (refer again to Figure 7.21). These components represent mainly low-level algorithms for pre-processing purposes and rules that operate on localised data in order to generate information and events in a form most suitable for the system services, Figure 7.22.

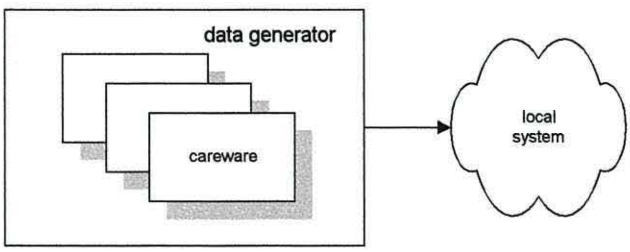

Figure 7.22. Device-level or 'smart sensor' CareWare.

The scope for device-based CareWare involves mainly two categories of monitoring, namely: discrete-state and analogue monitoring. This work has established that by far the most common form of discrete-state monitoring involves Boolean properties. Thus, the discussion of state-based monitoring will revolve around Boolean properties. Many of the concepts presented during the discussion of Boolean state monitoring may be applied to multi-state monitoring with only slight modifications.

Boolean State Monitoring

In terms of deriving knowledge of the local domain from Boolean sensing devices, there are two mechanisms of note: *event reporting* and *event monitoring*, Figure 7.23. Event reporting is used by an event-generator to inform interested event-consumers (i.e. other devices or people) that a particular event to which they have subscribed has occurred.

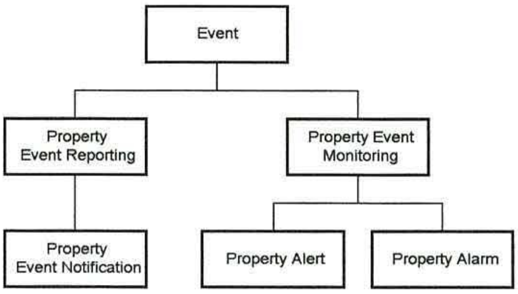

Figure 7.23. Mechanisms of event generation.

In general, events may be *reported* under the following conditions:

1. *Event activation notification* – for *mono-stable (or transient)* domain properties; e.g. *doorbellActivation_Event()*.
2. *State transition notification* – for *(bi-) stable* domain properties, where there is no knowledge of the current state (to be avoided as this can introduce an element of uncertainty if an event-transition is missed); e.g. *chairOccupancyStatusChanged_Event()*.
3. *State condition notification* – for *(bi-) stable* domain properties where there is knowledge of the current state; e.g. *chairOccupancyChanged_Event(Status)* (this provides an unambiguous alternative to state transition notification).

In addition to the passive nature of event-reporting, it is also possible to actively *monitor* particular events or event conditions. In doing so, it is necessary to define certain events or event conditions as being either *alerts* or *alarms*. Alert conditions are used to indicate that a state-condition has occurred which may require further attention (a typical system response is to check with the client). Alarms indicate that a state-condition has occurred which requires immediate external assistance. For instance, it is desirable in many situations to raise an alert and/or an alarm if:

1. A domain property enters an 'unsafe' or 'forbidden' state or leaves a 'safe' state – for example, if a client with a high-risk of falling were to remove their body-worn fall alarm during the day, then this might warrant an *alert* condition.

2. A domain property remains in a single state in excess of a specified *alert* or *alarm* time - for example, an alert may be required if the client occupies the bath for an abnormal amount of time. Alternatively, an alert may also be required if the client *does not* use the toilet for a period greater than a specified *alert* time. Often, an alert may be re-triggered periodically up to the point at which the alarm threshold is met. At this point, an alarm is automatically generated, irrespective of the number of times the client has cleared the alert condition.
3. A domain property enters an 'unsafe' state, leaves a 'safe' state, or remains in a single state for an excessive amount of time *within a specific time period* - for example, an alert may be required to warn a local informal carer if a client with dementia with a habit of wandering out of the home during the night were to open the front door in the middle of the night (i.e. a *frontDoorStatusChanged_Event(Open)* is interpreted as a *frontDoorStatusChanged_Alert (Open)* during the hours of 22:30 to 07:00).

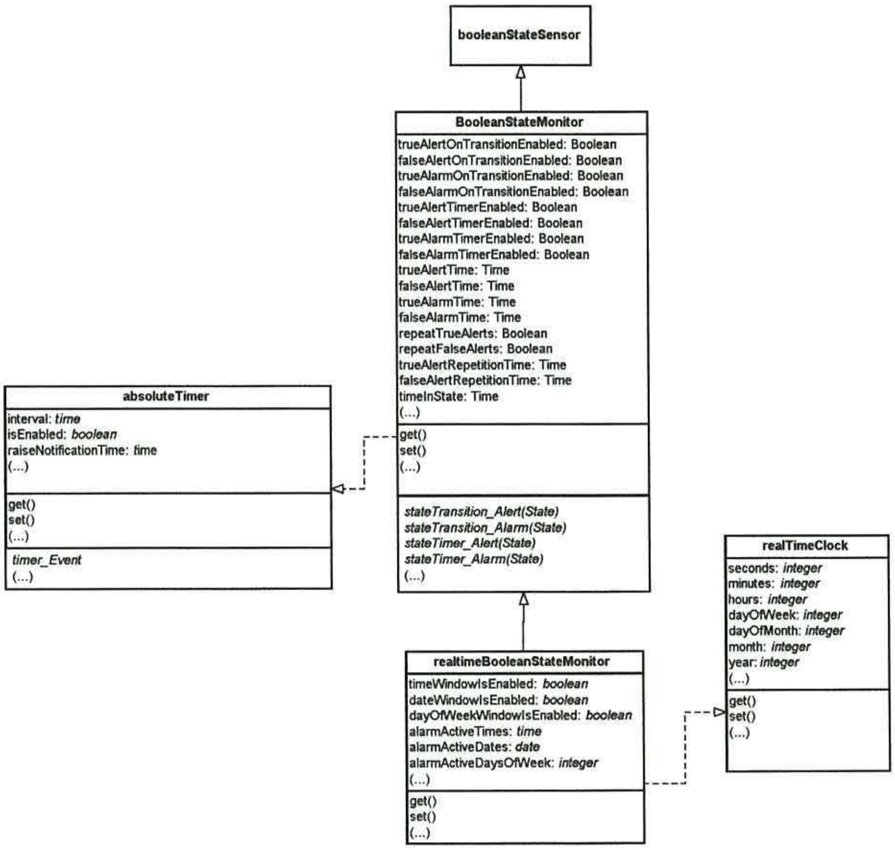

Figure 7.24. *booleanStateMonitor* and *realtimeBooleanStateMonitor* class hierarchy (with *timer* and *realTimeClock* dependencies).

Figure 7.24 illustrates the additional characteristics and behaviours associated with the *booleanStateMonitor* and *realtimeBooleanStateMonitor* CarerNet device classes in addition to those inherited from the *booleanStateSensor* class. The diagram also illustrates their use of a generic *timer* and *realTimeClock* class in order to implement the various timing services. By separating these components into their own classes, it is possible to implement the timing functionality at the most convenient point in the system. For example, it may be performed on the smart sensor itself, or, alternatively, could be performed centrally at the LIU, if desired.

The *realtimeBooleanStateMonitor* class introduces extra functionality by enabling alerts and alarms obtained using the absolute timer class to be filtered according to the time of day, the day of the week, and (if required) the date. Furthermore, it is also capable of generating its own alerts and alarms if a particular state is True or False at a particular time.

In order to meet the requirement that services be tailored to the needs of individual clients (and carers), a number of CareWare operating parameters are made available to the system so that device behaviour may be modified accordingly. For instance, the period of time over which a *bedUnoccupied_Alarm* may be raised can be set to coincide with the period for which the client is expected to be in bed. What's more, it is also possible to enable or disable individual CareWare services. For example, a *fridgeUsageMonitor* can be set-up, in the first instance, to only *monitor* the client's use of the fridge. Following a suitable assessment period, it may be established that the client is prone to accidentally leaving the fridge door open. Subsequently, the same device can be tailored to raise an alert if the door is left open, therefore acting as a memory aid for clients. The *realtimeBooleanStateMonitor* is also capable of allowing CareWare operating parameters to be modified according to the time of day, etc. Thus, it may be noted that each possible event, alert or alarm notification condition may be enabled or disabled and its corresponding threshold value may be programmed as required. Figure 7.25 and Figure 7.26 illustrate the CarerNet classes that may be considered to be Boolean state monitor's and Real-Time Boolean state monitor's respectively[9].

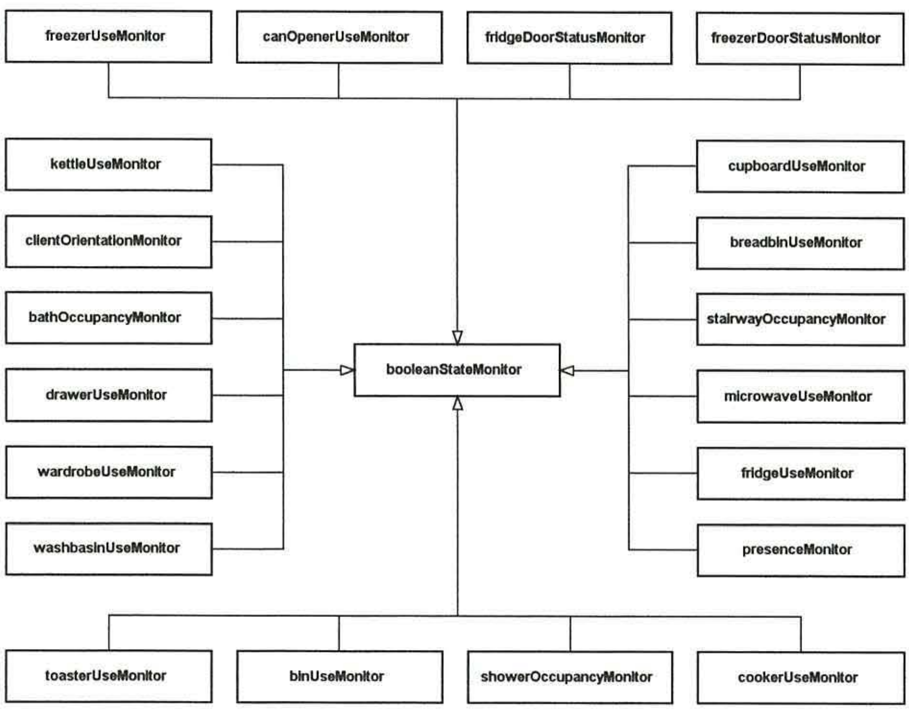

Figure 7.25. Examples of the *booleanStateMonitor* class.

[9] *Note that each device may not necessarily expose every attribute or method associated with its super-class.*

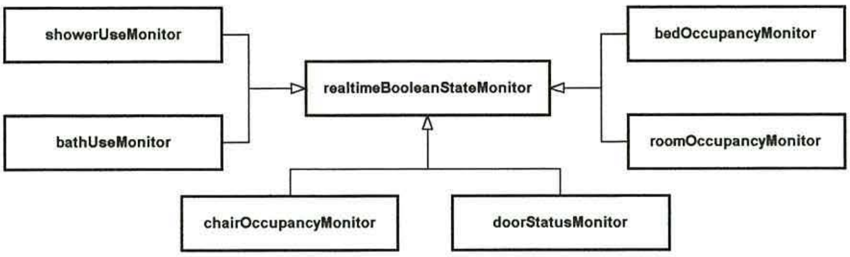

Figure 7.26. Examples of the *realtimeBooleanStateMonitor* class[10].

Analogue Monitors

Analogue domain properties are similar to event-based properties in the sense that data can be *reported* as well as *monitored*. Data reporting or *logging* involves the storage of data samples for further analysis. Data monitoring involves pre-processing the sampled data in order to identify significant features, events, alerts, and/or alarm conditions. Furthermore, because many of the domain properties will vary slowly over time (e.g. room temperature) it is possible to establish the overall picture of the data by performing interval monitoring (as described in Chapter 6).

A basic analogue sensor will present a discrete sample of its domain property on-demand, refer to the *analogueSensor* class in Figure 7.27. This data may subsequently be processed in a variety of ways according to the type of information required. Some analogue properties are only used to determine event notifications, including alerts and alarms. In such cases, there is little interest in the actual value of the property per se, other than when it crosses pre-defined thresholds. Because such properties are not logged for long-term historical analysis and threshold transitions are the only information of interest, these may be effectively be considered as Boolean or multi-state devices. They are, however, significantly different from their event-monitoring counterparts as they require suitable threshold values to be allocated in order to define the boundaries of each state[11].

Figure 7.27 presents these characteristics in the form of an *analogueMagnitudeThresholdMonitor* class. Examples of CarerNet devices that inherit the properties and behaviour of the *analogueMagnitudeThresholdMonitor* class are illustrated in Figure 7.28. These devices are capable of raising event, alert or alarm notifications, for example, a *bathWaterLevelMagnitudeThresholdMonitor* might be required to obtain the following domain information:

- *bathWaterLevel_Event("bathIsFilling")* and *bathWaterLevel_Event("bathIsEmptying");*
- *bathWaterLevelHigh_Alert()* and *bathWaterLevelHigh_Alarm()*.

[10] *Devices such as these may not always require the real-time functionality and would therefore just inherit the characteristics of the booleanStateMonitor class.*
[11] *It is also sometimes desirable to be able to modify these thresholds for the domain in question*

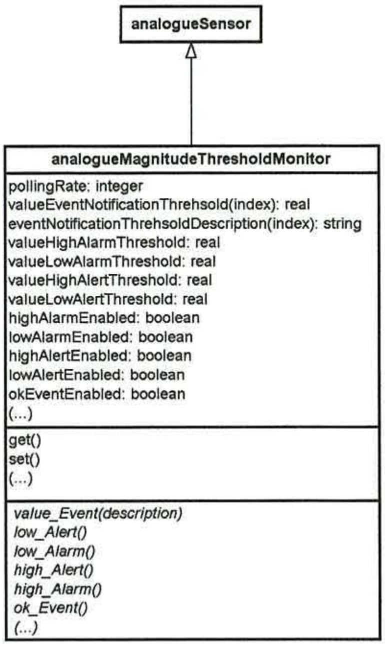

Figure 7.27. analogueSensor and analogueMagnitudeThresholdMonitor class hierarchy.

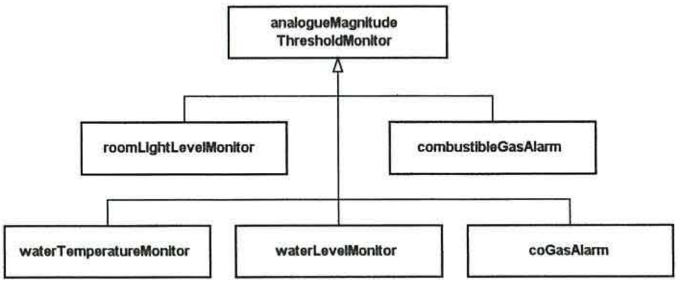

Figure 7.28. Examples of the *analogueMagnitudeThresholdMonitor* class.

The next level in sophistication is trend monitoring, where there is interest in the rate of change of a particular domain property. For instance, a *roomTemperatureMontior* might raise an alert to warn the client if the temperature within a room which is occupied by the client were to drop below 18°C or go above 24°C for a significant period of time [169]. An alarm might be raised if the temperature of the room did not subsequently improve following the alert notification. In addition to this magnitude threshold behaviour, it might also be desirable for the unit to monitor the rate of change of room temperature, which might help identify a fire. Other non-alarm based applications might include the mapping of temperature profiles to the use of an oven or a hob in the kitchen, or the use of a shower or bath in the bathroom.

Trend monitoring is also integral to the concept of interval monitoring, described in Chapter 6 as a method of 'data compression'. Interval monitoring is used to monitor slowly-varying properties and involves determining whether the property is 'stable' or 'unstable' over a predefined monitoring interval. The stability of the property is determined by its percentage change over successive sampling periods (i.e. a trend-based calculation). If the property is determined to be stable over an entire monitoring interval, then it is sufficient to represent the value of the property over the entire interval by its mean. It may also be appropriate to supply the minimum and maximum values obtained over the interval. However, if the monitored property were to drift by more than the predefined stability threshold, then it would be necessary to curtail the interval, report the current value, and begin another.

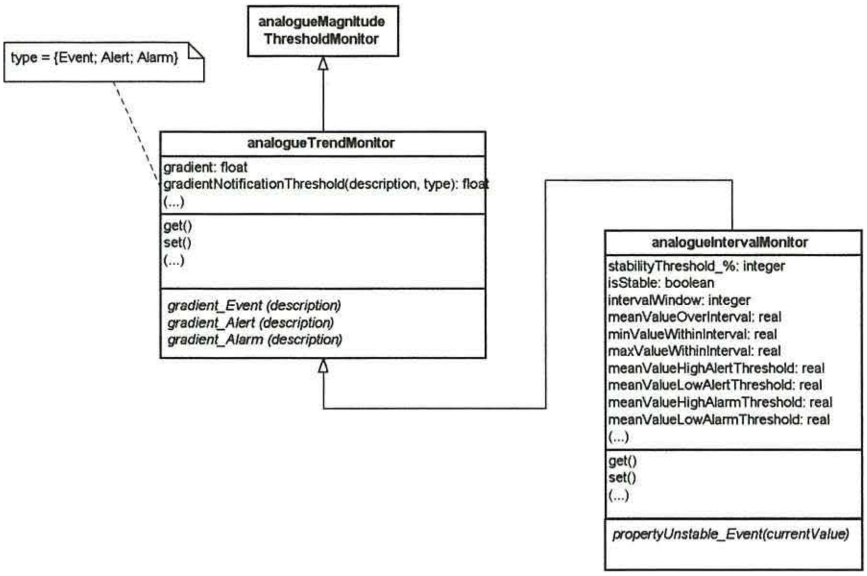

Figure 7.29. *analogueTrendMonitor* and *analogueIntervalMonitor* class hierarchy.

It is apparent that this is a form of data compression as the number of data-points transmitted is proportional to the rate of change of the property (which is supposedly normally stable). Figure 7.29 illustrates the properties and behaviour of the *analogueTrendMonitor* and *analogueIntervalMonitor* classes. Examples of the latter are provided in Figure 7.30.

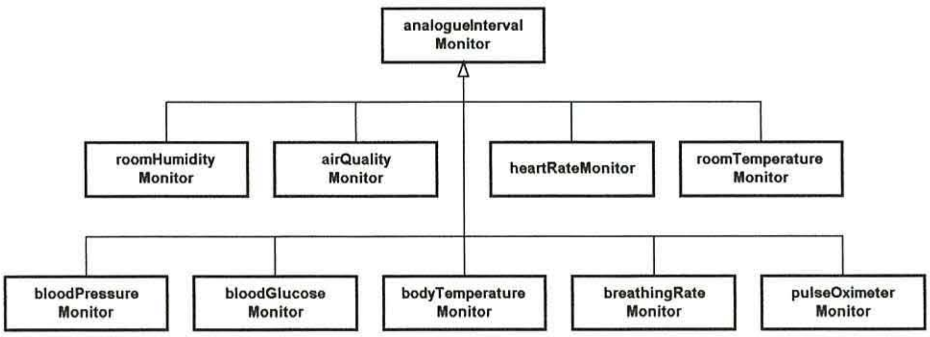

Figure 7.30. Examples of the *analogueIntervalMonitor* class.

The final classification of analogue inputs is concerned with Real-Time signals, where the waveform itself is of interest, Figure 7.31. These signals may subsequently require analysis in order to identify data sequences of particular interest. Examples include: an electrocardiogram (ECG) monitor, arrhythmia monitor, breathing monitor, and pulse oximeter (pulse waveform).

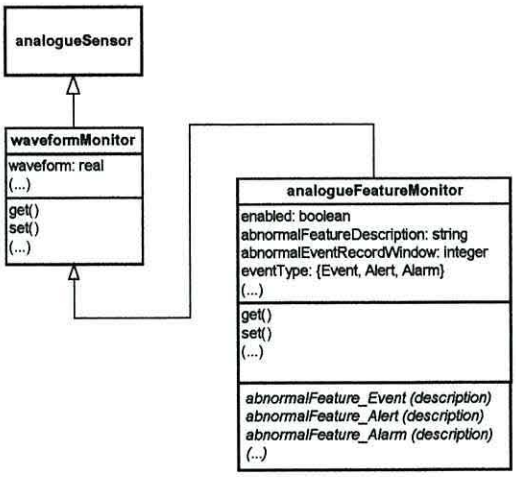

Figure 7.31. The *analogueWaveformMonitor* and *analogueFeatureMonitor* classes.

7.3.2 Inter-Device CareWare Classification

Several patterns of operation may be observed with inter-device CareWare components. In general, they may be segregated into one of the following categories, each of which will be discussed in turn:

1. Passive event-handler CareWare.
2. Virtual sensor CareWare.
3. 'Agent'-like event-processing CareWare.

Passive event-handler CareWare

Passive event-handler CareWare service events generated by the system by implementing rules associated with them. They compensate for the modularisation of system elements by acting as a form of 'glue-logic', bridging the gap between the responsibilities of data/event generators (e.g. smart sensors) and data/event consumers (e.g. actuators and external alarms) as well as user-interfaces, see Figure 7.32. They essentially perform the role of a go-between by converting events into appropriate requests for action and distributing them to the relevant system components, as required.

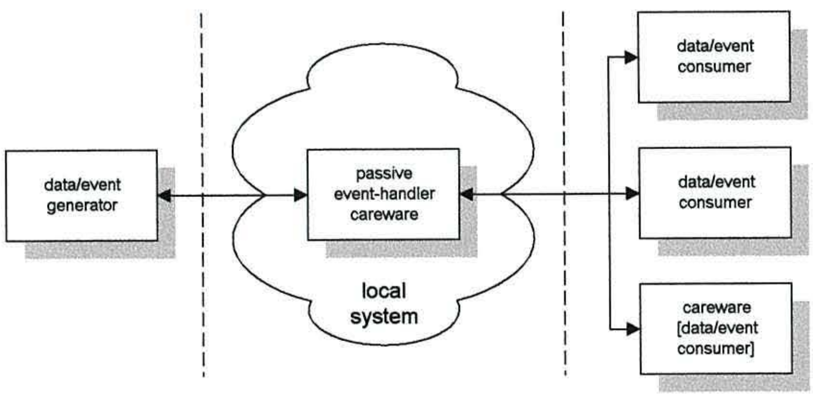

Figure 7.32. Overview of passive event-handler CareWare.

For example, consider Figure 7.33, which illustrates how a *bathWaterLevelHigh_Alert()* would be serviced by the *bathWaterLevelCareWare*, which would in turn prompt a *clientSystemInterface* to generate the appropriate message (using whatever means has been determined to be suitable for the client). Furthermore, upon receipt of a *bathWaterLevelHigh_Alarm(),* it would request an alarm to be generated at the *clientSystemInterface* and, if a *tapController* was installed, it would also generate a request to switch off the flow of water into the bath. The system-action would subsequently be logged at the LIU and also, if necessary, an external alarm would be raised in order to notify the most appropriate responder.

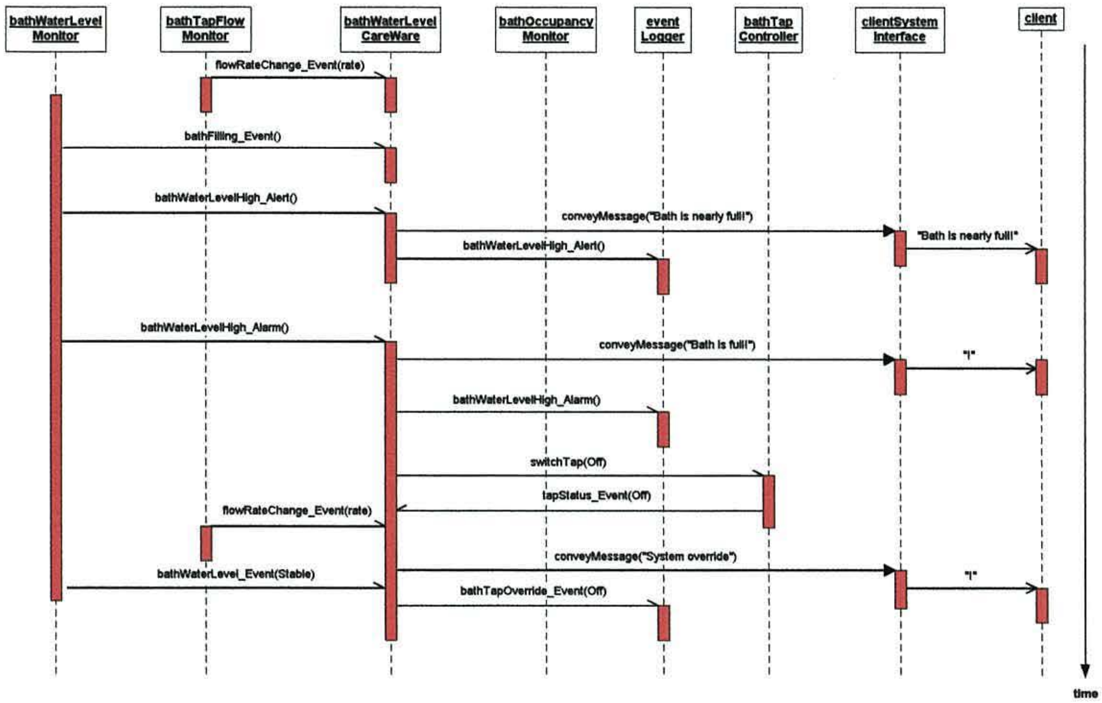

Figure 7.33. Partial sequence diagram describing events associated with client's use of bath.

Virtual Sensor CareWare

Virtual sensor CareWare components accept data from a number of sources and apply a combination of algorithms and rules in order to derive another usually more sophisticated domain property, see Figure 7.34. It is a conceptual model to describe the case when a particular property must be derived from separate sensors that are physically distributed throughout the home.

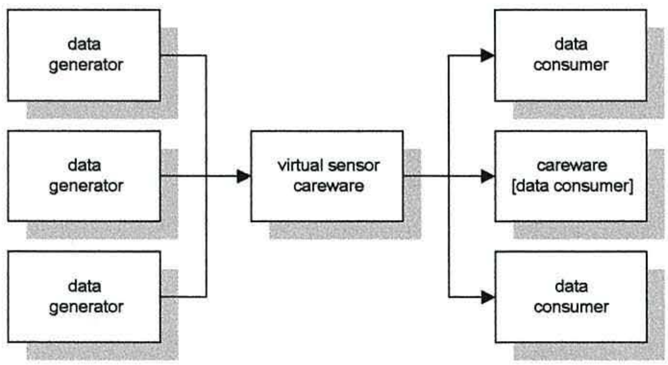

Figure 7.34. Overview of virtual sensor CareWare.

One example of a virtual sensor is a room occupancy monitor (see for example Figure 7.35 and Figure 7.36 for the case of a bedroom). These diagrams show how room occupancy can be determined from a combination of technologies that provide both transient and absolute room occupancy information. These technologies can either perceive the presence of the client within a room (i.e. somebody must be there – indicated in yellow) or they can monitor client-initiated activities within a room (i.e. somebody must have done that – indicated in grey). Figure 7.37 illustrates further examples of virtual sensor 'devices'.

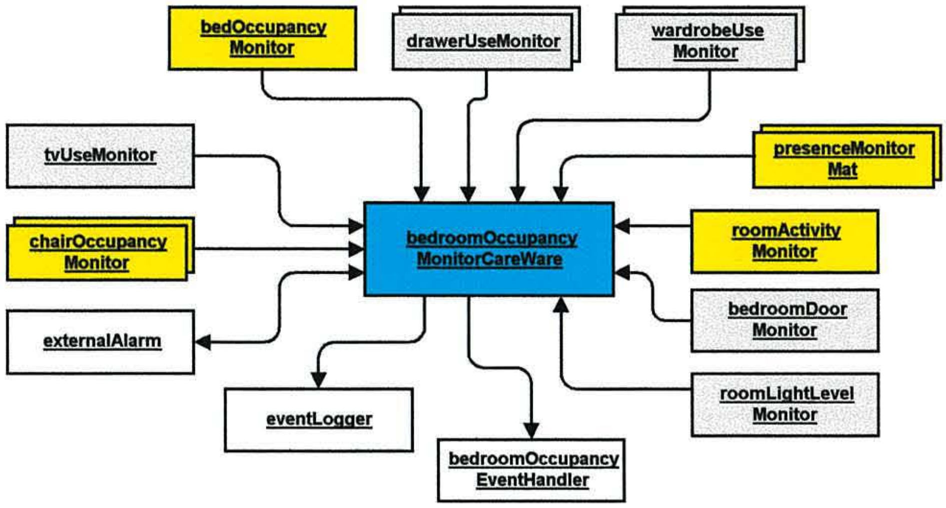

Figure 7.35. Class collaboration to determine bedroom occupancy status.

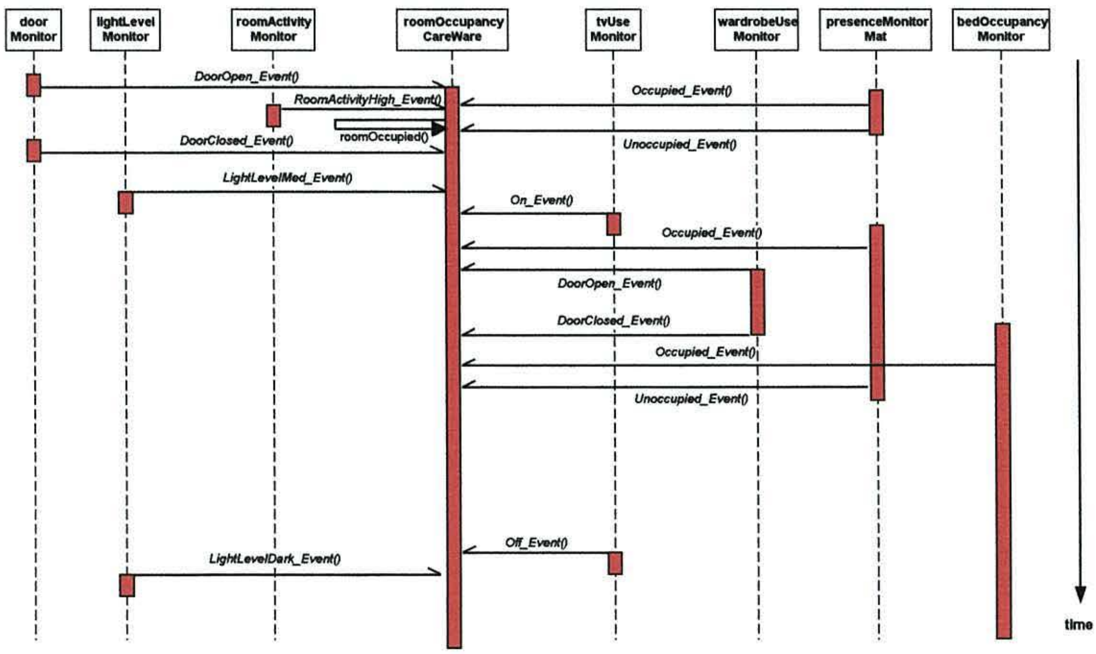

Figure 7.36. Basic sequence diagram for bedroom occupancy determination ("client to bed").

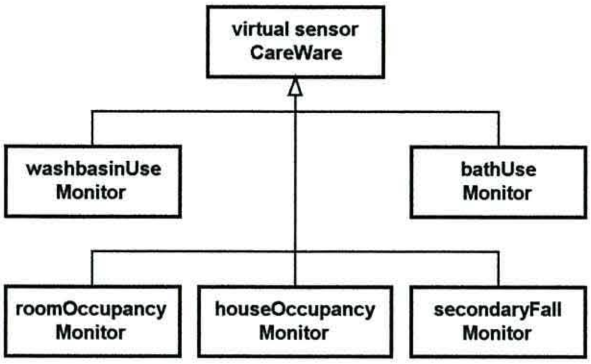

Figure 7.37. Examples of 'virtual' sensor CareWare components.

'Agent'-like Event Processing CareWare

Unlike their passive counterparts, active event processing CareWare have responsibilities of their own beyond that of merely passing messages between system components and may be compared with the basic concept of an 'agent' [170]. They are distinguishable from virtual sensors by virtue of the fact that they would typically output an action-event such as the raising of an alert or an alarm, rather than the derived value of a domain property.

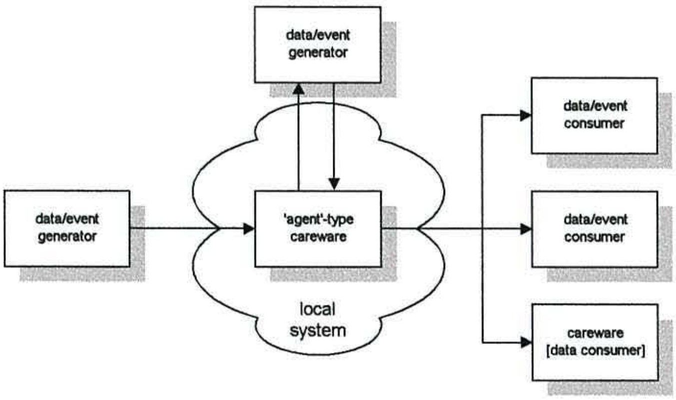

Figure 7.38. Overview of active event-handler CareWare.

Active event processing CareWare 'agents' are capable of not only reacting to the relevant events but also of interrogating relevant event/data generators in order to achieve their goal, see Figure 7.38. For example, consider the *safetyReminderCareWare* of Figure 7.39, which has responsibility for ensuring that the home is in a safe and secure state for client scenarios/activities where there may be an increased safety or security risk. Activities that may trigger the CareWare include when the client goes to bed, has a bath or shower, or ventures outside the home. It may therefore be triggered by the action of opening an external door; entering the bedroom late at night to go to bed (or getting into bed); or running a bath/occupying or turning on the shower.[12]

Thus, if the client goes to the bedroom at night with the intention of going to bed but has left a downstairs window open; has left the TV on; or has left a tap running in the bathroom, then the system will alert the client and/or automatically deal with it (if possible) using available home automation

[12] *It should be noted that the safety/security alerts generated will vary according to the trigger-event.*

capabilities. As well as displaying the necessary alerts using the nearest available user interface unit, the system may need to draw the attention of the client to the fact that there is a problem requiring their intervention. In this instance, it might be appropriate for the bedroom light to remain on until the alert is acknowledged and/or taken care of. Again, the level of automatic system intervention will be dependent on the particular needs and capabilities of the client. Figure 7.40 shows a selection of examples of 'agent'-like CareWare components.

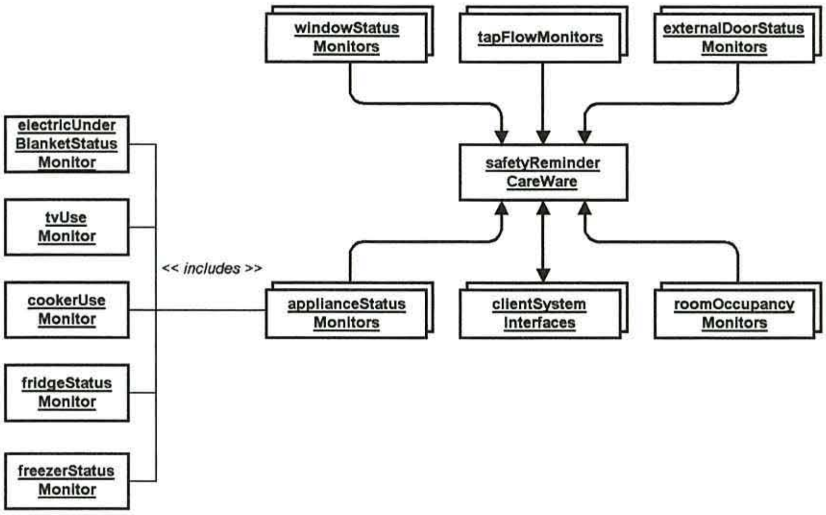

Figure 7.39. ***safetyReminderCareWare*** **collaboration diagram.**

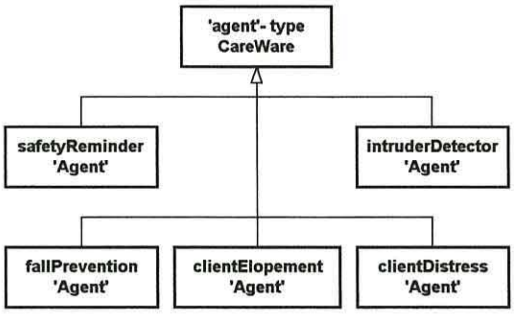

Figure 7.40. Examples of 'agent'-like CareWare components.

7.3.3 Domain Analysis CareWare Classification

These are services that run on the LIU in order to perform periodic analysis of historical data in order to determine long-term trends, calculate client assessments, and adapt the operating parameters of device-based CareWare to match the characteristics of the client, Figure 7.41.

For example, the average time that a client spends in the bath, or in bed, can be 'learned' by the system and used in the determination of suitable bed or bath occupancy alert/alarm thresholds. A hybrid approach involving Structured Query Language (SQL) queries and procedural algorithms (incorporated within the domain CareWare) can be used. Assuming a normal distribution, the domain CareWare may apply some multiple of the standard deviation to the mean value in order to determine the new intervention threshold. Many system-initiated alarms are preceded by an alert, the purpose of which is to request some form of response from the client in order to confirm whether there is a need for external assistance (a mechanism of reducing the number of false alarms). This feedback from the client can also be used to match the response characteristics of the system to the behaviour of the client. For instance, if the system raises a *bath occupied alert* and the client responds by clearing the alert (i.e. "I'm alright") then the system may increase the multiple of the standard deviation used in the calculation of the intervention threshold accordingly. Conversely, the multiple of the standard deviation may be reduced if the client complains of slow response times following a trauma.

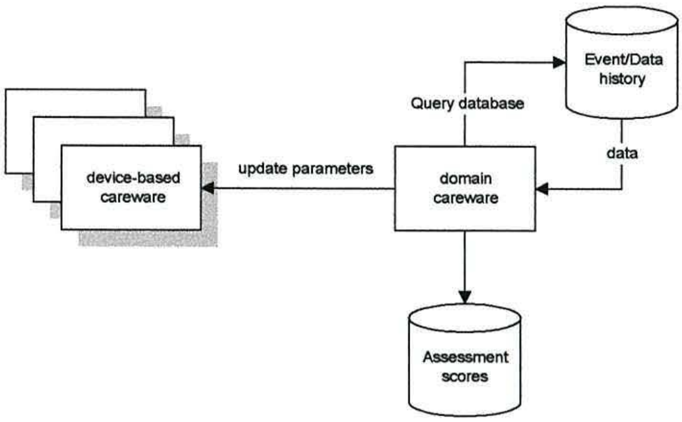

Figure 7.41. Overview of (scheduled) LIU CareWare components.

Another application of domain analysis CareWare is the calculation of assessment scores or indices based on a longitudinal analysis of various monitored or derived parameters. The ability to perform a variety of *continuous* assessments in the home of the client is likely to be an important driver for the take-up of telecare services [171]. The ability of CarerNet to be able to realise such services is dependent on its ability to identify key domain parameters within the home that may have significance for performing client assessments. Initially, it may be possible to make an educated guess, based on a knowledge of assessment techniques as to what these parameters might be (refer back to Chapter 3). For instance, Table 7.3 illustrates a selection of domain properties that may offer some potential for performing client assessments in the home of the client.

Table 7.3. Some domain properties with potential for client assessment purposes.

Client location	Number of times the client uses the toilet and for how long
Time spent in each room	Number of times client goes outside home and for how long
Frequency of changing room occupancy	Time taken for client to respond to someone at the door[13]
Time spent in chair	Number of times client uses washbasin
Time spent in bed	Number of times client uses wardrobe/drawers
Number of 'transfers' to and from chair	Number of alerts generated through client actions
Number of 'transfers' to and from bed	Number of alarms generated through client actions
Number of times kettle is used	Profile of water consumption in home over time.
Number of times fridge/freezer is used	Profile of electricity consumption in home over time.
Number of times that front door is opened	Number of times system has to remind client to perform an action/activity
Number of client-initiated activities	Number of times that client has a shower/bath
Number of times cooker/microwave is used	

[13] *e.g. doorbell to getting out of chair time; out of chair to entering hallway time; entering hallway to opening door time.*

However, it is necessary to perform extensive trials, preferably closed-loop (i.e. where the client and carers record over a period of time any significant deviations in well-being), so that the data obtained may then be correlated with known fluctuations in well-being. As part of the process of identifying potential domain parameters of use for assessment purposes, it is required that longitudinal data[14] obtained from a client's home be made available in a form suitable for analysis by a formal care expert. Part of this requires that the domain properties under investigation may be visualised in a form suitable to identify possible trends and abnormalities that may then be correlated with known well-being episodes from the event-record of the client and carers. In order to achieve this, it is intended that all events of note will be stored in a database capable of being interrogated using the Structured Query Language (SQL).

7.4 Service Realisation Examples

This section will consider several examples of how CareWare components may be combined to realise a number of key services within the home of a client. In order to realise services that provide value to system stakeholders in the form of care and support-related functionality, low-level services are required that are capable of generating an accurate representation of the local domain. Incomplete knowledge of the local domain has in the past impaired response times and resulted in a high number of false alarms with previous attempts at telecare [62]. Low-level domain knowledge, such as the ability to monitor client activity episodes, is instrumental in determining whether the client is in a 'stable' or 'unstable' state. It is therefore a key element in the process of identifying the abnormal behavioural profiles associated with potential indicators of client distress. Higher-level telecare services can subsequently be built upon the domain knowledge acquired. A selection of domain level and telecare level services will now be discussed.

7.4.1 Sitting/Lying Down & Sleeping

Knowledge of whether the client is up and about; sitting in a chair; or lying in bed is required for a number of services, from fall prevention and detection through to client distress monitoring and assessment. Chair and bed occupancy may be determined using furniture-based monitors and/or client-worn devices that monitor activity and/or orientation (such as with pedometer-style sensors). The furniture-based solution will be considered here.

A bed or chair occupancy monitor may be realised by using smart sensors of the *booleanStateMonitor* or *realtimeBooleanStateMonitor* class (or some derivative) according to the needs of the client, refer back to Figure 7.5. Event *reporting* functionality informs the system of whether the client is in bed or sitting in a chair, which can subsequently be used for determining whether the client is in a stable or unstable state.

In addition to passive event reporting, event *monitoring* services can be set-up to notify if any abnormal usage occurs. For instance, if, for some reason, the client was unable to get out of their chair, then

[14] It should be noted that the time interval over which this data is likely to be analysed will vary from – minutes, hours, AM, PM, day, week, month, through to years.

prolonged chair-occupancy may be used to raise an alert[15]. If the client fails to respond to a request to confirm their well-being, then an external alarm could be generated. Likewise, if the client were to remain in bed for longer than normal, perhaps due to illness, then a similar response mechanism could be triggered. Alternatively, an informal carer might wish to know if a partner who suffers with dementia gets out of bed during the night and does not return within five minutes.

7.4.2 Bath-Related Monitoring

Figure 7.42 illustrates devices and CareWare components associated with the client's use of the bath. One of the system-domain services involves determining bath usage. For the purposes of CarerNet, the bath is considered to be in use if it is occupied *and* filled with water[16]. It is subsequently considered not to be in-use when it becomes unoccupied *and* the water has been let out (or, alternatively if it has been unoccupied for greater than five minutes). The CareWare components that are specifically used for determining whether the bath is in use are highlighted.

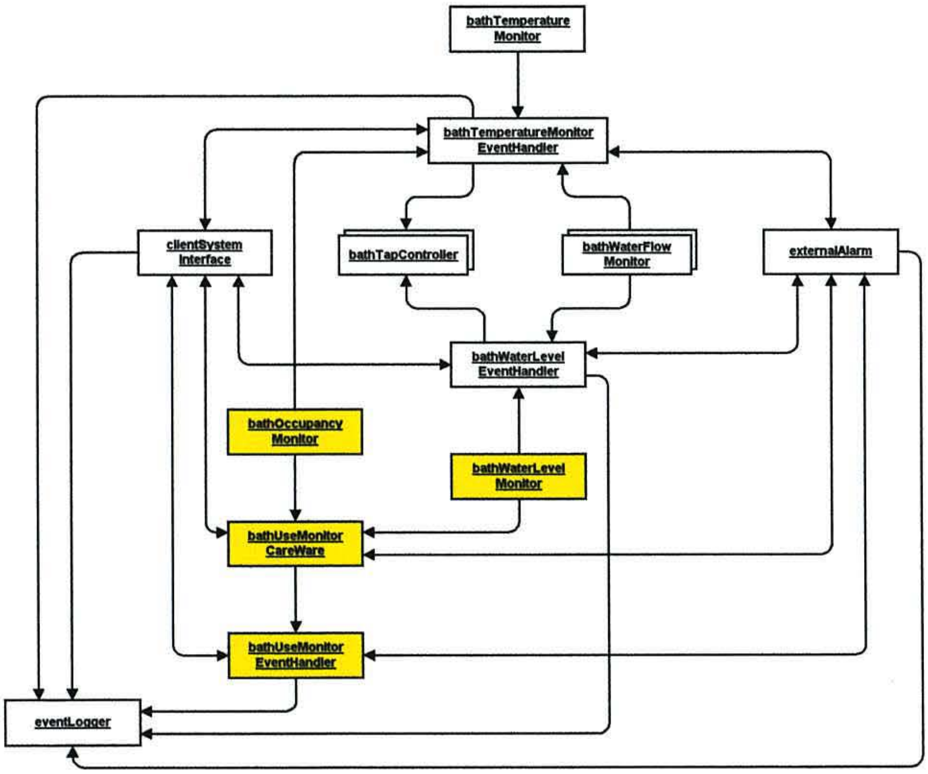

Figure 7.42. System devices and CareWare components associated with use of the bath.

In addition to the system domain services, there are many safety-related services associated with the client's use of the bath. Devices and CareWare are required for managing the risks associated with scalding and flooding. Several of these services are implemented using *analogueMagnitudeThresholdMonitor* CareWare on-board various smart-devices. The alerts generated are used to warn the client, and if no response is forthcoming, the system may either raise an external alarm or, if present, use local actuators to take control of any hazardous situation.

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[15] *as might the client failing to respond to external stimuli such as the telephone or door-bell within this time.*
[16] *System entities concerned with establishing usage of the bath are highlighted in Figure 7.42.*

7.4.3 Preparing & Eating Food/Drink

The ability to detect if the client is preparing and/or eating food and drink in the kitchen is important for performing an assessment of (instrumental) activities of daily living as well as being able to establish that the client is in a 'stable' state, i.e. not in distress. Client activities consistent with that of preparing/consuming food include: occupancy of the kitchen, cooker use, fridge/freezer use, cupboard use, kettle use (and other appliance-use), utensil drawer use, bin use, and chair use. The combination of events received within a given time-frame may be used to determine the likely activity of the client.

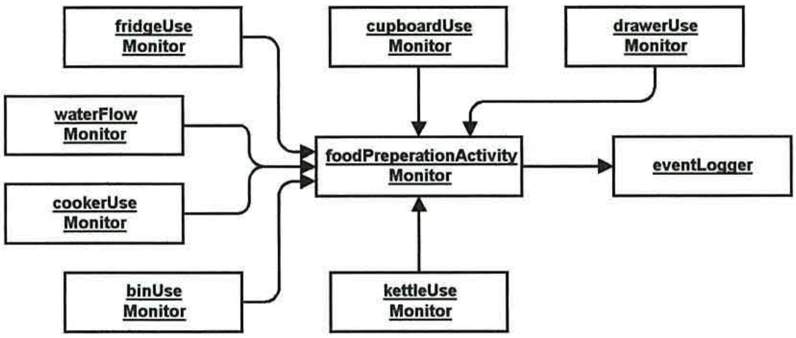

Figure7.43. (Partial) collaboration between system objects to determine client activity in kitchen.

In terms of client distress monitoring, the combination of room activity (i.e. the client moving about) and client-interaction with various room entities will enable the system to determine if the client is ok. In its crudest form, each client-initiated event can be used to reset a timer, which may be set to raise an alert if there are no client-initiated activities for an abnormally long period. This might mean that the client has fallen or is otherwise in distress. Important events or sequences of events may be passed on to the *eventLogger* for historical analysis.

7.4.4 Client Wandering Monitor/Elopement Alarm

The client elopement monitor (Figure 7.44) raises an alarm if the client has wandered out of the home and does not return within a set time limit (or immediately upon leaving the home). It is an 'agent' type CareWare component, which accepts as input events from an *externalDoorStatusMonitor*, and PIR activity events from the *hallwayOccupancyMonitor* (passed on from the hallway PIR). It can also interrogate the *houseOccupancyMonitor* for information pertaining to whether the house is occupied or unoccupied and which room is currently occupied.

It also incorporates some of the characteristics of a *realtimeBooleanEventMonitor* as the action of raising an alarm may be activated at particular times of the day and following a suitable absence period. The 'agent' is activated when the front door is opened; this starts an internal client wander timer which is reset each time the monitor receives a PIR event from the hallway. If the client leaves the home, then this timer will eventually trigger. The monitor will confirm with the *houseOccupancyMonitor* that the client has not moved onto another room and will raise a *clientWanderAlert*(). This is used to trigger the *clientElopementTimer* which will trigger unless the home becomes occupied again. This is used to create an external *clientElopementAlarm*.

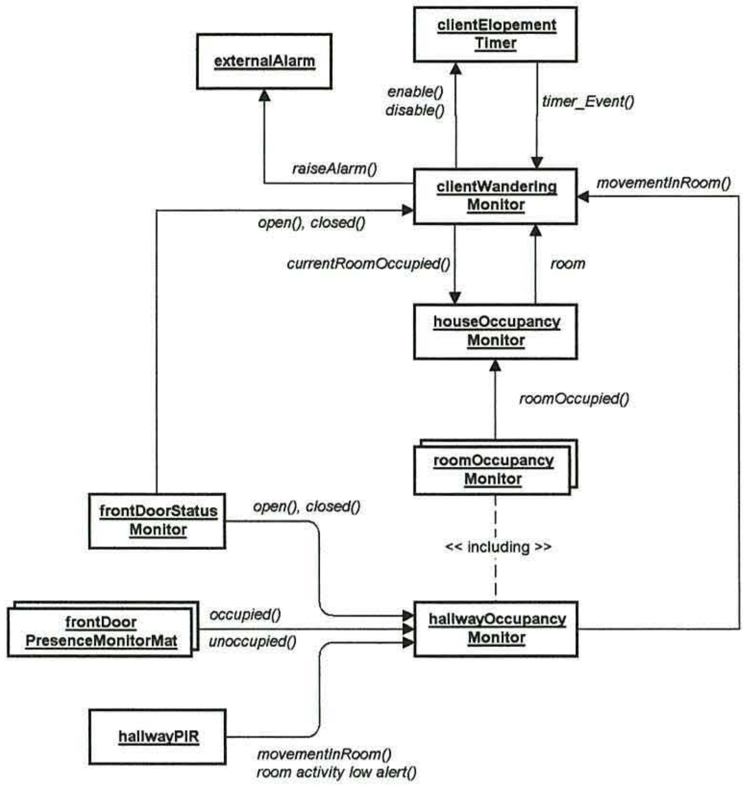

Figure 7.44. A client wandering monitor/elopement alarm 'agent'.

7.4.5 Diabetes Management

Aspects of the management of diabetes in the community suitable for telecare include helping a diabetic (especially newly diagnosed) to cope with the management of their condition. This might involve (in the case of type II), a reminder mechanism for performing blood glucose measurements, and subsequently monitoring the compliance to the measurement plan. Furthermore, it is possible to log blood sugar levels over time in order that a care specialist can analyse the trends, and, if a diary of activities/food-intake is also taken, can be used to fine-tune the management of a particular client's diabetes. It is also possible to warn the client if their blood sugar levels are dangerously high or low; with the option of raising an external alarm if this is deemed necessary. As part of a Calorie controlled diet, it may also be of use to monitor the client's weight.

Figure 7.45 illustrates some of the devices and associated CareWare that might be of assistance in this instance. Not shown is the fact that event handler CareWare can interrogate the *houseOccupancyMonitor* to determine which is the best user interface to use.

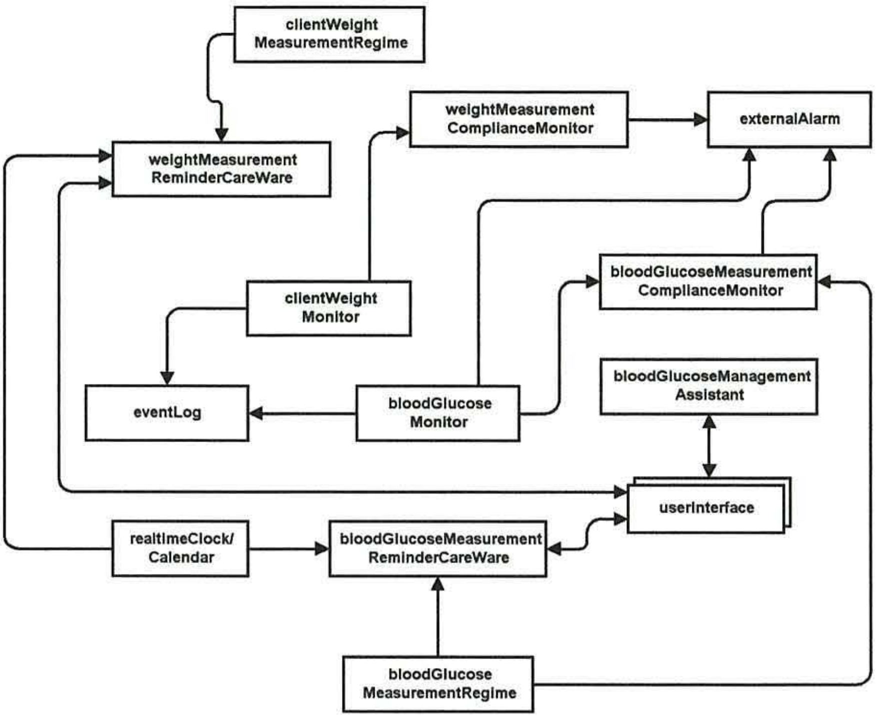

Figure 7.45. Diabetes example.

7.4.6 Medication Management

In cases where the client is subject to polypharmacy, it may be necessary to manage their prescription using technological assistance. Figure 7.46 illustrates some of the devices and CareWare components conceived for managing medication. Depending on the client, both pre-emptive (i.e. 'remember to take your medication!') and reactive (i.e. 'you've forgotten to take your medication!') reminder mechanisms are supported. For clients with poor memory or for those with especially complex medication, a medication container/dispenser unit could be beneficial. This would also permit the monitoring of the client's compliance with their prescription. This information may subsequently be used as a method of assessing the client's memory.

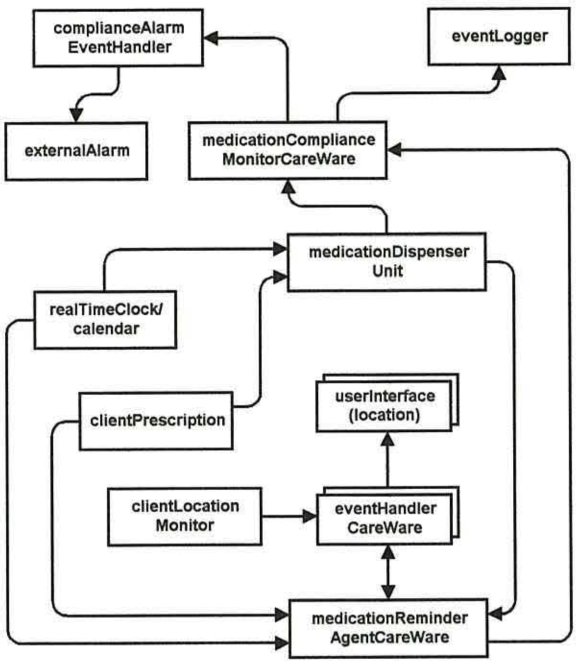

Figure 7.46. Example of medication management CareWare.

7.5 Conclusions

This chapter has described the object-oriented approach used to establish a modular, adaptable, component-based architecture for telecare services in the home. It has established that many telecare services possess common characteristics and can be implemented by re-using a relatively small number of common class-based components, either in isolation or in a hybrid arrangement. Several design frameworks have been identified to characterise the behaviour and interaction of the various CareWare components, which may be assigned to the home-based devices considered in Table 7.1 as required.

While system intelligence may ultimately be realised using neural networks or fuzzy logic techniques, a basic level of implementation may be achieved in the first instance by using a combination of 'production' rules, statistical analysis, procedural logic, and timers.

Chapter 8 will detail the implementation of this architecture as part of a prototype demonstrator system.

Chapter Eight

System Implementation

A selection of CarerNet services have been implemented as part of a demonstrator system. The principal aim of this implementation was not to construct an optimal solution using the most appropriate technology[1]. Rather, it was to provide a working 'proof-of-concept' prototype, allowing the principles discussed in the previous chapters to be demonstrated and investigated. Whilst most of the demonstrator system has been implemented using software, some sensor prototypes have been constructed to allow the data capturing capabilities of the demonstrator system to extend into the physical domain. Likewise, the use of a proprietary control bus and commercially available actuators have enabled the control of various actuators and appliances to be demonstrated. This chapter describes the practical work undertaken as part of this research.

8.1 Overview of Demonstrator System

The objectives of the demonstrator system are to illustrate the general principles of telecare and to enable the proof of concept of a number of telecare services, implemented within the framework of the CarerNet architecture. This proof of concept will be achieved by presenting a prototype implementation with data describing simulated and/or actual client-scenarios and monitoring its response. The aims of the demonstrator system include:

- Showing the advantages to be gained by employing an integrated systems-based approach, and that, in particular, it will:
    - Offer significant improvements in the range of services supported compared to those offered by community alarm systems and other single-domain 'systems'.
    - Provide a faster response than community alarm systems and previous attempts at telecare (most notably those based on off-premises or a 'centralised' model of lifestyle monitoring).
    - Produce significantly less false alarms than previous attempts at telecare that rely solely on the use of PIR motion detectors to determine the well-being of the client.
    - Enable services to be easily tailored to meet the changing needs of the client.
- Implementing various CareWare components in order to validate their design.
- Providing a visual 'front-end' to what are essentially non-visual services in order to better explain the concept of telecare to stakeholder groups.
- Acting as a research tool in order to develop new services before committing to a particular implementation:

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[1] *In any case, the resources available would not have allowed such an implementation.*

- For example, CareWare modules may be implemented on a prototype PC platform *before* being ported to a dedicated microcontroller-based implementation (simpler to develop and change).
- The use of scenario 'recording' and 'playback' facilities will enable real-life data to be re-analysed off-line in order to help improve software algorithms and rules.

- Implementing a selection of prototype sensors in order to show that CarerNet services are ultimately realisable.

8.1.1 Demonstrator System Realisation

The realisation of the demonstrator system has been undertaken in two strands, which together form a test environment capable of demonstrating the operation of telecare services. These two strands involve a *physical* realisation (system elements that have been implemented in hardware); and a *virtual* realisation (system elements that have been emulated in software using a virtual representation). The latter are software-based 'devices' that emulate their physical counterparts and which present data to the system as if they were physical manifestations. The spirit of the CarerNet architecture is conserved by implementing the virtual devices in an object-based fashion. Inter-device communication is achieved using a message-based communications infrastructure (COM). The software emulation of devices offers a low-cost means of 'mass production' by simply instantiating[2] as many devices of a particular type as required.

In order to demonstrate CarerNet services, appropriate test data capable of representing various client-scenarios must be presented to the system. One method of scenario generation includes the use of prototype devices in a test-flat facility[3]. However, it is not always possible nor desirable to have to act-out activities in order to test or demonstrate the operation of the system. This is particularly true when attempting to generate scenarios for which emulation is non-trivial, such as a client fall, high blood pressure, or cardiac arrest! Furthermore, such a technique will always require that the simulation is undertaken in real-time. This is unsatisfactory when working with services that operate on data or events obtained over a period of time, e.g. client assessment. Simulations performed at accelerated rates will enable results to be obtained more quickly. To accomplish this, a means of generating and/or presenting pre-determined (i.e. simulated) or pre-'recorded' (i.e. 'field'-obtained) test-data to the system is required.

Finally, the manifestation of the prototype system, whether for demonstration or validation purposes, should possess a significant visual component. This ensures that the status of the test-domain and the system, as well as their subsequent interaction will be represented intuitively. Importantly, this also facilitates an effective means of demonstrating the operation and potential of telecare services to stakeholders, i.e. it enables them to visualise how telecare services might respond to common scenarios.

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[2] *A term from the field of object orientation referring to the creation of an object (e.g. Ford Focus) which is an instance of a particular class (Car) – hence you may instantiate a car object from its class (e.g. set Ford_Focus = New Car).*
[3] *Assuming one is available.*

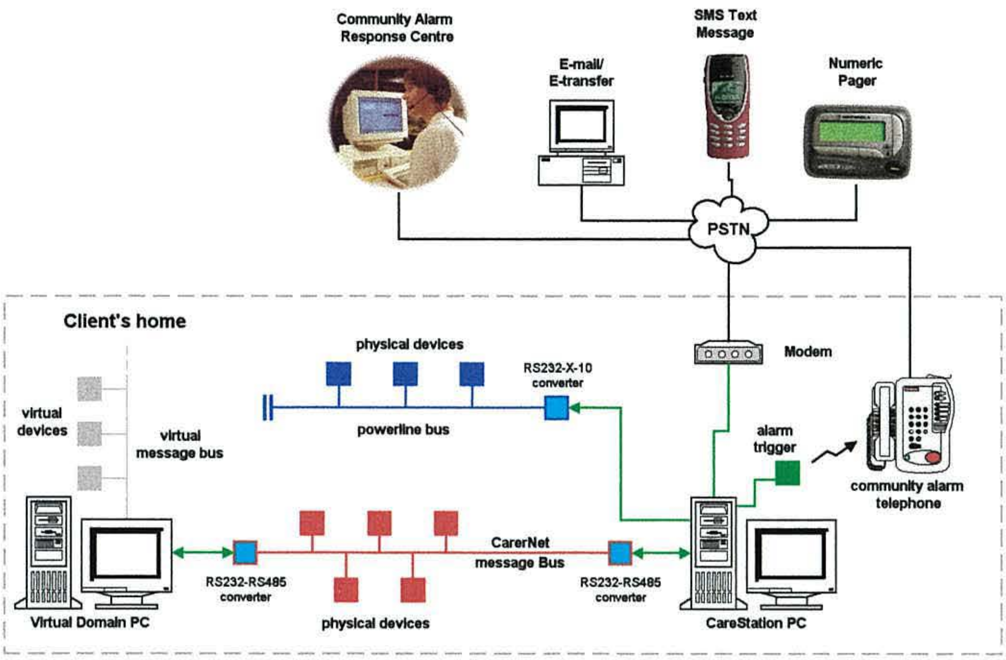

Figure 8.1. Demonstrator system overview.

Together, these components form a Virtual Integrated Care Environment (Virtual ICE), illustrated in Figure 8.1, designed to facilitate the validation and demonstration of telecare technologies and principles. The Virtual ICE consists of *five* main elements:

1. **The Virtual Domain PC** – *A personal computer running a 'virtual' model of a client and their local environment which is capable of generating data and events consistent with that of a physical domain (using a virtual device paradigm featuring the emulation of device-based CareWare). Sequences of events can be collated to form activity macros, which may subsequently be used to generate the required test scenarios. Domain visualisation software provides a graphical representation of the status of the domain. Various virtual appliances are implemented (e.g. user-interface) to enable client interaction with system elements to be simulated.*
2. **The CareStation PC**[4] – *This represents the local system intelligence and incorporates inter-device CareWare and (some) domain processing CareWare components capable of interrogating a database of system events and data. Domain visualisation software depicts the status of the local domain according to the local system (e.g. client location, chair occupancy status, room temperature, bedside-lamp status, etc.) and allows a comparison to be made with the actual status shown on the Virtual Domain PC. The CareStation PC also displays alert/alarm information as well as providing access to various CareWare operating parameter setup facilities. Finally, the CareStation PC provides a gateway to the outside world via a MODEM.*
3. **Prototype Devices** – *These are physical implementations of devices which can be used in isolation or in tandem with events generated by the virtual domain scenario.*

4. **System Message Bus** – *A multi-drop bus linking the Virtual Domain PC, the CareStation PC, and any prototype devices being used.*
5. **Power-line Bus** – *The control of mains-powered appliances (for the demonstration of automated control of lighting and other appliances) is easily realised by using a power-line communications bus such as X-10. A commercially available RS232 to X10 converter can be connected to one of the serial ports of the CareStation PC and used to send commands to various mains-powered devices.*

8.1.2 Prototyping Technologies

Numerous technologies have been used during the course of this work. This section will briefly describe them and the reason for their selection.

Visual Basic 6

The majority of the system software has been implemented using Visual Basic 6 (VB6)[5]. VB6 boasts a number of built-in or third-party components that offer high-level support for various relevant technologies, including:

- Database creation, access and querying (using SQL);
- Serial communications and networking;
- Text-to-speech generation and multimedia support;
- Automation/Control of mains-powered appliances using the X-10 protocol.
- Various Graphical User Interface (GUI) controls, including *user-drawn* controls.

While VB6 is not a true object-oriented programming language (significantly, it does not support inheritance), it does possess a number of object-oriented features. In any case, it is possible to simulate inheritance by using a combination of object containment and delegation[6]. Furthermore, VB6's support of the COM (Component Object Model) component based architecture offers a framework for the development of virtual system components. One of the most useful features of the COM architecture is event-multicasting, the process by which one object (the event-generator) may raise events in another (the event-consumer), providing the consumer is made aware of the generator and has been instructed to process the event. This mechanism may be modelled as a '*virtual system bus*' enabling virtual devices to communicate in a similar fashion to that of their physical counterparts. Information (i.e. data, events, alerts and alarms) may therefore be passed between virtual device objects such that one object can react to the events generated by another. Alternatively, an object may actively request the value of another object's property.

A further attraction of VB6 is its ability to allow the creation of custom *user-drawn* Active-X controls. These are high-level and re-usable software components that improve the efficiency and reliability of

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[4] *It is possible to run both Virtual Domain and CareStation software on the same PC, thus avoiding the need to setup a physical communications link.*
[5] *Microsoft Corporation, Redmond, Washington.*
[6] *This involves cascading private instances of objects within objects to create a suitable hierarchy and then delegating any 'inherited' state and behaviour to these embedded objects*

implementation. A comprehensive library of custom-designed Active-X controls capable of visualising the states (and events) associated with various domain entities has been developed.

PIC Microcontroller

The embedded processing/intelligence of prototype smart sensors have been implemented using a range of microcontrollers from Microchip's family of 8-bit Peripheral Interface Controllers (PIC)[7]. The PIC family boasts a wide range of features, each with a common core and hence backwards compatibility between more advanced controllers and their less advanced counterparts. The features that make the PIC an appropriate choice include:

- Support for serial communications, including hardware USART on some models as well as I^2C for Inter Integrated Circuit communications.
- On-board EEPROM for storing device parameters.
- Extensive Input/Output (I/O) capabilities including various digital I/O options as well as analogue options in the form of on-board comparators, analogue-to-digital converters and pulse-width modulation (PWM) outputs.
- A range of interrupts, including wake-up from sleep.
- Low power operation, advantageous for battery-powered devices.
- A free Integrated Development Environment (IDE) and low-cost programming tool as well as a low-cost C cross compiler for high-level language development.

A combination of native assembly language, cross-compiled C code (using the CCS PCM C compiler[8]) and Microchip's PICStart Plus programmer were used to develop firmware for prototype devices.

TIA/EIA-485 (RS-485)

TIA/EIA-485, more commonly referred to as RS-485, is an electrical specification for a multipoint network that operates over balanced (differential) lines [172]. An RS-485 bus is used to enable the Virtual Domain PC, CareStation PC and various prototype devices to exchange data and messages. It is a standard low-cost technique of enabling multiple devices to communicate over a twisted-pair. Each RS-485 transceiver has an impedance that presents a load to the bus with the maximum number of nodes on a single section limited to 32 unit loads (1UL = 12KΩ). However, manufacturers produce ½, ¼, and ⅛ UL transceivers, thus allowing up to 256 devices on the bus at any one time[9]. The maximum length of a single section of the bus is limited to approximately 1200 metres and the maximum data-rate is 10 Mbits/sec, although there is a trade-off between the data-rate and the length of the bus[10]. The short length of bus required for the demonstrator system means that almost any form of unshielded twisted pair (UTP) cable will suffice. A bit rate of 9600 bps, the use of slew-rate limited transceivers, and the short length of the bus ensured that there was no need for line termination resistors.

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[7] *Microchip Technology Inc., Arizona, USA.*
[8] *Custom Computer Services Inc., Brookfield, WI, USA.*
[9] *Both the length of the bus and the number of nodes can be extended using repeater units.*
[10] *i.e. you can't achieve a data rate of 10 Mbits/sec **and** have a cable length of 1200 metres.*

X-10

X-10[11] is a protocol which enables the control of mains powered equipment such as lights, heaters and other household appliances using the existing mains wiring as a communications medium. X-10's combination of 16 House address codes and 16 unit I.D.'s corresponds to a maximum of 256 uniquely addressable nodes on the mains network[12]. There are various X-10 products available on the market, including appliance modules, light dimmer modules, PIR modules, camera modules, and remote controls, and it has established itself as one of the most popular home automation protocols. There are two main reasons for this popularity:

1. It does not require any extra wiring to be installed in the home.
2. It is simple and hence reasonably priced for the home market.

X-10 transmitters and receivers generally plug into standard electrical outlets although some must be hardwired into the system. The CM-12U[13] unit is a commercially available interface that enables a PC to communicate with X-10 controllers via the serial port, and various Active-X components exist that enable Visual Basic code to be written to interface these controllers.

8.1.3 Demonstrator System Constraints

To facilitate the practical development of the demonstrator system, it was necessary to limit the scope of its implementation. This was achieved by:

1. Limiting the number of services to be implemented according to how important they are in terms of meeting the *primary* goal of CarerNet, that is, to enable an individual to remain independent in their own home[14].
2. Implementing these services within the context of a well-defined and *fixed* local environment.

Service Constraints

The unwieldy number of telecare services identified in Table 5.3 (Chapter 5) must be rationalised into a more suitable selection for implementation as part of a demonstrator system. This rationalisation process was undertaken according to the priorities attributed to various telecare service classifications provided in Section 6.1.4 (Chapter 6). Thus, the services implemented, in the first instance, reflect the importance of managing issues related to client safety and risk management; emergency and client distress detection; client and carer support; and the provision of various monitoring services.

Less emphasis has been placed on client assessment and care management services, although they have not been ignored completely. This is partly due to the fact that assessment services will require substantial longitudinal trials in order to establish the precise importance of various indicators; whereas the efficacy of the other services are often self-evident. However, the system has been designed to provide a platform upon which these assessment services may be developed.

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[11] *www.x10.com*
[12] *It does not necessarily follow that only 256 items can be controlled as more than one device can be attached to a single X-10 switching module (and more than one module can be set to the same address).*
[13] *www.x10.com*
[14] *or at least a dwelling with its own front-door.*

Table 8.1 lists a selection of services implemented in the prototype system. These services have been chosen as being applicable to a wide-ranging set of clients, with the exception of those that are tailored to meet the needs of confused people, including those with a dementia such as Alzheimer's disease.

Table 8.1. Selection of services to be implemented in first instance.

LOCATION	Service	
Safety/Risk management & Security	Fall prevention Scalding prevention Environmental alerts (room temperature, humidity) Warn/remind client if status of home is unsafe/insecure	Flood prevention & alarm Client wander monitoring & elopement alarm Appliance auto shut-off (e.g. cooker, heater, electric blanket) Intruder detection
Emergency/ Client Distress	Client stuck in chair/bed/toilet/bath Various threshold intervention alarms Manual alarm generation	Nocturnal hypoglycaemic attack Client distress alerts (unstable behaviour) Fall alarm
Client/Carer Support	Various client reminder services, e.g.: medication, external door left open, water running, important dates, self-measurement, appliance status, etc.. Temporal re -orientation	Climate control Assistive home automation
Monitoring & Assessment	Blood glucose monitoring Blood pressure monitoring Environmental status monitoring	Client weight monitoring Heart-rate monitoring Medication compliance
Care Management	Incontinence alarm (notify carer that pad needs changing) Device tamper alert Activities of daily living	Device use monitoring Medication dispensing Data visualisation Pressure Area Management

A Test-Bed Local Environment

The (internal) local environment consists of a virtual dwelling with infrastructure, furnishings and domestic appliances (refer to Figure 5.4, Chapter 5). In order to allow various home-categories to be considered, the 'construction' of a virtual dwelling was achieved by restricting the characteristics of individual rooms. Thus, each dwelling for consideration was constructed from a selection of the following common room-types:

1. Lounge/Living-room.
2. Kitchen (including utility-type room).
3. Master & Spare bedroom.
4. W.C.
5. Bathroom.
6. Hallway (including a landing and stairway if dwelling has more than one level).

To simplify the implementation of the local domain, a single-floor bungalow or flat was used as the basis for the construction of the prototype system. The number of *internal* rooms or room-like entities was restricted to five to accommodate one room from each of the most typical categories (the W.C. has been incorporated into the bathroom). These decisions were based on the current trend in new-build sheltered or very sheltered housing schemes[15], which share similar features to the 'virtual' dwelling of Figure 8.2, which shows room names and connectivity.

[15] *For example those managed by Bield Housing Association or Housing 21.*

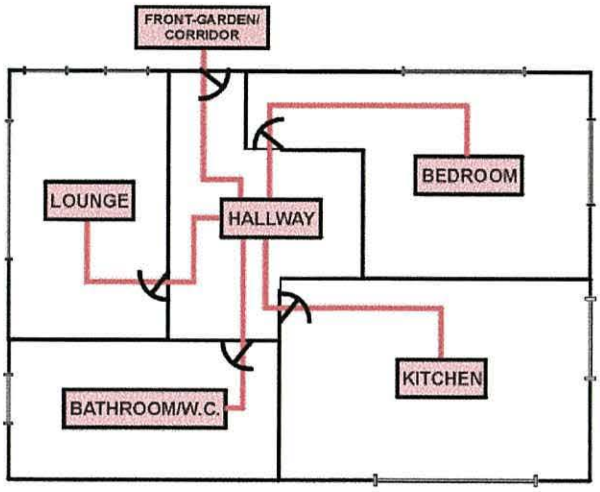


Figure 8.2. Room floor-plan and connectivity for 'virtual' bungalow.

Figure 8.3 to Figure 8.9 illustrate each of the rooms, their infrastructure, furnishings and various appliances, which together make-up the local domain. They also show various devices 'installed' in order to enable the services of Table 8.1 to be implemented. The primary functionality of these devices may be determined from the class inheritance diagrams of Chapter 7.

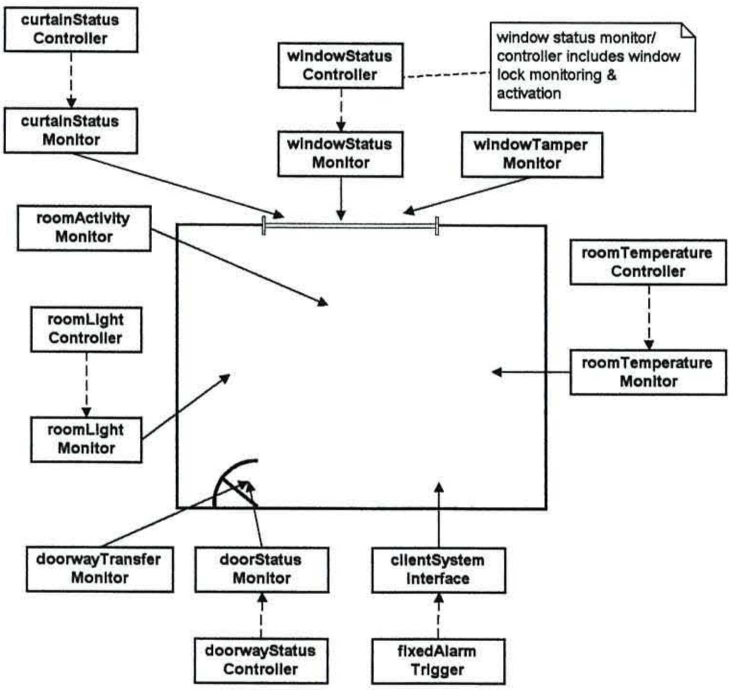


Figure 8.3. Generic room devices.

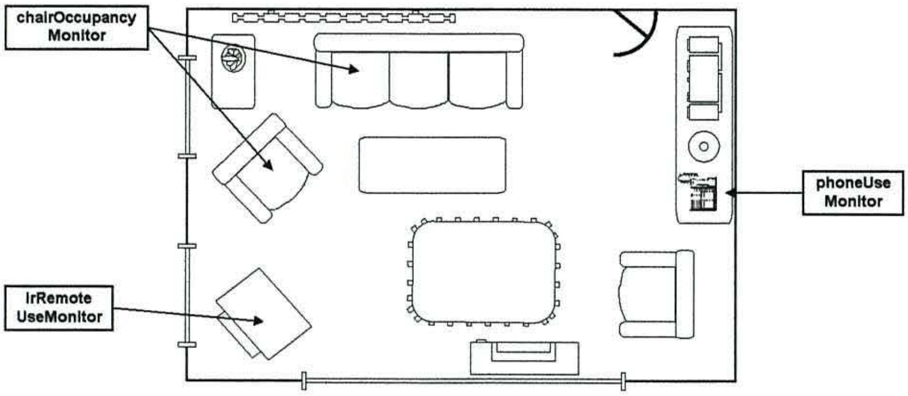


Figure 8.4. Lounge devices.

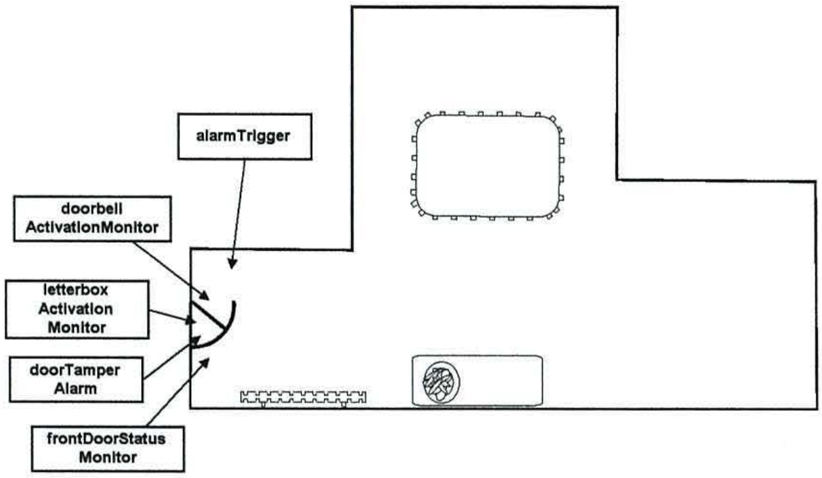


Figure 8.5. Hallway devices.

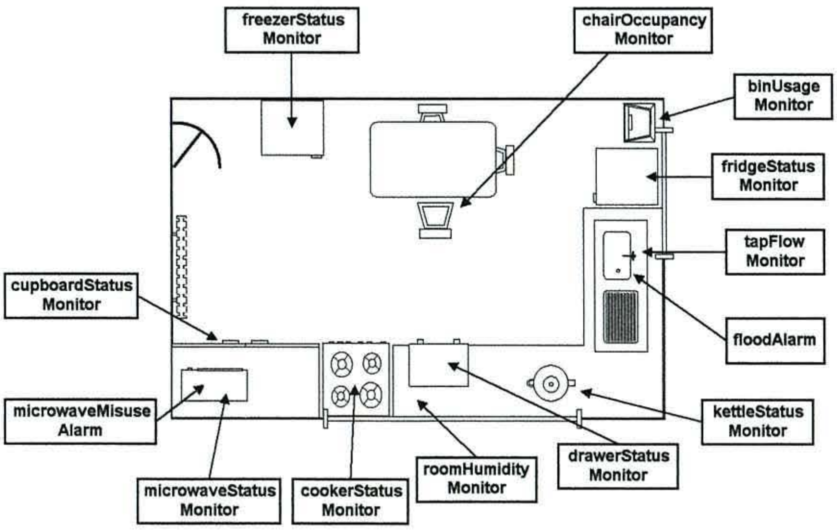


Figure 8.6. Kitchen devices.

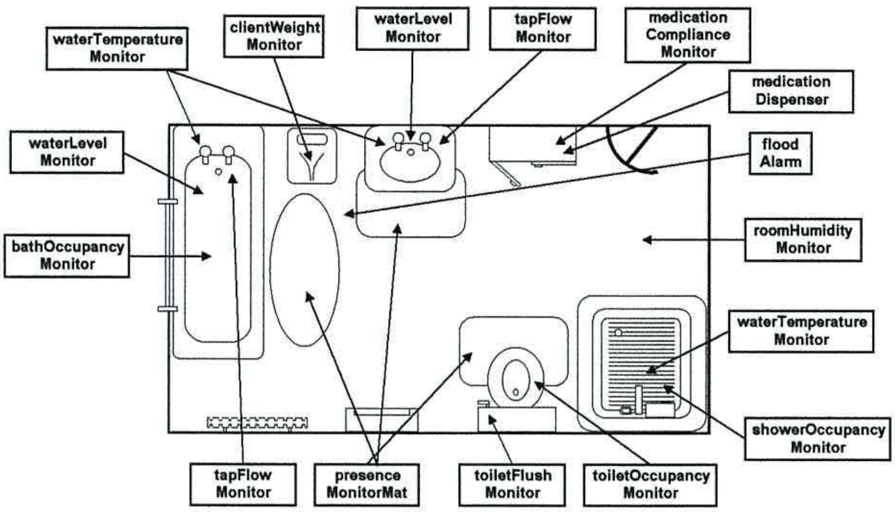


Figure 8.7. Bathroom devices.

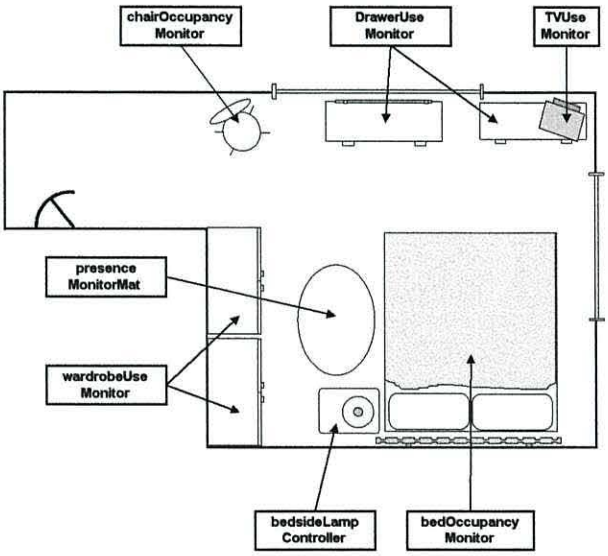


Figure 8.8. Bedroom devices.

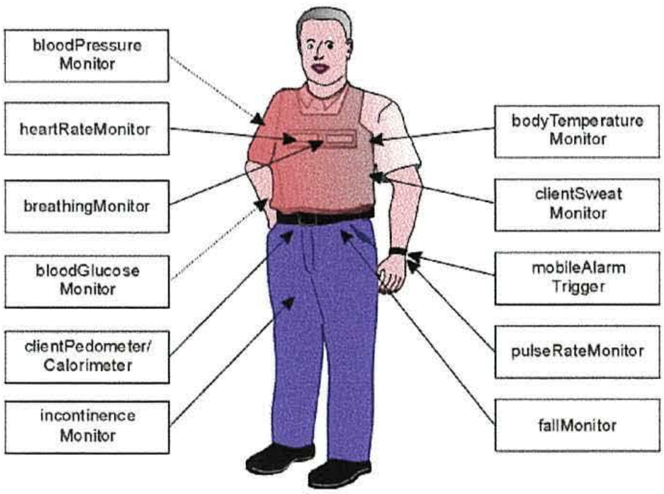


Figure 8.9. Client devices.

Figure 8.9 illustrates several physiological monitoring devices integrated into a 'smart vest' arrangement [29, 173] as well as several other peripheral devices situated upon the client's person. The use of such a vest (or other permanently worn monitors such as watch-based heart-rate monitors [174] or non-invasive blood glucose analyser [175]) might be considered if continuous monitoring is required, e.g. for performing a general well-being assessment or for investigating problems such as with an undefined arrhythmia. Other (usually invasive or cumbersome) devices such as standard blood glucose monitors [176] or blood pressure monitoring cuff's [177] are used intermittently and on-demand.

Note that client-based devices need not necessarily be physically located upon the client. For example, incontinence monitoring might take place on the bed to detect incidents of nocturnal enuresis. Likewise, sweat monitoring might also be performed in the client's bed for identifying incidents of nocturnal hypoglycaemic attacks.

8.2 Virtual Device Implementation

In order for the virtual domain to be capable of generating the appropriate system events and of responding to system commands, it is necessary to embed within it a suite of virtual devices. These must emulate, amongst other things, the device-based CareWare discussed in Chapter 7. Virtual devices can be developed that are simply high-level event generators or they can be extended to react to input data.

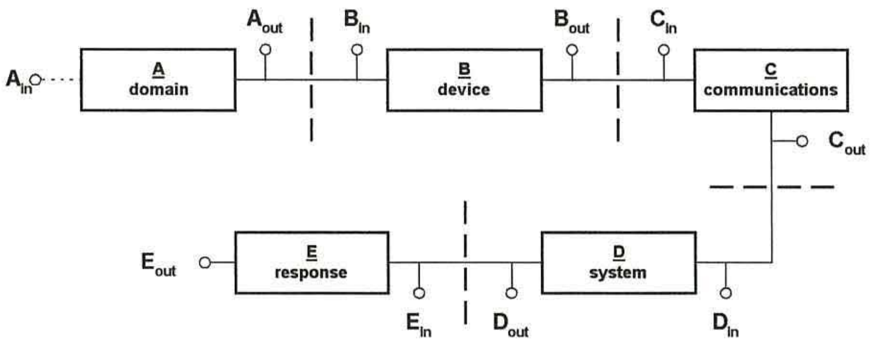


Figure 8.10. Potential CarerNet system 'data-injection' points.

Figure 8.10 illustrates the points at which virtual-data may be generated and subsequently 'injected' into the system, whether for demonstration or experimental purposes. The level at which test-data is presented to the system will depend on the purpose of the simulation. Inter-device CareWare may be tested using high-level device-generated messages (i.e. at B_{out}/D_{in}, assuming a transparent and reliable communications channel, C). However, in order to test device-level CareWare, it is necessary to present suitable data at point B_{in}. The virtual devices implemented incorporate a hybrid approach, whereby they can accept data as input but can also be requested to generate high level events on-demand.

8.2.1 Passive Sensors & Actuators

Passive devices are those which require little or no interaction with the client in order to operate. They mainly consist of devices that monitor or effect the status of the local environment and which do not incorporate a client-interface. The object-oriented analysis presented in Chapter 7 illustrated how the majority of smart telecare sensors/monitors & controllers could be considered as inheriting the functionality (i.e. state and behaviour) of a relatively small number of generic classes. It is possible to implement these devices in software by instantiating objects based upon one or more of these generic classes. Modifications can be made to the interface presented in order that device properties are entity specific. Figure 8.11 illustrates how Boolean event monitoring has been implemented using Visual Basic.

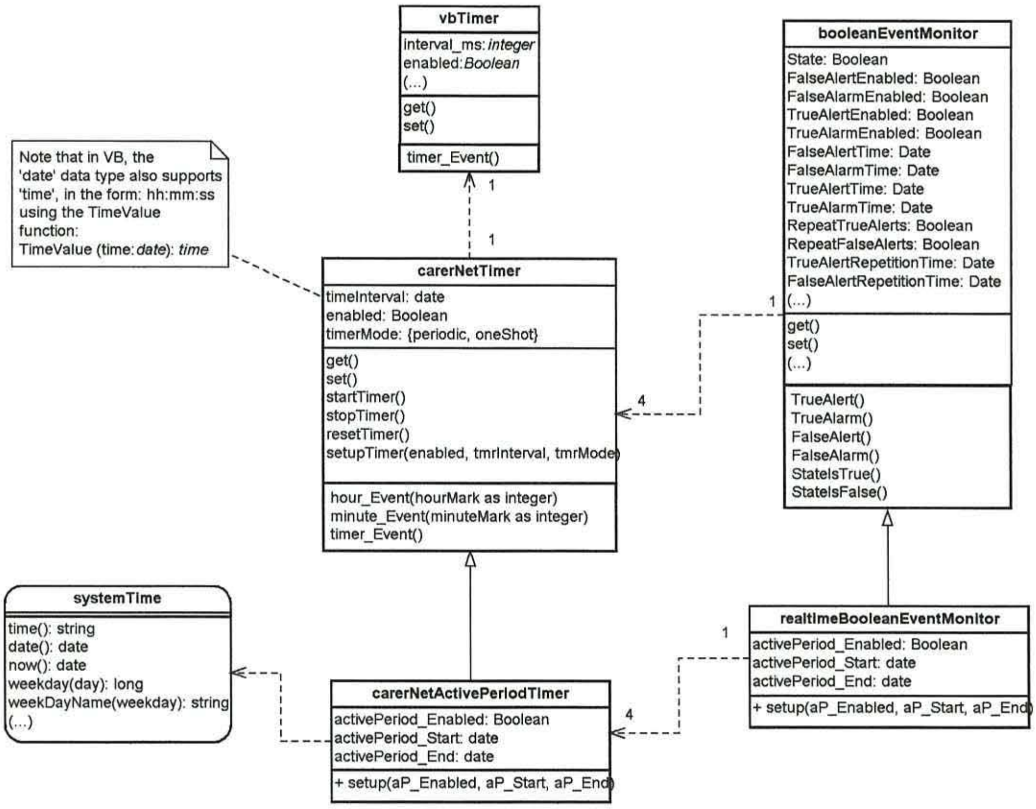
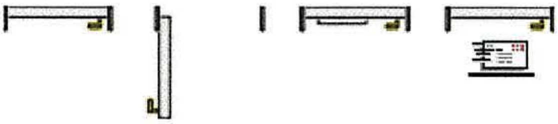
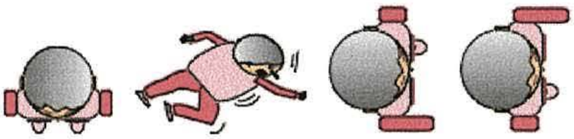
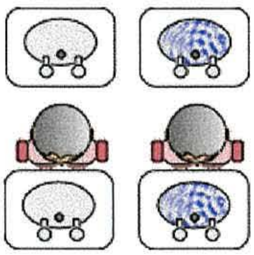
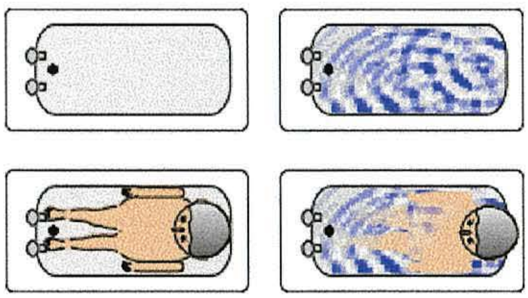
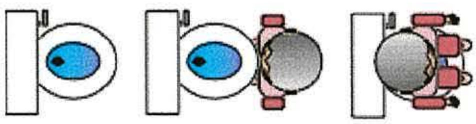
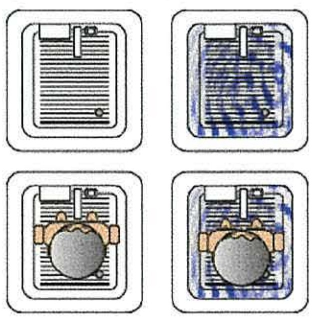


Figure 8.11. Boolean event monitoring.

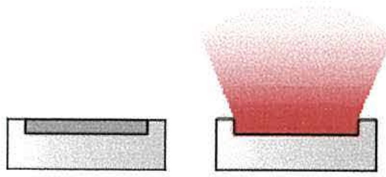
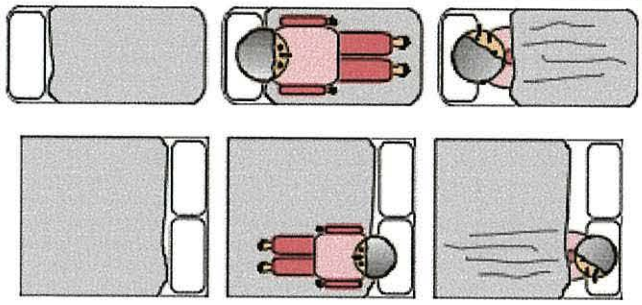
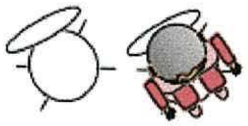
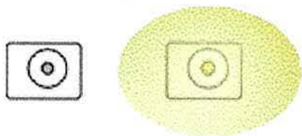
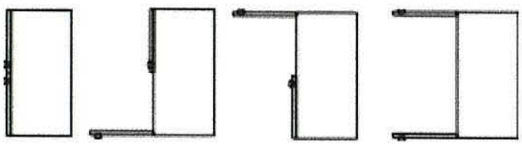
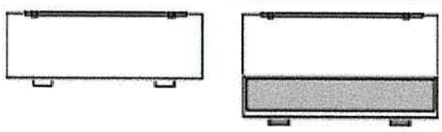
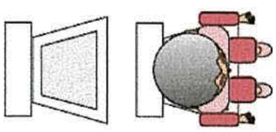
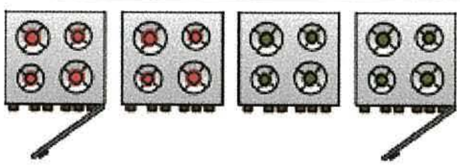
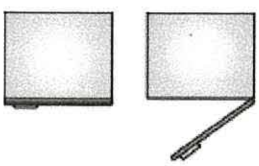
As an example, consider a bed absence monitor, a device that raises an alarm if the client gets out of bed during the night and fails to return within a specified amount of time. It is constructed out of a *realtimeBooleanEventMonitor*, whose functionality is dependent on the *carerNetActivePeriodTimer* (a generic custom Active-X control[16] which extends the functionality of the *carerNetTimer,* which itself extends Visual Basic's own built-in Timer control, by collaborating with the *systemTime* object before raising an alarm). Consider Table 8.2, which illustrates a selection of Active-X control objects developed using Visual Basic to represent the status of the local domain[17].

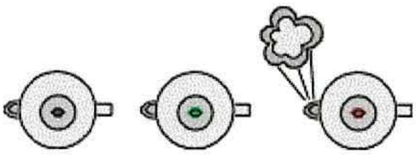
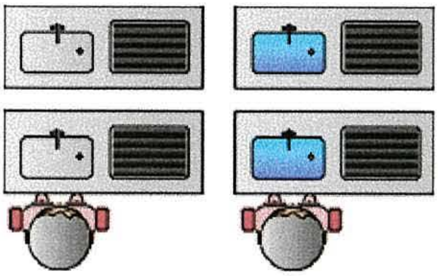
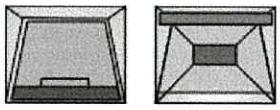
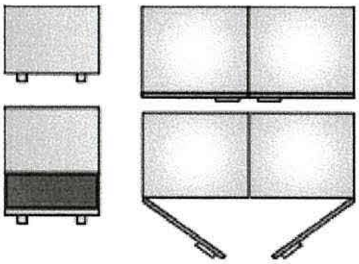
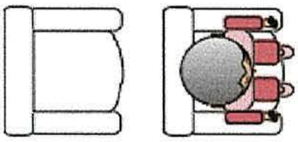
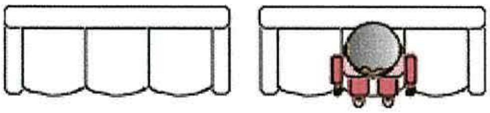
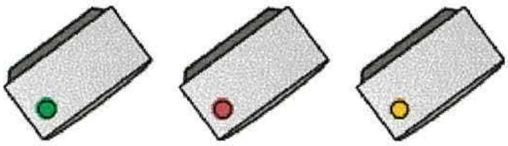
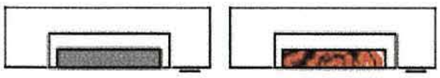
[16] *An Active-X control need not possess a visual component.*
[17] *The graphics were created with CorelDraw 7.*

Table 8.2. A selection of smart Active-X dual-purpose objects[18].

Room	Domain object/control	Description
Generic		Internal door (open, closed)
		External door (closed, open, letterbox-use/new-mail)
		Client 'up and about', (potential) client-fall, walking.
		Radiator/room-heater {'on', 'off'}
Bathroom		Washbasin water-level & occupancy status.
		Bath water-level & occupancy status.
		Toilet use.
		Shower water-flow and occupancy status.

[18] *Note that Active-X objects may be run using Internet Explorer and hence can be used to convey status over the web if required.*

Room	Domain object/control	Description
Bathroom		Infra-red 'Halogen' heater {'off', 'on'}
Bedroom		Bed occupancy status. (unoccupied, occupied {awake}, occupied {asleep})
		chair occupancy {'unoccupied', 'occupied'}
		Table-lamp status (off, on)
		Wardrobe-door status.
		Dressing table drawer-status.
Kitchen		Chair occupancy status
		Cooker status (on/off and door status)
		Fridge/Freezer door-status.

Room	Domain object/control	Description
Kitchen		Kettle status (off, on, boiled).
		Sink water-level and occupancy status.
		Bin-use status.
		Drawer/Cupboard status (open, closed)
Lounge		Armchair occupancy status.
		Sofa occupancy status.
		TV-use status (on, off, infra-red remote control activity)
		Room (gas/electric) heater status (off, on)

The Active-X controls of Table 8.2 may be used for various purposes:

1. They may be used in isolation, in a passive role, superimposed upon the room layout of a dwelling to represent graphically the status of the various domain-entities;
2. They can be extended, in a more active role, by embedding within them the appropriate device-level CareWare, making them 'smart' and subsequently more powerful (thus the

control used to visualise the status of a fridge also becomes the control which emulates the fridge status monitor).

3. They can be used as a means of generating particular events, e.g. the control for a door can be made to alter its status, 'transmitting' the appropriate system message in doing so (i.e. it may be used as a true virtual representation of a domain entity with which it is possible to interact and effect). Alternatively, this may be modelled as the control having a door actuator controller built-in.

Consequently, the graphical representation of a domain entity can include, or otherwise be associated with, the CareWare related to the monitoring/control of the entity. This is achieved by porting the necessary classes across to the control or by pointing the control to an instance of the particular domain entity monitor in question. Figure 8.12 illustrates this process and also shows how the state of a particular domain entity may be controlled by a simulation data file (i.e. point B_{in} in Figure 8.10); a simulation event file (i.e. point B_{out}/D_{in} in Figure 8.10); or manually using the entity status form (see below). The figure also shows the encapsulation of the representation of a domain entity, its visualisation, and the device-based CareWare within the Active-X control.

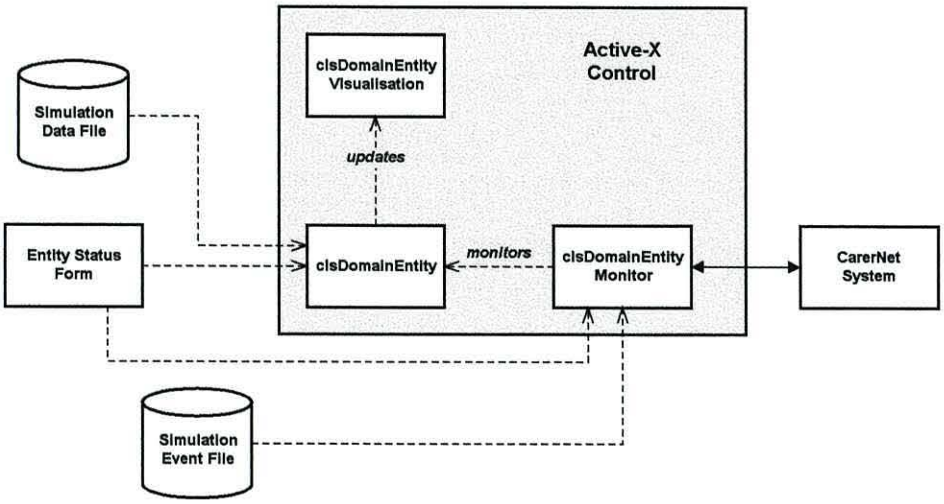


Figure 8.12. The Active-X control can perform the function of three classes in one.

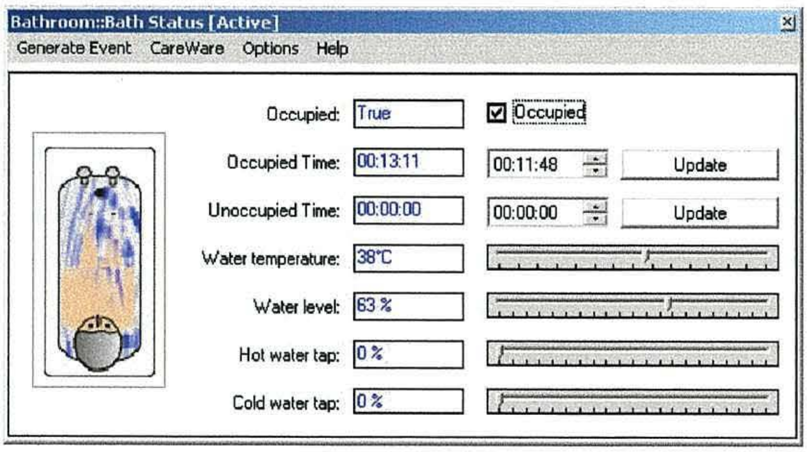


Figure 8.13. An entity status form for a virtual bath.

Thus, as well as providing a means of visually representing the status of a domain entity, an Active-X component may also emulate the functionality of the associated monitoring device (or actuator), generating the desired data or *alert/alarm* events as required. The latter may be in response to real data; simulated data/events; or by manual (and virtual) interaction using the entity's status form, e.g. see Figure 8.13 which shows the form for a bath & associated monitoring/control devices.

8.2.2 Active Devices

In addition to the devices that are designed to monitor and effect domain entities, there are those which require significant interaction with the client via some form of user interface or user-initiated action. Examples include: an LCD user-interface module, blood glucose monitor, client weight monitor, and medication dispenser, etc. A selection of which will be described in the remainder of this section.

Virtual User Interface

In order for the demonstrator system to simulate interaction with the client, a Virtual User Interface (V-UI) has been developed. This is modelled on a touch-screen LCD display unit, see Figure 8.14. System messages can be displayed on the LCD display with the action of depressing areas of the screen simulated using the mouse-pointer. The V-UI includes a standard 'panic' button to automatically raise an external alarm in the event of an emergency. Three LED-type indicators provide a simple indication of whether everything is OK (green); there is an alert/problem requiring the client's attention (amber); or that an alarm condition is present (red).

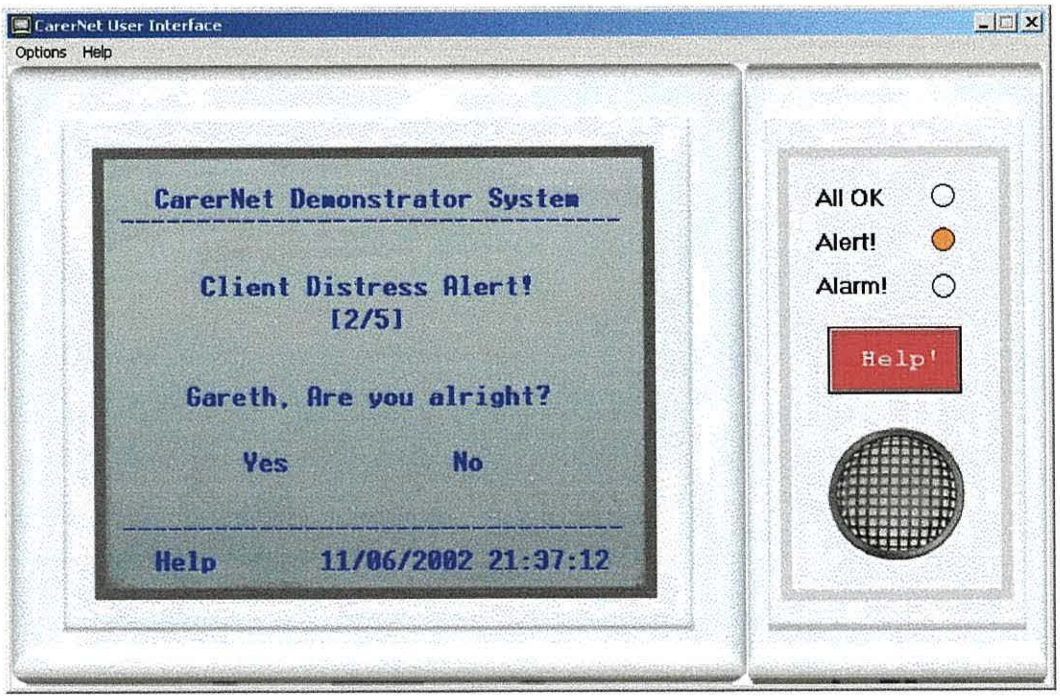


Figure 8.14. Virtual LCD touch panel user-interface display.

The V-UI is capable of generating synthesised speech using Microsoft's Text-To-Speech engine, and also of reproducing pre-recorded speech messages (or other appropriate audio) stored using the wave file format[19]. This simulates the ability of the system to use the recording of a familiar voice to communicate with the client. Table 8.3 provides a selection of example audio output and proposes possible mechanisms of realising the user interface in order to best serve the needs of the client. For example, if the client always uses the washbasin in the bathroom every morning, then this might be an ideal location to provide the client with any reminders that are required for that day.

Table 8.3. Example audio output from Virtual User Interface.

Possible User Interface Realisation	Example Trigger-Event	Audio Output
Incorporated into or alongside mirror above washbasin.	Standing in front of washbasin in the morning.	*"Gareth, your home-help will arrive one hour later this morning at eleven."*
	15 minutes before medication is due.	*"Gareth, don't forget to take your diabetes tablet this morning."*
	15 minutes after medication is due if not taken.	*"Gareth, you need to take your diabetes tablet this morning!"*
	In accordance with monitoring instructions.	*"Gareth, please measure your blood pressure this morning."*
Bedside Unit	Client gets into bed but has left the front door open.	*"Warning! You have left your front-door open!"*
	Getting out of bed in the morning.	*"Good morning Gareth. Today is Wednesday. The time is nine fourteen."*
Located by the side of the front-door.	Client steps by external door.	*"Don't forget to wrap up warm, it is cold outside."*
	Client is up and about for some time/client opens external door in the early hours.	*"Gareth, you should go back to bed, it is three in the morning!"*
Situated by bath/shower unit	Shower water temperature exceeds 'high-alert' level.	*"Gareth, be careful! The temperature of the shower is a little high."*
	Bath water level exceeds 'high-alert' level.	*"Gareth, The bath is nearly full!"*
Watch-based UI	Various alerts.	*"You have 5 minutes to cancel the alert before the system calls for help."*
	Client has not responded to alert.	*"Do not worry! CarerNet is requesting assistance."*
	Client in unstable state for extended period.	*"Gareth, Are you alright?"*

Medical Devices

Medical/physiological devices are reasonably straightforward to implement by creating virtual instances based on the most appropriate class structure and allowing values to be passed to them either manually or from a designated data/simulation file. However, there are several devices that require some form of user interaction in order to operate – even if this is just some form of activation (often these devices are used only intermittently or on-demand). In order to demonstrate the user-interaction element of some of these devices, a selection have been augmented with a graphical front-end for the underlying class-based functionality.

Figure 8.15 illustrates the graphical realisation of a virtual bathroom scales and glucose meter. Whilst both of these devices may be linked to a simulation data file, they can also be used 'as if they were real' by interacting with their graphical user interface (GUI). Data values may be input manually in order to test any associated CareWare services. Figure 8.16 illustrates the GUI for a virtual medication dispenser. The unit highlights by way of a bi-colour LED arrangement which compartment is currently 'active' – i.e. which compartment to take the medication out of. If the LED's are green it means that the

[19] *The V-UI also includes the ability to display video, thus enabling it to simulate a video doorbell/intercom.*

medication is ready to take; if red, then the client is more than half an hour late in taking it (or whatever the time has been set to). The compartments are 'locked' until the medication is designated as being ready for administering.

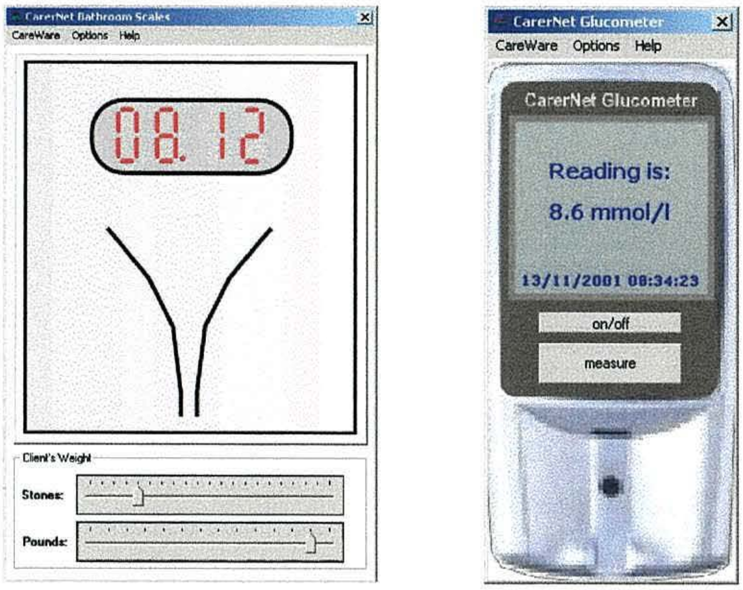


Figure 8.15. Virtual bathroom scales and glucometer, with graphical user interface.

The dispenser communicates with the medication reminder CareWare, which subsequently requests a suitable message to be displayed/generated at the V-UI. Various other CareWare modules are capable of interacting with the medication dispenser as was illustrated in Figure 7.46 (Chapter 7).

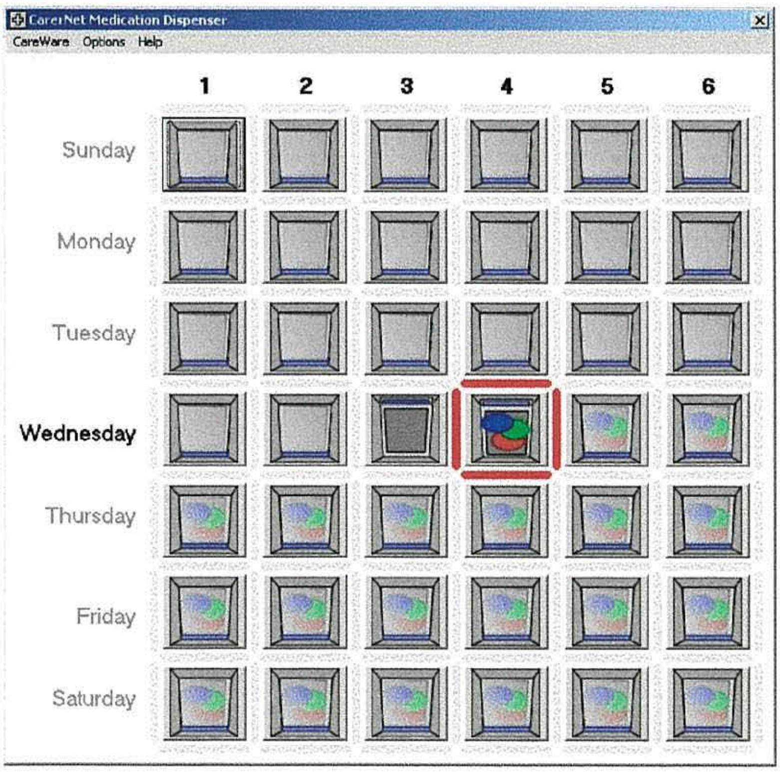


Figure 8.16. A virtual medication dispenser appliance.

8.3 Physical Device Implementation

A small number of prototype sensors have been developed, capable of indicating the status of various domain entities or raising an alert/alarm in the event of potential client distress. Their development was a useful exercise enabling various human factor, safety, and general design issues to be considered. Their construction ensured that a small number of services could be tested using real-life experimentation. Figure 8.17 illustrates a generic block diagram of a smart sensor arrangement built around a PIC microcontroller.

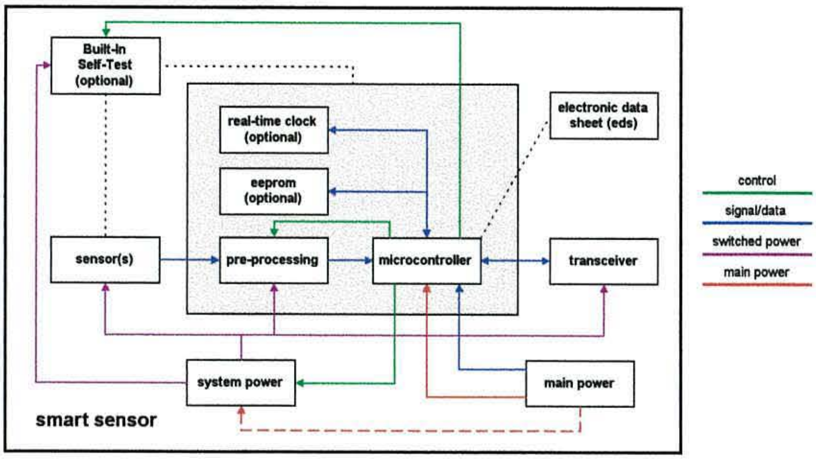


Figure 8.17. Block diagram of a generic smart sensor.

8.3.1 A Generic Conductivity Monitor

A prototype conductivity monitoring circuit has been developed for use in a variety of monitoring applications. Table 8.4 lists a selection of telecare applications for which the use of conductivity monitoring may be applied.

Table 8.4. Telecare applications for conductivity monitoring.

Data Type	Device	Comments
Boolean	Incontinence monitor	Monitors conductivity across inter-digitated array within absorbent incontinence pads (body-worn or bed-based variety)
	Sweat monitor	Monitors conductivity across inter-digitated array to detect an excessive amount of sweat on bed-sheets. Conceived for use with detection of nocturnal hypoglycaemic attacks in diabetics.
	Flood monitor	Monitors conductivity between point-electrodes/inter-digitated array to detect an excessive amount of water at floor level.
	Toilet flush use	By monitoring for the presence of water at the top of the cistern, it is possible to detect when the flush has been operated as the conductivity path between two electrodes will be broken when the flush is pulled.
	Water flow monitor	A crude form of (Boolean) water flow monitoring may be achieved by placing an electrode pair in the path of the water flow.
	Touch-sensitive switch	The conductivity of a client's finger can be used to perform the action of a touch-sensitive switch. Can be combined with 50Hz monitoring.
Analogue	Bath/washbasin water level monitor	By monitoring the conductance across a pair of electrodes that span the height of the bath/washbasin, it is possible to determine the water level.
	Rain monitor	Monitors conductivity across inter-digitated array to detect presence and/or intensity of rain-fall at ground/roof-level.

The same hardware is capable of supporting all of these services, with only slight modifications to the firmware and the characteristics of the sensor itself required to change between applications.

Exceptions to this rule include applications that monitor the level of conductivity (i.e. where an analogue output is required) as opposed to a switching function (i.e. a Boolean output that represents the presence or absence of a particular conductivity-related event).

Principle of Operation

When dry, an open-circuit will exist between the electrodes, but when exposed to moisture, the combined impedance of the arrangement will vary according to the conductivity and quantity of the conducting medium (e.g. water, urine). Figure 8.18 illustrates how such an arrangement can be used for determining the presence and level of water in a bath and a typical pattern for an inter-digitated array used for monitoring the presence of water/fluids (e.g. rain, sweat, urine). The detection circuitry must be capable of monitoring the impedance across the electrodes (A and C).

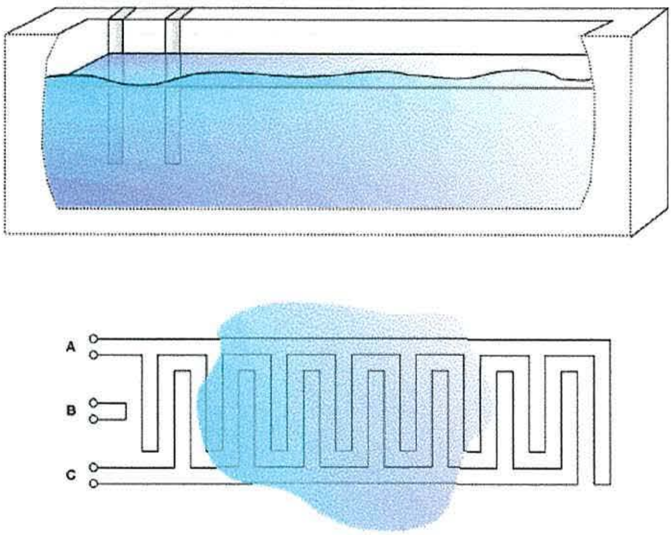


Figure 8.18. Bath water level monitoring and inter-digitated conductivity array sensor arrangement.

The sensor pre-processing must do two things:

1. Generate a suitable signal at one electrode to be used as the sensor excitation signal; and
2. Monitor the variation in conductance/impedance between electrodes A and C.

In order to minimise the effects of corrosion, an oscillating excitation signal should be employed. Figure 8.19 illustrates the circuit used for the prototype general-purpose conductivity monitor.

The excitation circuitry, which can be enabled/disabled by the PIC, consists of a standard astable oscillator which is a.c. coupled to the 'transmitting' excitation electrode. The electrode-pair and the medium being monitored form one-half of a potential divider with a 'preset' resistor. When the electrode is dry, its impedance is such that the voltage dropped across the sensing arrangement is large enough to switch the input of a Schmidt input NAND gate, whose other input is tied at logic level '1'. For Boolean monitoring, this oscillating signal is passed through to a capacitor which stores up the charge and keeps the output of the last NAND at logic level '0'. If the electrodes become exposed to moisture then the input to the first NAND gate stays low (the level at which this occurs can be adjusted using the variable resistor). This results in a permanent logic level '1' at the output of the first gate, which is inverted and fed into the final gate, resulting in a logic level '1' at its output. This change in signal wakes up the PIC which processes the event as appropriate.

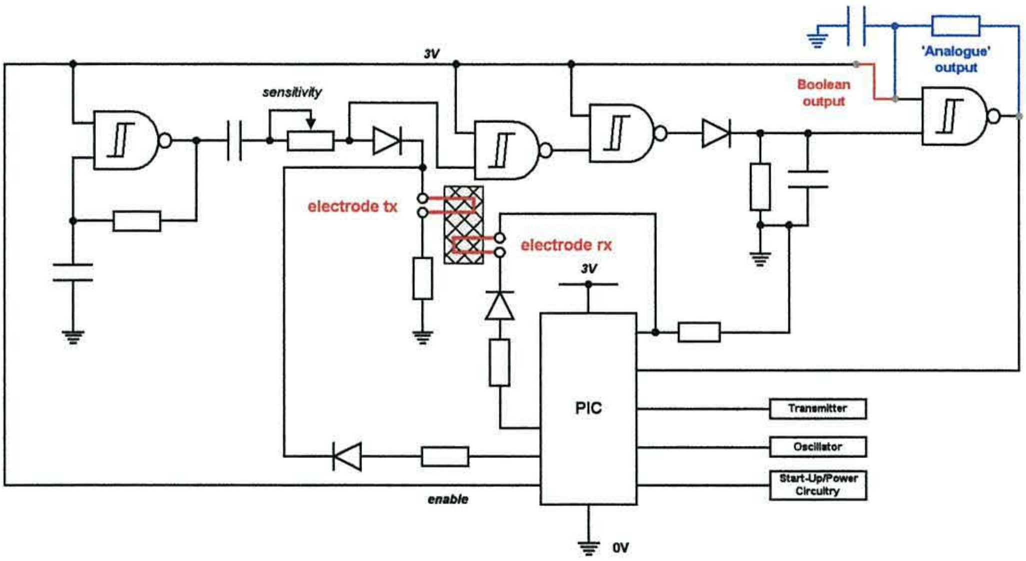


Figure 8.19. Generic conductivity monitoring circuitry (adapted from [178]).

The correct functioning of the sensing electrodes can be confirmed by the application of appropriate test signals to test for continuity (a form of Built-In Self Test). The oscillation signal may be generated by the PIC, allowing it to be varied (and hence introducing another means of altering the circuit's sensitivity), but at the cost of an increased power consumption.

An alternative prototype employing an inductive link between a sensor placed under a bed sheet and a surrounding detection coil, affording a wireless link between the sensor and its processing electronics, is described in [179].

8.3.2 A Simple Boolean State Sensor

This simple interrupt-driven device has been conceived to monitor the state of various domain entities with Boolean status characteristics. The hardware implementation is trivial, involving the use of a potential divider and an interrupt-based input to a PIC. Table 8.5 lists a selection of domain entities for which generic Boolean-state monitoring can be applied, with minor variations in sensor technology.

Table 8.5. Applications and sensor technologies for generic Boolean-state sensing.

Domain Entity	Example Sensor Technology
Door/Window status monitoring.	Magnetic proximity switch.
Fridge/freezer use.	Magnetic proximity switch or possibly a Light-Dependant Resistor (LDR).
Drawer/Cupboard/wardrobe use.	Magnetic proximity switch.
Bin/bread-bin use.	Magnetic proximity switch.
Letterbox use.	Magnetic proximity switch.
Client presence	Pressure pad.
Client sitting-up in bed	Pressure pad (under pillow).
Client (vertical) orientation	Mercury tip-over switch.
Toilet-seat occupancy	Force Sensitive Resistor (FSR).
Appliance power (e.g. fridge)	Inductive coil pick-up

The firmware implements a *booleanStateSensor* interface (if timing is implemented at the CareStation) or, alternatively, a *booleanStateMonitor* or *realtimeBooleanStateMonitor* interface (if timing is to be implemented locally).

8.3.3 Client Presence/Occupancy Monitoring

Lifestyle or behavioural monitoring is a key area of telecare. This work has proposed a technique based on whether the client is perceived to be in a 'stable' or 'unstable' state as determined by heuristic assumptions, and ultimately, experience of the client's unique lifestyle signature. Along with client location (i.e. room occupancy), a number of other client-initiated activities and events have been identified as being relevant both in terms of determining room occupancy and in establishing an indication of the Activities of Daily Living for the client. The present technique of monitoring the number of PIR activations is unlikely to provide, in isolation, an accurate representation of client activity. Therefore, a number of prototype devices have been developed with a view to investigating further the potential of lifestyle monitoring techniques.

The ability to identify the location of the client, whether on a room by room basis or to within specific areas of a room (e.g. by front-door; by washbasin; in chair; in bath; in bed) is a key feature of CarerNet. Table 8.6 lists a selection of client presence monitoring technologies. In general, client location may be determined using two techniques: those based on the 'visibility' of a client and those based on the detection of client-initiated events[20]. The latter are particularly relevant for performing lifestyle monitoring and assessment.

Table 8.6. Client presence monitoring techniques.

Client-'visibility'	
Video surveillance and pyroelectric 'imaging'	Electric Field Absorption Systems
Motion Detectors (PIR, Ultrasound)	Physiological Monitoring (e.g. temperature, ECG, etc.)
Pressure/Variable impedance pads (switches/weight sensing)	Load-cell/Strain-gauge based detectors/Force Sensitive Resistors (FSR)
Charge-based devices (capacitive, piezoelectric or electret-based sheets/pads)	Radio Frequency Identification (RFID) Tags
Volumetric Sensors (Microwave)	Beam & Twin-Beam Interrupt Technologies (Infrared)
Client-Action	
Operation of light switch	Transfer to/from chair or bed
Opening/Closing of door or window	Use of furniture (e.g. opening/closing drawers/cupboards)
Operation of Domestic Appliance	Operation of IR Remote Control
Telephone Off-Hook	Appliance use (e.g. kettle, fridge, Hi-Fi, microwave).

Piezoelectric Presence Monitor Pad/Cell

Standard pressure pads such as those used for intruder alarms consist of two metallic foil sheets separated by a thin piece of insulating foam, encapsulated within a plastic covering. The foam layer contains an array of holes which permit conduction to take place between the two metallic sheets upon the application of a suitable amount of pressure. These pads are designed for transient depression rather than frequent and prolonged depression, however, commercial devices that exploit a similar technology

[20] *Room occupancy determination can be segregated further into systems that operate* within *a room and systems that monitor the* transfer *across the interface between rooms (i.e. doorway monitoring).*

(they actually employ a conducting foam layer) are available for chair and bed occupancy monitoring for use in institutional care homes. These are considered to be disposable items with a finite lifetime (of between 90 days to 1 year). These 'switches' provide a Boolean representation of presence (i.e. occupied/unoccupied). Various other technologies have been considered for chair and bed occupancy monitoring including force sensitive resistors; temperature profile mapping; and strain-gauge/load cells.

To augment these devices, a range of prototype piezoelectric client presence monitoring sensors have been developed to identify the presence and/or occupancy of the client in or at a number of locations within the home. These devices are intended as proof of concept implementations and as such, the physical implementation of the sensing elements may be replaced with a more practical or innovative solution as appropriate. In particular, piezoelectric polymer and electret films are becoming increasingly available for application in presence (and physiological) monitoring [180]. The advantage of a piezoelectric device, for instance over a strain-gauge based implementation, is that the piezoelectric material possesses a self-generating signal so a monitoring device can be placed in a low-power mode for the majority of time. There are also less issues concerning calibration to adjust for various combinations of bed/chair and client weight & position. Piezoelectric sensors may also extend the quantity of services supported using the same sensor (see later). The applications to which these prototypes have been put to use include:

1. Bed and chair occupancy determination.
2. Washbasin use.
3. Toilet use (partial).
4. General-purpose presence-locating.
5. Stairway transition time monitoring.
6. Doorway transition monitoring.

The high-sensitivity of piezoelectric materials allows very low levels of vibration to be monitored. Even when an individual remains apparently motionless, there are a number of quasi-random 'micro-movements' that can be detected, caused by various factors, including: blood flow, breathing, and muscle tremor. These produce low voltage signals typically of the order of millivolts and mainly in the 1 – 100 Hz range. Large movements such as sitting in, or re-positioning oneself on, a chair will produce much faster voltage transients with signal levels several orders of magnitude higher.

Two basic varieties of piezoelectric sensor have been constructed: a 'cell' arrangement designed to be placed under the feet of a chair or bed; and a 'pad' and mat arrangement designed to be placed under a chair cushion, bed mattress or under a rug or carpet. Figure 8.20 illustrates the two options in the case of chair/bed occupancy monitoring (in practice, only one type of sensor would be chosen). The leg-based sensor consists of a piezoelectric unimorph embedded within a standard carpet protector housing, whereas the sub-cushion/mattress variety consists of a sheet of plastic or steel upon which a pair of piezoelectric unimorphs have been attached. Figure 8.21 and Figure 8.22 illustrate the sensor placement options for chair and bed occupancy monitoring, respectively.

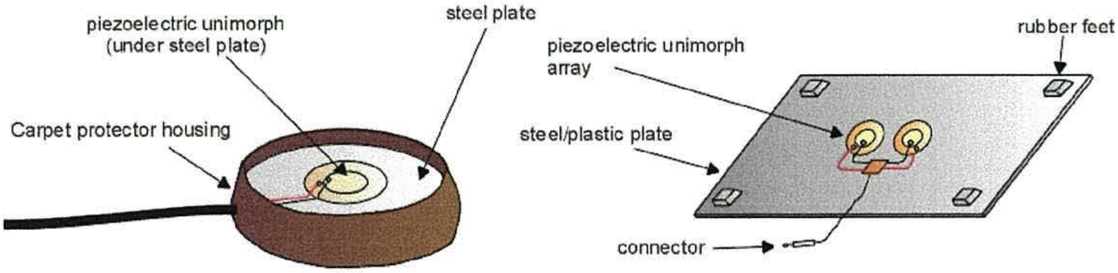


Figure 8.20. Prototype piezoelectric cell and pad for chair/bed occupancy monitoring.

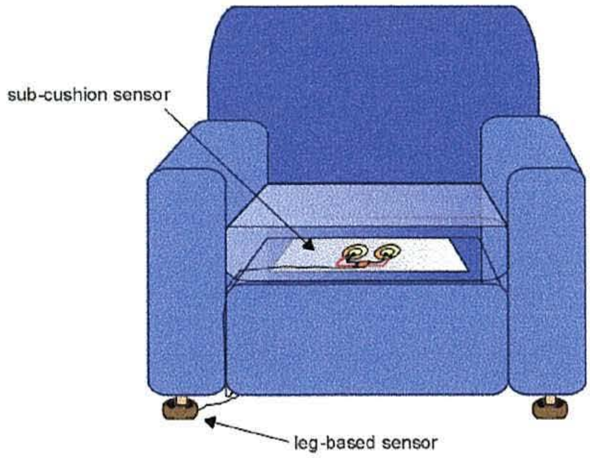


Figure 8.21. Sensor placement options for chair occupancy monitoring.

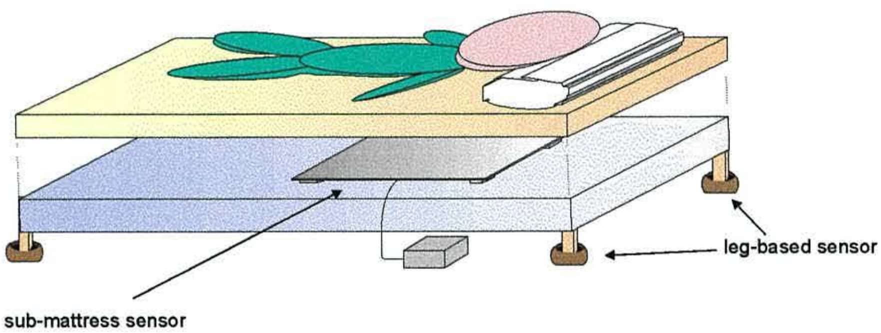


Figure 8.22. Sensor placement options for bed occupancy monitoring.

A third variety of piezoelectric presence pad has been constructed for use in more general purpose client presence/occupancy monitoring. Figure 8.23 illustrates the construction of the presence monitoring 'mat' and a selection of possible applications. An array of piezoelectric unimorphs are sandwiched between a pair of self-adhesive vinyl floor tiles, which can be placed underneath a rug or carpet in order to detect the presence of a client. Such a mat has been successfully used in the author's bathroom to detect the presence of a person by the washbasin and the toilet. With a slight modification to the circuitry, a similar device could also be used in doorway transfer monitoring and in stairway transition monitoring.

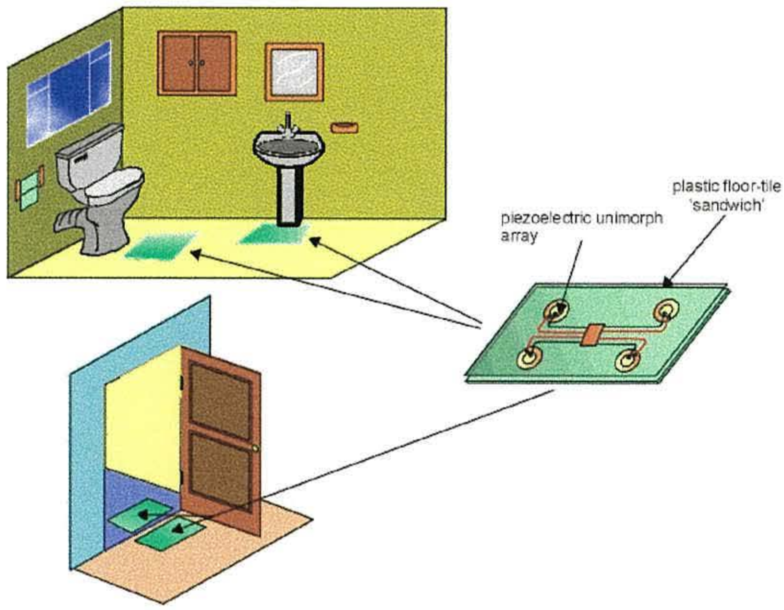


Figure 8.23. Piezoelectric presence 'mat' with example applications.

The prototype circuit arrangement implemented for processing such signals is presented in Figure 8.24. It consists of a pre-processing element that includes a diode limiter that clamps the magnitude of the input signal to within approximately ± 0.6V to protect the circuitry (running at 3V) from high-voltage transients generated by the piezoelectric crystal, which can be in excess of 40V. This is then buffered into a circuit which provides as output an absolute value of the input signal, i.e. a positive output equal to the magnitude of the input signal (effectively a full-wave rectifier, with gain). This signal is then split into two stages: one which determines the presence of the high magnitude transients associated with a client stepping onto a mat, or sitting on a chair, or lying on a bed; and another which is responsible for monitoring the low voltage signals produced when the client is effectively 'motionless'.

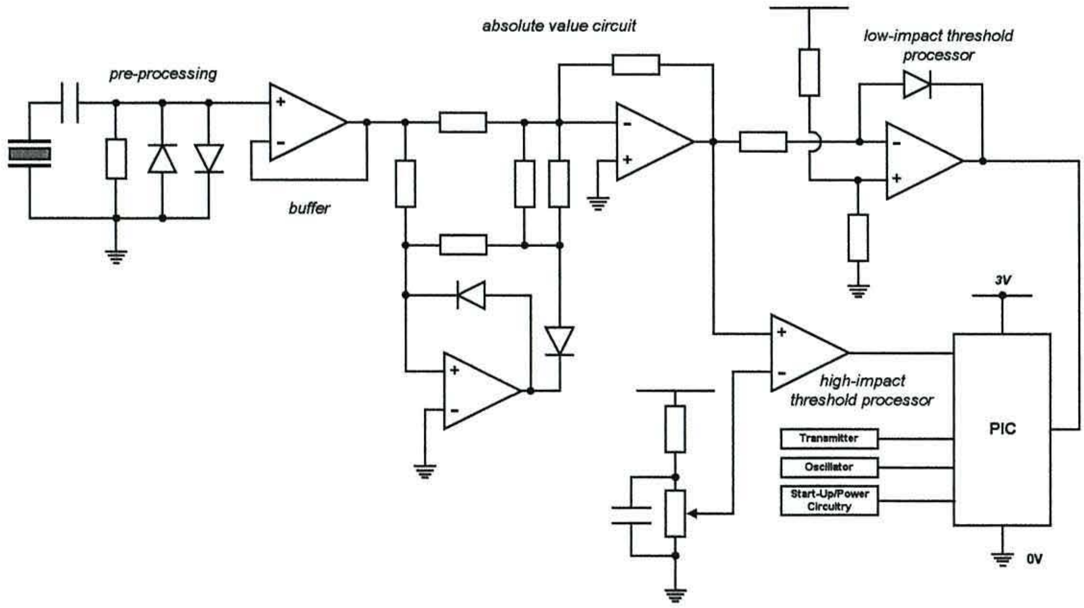


Figure 8.24. Schematic of piezoelectric client presence monitoring circuit.

The implementation illustrated in Figure 8.24 relies on a firmware algorithm to effectively 'integrate' and compare the measured signal with a pre-determined occupancy threshold in order to establish the presence or absence of a person[21]. The algorithm used to determine presence/occupancy status is described in Figure 8.25. For applications that require simple impact-detection (e.g. stairway monitoring or doorway transition monitoring) then a simple flip-flop arrangement using a low-power CMOS circuit will suffice.

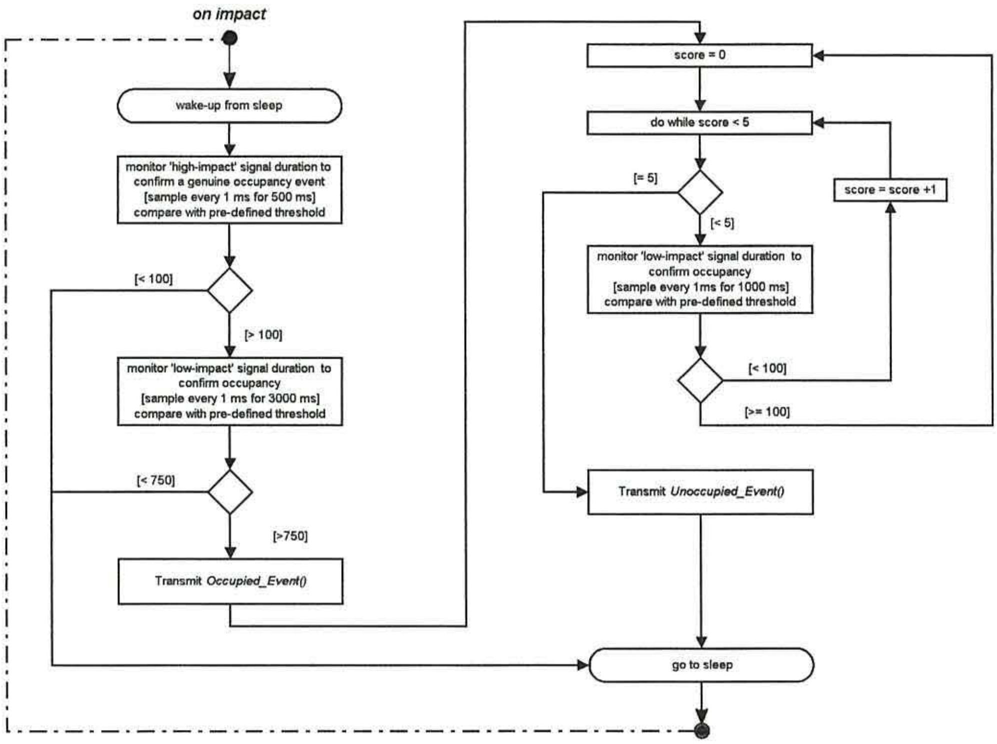


Figure 8.25. Chair/bed occupancy algorithm.

Figure 8.26 is an illustration of the output signal from the low-impact threshold processor generated from a leg-based sensor when sitting in a chair (A), occupying it for a short time (B) and then getting up again (C)[22]. The trace shows the extended drop in signal produced by sitting in the chair (an effect caused by a high-voltage transient produced through the action of sitting in, and to a lesser extent exiting, the chair). In between transfers, when the chair is occupied, and the occupier remains fairly inactive the number of transitions (and the duration of the 0V pulse) is very small, but even a slight readjustment in the seat will produce significant transients.

Because a level of activity may be determined from the mark-to-space ratio and the number of transitions (effectively an integration of the signal) it is possible to determine whether the client is restless during the night, which might be symptomatic of a diabetic hypoglycaemic attack or of some form of sleeping disorder. Another application which may be suited to this type of arrangement is the detection of nocturnal epileptic seizures.

[21] *An implementation using hardware equivalents was also investigated and may offer a lower-power solution. However, the firmware implementation offers the potential of increased flexibility in terms of tailoring the device to its environment.*
[22] *The occupancy states represented in Figure 8.26 have been 'compressed' in duration in order to fit on the diagram.*

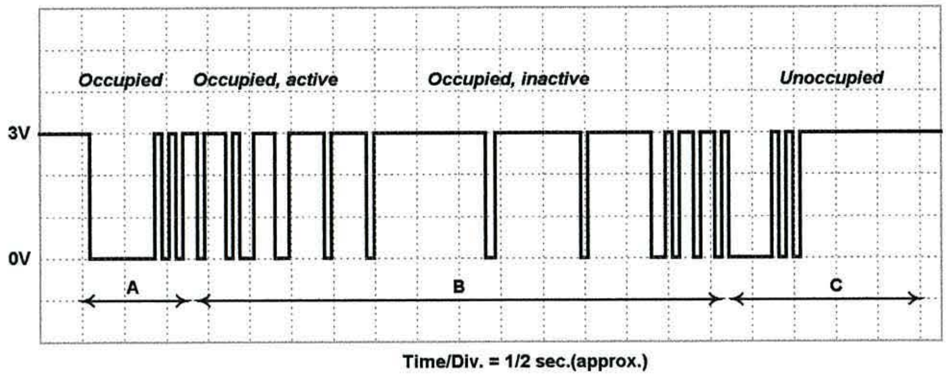


Figure 8.26. (Impression of) processed output from sensor front-end.

It may be possible to extract an individual's heart-rate and breathing pattern using similar sensing techniques and additional signal processing. Thus, this technique provides greater scope for implementing telecare services than basic pressure pads. The CareWare components associated with each service may be enabled/disabled depending on the care needs of the client.

TV/Remote Control Use Monitor

The prototype implementation of the television usage monitor is based upon the use of a remote control to operate the TV (or Hi-Fi). Whilst a simple detector of an infra-red signal may provide a simple Boolean indication of infra-red remote control use, it is possible to derive the actual status of the unit by demodulating the infra-red signal from the remote control and decoding it. Most modern TV sets use the channel buttons to turn on the device, and have a dedicated off button to place the unit into standby mode.

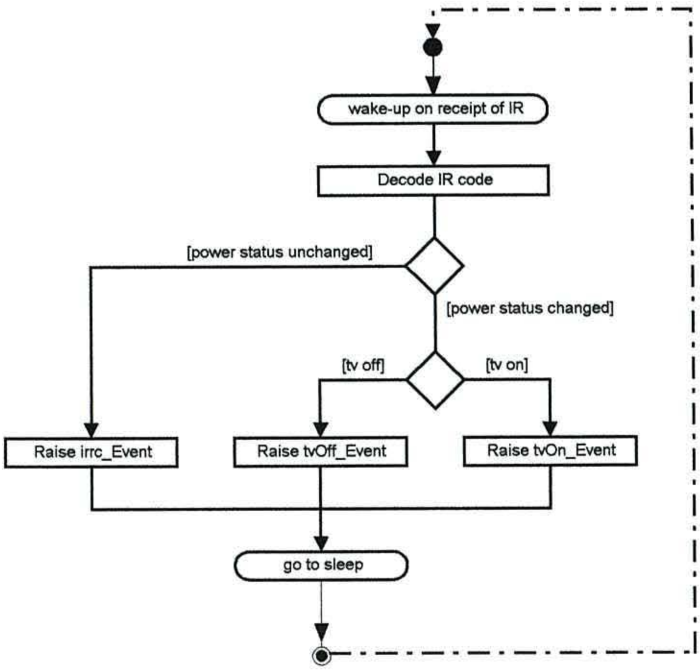


Figure 8.27. Simple determination of TV status from infra-red signals.

The advantage of using a remote control use monitor over (or as well as) a power-use based detector is that additional client-initiated 'activity' information may be derived from the signals produced by channel hopping and volume adjustment, etc. This data can be used to re-affirm the location of the client as well as to compare with normal trends (if an individual is feeling unwell, then they may be disinclined to watch as much television as normal). It may also be used to extend a chair occupied alert threshold, if the client happens to be sitting in the chair for longer than usual. The prototype uses a Sharp IS1U60, an industry standard infra-red receiver with on-board processing and demodulation of the infra-red carrier (typically of the order of 40 kHz). The demodulated signal is input into the PIC for decoding, see Figure 8.27.

A PIR-Based Room Activity Monitor

Whilst the reliability of *lifestyle* data obtained using PIR's in isolation has been questioned, their ability to detect an individual moving around a room does provide a useful indication of client *mobility*. This data may be applied to the determination of room occupancy and hence client location (assuming that the client lives alone). A PIR is not capable of identifying a particular individual like a Radio-Frequency Identification (RF-Id) tag would. However, a good indication of room occupancy, especially during transitions from one room to the next, will be provided, providing that the field-of-view of the PIR is setup correctly[23].

Standard PIR motion detectors have been implemented in community alarm systems before (to perform inactivity monitoring) and in a handful of telecare trials across the UK. Due to the retro-fit nature of such installations, the majority of these PIR's employ a wireless communications link in conjunction with a local emergency telephone unit or data-logger. The PIR transmits its unique identifier when it is triggered by activity within its field of vision, with a typical re-transmit rate of 15 seconds (to conserve battery power and minimise radio-frequency 'pollution' that may block other radio-based devices).

This mode of operation is however inefficient when used as part of an integrated telecare system. If other non-transient forms of room occupancy determination are available (e.g. chair occupancy monitor), then there is less demand for continuous updates of PIR activity. However, interesting variations in client activity (e.g. activity high or low alerts) are of use, as are periodic updates of PIR activity over time. This functionality is particularly important if the client is 'up and about' in the room for determining whether the client is in a stable or unstable state.

Thus, a prototype client activity monitor that keeps track of the level of mobility within a room has been developed based on a PIR. The implementation is based upon the *intervalMonitor* class described in Chapter 7. Typical activity scores were presented in Table 6.1, Chapter 6. In addition to providing mobility scores (i.e. number of activations per minute), the device is capable of raising an alert if the level of activity in the room changes by a significant amount. This information can be useful for determining if the client is in distress (e.g. secondary fall detection).

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[23] *i.e. looking in towards the room and not directly towards the entranceway to the room.*

8.3.4 Other Device Implementations

Various other 'one-off' prototype devices have been implemented to varying degrees of completion during the course of this work including: a smart body-worn fall monitor (including client impact and orientation information) [28]; a combined heart-rate monitor/breathing-rate monitor chest-strap (simple prototype) [173]; a generic temperature monitor; light level monitor; and sound level monitor.

8.4 CareStation Software

For the purposes of the demonstrator system, the CareStation software will incorporate a suite of software applications that will perform a variety of functions, including:

- Implementation of inter-device and domain analysis CareWare components.
- Domain visualisation & CareWare management software.
- External alarm notification and generation software.
- (Some) Data analysis tools.

8.4.1 Software Architecture

For the purposes of this initial prototype, the virtual sensor and inter-device CareWare components have been implemented at the CareStation. This is seen as a flexible mechanism with which to optimise and test the algorithms and rules so that they may be ported to their preferred network node with confidence. The nature of the CareWare was described in Chapter 7.

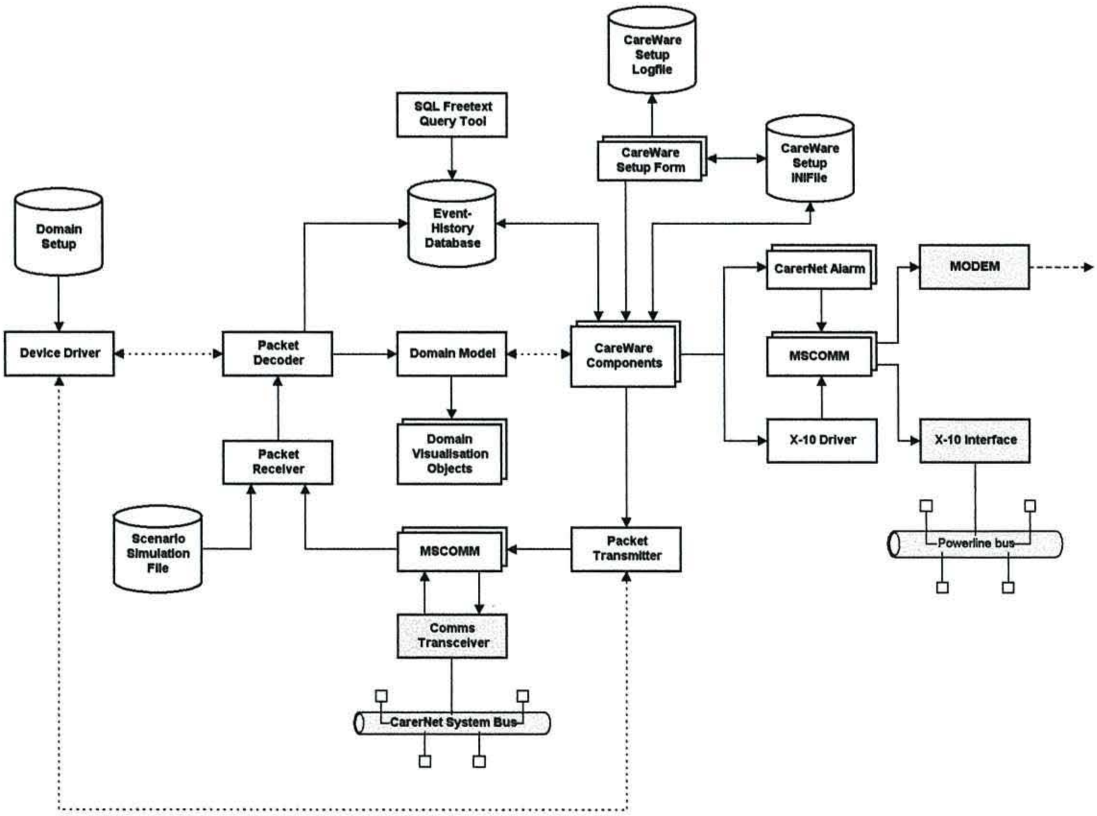

Figure 8.28. CareStation software overview.

Figure 8.28 illustrates an architectural overview of the CareStation software. MSCOMM is Microsoft's serial communications control which handles communications issues with a PC's serial port and the communications transceiver. Upon reception of a packet, the packet receiver is notified and structures the packet into a high-level object, thus assigning meaning to each byte. The packet receiver can also accept input from a scenario simulation file. Each packet object is then passed to the packet decoder which uses the device driver (which in turn uses knowledge of the domain) to determine the high-level information contained in the message. The packet decoder logs each event in the event-history database and updates the appropriate entity in the domain model accordingly. If a visual component has been altered, then the status of the corresponding Active-X control is also updated (this is performed automatically if the domain entity is actually represented by a graphical control rather than a class).

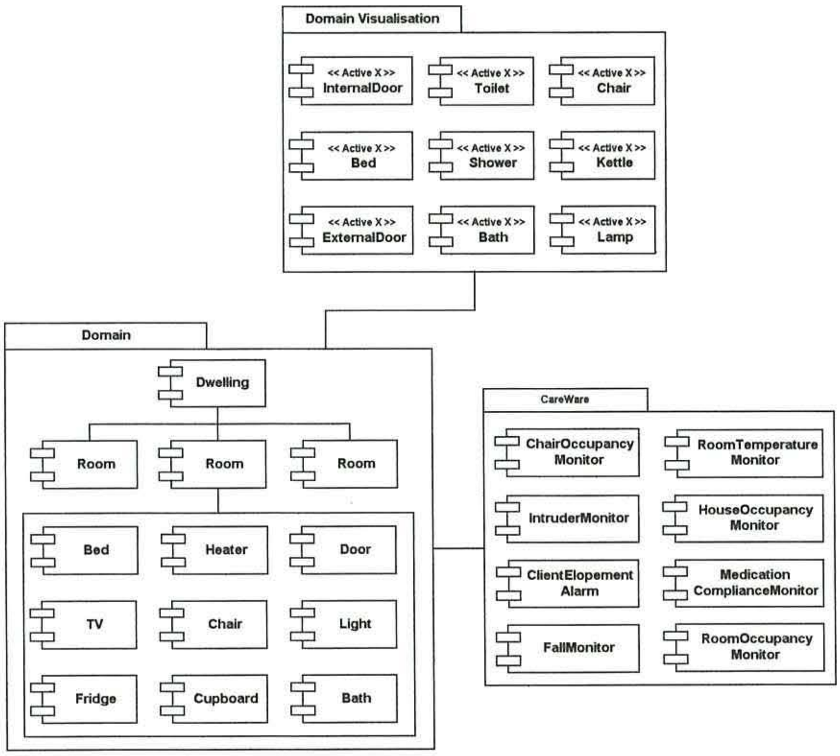

Figure 8.29. A partial package/component diagram of the local system 'intelligence'.

Figure 8.29 illustrates a hybrid package/component diagram describing the relationship between the implemented domain model and CareWare. Only a selection of components have been included, in order to simplify the diagram. The domain model is effectively a software construction of the domain analysis of Chapter 5, i.e. each domain entity that is of relevance will be represented by an object, the status of which will mirror its real-world counterpart (providing the device-level CareWare in the virtual domain has been setup to transmit the necessary events). CareWare components, compiled as dynamic link libraries (DLL's) and Active-X components, may then operate on these objects in order to monitor the status of the domain and respond accordingly.

CareWare components may interact with each other and with the domain model using the COM messaging mechanism. For instance, the domain model's Bathroom entity will be used by the *IntruderMonitorCareWare* to determine whether there may be an intruder within the dwelling. Figure

8.30 illustrates (for the case of the bathroom) the procedural software responsible for keeping track of the currently occupied and previously occupied rooms. It uses the 'neighbour' property of a room object to search whether the previously occupied room is a neighbour of the newly occupied room (refer to Figure 7.6, Chapter 7).

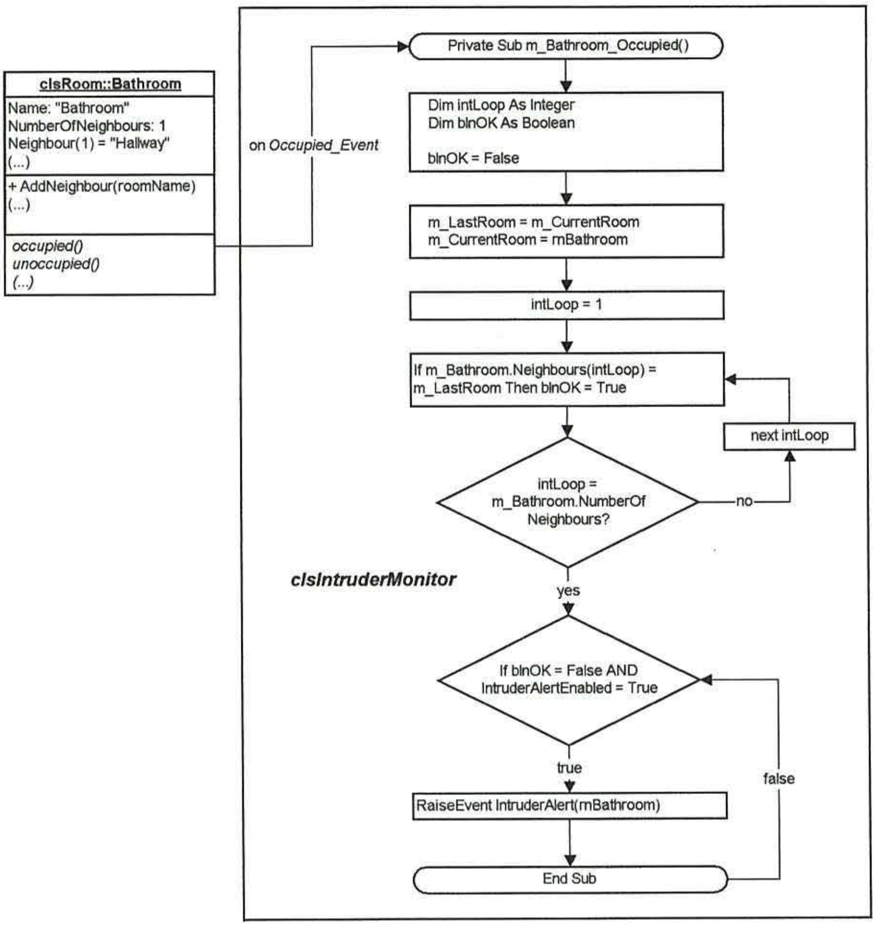

Figure 8.30. Intruder monitor CareWare example.

If required, CareWare components are capable of returning messages to the virtual domain via the packet transmitter in order to control an actuator or generate an alert. External alarms may be also be generated, if necessary, and if any devices are connected to the power line, they may also be controlled according to the CareWare components installed via the X-10 driver.

8.4.2 Domain Visualisation & CareWare Management Services

Domain Visualisation

In order to enable test scenarios and the status of the local domain to be represented, it is necessary to populate the virtual dwelling with fixtures and infrastructure; furniture; domestic appliances; and a client. Because this particular implementation is a *demonstrator* system, issues of privacy are not as pertinent as if it were a real-world implementation. The purpose for which the demonstrator system is to be used means that it is actually desirable to be able to visualise the status of the local domain (real or virtual).

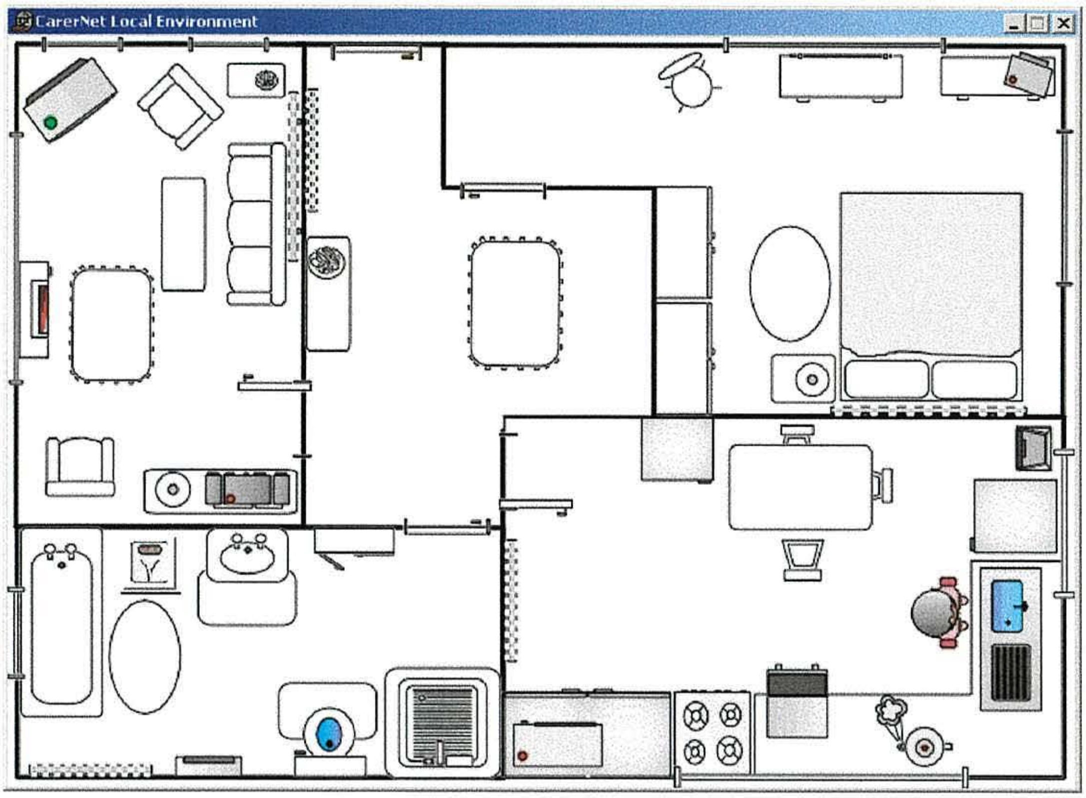

Figure 8.31. Populated floor-plan for 'virtual' dwelling.

Figure 8.31 is a screenshot of the visualisation of the virtual domain as perceived by the CareStation which illustrates the floor plan of the virtual dwelling populated with various virtual domain entities, and a client. These Active-X objects are linked in with the system's representation of its domain and are updated accordingly. Double-clicking on a domain entity of interest (which are highlighted when the mouse is placed over them) will load up an individual form describing in more detail the status of each of the entity's properties (as in Figure 8.13).

Alarm Generation & CareWare Setup

Apart from system-operator like message-boxes, various other alarm generation mechanisms have been implemented, including:

- Transmission of a numeric code upon detection of an alarm condition (e.g. client still in bed alarm) to a numeric pager[24].
- Transmission of an e-mail upon detection of (for instance) persistent failure to take medication.
- Use of a radio-doorbell device to inform a live-in carer when a client with dementia has got out of bed/out of a chair/left the fridge door open, etc.
- Use of a community alarm platform for generation of an external alarm to a community alarm response centre (e.g. fall detection)[25].

[24] *A numeric pager is easier to communicate with than an alphanumeric pager but illustrates the principle just as well.*
[25] *Supplied courtesy of Technology In Healthcare Ltd. and Tunstall Group Ltd.*

The CareStation software enables the CareWare operating parameters to be altered manually. Figure 8.32 illustrates the CareWare status and setup forms for bed-based monitoring services. CareWare operating parameters are stored in the setup initialisation file and each alteration of CareWare properties is logged in the setup log file, for auditing purposes.

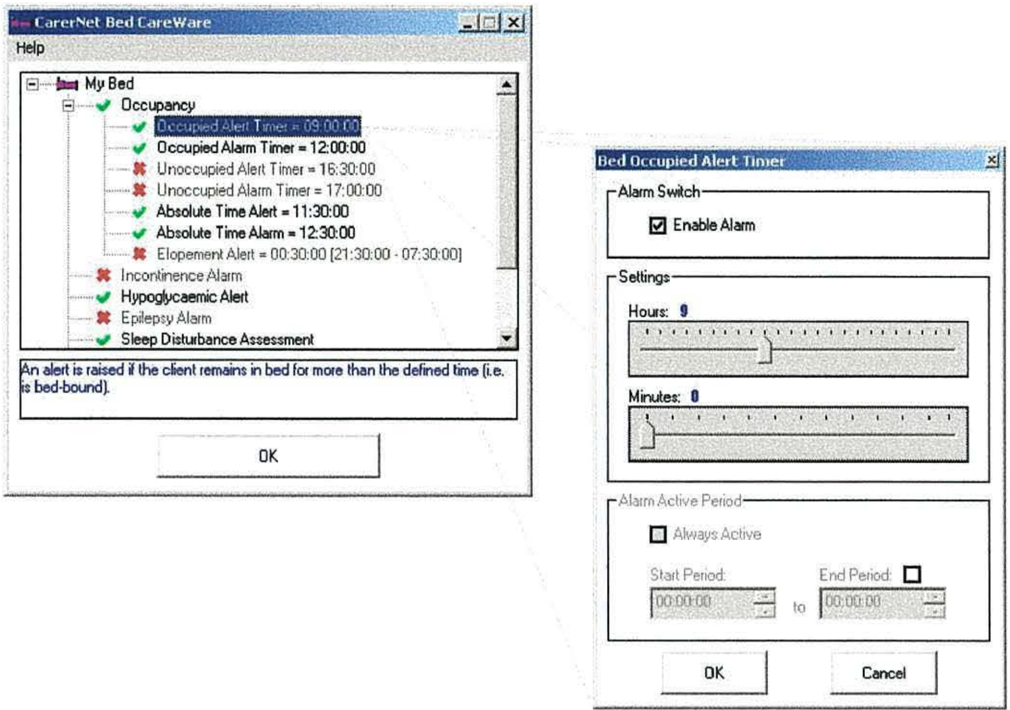

Figure 8.32. Example CareWare setup form for bed-based services.

8.4.3 Data Logging & Analysis

Each event received by the CareStation is logged in the event history database. This database may be viewed in real-time in order to confirm that the system is responding as expected, Figure 8.33. Structured Query Language (SQL) database querying capabilities allow pre-defined or free-text SQL queries to be formed in order to analyse the event data. SQL queries can be used to generate longitudinal plots of monitored data for visual analysis. For instance, Figure 8.34 illustrates a plot of self-administered blood glucose measurements over a period of approximately 8 weeks. The dashed lines superimposed upon the graph indicate the minimum, maximum, and mean values over that period.

CarerNet Event History Database

Event History

EventNumber	EventDate	EventTime	EventLocation	DomainEntity	Event	Data
27	22/05/2001	21:34:38	Kitchen	Kettle	On	
28	22/05/2001	21:34:44	Kitchen	Cupboard	DoorOpen	
29	22/05/2001	21:34:54	Kitchen	Cupboard	DoorClosed	
30	22/05/2001	21:34:57	Kitchen	Cupboard	DoorOpen	
31	22/05/2001	21:35:07	Kitchen	Cupboard	DoorClosed	
32	22/05/2001	21:35:11	Kitchen	Chair	Occupied	
33	22/05/2001	21:36:42	Kitchen	Kettle	Off	
34	22/05/2001	21:36:47	Kitchen	Chair	Unoccupied	
35	22/05/2001	21:36:49	Kitchen	Fridge	DoorOpen	
36	22/05/2001	21:37:05	Kitchen	Fridge	DoorClosed	
37	22/05/2001	21:37:34	Kitchen	Room	LightOff	
38	22/05/2001	21:37:36	Hallway	Room	Movement	

Figure 8.33. The event history database logs each event received at the CareStation.

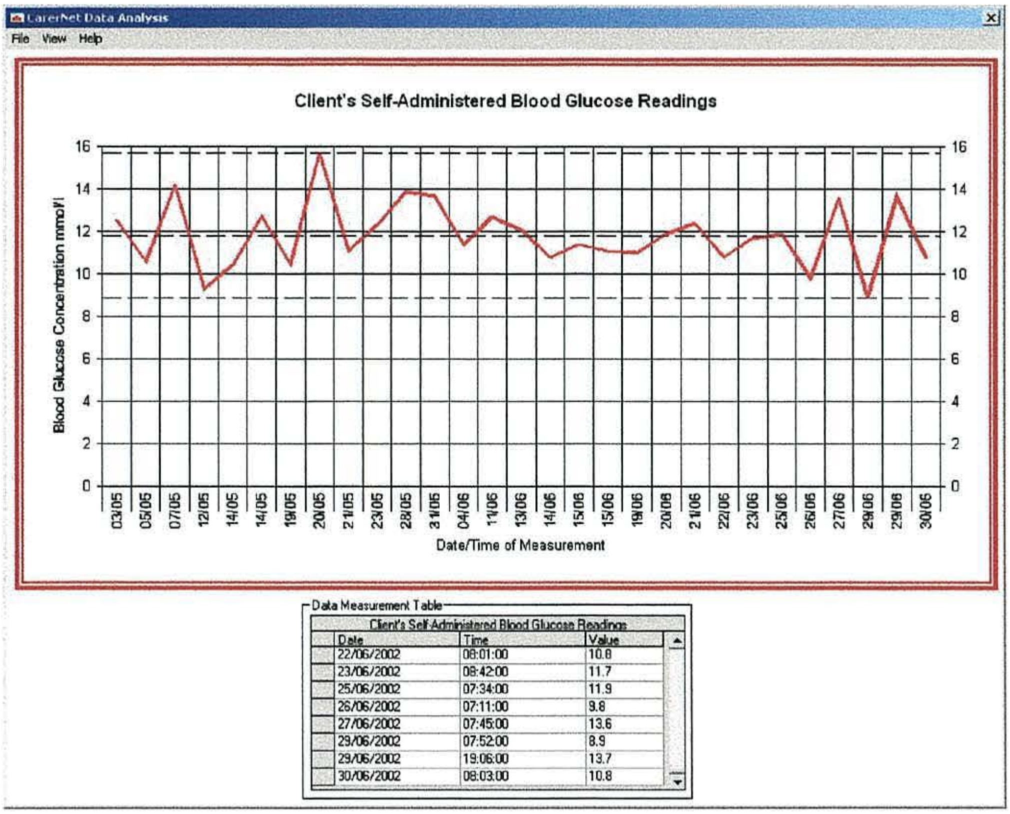

Figure 8.34. Example chart of blood-glucose readings over the course of an 8 week period.

These SQL 'scripts' may be automated in order to establish a trend or an average value for particular properties in order to feedback operating thresholds into the CareWare components (a crude form of learning). For instance, a combination of an SQL query and procedural routines are capable of adapting the operating properties of the *bedOccupancyMonitor* CareWare for the client[26]. This involves establishing the mean bed occupancy time for the client and using some multiple of the standard deviation (SD) to set an intervention alert threshold. The multiple of the standard deviation used to raise an alert may start off low and be steadily increased if there are repeated false alarms.

The example of Figure 8.35 shows an SQL query selecting a number of days worth of bed occupied times from the event history database and loading them into an array. These time-values are subsequently converted into a number of minutes in order to simplify the calculation of the mean bed occupancy time and their standard deviation. Once calculated, the appropriate threshold value can be assigned; for example the *bedOccupiedAlert_Threshold* may be assigned to [mean + 2SD] and the *bedOccupiedAlarm_Threshold* to [mean + 2.5SD][27]. This value is then converted back into time format and used to alter the *bedOccupancyMonitor*'s bed occupied alert and alarm thresholds accordingly.

[26] *This routine may be used for other timer-based CareWare.*
[27] *Assuming a normal distribution.*

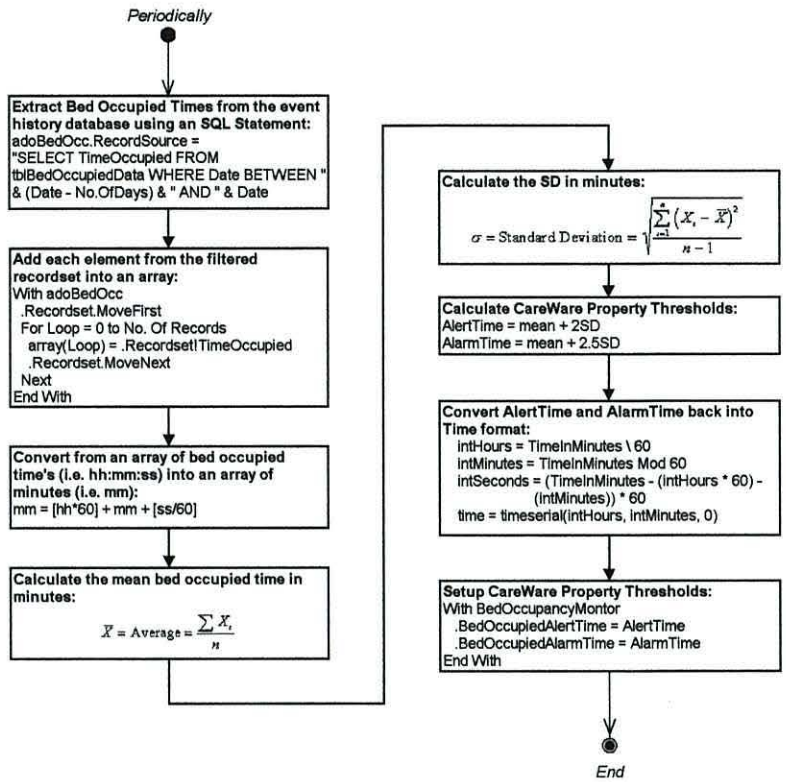

Figure 8.35. Algorithm for calculating rolling threshold for bed occupied alert/alarm.

8.5 Conclusions

The practical work presented in this chapter provides a platform upon which the principles of CarerNet may be investigated. The realisation of a virtual domain and associated virtual devices within an integrated care environment (V-ICE) has paved the way for a means of testing CareWare components by means of event-based scenario generation, described further in Chapter 9. The V-ICE may be considered a research tool capable of developing and demonstrating various telecare services. The PC-environment provides a more flexible development platform for potential services to be conceived prior to porting the necessary code to an embedded microcontroller. The domain visualisation components developed provide a useful method for representing the status of the client and the local domain. Whilst they may not be suitable as a means of monitoring the client while at home (due to privacy issues), they are useful when analysing test data.

The physical prototypes that have been constructed have proved that many devices may be implemented using common sensing technologies and circuitry which may have important implications for providing low-cost solutions. Furthermore, they have extended the potential for system testing into the real world, allowing real–life experimentation to take place.

The high-level nature of the development software, allowing events to be stored in a relational database format (with SQL querying capabilities) provides a ready-made platform upon which data analysis may be performed. Furthermore, a variety of alternative external communications mechanisms (i.e. e-mail, SMS, pager, community alarm) have been realised in prototype form.

Chapter Nine

System Verification

This chapter will describe some of the verification work that has been undertaken in order to test the implementation against the requirements set out in previous chapters. In order to perform this testing, it was necessary to develop simulation software capable of generating relevant test-data. A description of the simulation software and the results of the preliminary tests will be presented. Furthermore, some of the CareWare components identified in Chapter 7 have been ported to an embedded solution as part of a 'smart' sensor implementation. Finally, some of the work presented in this thesis has been implemented or selected for implementation at a number of telecare trial sites throughout the UK, and aspects of this work will also be described.

9.1 Software Component Testing

Figure 9.1 illustrates the sequence of tests undertaken in order to verify the operation of CarerNet services with the prototype implementation. Each of these tests will be described with reference to a number of example services.

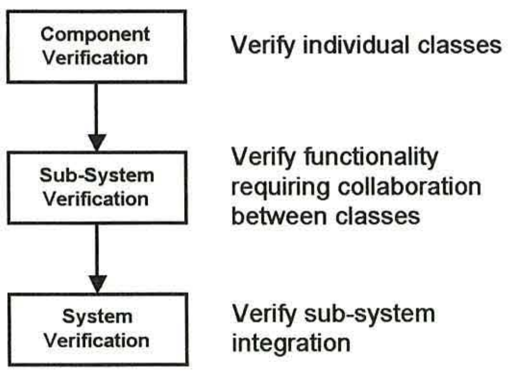

Figure 9.1. System verification strategy.

9.1.1 Component Verification

Many services are realised using the common class structures identified in Chapter 7. Therefore, the first level of verification must involve the isolated testing of these underlying CareWare classes. In order to achieve this, test code was implemented allowing each method and property of the class to be altered manually using a test form. Figure 9.2 illustrates the form produced to test the functionality of the *CarerNetBooleanEventMonitor* class. Figure 9.3 illustrates a similar arrangement used for testing the *CarerNetIntervalMonitor* class.

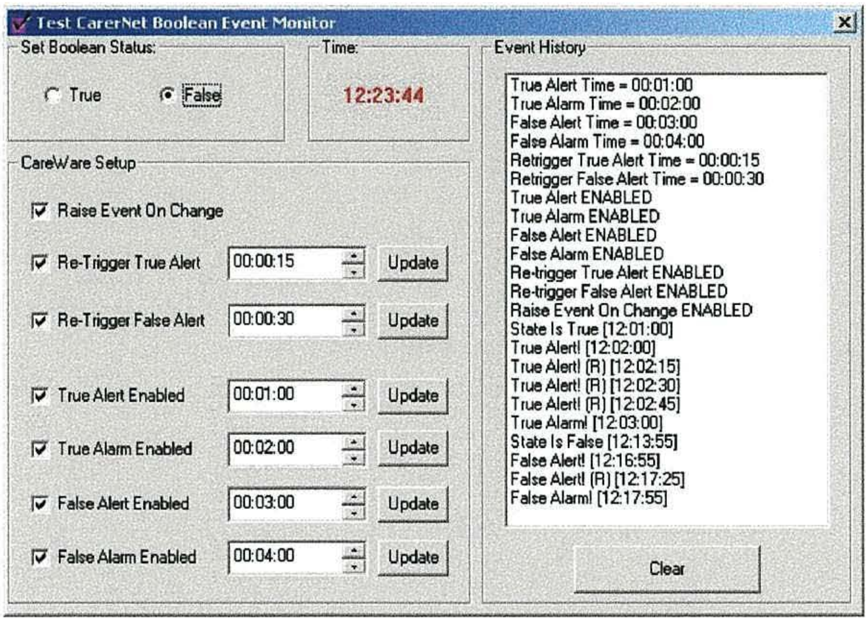

Figure 9.2. Test form for *CarerNetBooleanEventMonitor* class.

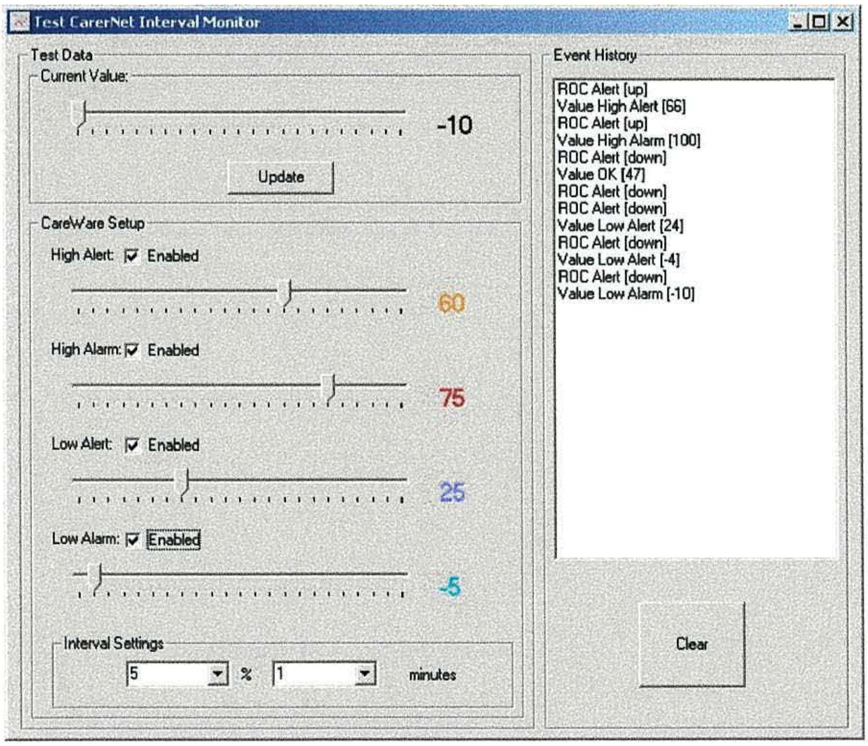

Figure 9.3. Test form for *CarerNetAnalogueMagnitudeThresholdMonitor* class.

Once the operation of a component has been verified, it may be applied with confidence in the various sub-systems that depend on it. Each component was thoroughly tested in this manner for all possible combinations against the behaviour implied in the class analysis of Chapter 7.

9.1.2 Sub-System Verification

Once individual software components have been verified, it is possible to implement and test the various sub-systems. In particular, it is necessary to verify the operation of the packages of interacting classes that must collaborate in order to perform a function or service (e.g. inter-device CareWare) as this is where the real benefit of adopting a systems approach may be realised. Because these services involve multiple classes, and (sometimes) complex interactions, the testing strategy is more involved. In order to systematically test these sub-systems, a means of automating the testing process was conceived.

Virtual Domain Software Overview

Figure 9.4 is an overview of the architecture for the Virtual Domain software, which includes many of the components whose function was described in Chapter 8 (in relation to the CareStation software). The components unique to the virtual domain include the virtual device CareWare (also described in Chapter 8) and those responsible for creating and generating the test scenarios. The latter include: the Event Generator, the Simulation Timer, the Scenario Manager, the Scenario Simulation database, and Client Activity Macros. The function of each of these will be described during the course of this chapter.

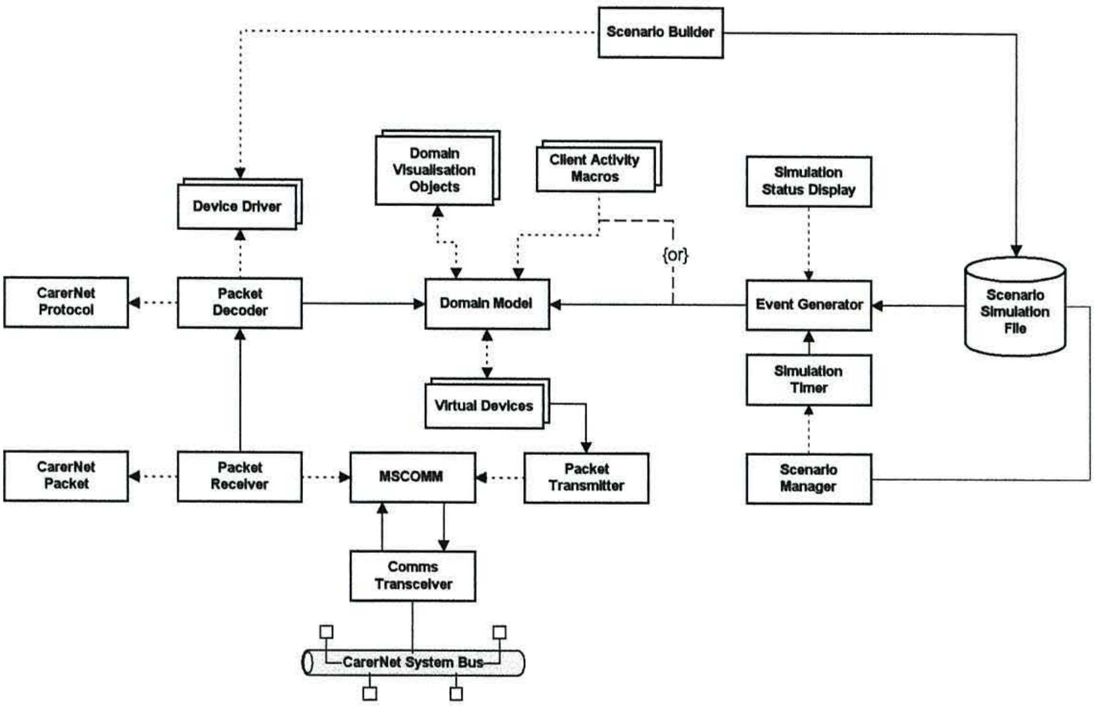

Figure 9.4. Overview of software architecture for virtual domain.

Event-Based Client Scenarios

In general, telecare services involve the detection of when domain properties:

- Exceed permitted thresholds (e.g. time in bed > *bedOccupiedAlertTime*);
- Vary according to a particular pattern (e.g. the client is not moving around as much as she used to);
- Have or have not changed state (within a given time frame) (e.g. client has not taken their medication with their breakfast this morning);

- Occur in a particular sequence (within a given time frame) which may indicate a problem (e.g. client gets out of bed, but does not move into the hallway, and an activity low event is raised in the bedroom – check whether the client has fallen.).

So while some services may be tested simply by generating suitable data values in excess of the set thresholds, others require suitable events to be generated in a designated sequence and at an appropriate time. These sequences of events often correspond to particular scenarios that the sub-system under test has been designed to monitor and/or react to. These scenarios may be generated in a number of ways:

- **Manually** (and in real-time) – either by acting out the required activities or by generating simulated events using test software;
- **Automatically** – by generating pseudo-random sequences of client activity or by using a pre-determined event-database of simulated or real-life scenarios.

Chapter 8 mentioned briefly some of the issues concerned with testing telecare services (Section 8.2). The testing process must ultimately revolve around event-based scenario generation, with the level at which events are injected into the system being the only consideration. In the first instance, this involved software-generated high-level scenarios that directly manipulate the properties of the virtual domain (i.e. client and local environment), which subsequently act as input to the sub-systems under test.

Client Activity Macro's

As mentioned in Chapter 6, the activities that one might expect an individual to perform will depend on the room that they are in. Furthermore, Table 6.2 listed some of the sub-activities/events that correspond to these activities of daily living. Figure 9.5 illustrates a selection of activities that a client might reasonably be expected to undertake on a room by room basis.

Each of these activities may subsequently be decomposed into a series of events, which can be used to simulate its occurrence. For instance, it is conceivable that the "answering door" activity may be simulated by generating the following sequence of events[1]:

1. Hallway occupied event;
2. Front door (internal) presence event = True;
3. Front door open event;
4. A delay;
5. Front door closed event;
6. Front door (external) presence event = False;
7. Front door (internal) presence event = False;

Thus, each of the activities of interest may be decomposed into a sequence of events that can be used to simulate the everyday interaction of the client with their local environment. The realisation of these specific sequences of events as executable pieces of code have been termed *client activity macro's*.

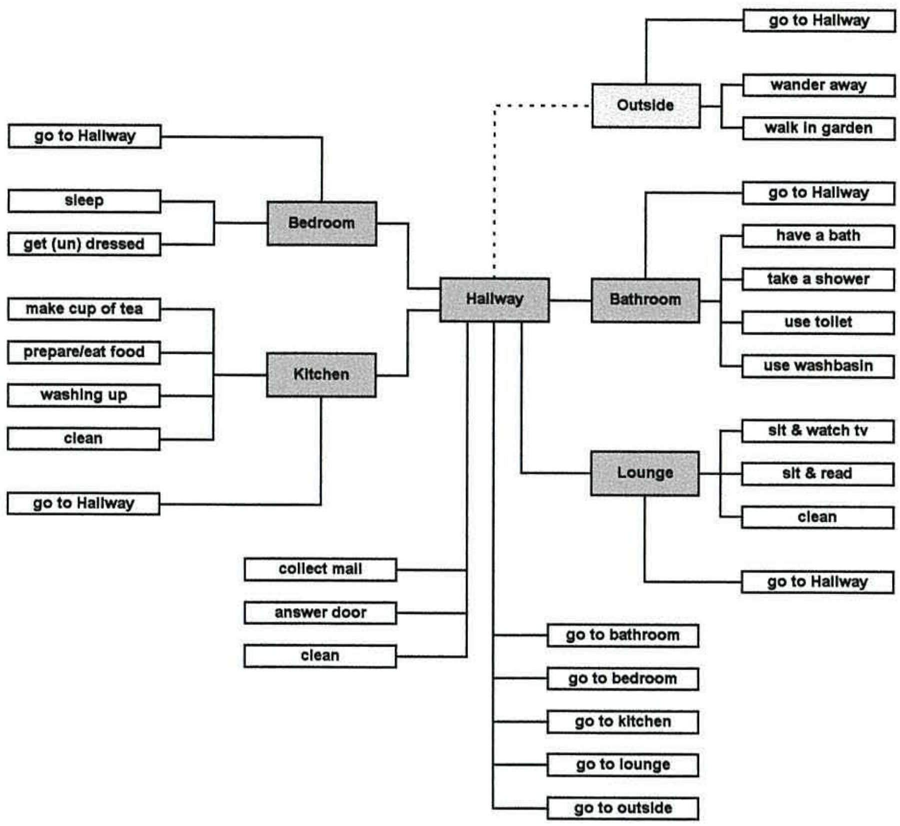

Figure 9.5. A selection of room-specific client activities.

The duration of an activity macro that is non-instantaneous can be set using a random number generator that outputs in time format (e.g. "00:03:45" – 0 hrs, 3 min & 45 seconds). Either a standard random number generator may be used (i.e. evenly distributed over a given range) or one that generates time according to a normal distribution, given a mean time and standard deviation. The latter enables 'normal' times to be applied, but with a variance that is capable of generating potential alert conditions[2]. This is useful for testing services such as client distress alerts (e.g. for generation of room, bath, bed or chair occupied/unoccupied alerts, etc.) or for generating random times for how long the front door is left open or for how long the client has been out of the home. Figure 9.6. to Figure 9.8. illustrate client test scenarios involving the use of various client activity macros.

[1] *Proceeding events might include: Front door (external) presence event = True; Doorbell event; Chair (lounge) unoccupied event;*

[2] *For example, one sample run with a mean of 1 min. and a SD of 30 sec. generated 22 values greater than 2 min. [Mean +2SD] in 1000 events (2.2%) which is of the order to be expected (>2SD approx. = 2.5% of area under normal distribution curve).*

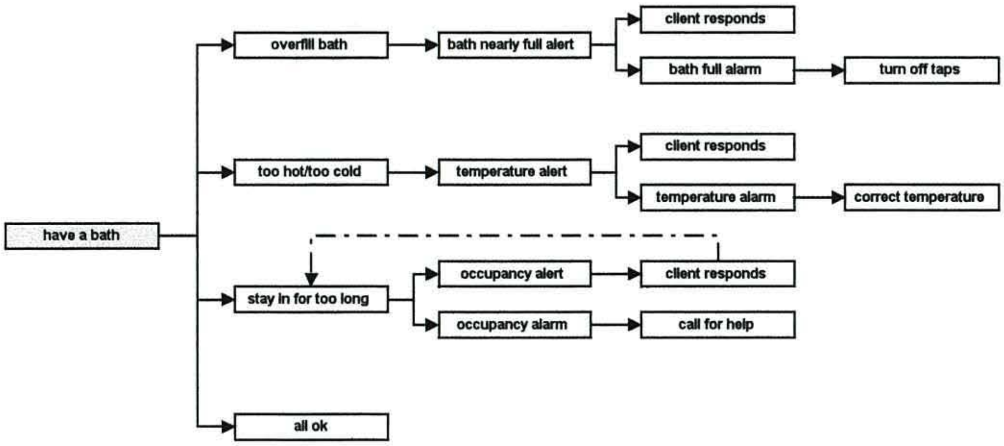

Figure 9.6. Test scenarios to verify operation of *bathSafetyCareWare* package.

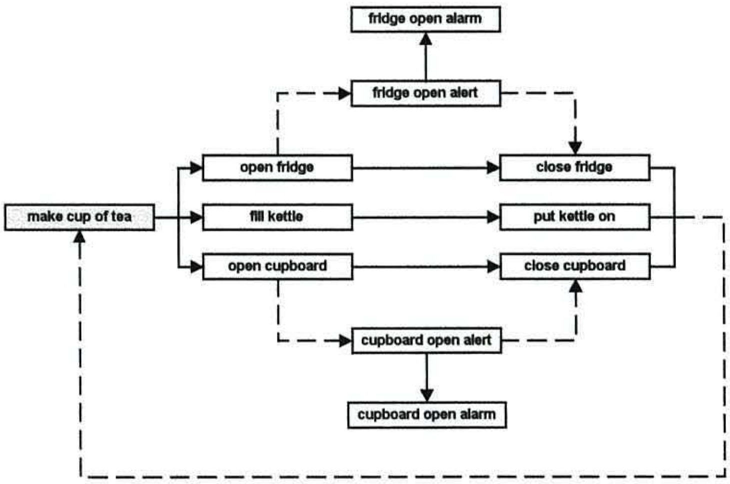

Figure 9.7. Test scenarios to part-verify operation of *clientDistressAlert* CareWare in the kitchen.

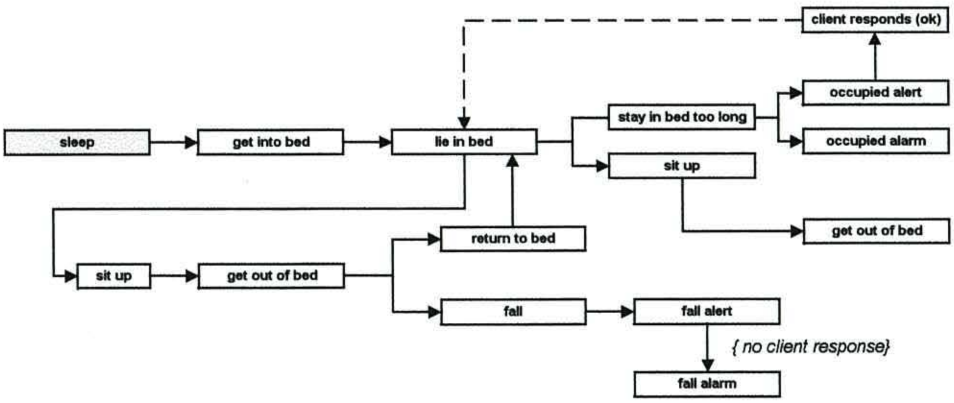

Figure 9.8. Test scenarios to verify operation of various bed-related CareWare packages.

Example 1: Client Elopement Alarm Service

For example, consider Figure 9.9 which illustrates the test environment used to verify the correct operation of the *clientElopementAlarm* service. This might be prescribed for a client with dementia who is prone to wandering away from their house and getting lost. It raises an alarm if the client leaves the house for a period greater than the allotted *clientElopementTime* and may be enabled or disabled manually or according to the time of day.

The test environment must represent each of the domain entities with which the subsystem interacts. In order to confirm the correct operation of the *clientElopementAlarm*, a sequence of events were generated that moved the client 'randomly' between various rooms in the home (always via the hallway, i.e. it conformed to the room connectivity of the home, refer back to Figure 8.2) and while in the hallway would trigger one of the client activity macro's of Figure 9.10 in a random fashion.

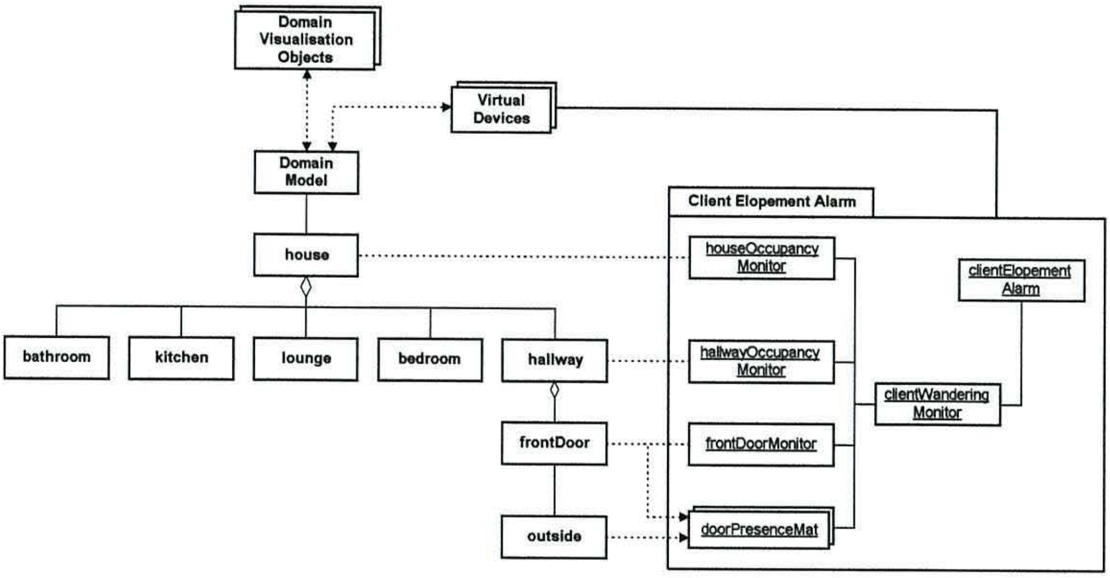

Figure 9.9. Domain entities used for verifying the operation of the *clientElopementAlarm*.

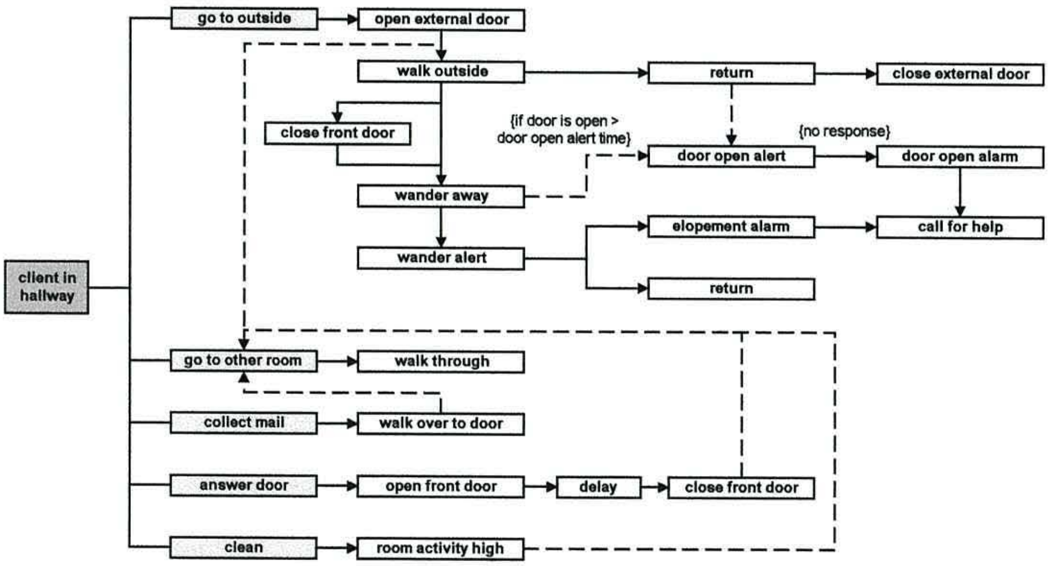

Figure 9.10. Test scenarios to verify operation of *clientElopementAlarm* package.

Table 9.1 lists some of the example scenarios used to test the *clientWanderingMonitor* and *clientElopementAlarm* services.

It is possible to simulate client activity/mobility in a room by generating the equivalent of a PIR movement event in the room at a rate proportional to the level of activity required. This is possible by calling the *roomActivityMonitor's* (i.e. PIR) *GenerateMovementInRoom* test method. This event is then processed by the roomOccupancyMonitor and any other dependent components. The rate at which the PIR is triggered is determined by the use of a random delay between events, the range of which is altered according to the desired activity level in the room.

Table 9.1. Example test scenarios for *ClientWanderingMonitor* & *ClientElopementAlarm*.

Example Scenario	Simulated Events	Required Response	Pass
Client enters hallway and passes through (e.g. to lounge)	*Hallway Activity Change Event* *Lounge Activity Change Event*	< none >	✓
Client enters hallway and opens front door but does not go outside, closes door and leaves hallway	*Hallway Activity Change Event* *Front door (internal) presence event = true* *Front door open event* *Front door closed event* *Front door (internal) presence = false* *Kitchen Activity Change event*	< none >	✓
Client enters hallway, opens front door for fresh air and remains in hallway, does not close door, client cleans the hall.	*Hallway Activity Change Event* *Front door (internal) presence event = true* *Front door open event* *Front door (internal) presence event = false* *{Hallway PIR remains active}*	< none >	✓
Client enters hallway, opens front door and leaves hallway into another room (i.e. does not leave the home).	*Hallway Activity Change Event* *Front door (internal) presence event = true* *Front door open event* *Front door (internal) presence event = false* *Bedroom Activity Change event*	< none > {*DoorStatusMonitor* will eventually raise an alert}	✓
Client enters hallway, opens front door and goes outside, closing door behind them. Client returns within the specified client elopement alarm time.	*Hallway Activity Change Event* *Front door (internal) presence event = true* *Front door open event* *Front door (external) presence event = true* *Front door (internal) presence event = false* *Front door closed event* *Front door (external) presence event = false* *Hallway Activity Low Event*	ClientWander_Alert	✓
	Front door (external) presence event = true *Front door open event* *Front door (internal) presence event = true* *Front door (external) presence event = false* *Hallway Activity change Event* *Front door closed event* *Front door (internal) presence event = false*	ClientWander_OK	
Client enters hallway, opens front door and goes outside, closing door behind them and does not return within specified client elopement alarm time.	*Hallway Activity Change Event* *Front door (internal) presence event = true* *Front door open event* *Front door (external) presence event = true* *Front door (internal) presence event = false* *Front door closed event* *Front door (external) presence event = false* *Hallway Activity Low Event* *{clientElopementAlarmTime} later ......*	ClientWander_Alert ClientElopement_Alarm	✓

Example 2: Testing CareWare Threshold 'Learning' Algorithm

It was not within the remit of this work to develop in any great detail the intelligent algorithms capable of learning and hence adapting to their environment. However, it has been possible to implement a simple illustration of how the system could adapt to the behaviour of its client by employing basic statistical methods and assuming normal distributions. This particular example is concerned with determining the best value for the *bathOccupiedAlertTime* for a particular client.

A number of bath use events were simulated with duration generated randomly according to a normal distribution with a mean of 00:19:32 and a standard deviation of 00:02:31[3]. In this example, the *bathOccupiedAlertThreshold* is set to (Mean + 2 x SD).

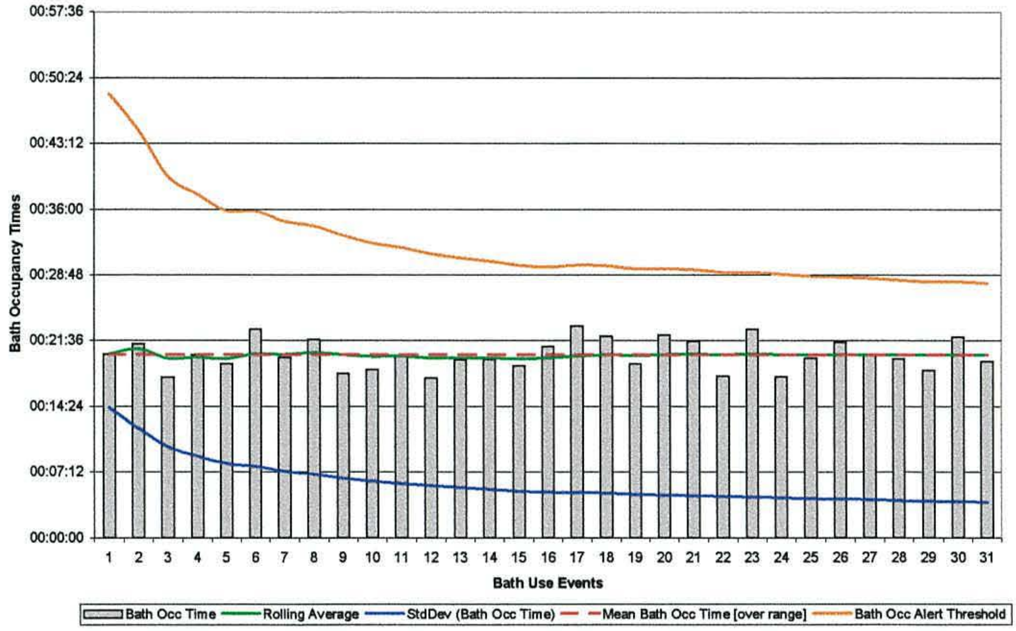

Figure 9.11. Example of system 'learning' using averaging methods (for bath occupancy).

Figure 9.11 shows how a rolling average of bath occupancy times in conjunction with a calculation of the standard deviation eventually stabilises after a suitable number of bath occupancy events have occurred. The system could, in practice, be set up to use a pre-defined threshold up until the 'learned' value became stable (or less than the pre-defined value, e.g. start off by asking client how long they typically spend in the bath and add 10 – 15 minutes - in this e.g. set pre-defined to 30 minutes and switch to learned value after approximately a dozen events).

9.1.3 Sensor Prototype Verification

The prototype sensors were tested in the laboratory (and some in the author's home) and connected to the RS-485 bus in order to feed events/data to the virtual domain. They worked reasonably well and were used during some scenario testing in place of their virtual counterparts.

There is an issue with the algorithm for determining chair/bed occupancy using the piezoelectric sensor. It currently takes in the order of 4 seconds to determine if the client has got out of the chair/bed, due to the 'integration' process. This might be a problem if this information is required to trigger an action such as fading up a light. It is likely that further refinement of the circuit/algorithm will enable this time to be shortened. This is not a significant issue for lifestyle monitoring applications.

Further verification of device-based CareWare components will be discussed in relation to a range of smart sensors designed for use with extended first generation telecare trials (see Section 9.3).

9.2 System Integration

In order to perform integrated system-wide testing, it is necessary to be able to generate more complex scenarios. In order to achieve this, scenario generation software has been developed capable of generating events according to a scenario definition file and in a form suitable for the CareWare components implemented on the CareStation PC. These scenarios are stored within tables of events that form part of a scenario database[4] file. The structure of the event table is presented in Table 9.2.

Table 9.2. Structure of Event Table.

Field Name	Data Type	Description
Event Number	Auto-number	Unique Event ID, automatically assigned by the database.
Event Date	Date/Time	The date upon which the event occurred/is to be generated.
Event Time	Date/Time	The time at which the event occurred/is to be generated.
Event Location	Text	The location of the event, i.e. a room name or client name.
Domain Entity	Text	The domain entity to which the event belongs, e.g. chair.
Domain Entity ID	Number	Used to distinguish between similar entities at the same location (e.g. chair #1 and chair #2)
Event	Text	The event itself, e.g. *Occupied_Event*
Data	Number	Any data associated with the event in question, e.g. if event was 'current room temperature'; then the data field may contain '23'.

9.2.1 Scenario Management & Event Generation

The virtual event generator controls the status of the virtual domain, in which a selection of virtual devices have been 'installed'. These devices transmit messages onto the CarerNet system bus according to the events generated by the current scenario. Once the simulation file is loaded into memory, the Scenario Simulation Timer can be setup to begin the simulation, see Figure 9.12.

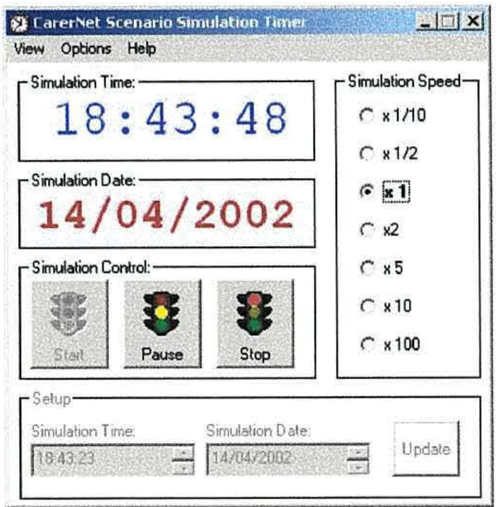

Figure 9.12. The CarerNet Scenario Simulation Timer.

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[3] *The data in the graph does not possess these characteristics as too few samples have been plotted, the data does eventually tend towards the figures specified over time [over the range shown, mean = 00:20:04; SD = 00:03:54; 2SD = 00:27:52].*

[4] *The scenario was stored using the Microsoft Access database format.*

The speed at which the scenario is run can be controlled by selecting the appropriate 'radio button' – the range spans from 1/10th real-time to 100 x real-time[5]. The simulation may be paused (time is suspended) or stopped (time is suspended and the scenario is reset back to the first event).

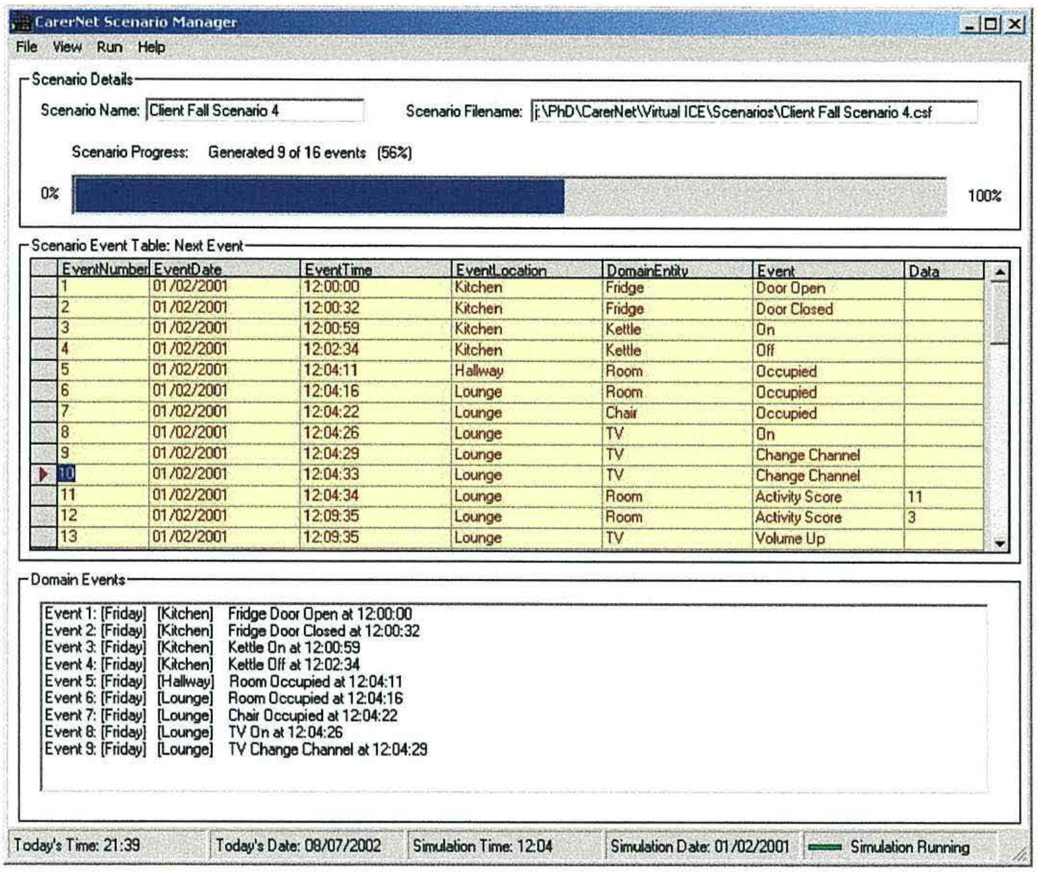

Figure 9.13. Scenario Manager Software.

The management of the simulation is undertaken using the Scenario Manager form, Figure 9.13. This form displays details of the current scenario, including the progress of the current simulation (in terms of a percentage of the total events generated). A table displaying the events that constitute the current scenario also indicates the next event to be generated (highlighted and indicated with arrow). In addition, the domain event display provides feedback when an event is actually generated, as does the domain visualisation form (refer back to the CareStation software, Figure 8.32, Chapter 8).

In addition to the pre-defined scenario simulation files, it is also possible to manually control the activities of the client.

9.2.2 Results

The CareWare components implemented all functioned as intended. However, in order to really assess their ability, it is necessary to expose them to real data, from a complex and truly un-deterministic environment. This will require suitable trials to be setup with *genuine* second generation telecare technologies in place. However, it has been a useful exercise, because it has at least shown that the

[5] *Other speeds are possible.*

system can successfully respond to a series of test scenarios. The next section will describe how some of the work performed has been applied in several trial sites across the UK. This strand of the experimental work has offered another means of testing the concepts discussed in this thesis and has offered the added advantage of genuine user feedback for service validation purposes.

9.3 UK Trial Site Implementations

A small subset of the work presented in this thesis has been converted into a form suitable for use with extended first generation telecare implementations and MIDAS, Technology In Healthcare's[6] (TIH) prototype second generation telecare development platform [38]. Trials of extended first generation solutions and of MIDAS are currently in place or planned at locations throughout the UK. Some of this work will now be described.

9.3.1 Extended First Generation Projects

A range of prototype 'smart' sensors have been developed by TIH that implement a number of the services identified in this work and which are based on some of the generic CareWare components of Chapter 7. This work has offered a parallel course of testing, which has also provided some client/carer feedback that can be used to *validate* the *service* as well as *verify* the *functionality*. A selection of the devices implemented is described in Table 9.3.

Table 9.3. A selection of the monitoring devices implemented for trials.

Monitoring Device	Description of Operation
Bed occupancy monitor	Monitors the time spent in bed and raises an alarm if the client leaves bed during the night and does not return within a pre-determined absence time. Can also be used to switch on a bed-side lamp (and other lights throughout the home) using X-10.
Client Wandering monitor	Raises an alarm if the client wanders away from the home. Inputs are limited to a PIR and door contact. If the door is left open and no movement is detected, then this results in an ambiguous state as the system is unable to determine whether the client has left the home or has just gone to another room. A door open alert may eventually be raised instead.
Fridge Use Monitor/Alarm	Monitors use of fridge and raises an alarm if the client leaves the door open or if the client does not use the fridge for an extended period. The device relies on a single PIR to determine whether the client is in the home (i.e. although this is clearly prone to error and a good example of why second generation systems are required to share data across the system).
Fall detector	Monitors client impact and orientation in order to detect falls and raise an alarm.

These prototypes may be considered smart in the sense that they generate a high-level alarm based on some property of the low-level domain data monitored, and in doing so, shift some of the burden of processing to the front-end. They fall short of various other features of smart sensors due to the limitations of the community alarm platform in the home.

These devices have yielded useful design and user-interface issues (some of which are detailed in Appendix B). One such issue is the limitations of using leg-based bed and chair occupancy sensors. These can sometimes be difficult to install in client's homes, especially when the client has a double-bed in the corner of the room. Furthermore, the variation in the size and shape of bed and especially chair legs means that there needs to be a range of sensor sizes if leg-based devices are to be used. This

[6] *A subsidiary of the Tunstall Group Ltd.*

is likely to result in a more expensive solution and hence the use of a sub-cushion/mattress sensor (especially if it could be a 'one size fits all' approach) is likely to offer a superior solution.

In general, the services offered by these devices have been well received by care providers who are generally encouraged by the possibilities that even extended first generation services can offer. One of the limitations of this approach is the manner in which 'CareWare' can be tailored to the individual requirements of each client. The only practical solution which has been successful is the use of a palm-based PDA that enables a carer to set-up various operating parameters during the installation process using a piece of software with a graphical front-end and a stylus to input data.

These prototypes are currently undergoing trials at various sites, both sheltered schemes and so-called dispersed locations (i.e. client's own home) across the UK including: West Lothian Council's "Opening Doors for Older People" telecare project; Durham Social Services' "People at Home and In Touch" project (see later); and Fold Housing Association's Seven Oaks extra care sheltered housing facility for people with dementia in Northern Ireland.

9.3.2 Second Generation Projects

An overview of the MIDAS system is presented in Figure 9.14, focussing on the arrangement in the home. The preliminary implementation of MIDAS uses a centralised PC based architecture and a range of simple sensors (i.e. sensors that only provide data). The MIDAS PC is responsible for logging data in a form suitable for periodic uploading to a data server in Whitley Bridge (Tunstall HQ) and for determining alarm situations using a selection of CareWare modules developed during the course of this work.

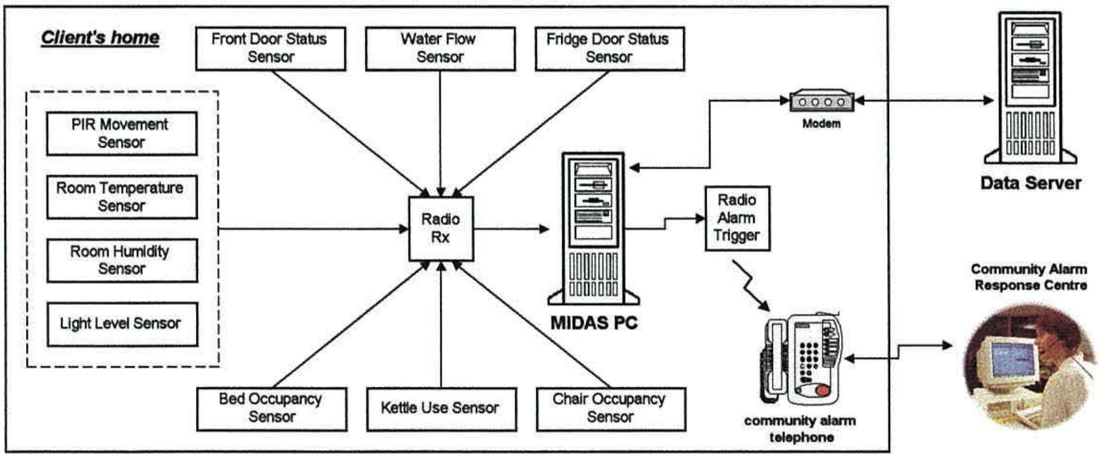

Figure 9.14. Overview of MIDAS system, focussing on home-based technologies.

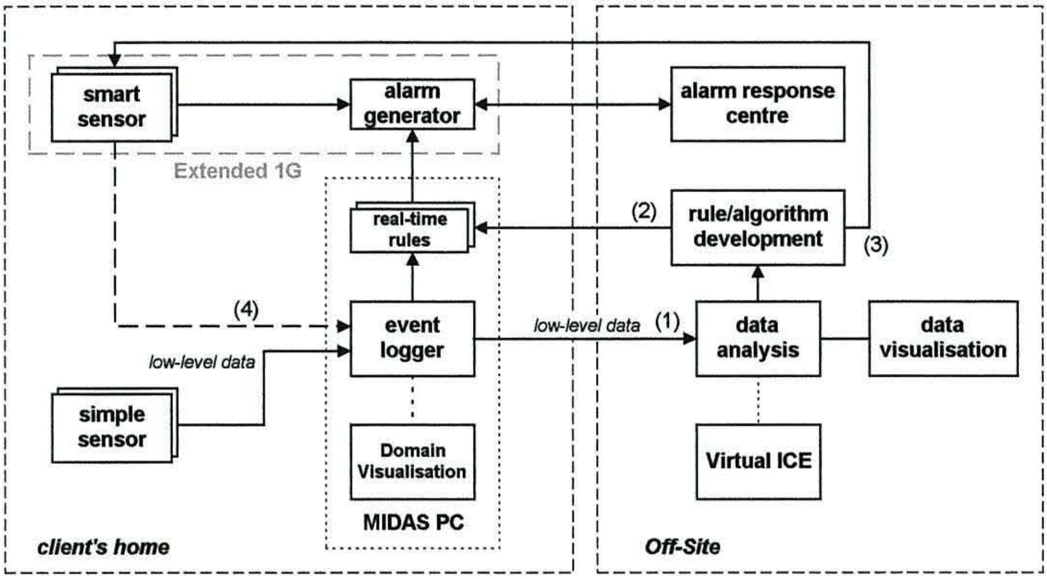

Figure 9.15. MIDAS and Extended First Generation Implementations.

Figure 9.15 illustrates the combination of MIDAS services and extended first-generation services available in the client's home. There are several stages to this development (refer to numbers in Figure 9.15):

1. Low-level data is uploaded from the home for off-line analysis. This is performed via a combination of proprietary data analysis software and the Virtual ICE environment. Relevant data sets (e.g. client-initiated activities) may be extracted and converted into a suitable graphical representation for web-based viewing by the project care team.
2. Real-Time CareWare modules developed off-site are ported to the MIDAS PC once they have been tested using the Virtual ICE environment (either by using simulated data or low-level data captured from a trial site).
3. Once CareWare modules are established, and if they are amenable to first generation implementation, then they can be converted into a 'smart' sensor implementation for extended first generation applications (quicker time to market as infrastructure is already in place).
4. Eventually, once a suitable infrastructure has been established in the home, a combined telecare/alarm unit will be capable of performing the function of the care phone and an intelligent data logger.

The use of MIDAS to generate real-time alarms will now be discussed further in relation to the 'People at Home and in Touch' project being run by Durham County Council Social Services department.

Real-Time Alarm Services

This aim of the 'People at Home and in Touch' project is to look into:

- The use of Information and Communication technologies to overcome social isolation.
- The use of smart sensors and intelligent monitoring systems to help rurally isolated older and physically disabled people.

- The use of technologies as part of a preventative strategy to help address the problems of falls, hypothermia and rehabilitation.
- The use of technologies to complement a hip protection pilot.

As part of this project, the project team have selected a range of extended first generation solutions (see previous section) as well as three MIDAS installations.

In order to introduce 'real-time' MIDAS services into the home of the client, a selection of rules were chosen by the project team. In the first instance, only fairly straightforward rules have been chosen for implementation. These rules are listed in Table 9.4, with the underlying CareWare classes used to for their implementation.

Table 9.4. Simple telecare services required for first phase implementation.

Telecare service required	CareWare Implementation
Raise an alarm if the client remains in a particular room for more than a particular amount of time.	BooleanEventMonitor
Raise an alarm if the client remains in a particular chair for more than a particular amount of time.	BooleanEventMonitor
Raise an alarm if the room temperature in any of the rooms goes out of safe bounds	AnalogueMagnitudeThresholdMonitor (activated only if occupied)
Raise an alarm if the client wanders away from the home	ClientWanderingMonitor (RealtimeBooleanEventMonitor)
Raise an alarm if the client leaves their front door open	BooleanEventMonitor
Raise an alarm if the client leaves their fridge door open	BooleanEventMonitor
Raise an alarm if the client does not use their fridge (over a period of time to be set by carer)	BooleanEventMonitor (activated only when house is occupied)
Raise an alarm if the client remains in bed for more than a particular amount of time	RealTimeBooleanEventMonitor
Raise an alarm if the client gets out of bed at night and fails to return within a set absence time.	RealTimeBooleanEventMonitor

These services have been tested with the necessary MIDAS device driver software (this converts the MIDAS events into high-level domain knowledge suitable for the CareWare to operate upon) and by using various client activity macros and test scenarios. Following a test installation in a suitable flat, the services are due to be installed on-site sometime in August/September 2002.

Domain Visualisation Projects

The Columba project is concerned with the use of information and communications technologies (ICT) to deliver services for those in need of care and social support ('telecare') both within their homes and in other physical environments. It is jointly run by Bournewood Community and Mental Health NHS Trust and Surrey County Council Social Services.

Elements of the domain visualisation software have been used in conjunction with a MIDAS system that has been installed in an intermediate care facility. In the first instance, the domain visualisation software will be used as a means of raising awareness of the potential for telecare amongst care and health professionals, see Figure 9.16. The second phase of the project will investigate the use of telecare in assessing a client's activities of daily living both in the intermediate care facility and once they are back in their own homes.

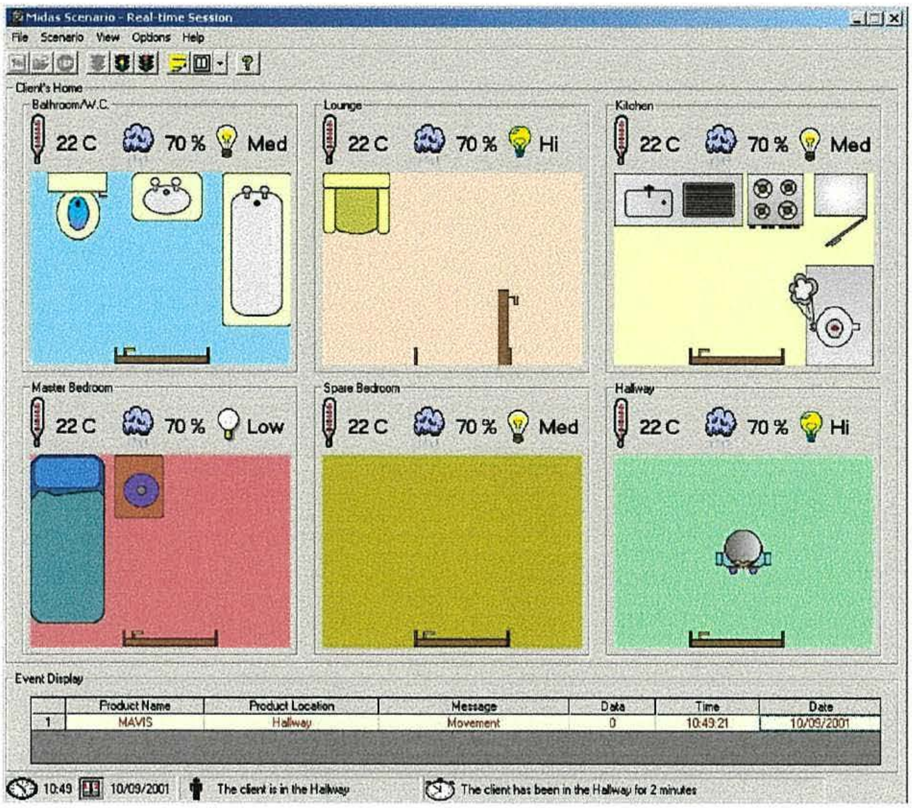

Figure 9.16. Domain visualisation software for MIDAS[7].

9.4 Conclusions

A suite of software has been produced capable of presenting test-data and events in the form of scenarios (either manually, randomly or from a database). This has been used to verify the correct operation of the CareWare components realised during the course of this work. The simulation software developed also offers a means of re-analysing field-obtained data, opening up the possibility of it becoming a useful research tool for analysing data and helping to develop intelligent algorithms.

The 'smart' sensors implemented for use over an extended-first generation system, while limited to localised domain knowledge, do offer a real improvement over existing client-initiated alarms. They have been used successfully in several trial sites (not withstanding the usual problems with any prototype technology used for the first time) and the functionality provided by such systems has been welcomed by clients and care providers alike.

Ideally, it would have been nice to have performed more experimental work using real devices as part of a truly distributed implementation, but this was not feasible within the timeframe of a Ph.D. or with the resources available. However, this work has shown that the principles discussed and the model developed is capable of supporting integrated services and offers a significant improvement over existing community alarms.

[7] *Populated with test data.*

It has been shown how it is possible to alter the operating parameters in order to tailor the response of the system to meet the needs each individual client. The possibility of automatically adapting these parameters according to the lifestyle of the client has also been illustrated, albeit in a simplified fashion. Further flexibility in the form of being able to enable/disable various services according to need, time of day, house occupancy or manually (e.g. if a carer is paying a visit) has also been shown.

Chapter Ten

Discussion & Conclusions

The purpose of this work was to develop a generic system architecture for supporting integrated telecare services in the home and in doing so, identify the nature of the devices and system intelligence required. Figure 10.1 provides an overview of the work performed and illustrates how *client needs* can ultimately be transformed into *care requirements*, with corresponding *telecare services*, that operate over a given *system architecture*, using a range of *devices* that monitor and effect the *local domain*.

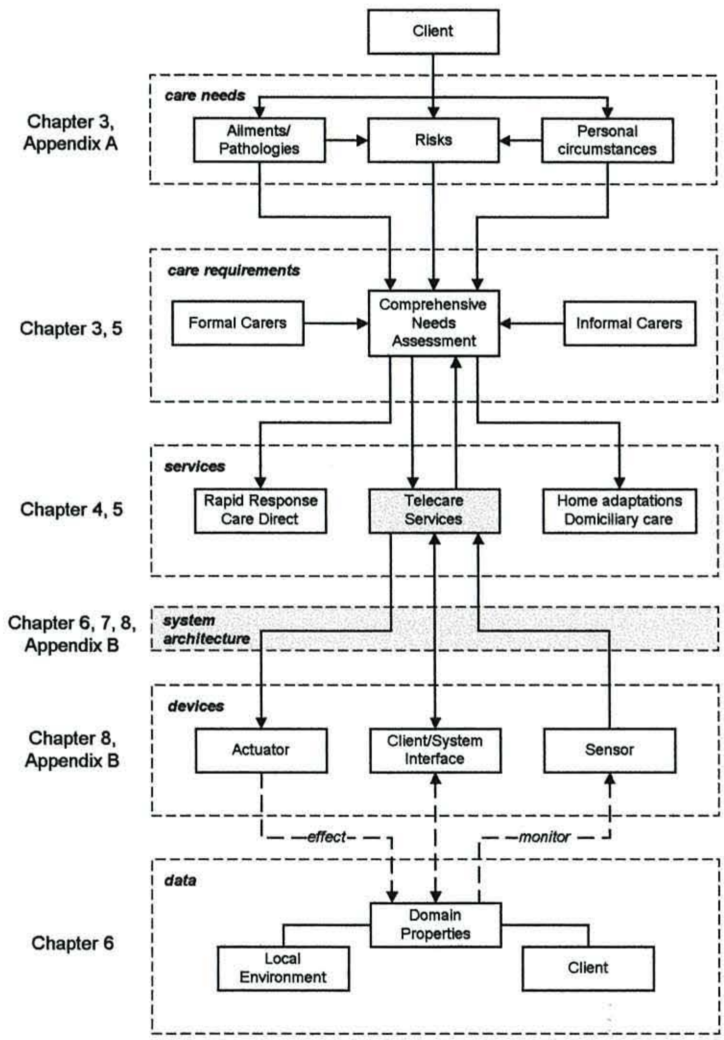

Figure 10.1. Overview of project work undertaken in relation to a systems methodology.

The work performed in order to progress from an identification of care needs all the way through to the specification of the devices in the home required a multi-disciplinary effort performed at a number of levels, both analytical and technical, including:

- Requirements elicitation & analysis (mainly concerned with aspects of gerontology, stakeholder opinion and UK healthcare policy).
- Safety analysis (this includes environmental, human and technical factors).
- System analysis and design.
- High-level software design & implementation.
- Embedded (microcontroller) software design & implementation.
- Analogue and digital electronic design & implementation.
- Simulation & testing.

This chapter begins with an overview of the work presented in this thesis, which will be discussed under the following headings:

1. System Analysis.
2. System Design.
3. System Implementation & Testing.

It will then discuss a selection of projects that might warrant further work based on the findings of this thesis and will conclude with a general overview.

10.1 Overview of Thesis

10.1.1 System Analysis

A significant proportion of the work undertaken throughout the course of this project involved the elicitation and analysis of stakeholder requirements. In order to achieve this, it was necessary to investigate several aspects of gerontology, healthcare policy, and obtain several viewpoints from various domain experts. These requirements were used, in the first instance, as the basis for identifying potential telecare services. This work was presented in Chapter's 2, 3, and Appendix A and the services conceived were detailed in Chapter 5. A wide spectrum of potential telecare services were identified.

An analysis of first generation technologies, presented in Chapter 4, concluded that while they were capable of supporting some telecare services, they were not capable of supporting all of them, and certainly not using a common infrastructure. However, it was noted that the use of smart sensors and the existing community alarm infrastructure may, in the short-term, be a viable mechanism of implementing passive alarms. However, the use of these so-called *extended first-generation* systems often leads to a duplication of functionality, resulting in inefficient solutions. Furthermore, uncertainty caused by a lack of 'global' knowledge of the local domain due to an inability to share information with other devices may, under some circumstances, result in unreliable performance.

A preliminary model capable of supporting second-generation telecare services was introduced in Chapter 5, based on: the viewpoint relationships and information flows between various system elements; the results of a domain analysis; and a consideration of a number of service delivery models based on a consideration of a series of client vignettes. A subsequent analysis of the system requirements performed in Chapter 6 resulted in a high-level distributed architecture for system components situated in the home and the concept of knowledge zones, with information only leaving the home on a need-to-know basis. This architecture resulted from a number of non-functional requirements that were identified during this analysis process. These included aspects of client privacy and intrusion, informatics, and safety, many of which were the result of a compromise between various conflicting stakeholder viewpoints.

The analysis also identified a series of domain properties with significance for telecare, which could subsequently be used to identify sensor and actuator requirements in the home. These 'plug and play' devices must operate using a common, modular, infrastructure with operating characteristics capable of being tailored to meet the individual needs of the client. In order to realise such a system, it was necessary to characterise in greater detail the nature of the telecare services required. In order to achieve this, an object-oriented approach was chosen.

Finally, the risks of using home-based technologies have been assessed under three categories: environmental factors, human factors, and technological factors. This work has resulted in a proposed framework for the consideration of safety when developing or prescribing telecare services/devices. Furthermore, as part of the development of a range of extended first generation devices and smart second generation devices, a series of design guidelines believed to represent good practice have been documented. This work is presented in Appendix B.

10.1.2 System Design

A detailed object-oriented architecture characterising the nature of the services identified for second-generation telecare services was presented in Chapter 7. This analysis identified areas of functionality and design patterns that were common throughout the system. These software/firmware components were referred to as CareWare. This analysis was performed without knowledge of the actual methods of implementation for each class, resulting in the specification of standard 'interfaces' to which various devices must subscribe in order to provide the necessary level of interoperability and implementation independence. It was established that a large number of second-generation services may be implemented based on a relatively small number of these CareWare components. Furthermore, details of the collaboration required between various system components in order to realise services based on distributed domain parameters were established.

One such application was client distress monitoring, where abnormal client behaviour is used to trigger an alert (in real-time, i.e. not using off-line processing of an event database). Chapter 6 detailed a mechanism for improving the method of identifying potential client distress based on lifestyle/behavioural monitoring. The concept of 'client stability' was introduced which required access to more information concerning client activities and which offers a real improvement on currently available systems that rely solely on PIR activity.

Various sensors and actuators were identified as possible candidates for inclusion in the home based upon knowledge of the domain parameters of interest. One of the benefits of an object-oriented approach to the characterisation of system services was the identification of a range of services that could be implemented using common functionality (CareWare) and even common circuitry/sensors. This should result in implementations with lower-costs and higher reliability.

10.1.3 System Implementation & Testing

The practical work was performed in the form of a demonstrator system and was presented in Chapter 8. It consists of the Virtual Integrated Care Environment (V-ICE) software running on two PC's linked via an RS-485 bus, and a number of prototype sensors.

The V-ICE software was used to create a virtual domain and has been used as a test-bed for developing a number of telecare services using modular CareWare components based on the architecture defined in Chapter 7. In addition, the V-ICE can be used to generate test data (either randomly or from a pre-defined database of events). This is a useful piece of software that enables CareWare components to be tested conveniently in the laboratory before being released into a live trial either on a PC or ported onto the firmware of a smart sensor/node. A number of CareWare components have been implemented and tested in this way. Furthermore, when used in conjunction with the domain visualisation Active-X components, it can be used as a means of visualising the operation of telecare services.

A number of prototype sensors were also produced during the course of this work, including a generic client occupancy monitor based on a piezoelectric sensor; an infra-red remote control monitor; a 'smart' PIR; a smart body-worn fall detector; and a range of conductivity-based devices including an incontinence monitor and a bath water-level monitor.

A small selection of the CareWare components developed using V-ICE have been ported to the MIDAS telecare platform for providing 'Real-Time' rules in the 'People at home and In Touch' project in County Durham. Three MIDAS systems will go live, providing (in the first instance) *basic* Real-Time services sometime in August/September 2002. Other more involved services will be introduced gradually following a successful outcome of the first phase of the trial. Some of the CareWare components devised have been implemented on a range of smart sensors developed for use with community alarm systems and have been tested or are undergoing tests in a number of field trials throughout the UK. The domain visualisation and scenario playback facilities of the V-ICE software are also undergoing use in several trial sites including Londonderry/Derry City and Woking.

10.2 Recommendations for Further Work

There are a number of projects that are related to work presented in this thesis that would be worthwhile investigating in any future work, some of these include:

- It is important to investigate the concept of the 'data efficiency' of a telecare system. In other words, is there an optimal number of sensors that will provide the maximum (or most useful) number of services before the laws of 'diminishing returns' apply? This would have important implications for determining the make up of a core, entry level package for telecare.
- Assuming that telecare becomes a standard mechanism of supporting self- and domiciliary care, and that a single assessment process is adopted, then the availability of an automated telecare assessment tool would be essential. This would be a piece of software (possibly an expert system) that would be capable of matching client pathology, impairments, handicaps, risks, needs, personal circumstances, and subsequent care requirements onto available telecare services, taking into account budgets constraints and special circumstances.
- There is a need to develop further the concept of client assessment indices based on long term assessments and intervention thresholds. In particular, work on a 'fall prediction index' and a 'risk of living alone index' would be of great benefit. This would need to establish the most sensitive domain properties and the relevant algorithms.
- Develop more intelligent algorithms/agents to identify a number of client activities or possible client distress. Perhaps investigate the use of fuzzy logic and neural networks in order to introduce more advanced forms of domain adaptation/learning.
- Individuals spend a long time in bed or in their favourite armchair. While some work has been performed to develop bed-based monitoring of physiological parameters, the development of a similar arrangement for a chair is an obvious candidate for further research. In addition to the regular physiological signals (e.g. heart-rate, ECG, breathing), it might also be possible to assess the client's use of the chair as an contribution towards a calculation of their ADL, e.g. do they use arm-rests, do they sit down gently, or do they drop in, etc.
- It is necessary to implement the full distributed CarerNet architecture in hardware, porting more of the high-level CareWare implementations to their firmware equivalents on a microcontroller platform with bi-directional wireless connectivity (e.g. using Bluetooth) between nodes.
- A key area requiring investigation is the development of an open protocol for the of transfer information to and from the home. The eXtensible Mark-Up Language (XML) might offer a suitable means of organising knowledge of the domain into a database-independent format.
- One of the most important aspects of a telecare system is the manner in which it will communicate with the client. Work needs to be performed on establishing the precise user-interface requirements for telecare and to establish whether it needs to be speech-enabled, have voice recognition, be based on a touch-screen LCD platform or perhaps even a television.

Finally, there is a need for second-generation telecare services and technologies to be validated in well managed long-term trials. Such a project would require the co-operation of a number of clients, who should ideally be asked to keep a diary of events, and well-being, in order to provide feedback with which to compare with data monitored using the telecare system. The clients would ideally be continuously assessed in order to determine any variations in well-being or activities of daily living and this information could again be used to correlate with monitored data. Such a project would require significant funding, ethical approval, the relative 'mass-production' of prototype devices, access to appropriate (and willing) clients, and an on-going assessment programme in order to be feasible.

10.3 General Conclusions

The period over which this research has taken place has seen telecare emerge from the shadows of telemedicine to be recognised as a field in its own right and a genuine contender for delivering care services to the home. In July 2002, the Commons Health Select Committee Report on Delayed Discharges [181] concluded that:

"... telecare solutions have a major contribution to make as part of the strategy for developing alternatives to hospitalisation ... ... We recommend that the Department [of Health] should establish a national strategy to promote the systematic development of telecare solutions as part of the spectrum of care at home, perhaps beginning with some properly audited pilots ... Telecare has the potential not only to achieve cost savings, particularly in the management of acute conditions, but also to be a key component in the drive to allow people the choice of staying longer in their own homes. An additional benefit is that patient autonomy will be increased in that patients will play a more active role in managing their own conditions. We believe that the Government should examine ways of facilitating greater uptake of telecare solutions within both health and social care ..." [181].

The application of a systems approach to the design of an *integrated* telecare system with consideration to a wide spectrum of services should go some way to making telecare a practical alternative to institutionalisation. This work has identified a large number of services that may have application in future second generation telecare systems. It has characterised these services and identified that a great many may be implemented using only a handful of classes (sensors, actuators, threshold comparison, rate of change, status monitoring and timing). It has also begun to consider the safety implications of such integrated telecare systems. As far as the author is aware, such a detailed architecture for integrated telecare has not been presented in the literature before.

The field of telecare is still relatively young and hence suffers from a large number of questions that require answers. Unfortunately, it has not been possible to investigate every topic relevant to the development of an integrated and intelligent second generation telecare system in depth within the timeframe of a Ph.D. However, it is hoped that the breadth of the work performed during the course of this project will provide a solid foundation with which to continue such work.

Appendix A

Health Issues in Old Age

The following sections provide a brief discussion of the characteristics and epidemiology of some of the more common chronic ailments that affect the elderly. This provides additional background material to the discussion of care-related issues presented in Chapter's 2 and 3.

A.1 Anthropometrical Changes & Sensory Impairment

As the human body ages, it experiences a number of changes. Body-weight decreases slowly after the age of about 65-70 as does the range of motion of the joints. General strength between the ages of 71-75 is estimated to be 60% of that at ages 31-35 [182]. Furthermore, sensory impairment is often an inevitable consequence of the ageing process and presents some people with a significant disability.

A.1.1 Immobility

Immobility is one of the most common symptomatic presentations in the elderly. As one grows older, age-related decline in physical capacity is to be expected; however, this problem becomes significant when the decline is so great that it impacts on the ability of the person to undertake everyday tasks and activities. For example, the ability of an individual to transfer safely, i.e. to transfer from chair to bed or from chair to toilet is imperative in order for their independence to be maintained.

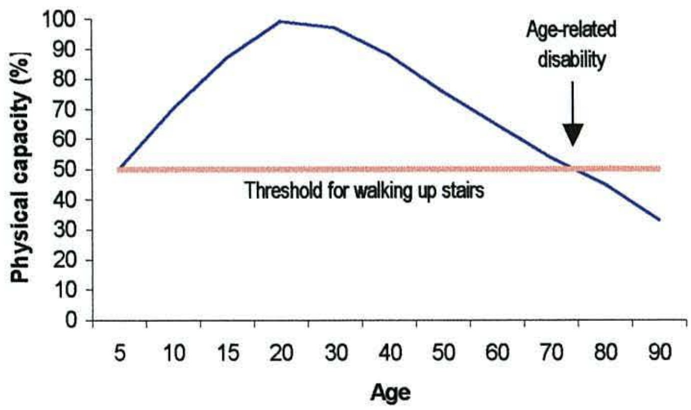

Figure A.1. Age related change in physical capacity.

A change in the client's patterns of mobility may therefore give an important indication of potential health problems. An acute illness or an extended period of bed-rest may amplify any decline in physical capacity. This, in turn, can have a significant impact on the ability of an individual who is already close to the threshold of being unable to independently perform various activities of daily living (e.g. climbing the stairs, see Figure A.1) [3].

One of the most important aspects of assessing the immobility of a client is to ascertain how their patterns of mobility have altered over the course of time. Factors such as the rate of decline (which might be measured over hours, days, weeks, months or years) and the frequency of episodes of immobility will highlight whether the underlying cause is an acute or chronic [3].

A.1.2 Sensory Impairment

Vision

The eye's ability to compensate for dark environments is compromised with increasing age. Other common problems include myopia, macular degeneration, glaucoma, cataracts and diabetic retinopathy. The resulting effects of such visual impairments include a reduction in visual acuity (sharpness of vision), which gradually worsens [182]. As visual acuity diminishes, so does the ability of the individual to distinguish between areas of contrasting information (e.g. text on a screen), which calls for special consideration of contrast with visual displays in terms of font size, type and colour.

In the UK, there are approximately 1 million people who are registered as blind or partially sighted, 66% of whom are over the age of 75. Ninety-seven percent of all people aged 65 and over wear glasses or contact lenses [183]. However 22% of this age-group still report having difficulty with their eyesight even after using corrective measures.

Hearing

The minimum amplitude required in order to hear increases and the frequency response of the ear decreases as an individual ages. In addition, frequency or tone discrimination diminishes with increasing age resulting in difficulty in being able to distinguish between similar sounds. Hearing impairment can lead to social withdrawal and increase the risk of depression.

There are an estimated 8.7 million deaf and hard of hearing people in the UK, a number that is set to rise with the ageing population. Hearing loss is very common amongst the elderly, with over half of those aged 75 years and over experiencing some form of auditory problem [184]. Approximately 2 million people in the UK own hearing aids, but probably just over half use them regularly.

Other Sensory Effects

A reduction in the ability to accurately notice extremes of temperature place the elderly at an increased risk of hypothermia in cold environments and also of experiencing a serious burn injury or scald due to hot water or other hot surfaces (e.g. radiator). There can also be a marked reduction in the sense of smell of some elderly individuals, which can result in hazardous situations as it impairs their ability to identify spoiled food or recognise that their gas hob has not ignited correctly. Other sensory impairments include: a gradual decline in taste perception (which may lead to a loss of appetite); and a reduced sense of balance. These, when combined with impaired motor control and dexterity and failing vision increases the likelihood of falling [185].

To summarise, sensory impairment distorts the client's perception of their local environment, which increases the risk of a hazardous situation occurring. Sensory impairments can therefore lead to a variety of problems, including:

- An increased risk of accidents, including the incorrect setting of dials, misreading instructions for the consumption of medication, an increased risk of falling, and an inability to sense gas leaks or identify spoiled food.
- General difficulties with communication and social interaction.
- Difficulties with conveying information, interpreting alarms, and requesting appropriate responses.

A.2 Confusion & Dementia

A.2.1 Confusion

As a person ages they are increasingly susceptible to bouts of confusion that may be acute or chronic in nature. Acute[1] confusion may be a presenting symptom for such diverse conditions as myocardial infarction, pneumonia or a urinary tract infection. The symptoms include disorientation in time and space, poor short-term memory, hallucinations, altered activity levels (agitated, restless and wandering or drowsy and lethargic) and speech abnormalities [3]. Non-reversible chronic confusional states are invariably due to some form of dementia [3].

A.2.2 Dementia

Dementia is a progressive and chronic illness caused by organic brain disease that leads to an irreversible and, ultimately, catastrophic decline in mental function. One definition of dementia is:

" *... a group of diseases associated with progressive, chronic disturbance of intellectual function which results in global deterioration of memory and thinking, sufficient to disturb function in activities of daily living*"[2] [186].

The prevalence of dementia increases quite dramatically with age from around 1 in 50 for people between the ages of 65 and 70 increasing to 1 in 5 for the over 80 age group [187]. There are an estimated 1 million people currently suffering from dementia in the UK, over half of which are suffers of Alzheimer's disease [187]. However, some figures estimate a doubling in the number of reported cases of dementia to 2 million by 2051 [188]. In the example of Alzheimer's-type dementia, the average total disease duration before death intervenes is 8.5 years [189] and the gross annual cost in the UK is estimated to be between £7.06bn and £14.93bn [72]. The process of dementia can be retarded in some cases using drug therapies, resulting in people being able to remain in their homes for longer, though the success is largely dependent on early diagnosis. Currently, an estimated 80% of dementia sufferers live in their own homes, with approximately 30% of these living alone [190].

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[1] *In this context, 'acute' can imply symptom-onset from within a few minutes to perhaps a matter of days or weeks, up to approximately three months.*
[2] *Multiple symptoms must usually be present for a period in excess of six months before a reliable diagnosis can be made.*

The type of care required by sufferers of dementia in a home-based setting includes help in getting into and out of bed; help with personal hygiene; cooking and feeding; controlling gas supplies; dressing; medication management; temporal and geographical reorientation; and companionship. In fact, such is the strain on informal carers they often go through their own needs assessment process. Often a spouse or living partner, who is effectively caring full-time, will often:

1. Experience sleep disturbance.
2. Suffer annoyance and/or embarrassment due to difficult behaviour of client with dementia.
3. Lead a restricted social life (caring is time-consuming and there is often a fear of leaving the client alone or with others).
4. Suffer general anxiety concerning the well-being of the client.
5. Neglect own health in favour of the that of the person with dementia.

Alzheimer's Disease

Alzheimer's disease is a gradually debilitating illness, which is often described in terms of clinical stages, see Table A.1 (although symptoms from various stages often overlap [117]). As the disease progresses, the symptoms become more severe and have a greater impact on the ability of the individual to live independently. The first noticeable change due to Alzheimer's is a loss of short-term memory, followed by a reduction in powers of judgement and reasoning. This leads to anxiety, depression and delusion. Personal habits then change as sufferers' sense of time, dress, feeding and personal hygiene are compromised. These changes are first noticed by friends, neighbours and by carers who instigate an assessment to confirm the diagnosis.

Table A.1. Symptoms of Alzheimer's disease.

Early Stages	Intermediate Stages	Advanced Stages
Difficulties with language; Significant memory Loss, esp. short-term; Temporal confusion/disorientation; Become lost in familiar places; Difficulty in making decisions; Lack of initiative and motivation; Signs of depression and aggression; Loss of interest in hobbies and activities; Difficulty in performing everyday routines, e.g. preparing meals; Decline in personal grooming and personal hygiene;	May become very forgetful of recent events and people's names; Suffer problems when living alone; Unable to cook, clean or shop; May become extremely dependant; Need assistance with personal hygiene, including visiting the toilet, bathing and washing; Needs help with dressing; Increased difficulty with speech; Wanders and sometimes gets lost; Behavioural abnormalities – unprovoked aggression; constantly following the carer around the house; May suffer from hallucinations;	Difficulty eating; Inability to recognise friends & relatives and familiar objects; Difficulty understanding and interpreting events; Unable to find way around own home; Difficulty walking; Suffer Bladder and bowel incontinence; Display inappropriate behaviour in public; Confined to wheelchair or bed;

Wandering or 'sun-downing' can lead to sufferers becoming disoriented and, ultimately, lost. This poses real problems for the emergency services as it can be several hours or even days before they are alerted to the situation of a missing person. The locking of external doors used to be the only remedy but the idea of 'imprisoning' a client cannot be justified except in extreme circumstances. Some techniques involve tagging the client in a manner similar to that introduced to some prisoner release schemes. Sufferers of dementia often experience weight loss due to this tendency to wander because they use up many calories and they may also forget to eat healthily, which can lead to sub-nutrition.

The loss of short-term memory presents the greatest problems to dementia sufferers. Simple compensation is usually achieved by repetition and by the use of paper-based reminders e.g. post-it notes scattered around the house. Ultimately, the notes are repeated and the individual becomes more confused by the mountain of paper generated. Medication regimes are compromised irrespective of the availability of simple pill storage devices. The absence of a family or friend to provide reminders can lead to serious problems and accidents, such as a failure to switch off or light gas supplies. The loss of ability to rationalise leads to apparently perverse behaviour such as a desire to go out undressed in the rain or to use the vacuum cleaner or play loud music in the middle of the night.

People with Alzheimer's who live in the community can therefore present a risk to themselves and to their immediate neighbourhood. If the risks associated with their living in the community are not managed effectively, either by a carer or by other means, then there is little alternative but to provide institutional support, which leads to high costs and a loss of independence.

A.3 Pressure Sores

Pressure sores, or bedsores, are ulcers of the skin caused by irritation and continuous pressure on parts of the body, such as the buttocks, heels, elbows, and shoulders. Pressure sores are most likely to occur in older patients. Community-based risk factors include: immobility, malnutrition, prolonged sitting in chairs/lying in bed, incontinence, chronic illness and falls resulting in a long-lie [191].

Special pressure relieving materials and air-based ripple-mattresses may be employed for chairs and beds, although the latter are an expensive option for the home. The aim of pressure area management (PAM) is to ensure that patients do not remain in the same position for more than a pre-determined length of time. Dependent on their risk category, this time may range from 30 minutes for high-risk cases to perhaps 4 hours for low risk cases.

The exact incidence of pressure sores in the community is unknown. However, it is estimated that 10% of all admissions to nursing homes show some degree of pressure damage [192] and that 30% of hospital patients with a pressure sore had the sore at the time of admission [193]. The annual cost of treating pressure sores in the UK is estimated to cost up to £40,000 per patient, or £600 million per annum [194].

A.4 Urinary Incontinence

Incontinence is defined as "*the inappropriate involuntary passage of urine*" although in some extreme cases it is also possible to suffer from faecal incontinence [195]. Any interruption to the normal process of urination will result in incontinence. This may be attributable to environmental factors such as a cold bathroom or even the distance or effort required to get to the bathroom; problems with memory (e.g. cannot remember in which room the toilet is, or how to get there); and difficulty with mobility or transferring, e.g. difficulty in getting out of a chair.

Elderly people with incontinence, depend, almost exclusively, on the use of containment products to manage their symptoms. These include pads or garments that are designed to absorb and contain urine, thus protecting the client somewhat from the risk of developing pressure sores and also of protecting clothing, furniture, and bedding. The home delivery of incontinence products is available to clients and it is imperative that their use is managed effectively in order that the client does not pick up any unnecessary infection or increase their risk of developing pressure sores.

The best estimate of how many people are affected with incontinence in the UK was made in 1995 by the Royal College of Physicians. They found a prevalence of urinary incontinence for the 65+ age group living at home at between 10-20% amongst women and 7-10% amongst men (this corresponds to between approx. half a million to a million men and women in the UK) [196].

A.5 Hypo- & Hyper-thermia

A.5.1 Hypothermia

Accidental hypothermia is a medical emergency with high morbidity and mortality that is defined as a core body temperature of below 35°C [3]. The occurrence of accidental hypothermia in the elderly living at home is typically related to the ambient temperature of their living environment. Hypothermia may be brought about by short exposure to extreme cold or by prolonged exposure to mild cold (-1°C to 18°C). Temperatures below 12°C can induce transient increases in blood pressure that may be contributory factors towards increased morbidity caused by heart attacks and strokes [197]. The World Health Organisation (WHO) recommends a minimal indoor temperature of 18°C and a maximum of 24°C, with a 2°C – 3°C warmer minimal temperature for rooms occupied by the sedentary elderly [169]. Below 16°C, resistance to respiratory infections may be diminished, although deep body temperature does not usually fall until resting clothed elderly people are exposed for two or more hours to an ambient temperature of 9°C or below.

Britain has 40,000 more deaths in the winter months than would expected from the death rates in the other months of the year [198]. Most of these extra deaths were for people who lived in dwellings that were poorly heated and who had low-energy efficiency ratings and those predicted to have low indoor temperatures during cold periods. [198] found that mortality rises by 2% for each °C fall in outdoor temperature below 19°C.

One of the major contributing factors in cases of hypothermia includes the inability of the subject to appreciate ambient temperatures and respond accordingly. Individuals may find it more difficult to increase their body temperature due to mobility problems or due to a sedentary lifestyle enforced by cardiovascular disease. Drugs commonly prescribed may add to this impairment with those that may increase the likelihood of a fall being a concern, as this would predispose the subject to a situation in which hypothermia is a risk. Other risk factors for hypothermia are listed in Table A.2. A low ambient temperature can also result in a reduction in alertness, concentration and in the functionality of peripheral joints. Some of the more common clinical features of hypothermia are listed in Table A.3.

Table A.2. Risk factors for hypothermia.

Confusion/dementia	Houses with no central heating
Socially isolated	Outside W.C.
Lower income	Poor lighting (and other fall-related risks)
Malnourished	Inadequate clothing
Medication, esp. polypharmacy	High dependency on formal (statutory) care services
Inadequate or malfunctioning heating	Diseases that affect metabolism (e.g. hypothyroidism), circulatory system or client's mobility.

Table A.3. Some clinical features of hypothermia.

System	Effects
Skin	Cold, marble-like, pallor, subcutaneous oedema (causing puffiness)
Neurological	Confusion, disorientation, slurred speech, slow reflexes, drowsiness and coma.
Cardiovascular system	Poor pulse volume, slowing to atrial fibrillation or sinus bradycardia; BP falls; J-wave in lead-1 ECG.
Respiratory	Respirations get slower and shallower
Cognitive	Impaired judgement, confusion, slurred speech, sleepiness
Mobility	Slow and clumsy movements

A.5.2 Hyperthermia

The effects of hyperthermia (an (oral) body temperature greater than approximately 41°C) can be serious for the elderly. The incidence of hyperthermia is higher in warmer climates, however, general hyperthermia can occur with an increased metabolic rate, such as in fever, or after heavy exercise. The symptoms of hyperthermia include headache, nausea and fatigue. Heat-related illnesses can become serious if preventative steps are not taken. Risk factors for hyperthermia are listed in Table A.4 with a description of the various heat-related conditions given in Table A.5.

Table A.4. Risk factors for hyperthermia

An inability to perspire, caused by inefficient sweat glands or medications including diuretics, sedatives and some heart and blood pressure drugs.	Heat, lung, and kidney disease, as well as illnesses causing general weakness/fever
Poor circulation	Polypharmacy
Inappropriate overdressing/very hot living environment.	Being substantially overweight/underweight
Hypertension	Alcohol consumption

Table A.5. The effects of various heat-related conditions [199].

Condition	Description
Heat stress	Occurs when a strain is placed on the body as a result of hot weather.
Heat fatigue	A feeling of weakness brought on by high outdoor temperature. Symptoms include cool, moist skin and a weakened pulse. The person may feel faint.
Heat syncope	Is sudden dizziness experienced after exercising in the heat. The skin appears pale and sweaty but is generally moist and cool. The pulse may be weakened, and the heart rate is usually rapid. Body temperature is normal.
Heat cramps	Are painful muscle spasms in the abdomen, arms, or legs following strenuous activity. The skin is usually moist and cool and the pulse is normal or slightly raised. Body temperature is mostly normal. Heat cramps often are caused by a lack of salt in the body.
Heat exhaustion	Is a warning that the body is getting too hot. The person may be thirsty, giddy, weak, uncoordinated, nauseous, and sweating profusely. The body temperature is usually normal and the pulse is normal or raised. The skin is cold and clammy.
Heat stroke	Can be life-threatening. Victims of heat stroke almost always die so immediate medical attention is essential when problems first begin. A person with heat stroke has a body temperature above 40° C. Other symptoms may include confusion, combativeness, bizarre behaviour, faintness, staggering, strong rapid pulse, dry flushed skin, lack of sweating, possible delirium or coma.

A.6 Cardiovascular Diseases

Cardiovascular disease (CVD) is the main cause of death in the UK accounting for over 40% (250,000) deaths a year. The main forms of CVD are coronary heart disease (CHD), which accounts for approximately 50% of all deaths from CVD, and stroke, which accounts for about a quarter. Approximately 1.5 million people suffer from angina: the most common form of CHD and about half a million people have heart failure [200].

CHD costs the health care system in the UK in the region of £1.6 billion a year. Hospital care for people who have CHD accounts for about 54% of this total, buying and dispensing drugs accounts for a further 32% [200]. Only about 1% of associated costs are spent on the prevention of CHD. CHD also costs the UK economy about £8.5 billion a year because of days lost due to death, illness and the informal care of people with the disease. Whereas mortality from CHD is rapidly falling, morbidity is not, and, in older age groups has risen by over a third over the past ten years [200].

A.6.1 Hyper- and Hypotension

Hypertension

Hypertension is high blood pressure and antihypertensive treatment is recommended in people over the age of 60 when blood pressure averages exceed 160 mmHg systolic and 90 mmHg diastolic [201]. Blood pressure is influenced by a number of factors with genetics, obesity, smoking, heavy drinking and a high dietary salt intake the most significant. Complications of hypertension include atherosclerosis, heart failure, stroke and kidney failure. Unfortunately there are usually no obvious symptoms until the symptoms associated with its complications develop. This means that an individual can suffer from hypertension for many years before it is identified by a routine visit to the GP or after investigation following an acute medical event such as a stroke. Hypertension may be treated by appropriate lifestyle modification (e.g. low-salt diet, low alcohol, weight loss) and/or by the use of antihypertensive medication. The elderly are particularly prone to suffer from hypertension, and have a higher risk of cardiovascular complications when compared to younger individuals. The classifications of hypertension are provided in Table A.6

Table A.6. Classification of hypertension by arterial pressure levels [202].

Classification	Systolic Pressure (mm Hg)	Diastolic Pressure (mm Hg)
Normal blood pressure	<130	<85
High normal blood pressure	130-139	85-89
Stage 1 hypertension (mild)	140-159	90-99
Stage 2 hypertension (moderate)	160-179	100-109
Stage 3 hypertension (severe)	180-209	110-119
Stage 4 hypertension (very severe)	> 210	> 120

Hypotension

Hypotension is a low arterial blood pressure (a persistent BP of approximately 100/70 mmHg, or less) and is usually not considered a threat to one's well-being provided that the individual feels well. However, the elderly are highly susceptible to orthostatic (or postural) hypotension, which is a reduction of greater than 20 mmHg in systolic, or 10 mmHg diastolic blood pressure upon standing upright after sitting or lying down for an extended period [66]. Orthostatic hypotension is a significant risk factor for syncope and falls in the elderly.

A.6.2 Stroke

A stroke is a disturbance in the blood supply to the brain; such a disruption for greater than 3-4 minutes causes permanent damage to the area of the brain affected. The resulting damage can cause a multitude of physiological and cognitive disabilities, depending on the location and severity of the stroke, including:

- Incontinence.
- Loss of balance.
- Communication and speech disorders such as dysphasia.
- Visual problems including hemianopia and neglect.
- Confusion/dementia.

Partial recovery is common and the process begins soon after the stroke; a full recovery is, however, not so common. The resulting functional impairments following a stroke can cause great difficulty for the sufferer and their carers, with a significant impact on their ability to function independently, see Table A.7 [203].

Table A.7. The recovery of functional independence following a stroke.

Function	% recovered		
	1 week	3 weeks	6 months
Bowels – continent	69	87	93
Urine – continent	56	76	89
Grooming	44	73	87
Lavatory use	32	61	80
Eating	32	62	77
Moving from bed to chair	30	58	81
Walking	27	60	85
Dressing	21	49	69
Stairs	20	47	65
Bathing	14	35	51

The risk factors for stroke include: hypertension, heart disease, trans-ischaemic attacks (TIA's), atherosclerosis, atrial fibrillation, diabetes, smoking, obesity, and increasing age. TIA's are 'mini-strokes' where the symptoms only last for few hours or a day and does not result in permanent brain damage. Treatment involves acute care, which may involve neurological surgery, followed by long-term rehabilitation from occupational-, physio-, and speech and language- therapists. People who suffer from a stroke can also be prone to depression, behavioural problems such as aggression, and to social isolation, all brought about by their combined functional and cognitive impairments. Stroke survivors with functional impairments may require a range of assistive technologies to aid in their ability to perform the activities of daily living.

Stroke is the largest single cause of severe disability in England and Wales, with over 300,000 people being affected at any one time [204] while every year approximately 110,000 people in the United Kingdom suffer from their first stroke. Strokes are one of the most expensive diseases managed in general hospitals, accounting for up to 20% of all acute beds and a quarter of long-term beds [204]. This is because many stroke patients stay in hospital for several weeks at a time, especially if recovering from brain surgery. The cost of strokes to the NHS is estimated to be over £2.3 billion and is expected to rise by 30% by 2023 [204].

A.6.3 Cardiac Problems

There are many problems which can occur which adversely affect the operation of the heart. The heart is electrically stimulated and if these electrical timing events become irregular or intermittent then difficulties can arise. A heart attack (or myocardial infarction) is due to the death of an area of the heart muscle due to a blockage in its own blood supply (c.f. stroke). Symptoms of heart failure include: tiredness & exhaustion; breathlessness on modest exertion or when lying flat; increased heart rate; feeling clammy and sweaty; an irregular heartbeat; swollen ankles; and chest pain [205]. Another common problem with the heart are abnormal heart-rate irregularities or arrhythmia's. The arrhythmia may be triggered by a particular event, such as physical exertion or emotional stress. A diary of activities and events such as emotional stress, falls, symptoms, and use of medications is usually compiled to correlate with an ambulatory electrocardiogram (ECG).

Heart-attack survivors often suffer from fear and anxiety following discharge from the 'safe' environment of the hospital (i.e. appropriate care is at hand). Individuals are sometimes frightened of doing anything strenuous such as climbing the stairs or of going outside. In particular, there is a requirement to be able to contact help if not feeling well or in an emergency – this particular anxiety is often suffered more by the relatives and carers of the individual concerned.

A.6.4 Diabetes

Diabetes is a metabolic disease where the ability of the pancreas to produce insulin is impaired or the body is unable to process the insulin produced effectively. This results in an inability to convert carbohydrates into energy effectively which leaves abnormally high levels of glucose in the blood. There are two varieties of diabetes: insulin dependent (or type I) diabetes and non-insulin dependent (or type II) diabetes [117]. Type II diabetes is often triggered by obesity in later life.

If unmanaged, diabetes will eventually result in damage to various internal structures. Arteriosclerosis (a build up of plaque on the blood vessel walls) is significantly more common in diabetics than non-diabetics and may cause blood circulation problems. It can also significantly increase the time it takes to heal after injury or after surgery. These complications mean that diabetics may experience a plethora of serious long-term complications including: heart attack, stroke, blindness, kidney failure, and foot and leg ulcers which if left untreated may lead to amputation.

Diabetes treatment to maintain blood sugar levels in the normal range requires strict control of weight, exercise and diet. Insulin dependent diabetes must be managed by the injection of insulin at appropriate times to control the levels of blood sugar. Non-insulin dependent diabetes may be controlled by lifestyle change or by the use of oral hypoglycaemic drugs.

Many of the complications of diabetes are chronic, however, some are acute and may lead to death if not treated immediately. Hypoglycaemia is caused when blood sugar levels are dangerously low; it must be treated quickly as it can soon lead to confusion, coma or in extreme cases permanent brain injury. The symptoms of hypoglycaemia have a fast onset and include: sweating, trembling, dizziness, blurred vision, headaches, sleepiness, stumbling, confusion and sudden hunger [117]. Symptoms of hyperglycaemia usually appear over a period of 24 hours or so, and include: thirst, excessive urine production, abdominal pain, vomiting, drowsiness, rapid breathing and flushed, dry skin.

Approximately 3% of the UK population suffer from diabetes although this figure is likely to be a conservative estimate as up to 1 million people are thought to have diabetes without being aware [206]. The prevalence of diabetes increases with age and obesity and is predicted to rise in the UK from 1.4 million to 3 million by 2010. People with diabetes consume high levels of hospital resources accounting for 5.4% of all completed hospital episodes, 6.4% of outpatient attendances and 9.4% of inpatient bed days [206].

A.7 Respiratory Illnesses

Many conditions can affect the respiratory system with the principal ones being: asthma, bronchitis, emphysema, pneumonia, pulmonary tuberculosis (TB), chronic obstructive airways disorder (COAD), and sleep apnoea. Some are chronic conditions that can present the sufferer with significant disabilities. The number of asthma cases in the UK has risen from 4% of the population in 1973 to 21% in 1996. It is estimated that around 3.4 million people are now affected. Somewhere in the region of 100,000 people are admitted to hospital each year after an asthma attack in the UK and 2,000 deaths a year are attributed to asthma, 80% of which could be avoided [207]. One study estimated between 4% and 6% of individuals of both sexes as being "...significantly affected..." by asthma i.e. the level of asthma is serious enough to warrant medical supervision throughout life [208].

A.8 Malnutrition

Malnutrition, whether sub nutrition or over nutrition can be caused by several factors including poverty, social isolation, bereavement, illness, loneliness or ignorance. Unfortunately, detection of malnutrition by caregivers or relatives often only occurs during the advanced stages [209]. The main nutritional problems that affect the elderly include protein-energy under-nutrition (sub-nutrition), vitamin deficiencies and obesity.

Weight loss is the single best factor for predicting persons at risk for malnutrition (a body mass index below 20 kg/m^2 may also suggest a problem). Body fat serves many useful purposes – it stores up excess calories, protects the internal organs and bones from high impacts and helps to maintain body temperature. The possible consequences of sub-nutrition include: fatigue; hypothermia; pressure sores; orthostatic hypotension; cognitive dysfunction; and frailty.

Mild vitamin deficiencies are very common amongst the elderly population and can be responsible for poor wound healing (pressure sores), anaemia, bruising, and cognitive impairment. Vitamin B12 deficiency, for instance, can lead to confusion/dementia, incontinence and orthostatic hypotension. Vitamin C deficiency is associated with increased bruising, poor wound healing and the development of pressure sores.

One study found a possible link between hospital admissions and the contents of elderly people's fridges [210]. The study found that elderly individuals with empty or poorly stocked fridges were more likely to fall ill than those whose fridges were well stocked. The research found that 10% of the study group had empty fridges. It was observed that the people with empty fridges were three times more likely to be admitted to hospital than those who had stocked up their fridge. The authors conclude that an empty refrigerator might be indicative of a clinically frail stage, when the elderly become unable to undertake everyday activities. An empty refrigerator may be considered to be equivalent to not using the refrigerator, thus, an empty or under-used refrigerator might trigger an assessment of an individual's activities of daily living in order to determine their support requirements for living at home with a reasonable amount of independence. A lack of use may also indicate a more acute problem if the client usually does use their fridge on a daily basis.

A.9 Depression & Isolation

The psychosocial circumstances in which the elderly typically find themselves, coupled with the functional loss, which typically accompanies ageing, often results in depression. Depression can develop over a period of days or weeks and can be a symptom of other problems, such as Alzheimer's disease. Research commissioned by Help the Aged and British Gas has revealed that there exists a widespread problem of isolation amongst the elderly population of Britain [134]. The research indicates that nearly one million older people are acutely isolated and over one million people aged 65 and over (12%) feel trapped in their own home. The most severely isolated and lonely are people over 75, particularly older women, those who are widowed and those living alone. The research also highlights the link between loneliness and poor health and poverty. Over 630,000 (7%) of people aged 65 and over reported feeling as if no one knew of their existence and more than 180,000 (2%) have gone a whole week without speaking to friends, neighbours or family.

Appendix B

Safety and Risk Issues in using Telecare

The increasing trend towards the adoption of technology to support independent living at home with extended first generation community alarm systems and, ultimately, second generation telecare systems poses some interesting questions concerning the safety of their use. A decision to allow an individual to remain at home with appropriate technological and domiciliary support must be justified against the risks involved. Furthermore, the implications of any failure of the technology must be addressed and managed effectively in order to provide a safe and reliable care service. This Appendix discusses some of the issues of safety and risk in telecare considered during this work. A safety classification system for telecare devices is proposed and a range of design guidelines are presented which, it is believed, represent good-practice. The scope of telecare is such that it has been necessary to focus this discussion on safety aspects which arise within the home as this represents the environment with the greatest level of uncertainty.

B.1 General Aspects of Risk

The concept of risk in telecare was considered at both human and technological levels with the intention of developing an evaluation framework for the allocation of safety integrity levels to telecare services. This would enable the level of safety-related effort associated with the service (and its associated devices) to be established, with possible implications also for the architecture of the local system. At the fundamental level, the risks involved with telecare tend to be related to human issues, Level 1 in Figure B.1. Some of these risks can be managed by the putting in place of an appropriate domiciliary care package, for instance a home-help for a number of hours a week. Telecare can also be prescribed as part of the package to help manage risks, for instance by notifying the client of problems or by preventing problems from occurring in the first place.

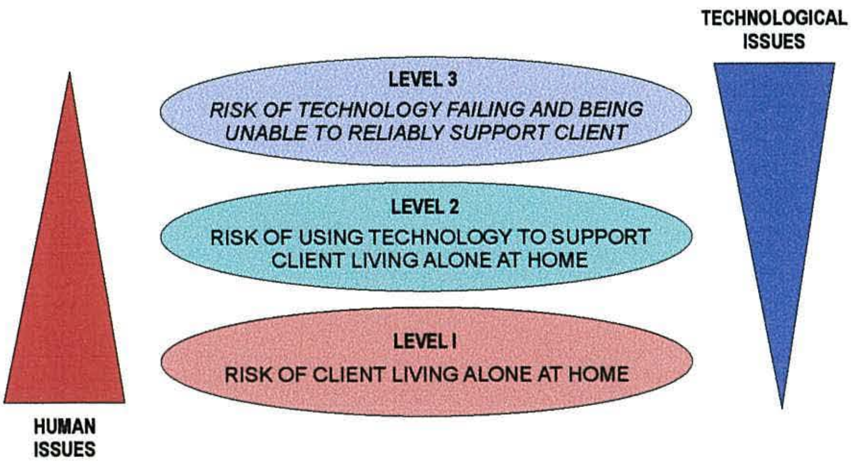

Figure B.1. Aspects of risk in telecare.

Table B.1. An example of some hazards and various risk management techniques.

Hazard	Risk of	Conventional Approach	Telecare Approach
Poor gait, weak limbs, loose rug or cabling, steep stairs	Falling	Walking frame, stick, physiotherapy, remove rug or fix down, remove/constrain cabling, remove need to go upstairs, install a stair-lift.	Employ integrated fall management care package – fall prevention and detection.
Poor vision	Falling & taking the wrong medication.	Correct vision using spectacles or corrective surgery.	Fall management services, remind client to wear spectacles, medication management.
Administering incorrect medication	Illness, weakness, injury, death	Use alternative sensory info to convey tablet type & quantity. Use pill-mill device, have a care worker call to administer drugs, explain importance and action of drugs, label bottles with clear instructions, avoid blister packs.	Medication management systems to remind client and monitor compliance and dispense medication if necessary.
Poor lighting	Trip, slip, fall, impact hazard	Install better lighting	Use automated 'smart' lighting systems; Use floor level lighting;
Poor hearing	Missing an alarm; Failing to hear door-bell.	Use visual cue.	Vibrating 'pager' unit. TV interrupt facility. Visual alternatives.
Over spilling bath/sink	Flooding	Overflow outlet pipe	Electronic flood detection; Bath-water volume monitor; Electronic taps.
Scalding hot water in bath	Burn/scald.	Test water temperature with hand; Thermostatic valve	Monitor and control bath-water temperature.
Gas taps left on / gas leak	Explosion Suffocation Fire	Gas alarm Smoke alarm Heat alarm	Automatic gas shut-off systems; Gas appliance status display/reminder systems by bed & exits.
Poor heating	Hypothermia Infection Stroke	Install insulation measures Close windows	Use smart technologies to regulate temperature throughout the home; Quartz halogen heaters can provide 'personal' heating zones;
Poor nutrition	Malnutrition/ general weakness	Meals on wheels	Monitor appliance usage (e.g. cooker, fridge, utensil, bin, bread-bin); monitor time spent in kitchen & client's weight.
Poor security	Burglary & distraction burglary	Use chain & eye-hole Yale locks	Electronic video door-bells and locks; PIR-operated lights and cameras, remote meter reading, appointment reminder systems.
Hypertension	Stroke, coronary artery & peripheral vascular disease	Diet change/take medication More exercise	Use ambulatory BP monitor, electronic drug dispensing and compliance monitor. Monitor client's weight.
Client unable to open front-door	Delay in providing help	Break down door; Leave key with neighbour	Use electronic access technologies.

However, the use of telecare increases the range of safety issues that must be considered if a client who requires a particular level of care is supported at home using technology, Level 2 in Figure B.1. These issues of risk can be broadly segregated into *human* and *technological* issues, although in reality they are closely linked.

Often, the services provided will act to reduce the risk associated with a particular identified hazard, see Table B.1. Consequently, the failure of any component associated with the management of risk will impact on its ability to control that risk and therefore its associated hazard, Level 3 in Figure B.1.

When considering the design of a telecare system, there are therefore a number of safety-related issues to consider, including:

1. The safety of the client.
2. The safety of the carers, both formal and informal.
3. The safety of the premises.
4. The safety of the immediate community.
5. The safety of the equipment.

B.2 Client Risk Assessment

The first level of risk assessment which must be undertaken is to ascertain whether it is safe for a particular client to remain at home at all. This is currently achieved using suitable ability tests, interviews and assessments, described in Chapter 3. These risks are invariably related to a combination of a sub-optimal living environment (e.g. old housing stock, no loft-insulation, poor lighting, steep stairs), tight financial constraints (e.g. no private pension, fuel-poverty), and various physical, sensory or cognitive impairments (e.g. abnormal gait, impaired vision, arthritis, confusion). The calculation of the risk of the client living at home should be re-assessed periodically (ideally by the telecare system itself) in order to ensure that the client has the most appropriate risk management package available. A compromise must eventually be reached between the client's desire to live at home and the inevitable risks associated with them doing so, particularly as their needs and hence reliance on technology increases. The detail of such assessments is beyond the scope of this thesis.

B.3 Liveware Safety Issues

Human interaction with technology can be unpredictable and human error can be considered as inevitable and should be guarded against. The human-factor, henceforth called *liveware*, includes the client, care providers, and all other people involved with the design and operation of the system. The liveware issues that have been considered focus on those aspects which impact on the system as a result of actions that occur within the client's home.

Human Reliability Assessment

The success of telecare will depend on the deployment of care technologies into the homes of clients who possess varying degrees of technical proficiency. In particular, the manner in which the client is required to interact with the system may have a significant effect on its overall level of performance. One of the factors with great variance is the physical and cognitive ability of the client, reconsider some of the candidate client groups, Table 2.8 (Chapter 2). This illustrates the wide range of physical and cognitive disabilities that a client may be expected to demonstrate. In order to help accommodate these groups, the principles of universal (inclusive/assistive) design [144] have been considered wherever possible (see Table 4.11, Chapter 4).

In order to investigate further, a human reliability assessment (HRA) has been undertaken of a range of services and devices which are currently under development [211], undergoing user trials in pilot studies or have been developed as part of this work. Following this assessment, it has been possible to derive a more generic set of rules and guidelines relating to the design of telecare services and devices. The HRA process considers the impact of liveware on system performance and can be used to evaluate the influences that human error has on safety and on the successful operation of the system as a whole. When the scope for human error has been identified, the likely consequences and actions must be derived from all available information. The procedure followed was as recommended in [212], and involved the following steps:

1. Identify and describe the tasks expected of the user.
2. Identify and describe possible erroneous actions in performing a task.
3. Identify possible consequences of erroneous actions.
4. Identify causes of erroneous actions.
5. Suggest measures to reduce human error probability.
6. Improve opportunities for recovery, and/or reduce the consequences of erroneous actions.

Tasks associated with the use of telecare devices were identified and were analysed for a range of devices in order to identify possible areas of human error. Eight tasks have been identified and these are described in Table B.2. Some of the conclusions resulting from this analysis are then presented in Table B.3.

Table B.2. Task Analysis for Human Error Identification.

Task	Responsibility	Description
Specification & design of device	Marketing department Engineering design team	The amount of safety-related effort that goes into the specification and implementation of the device, including its interaction with the system at-large is a key indication of device safety and reliability. Adherence to a quality system that includes consideration of system reliability and safety is imperative.
Installation of device	Service Provider/Installation personnel	This relates to the 'one-time-only' installation of the device in the home of the client and would typically be performed by a suitably qualified installation technician.
Explanation of device/ Training in use	Service provider Personnel/Carer/Client	Some devices will require user interaction and therefore the client must be 'trained' to operate the device correctly. The level of interaction will vary depending on the nature of the device.
Fitting of device (where applicable)	Carer or client	This is particularly relevant for body-worn devices where correct placement and positioning is critical for successful operation.
Operation of device	Carer or client	The user must operate the device correctly where some level of interaction is required. This includes the ability to receive and interpret alarm information and data.
Maintenance of device	Service provider personnel Carer / Client	Many devices will be maintenance free (unless they fail); some will however still require a small amount of maintenance ranging from the replacement of batteries to the calibration and servicing of equipment.
Storage/placement of device (where applicable)	Manufacturer Service provider personnel Carer/Client	Some devices may be sensitive to their storage position, both prior to installation in the clients home and after installation. E.g. some devices may be sensitive to their own orientation.
Removal of device	Service Provider Personnel	The removal of a device from the local network should not cause any problems for the remaining devices/services.

Table B.3. Good Practice for human-factors design of telecare devices.

Task	Good Practice
Device specification & design	• Employ a systems approach. • Adhere to a quality system. • Follow universal design principles.
Device Installation	• Complex devices should be installed by suitably trained and qualified personnel. • Devices should be simple to install and, if possible, Plug and play (PnP). • Devices which are sensitive to their installation position/location should provide feedback to the installer to ensure correct placement. • Devices should provide diagnostic feedback, on request, to confirm their correct operation. • Where a device can be installed by the client, the installation procedure should be automatic. • Battery-powered devices should be supplied with the correct battery type and mains-powered devices should be supplied with the correct mains connection interface/adaptor.
Device Instruction	• Instructions should be clear, unambiguous and be in the appropriate language and style. • Hazardous operation should be clearly highlighted with explanations of why some operations are dangerous in order to help encourage compliance. • Qualified personnel should train the client when required. • Multimedia techniques should be used, as appropriate, to explain difficult concepts.
Device Fitting	• Body-worn devices should be capable of detecting when they are being worn. The system and/or client should be informed of this status. • Body-worn devices should wherever possible be capable of detecting and confirming if they are being worn *correctly*; The system and/or client should be informed of this status. • Body-worn devices should be tolerant of incorrect placement and smart enough to inform the client if they have not been placed in a suitable position for adequate performance. • Any sensors which are required to be attached directly to the body should be as comfortable as possible and capable of being applied and removed painlessly. • Body-worn devices should where possible be integrated into everyday items of clothing or accessories (e.g. watch, vest, pager, or brooch.)

Device Operation	• Employ an Uninterruptible Power Supply (UPS) / Battery backup for critical systems.
	• The client/technology interface should be user-friendly and the level of interaction should be kept to a minimum to minimise the potential for confusion.
	• The local system should be kept informed of the status of devices that the client can manually switch between states such as: on/off/auto/system-control.
	• Alarm-cancel capabilities should be considered on a client by client basis.
	• Ergonomics, design, visibility and appearance all affect a device's acceptability. If body-worn devices are comfortable then clients are more likely to wear them, they will provide less discomfort and therefore more than likely supply more accurate and reliable data because the signal will be good, there will be fewer artefacts and the client will wear the device more often.
	• Alarms should be raised using multi-sensory means, thus maximising the chances of the recipient receiving it and also the number of people who will be able to receive the message. Problems include:
	    • Clients suffering from hearing impairments may not hear audible alarms, especially if the audio frequency of the alarm lies within the impaired area of their audio spectrum;
	    • Clients suffering from visual impairments may not see visual alarm signals well enough to respond;
	    • Clients suffering with some form of cognitive impairment may not immediately understand the meaning of a particular alarm, if at all.

Device Maintenance	• Where possible devices should require little or no maintenance. • Devices should provide diagnostic feedback to confirm their correct operation (Built-In Self Test (BIST) & Diagnostic port). • Battery-low warning (to system and client). • Main power source fail warning (to system and client). • Device should employ self-calibration techniques where applicable.
Device Storage	• Devices which are particularly sensitive to their storage conditions after installation within the home might benefit from a purpose built storage receptacle – this may then function as a docking system if required to download stored data for the day, alter device operating parameters or to re-charge batteries.
Device Removal	• Device should be easy to uninstall.

B.4 System and Technological Safety Issues

The reduction of risk using technology is a laudable concept provided that it works. While telecare might not be described as *safety-critical* in the same way that a commercial airliner might be, it does have components that possess significant safety-related features. For example, systems that manage risk such as controlling unlit gas supplies or that dispense medication are clearly safety-related (refer again to Table B.1). In addition, if the system were to produce erroneous data such that there were a number of false alarms, then this would inconvenience both the client and the response network. This may result in the system being 'switched off' or in genuine alarm conditions being ignored. Equally, missed alarms can also cause a lack of confidence which also has serious safety issues.

In the event of a client remaining safely at home primarily on the basis that they are in receipt of an integrated care package that includes an element of telecare, then it is essential that the telecare components of the package may be relied upon to be both safe and dependable. In order to ensure this, several measures must therefore be undertaken:

1. A comprehensive client assessment protocol is required in order to ensure that it is safe for a client to remain at home with an appropriate care package and that the most appropriate telecare services and technologies are prescribed;
2. System services should minimise the occurrence of unsafe circumstances or actions and should not themselves be primarily responsible for injury either due to inappropriate client behaviour, incorrect use or failure of devices, system upgrades, or by the introduction of new equipment into the system.
3. System services and elements should be reliable, fail-safe, and degrade gracefully such that failures may be tolerated for a period of time long enough for repair to be undertaken.

It should be noted that severe failure modes of telecare systems which might lead to client injury or even death can be segregated into one of two categories:

1. Failures which *directly* cause injury or death;
2. Failures which *indirectly* lead to injury or death;

For instance, it may be apparent that the failure of a pacemaker might lead directly to the death of the client. Whereas the failure of a fall alarm would not lead directly to client injury or death but may leave the client helpless after a heavy fall such that they are unable to summon help. If the client were to subsequently die as a result of their fall due to the fact that acute care was not supplied within the golden hour, then the failure of the fall alarm might be said to have contributed indirectly towards the death of the client. Individual failures which can indirectly lead to undesirable situations must therefore be identified and managed accordingly.

B.4.1 A Safety Integrity System for Telecare

IEC 61508

IEC 61508 is an international standard concerning the *functional safety*[1] of electrical/electronic/ programmable electronic safety-related systems [213]. The standard is meant to offer a common approach to the problem of functional safety across multiple application areas. It is also intended as a foundation for the development of application-specific standards and therefore offers a good basis for the consideration of safety-related issues in the field of telecare.

A Safety Integrity System for Telecare

In order to assess the safety-case for a particular device, the potential hazards which might result due to the failure of the device must be analysed. Table B.4 is a matrix of hazard severity categories for telecare which can be used in conjunction with Table B.5 (based on IEC61508 [160]) to asses the risks associated with their frequency of occurrence. Risks will generally fall into one of four broad risk categories as set out in Table B.6.

Table B.4. Hazard severity categories for telecare systems.

Category	Definition	Example
Critical	A failure condition which has serious and immediate consequences for the client's health & safety and/or their immediate neighbourhood.	Failure of a combustible gas monitor to detect a dangerously high level; Failure of the gas utility switching unit to switch the gas supply off; Failure of drug dispenser which leads to an incorrect dosage to be dispensed.
Significant	A failure which may have serious implications for the level of care which can be provided. The failure *may* have serious consequences for the client's subsequent health & safety.	Failure of a Blood Pressure (BP) monitor leading to inaccurate readings; Failure of automated room temperature system, especially if room becomes very cold. Failure of a bed occupancy monitor;
Marginal	A failure which could have a minor effect on the health & safety of the client perhaps in conjunction with other fault conditions. The fault may lead to false alarms with a subsequently high annoyance factor to both the client and the care providers.	Failure of a PIR (especially if providing data to a fall sensing algorithm);
Negligible	Has no immediate or long-term effect on the safety of the client or the local environment.	Failure of Infrared Remote Control usage Monitor.

Table B.5. Risk classifications (adapted from IEC61508).

Frequency	Consequences			
	Critical	Significant	Marginal	Negligible
Frequent	I	I	I	II
Probable	I	I	II	III
Occasional	I	II	III	III
Remote	II	III	III	IV
Improbable	III	III	IV	IV
Incredible	IV	IV	IV	IV

[1] *the ability of a system to carry out the actions necessary to achieve and maintain an appropriate level of safety both under normal conditions and when a fault or hazard occurs.*

Table B.6. Interpretation of risk classes (IEC61508).

Risk Class	Interpretation
I	Intolerable risk
II	Undesirable risk, and tolerable only if risk reduction is impracticable or if the costs are grossly disproportionate to the improvement gained
III	Tolerable risk if the cost of risk reduction would exceed the improvement gained
IV	Negligible risk

In order to approach the specification and development of telecare devices in a safety-conscious manner it is necessary to ascertain the safety integrity level required for each device. The safety integrity level assigned to a particular device must then be used as a guide to the quantity and depth of safety-related analysis which is undertaken in the specification, design, manufacture, operation and maintenance processes of those devices. Table B.7 suggests 6 possible safety integrity levels for telecare products ranging from class A for safety-critical products through to class F for the lowest level of safety required.

Table B.7. Guidelines for the allocation of Safety Integrity Levels for Telecare products.

CLASS	QUALIFYING SYSTEMS	EXAMPLE
A	Any system which provides 'life-support' type services and whose correct operation is therefore imperative. (Class A devices/systems are therefore typically medical devices and may typically include implants and hospital-at-home systems.)	Pacemaker; Kidney dialysis machine; Intra-Venous drug infusion systems.
B	Systems which are responsible for raising or responding to an alarm in acute conditions and whose failure to do so may result in exposing the client to an immediate high-risk situation.	Medical alarm monitors; Automatic fall detection systems; Hypoglycaemic alarm device; Combustible gas alarm/utility switching unit; Local intelligence unit;
C	Systems whose failure may result in an eventual hazardous situation (and subsequent alarm condition) for the client if left undetected for an extended period of time.	BP monitor; Electronic Drug Reminder Systems; Heating, Ventilation & Air-Conditioning; Chair/Bed-occupancy monitors;
D	Systems whose failure may cause serious inconvenience to the client and in some circumstances may eventually cause or lead to a reduction in the client's well-being.	Many assistive devices such as stair-lifts. Client-system interface. Flood alarm unit.
E	Systems where single failures would not be expected to impact significantly on system performance but where multiple failures may be undesirable. There may be a reduction in the quality-of-service provided if the fault were left undetected for an extended period of time.	Smart home devices; Appliance usage monitors; PIR's;
F	Standard consumer equipment that may be provided as part of a telecare package but do not provide services which directly affect client well-being. Usually their failure would be apparent to the client.	Devices which enable virtual social interaction e.g. Internet-based chat services;

There are potential problems in assigning safety integrity levels to some devices as this will depend on how the data that they produce is processed. For example, a chair-occupancy monitor provides *chair_occupied* or *chair_unoccupied* information for a particular chair in a particular room. In isolation, this is not a safety-critical function even if the chair occupancy monitor's data has a high weighting factor in the algorithm which determines room occupancy. If the system occasionally calculates this incorrectly then this can generally be tolerated. However, if it subsequently affects the algorithm which monitors client activity levels (and hence the algorithm which predicts the likelihood of a fall) then what seems like a relatively trivial error in itself may have a knock-on effect on the safety integrity of the fall prediction sub-system. Thus, the allocation of a particular safety integrity level for a device must be undertaken in the context of how its data is used to derive secondary information by other sub-systems within the overall telecare system.

B.5 Case Study – Fall Detection

The management of falls is likely to be a key element in future telecare systems. In addition to services that attempt to manage the risks associated with falling, in the event of a fall, detection mechanisms are also required. A number of techniques to detect a client falling have been considered. These techniques have been classified as being either *primary* or *secondary* techniques.

Primary techniques involve the client wearing a device which measures various properties including one or more from: client orientation (including rate of change of client orientation), impact forces, and subsequent levels of client activity in order to determine a fall condition.

Secondary techniques involve the use of a virtual sensor CareWare component monitoring a battery of smart sensors distributed throughout the home[2]. The latter technique frees the client from having to wear a device, which is particularly useful for situations in which the client is deemed unsuitable for a worn solution or for cover in situations where the client may not remember or be able to wear the device, e.g. if they have got up in the middle of the night, or if they taking a bath or shower.

B.5.1 Client Vignette

"Mrs. A is 70 and lives alone in a small dispersed bungalow in the suburban area on the outskirts of a small town. She suffers from arthritis in her hips and has difficulty walking further than her local shop. She has become, over recent months, progressively more confused and forgetful; her GP suspects that she might be suffering from Alzheimer's disease. Several weeks ago, Mrs. A flooded her bathroom because she had forgotten that she had started to run a bath. Because of this, upon her return to the bathroom, she suffered a heavy fall as she slipped on the wet linoleum floor. Luckily, Mrs. A has a dispersed community alarm phone in her home and she was able to raise the alarm by pulling the emergency cord in the bathroom; however, in her dazed state, she took over quarter of an hour to raise the alarm. This has resulted in a loss of confidence and she is now particularly frightened of falling again, especially because she sometimes does not have visitors for up to 3 days. She remembers how concerned she used to be over the safety of her late elderly brother, who also suffered from Alzheimer's. As the disease progressed, he would sometimes forget to light the gas from his oven and was lucky to have never caused a serious accident. As a result, Mrs. A has become weary of using both her gas oven and gas fire and has resorted to using her microwave more often for cooking her evening meal, even though she doesn't really enjoy her food as much from the microwave."

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[2] *Imaging devices for the detection of falls are currently under development, however, they are likely to represent an expensive option, especially as one device will be required in each room of the house.*

B.5.2 Risk Management Requirements

In order to manage the risks associated with Mrs. A living an independent life at home, several issues need to be addressed. In terms of the CarerNet model, a selection of CareWare modules must be selected to best meet the needs of Mrs. A. A consideration of some of the hazards and risks that Mrs. A might face that threaten her safety and independence are summarised in Table B.8.

Fall detection services will be used to illustrate some of the aspects of safety considered.

Table B.8. Partial Hazard and Risk Analysis for Mrs. A, with possible solutions.

Client Hazards	Risks	Preventative Measures	Reactive Measures
Confusion	Sun downing/Wandering (especially at night). Possible scalding caused by bath water being too hot. Possible hypothermia if bath water too cold.	Placement of mirror in hallway to prevent wandering Use audio/visual cues to remind client that it is night-time Control water temperature to ensure it cannot become too hot or cold	Generate alarm if client does not return to home within a specified amount of time or if it is late at night and/or cold outside Use bath-water temperature monitor to generate alarm if too high (or too cold) – use alarm to switch on cold water tap
Forgetfulness	Flooding bathroom Leaving gas on and unlit - risk of explosion Leaving gas on whilst lit – fire risk Leaving front-door or windows open - security Forgetting to wear body-worn fall monitor	Use written notes as reminders Use audio-visual cue's to remind client that water/gas is on Door/window status monitor and client reminder system Use audio-visual cue to remind client to wear fall detector	Flood alarm Gas alarm Smoke alarm Temperature alarm Secondary fall alarm
Poor-gait due to bad hip	Falling;	Monitor bed & chair occupancy and use to control night-lights, if dark	Smart body-worn fall alarm Secondary fall alarm

B.5.3 Fall Detection System

Wherever possible it is highly desirable to employ systems which can provide duplicate information. An example is the fall detection system employed within the CarerNet demonstration system. CarerNet employs two automated fall detection CareWare services. The first is a *primary* technique which directly monitors the fall status of the client using a smart fall monitor. The second utilises other *secondary* information which is available throughout the system and which may give a useful indicator of client fall status. Finally, of course, the client will possess a panic pendant upon their person. Figure B.2 provides an illustration of this redundancy within CarerNet.

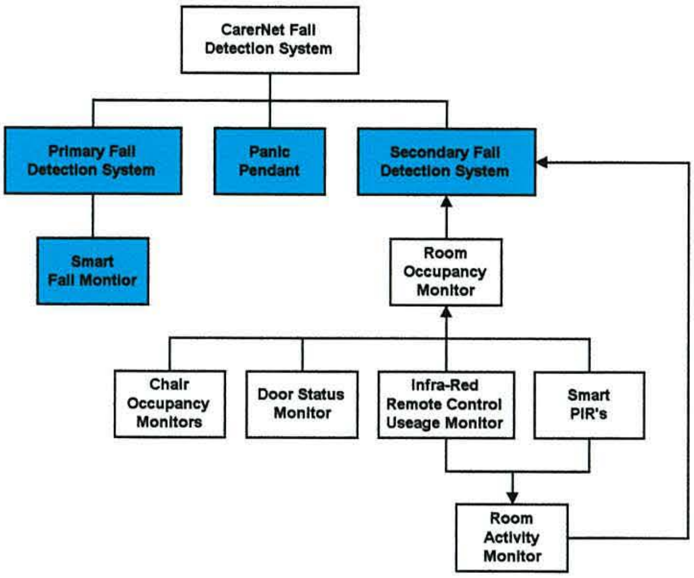

Figure B.2. Example of redundancy within CarerNet.

Thus, if the client were to fall in such a way that they were unable to activate the panic pendant then there are other systems available to raise the alarm. The fastest response will be provided by the primary sensing technique, the fall-monitor unit. This will send a *fall_alarm* message within seconds/minutes of the initial impact. If, for whatever reason, this unit did not produce this message, perhaps the device was not being worn, then the secondary fall detection system must be relied upon. The secondary fall detection system uses information gathered from the family of distributed devices throughout the home to identify client instability events consistent with that of a fall.

Primary Fall Detector

The primary fall detector prototype is pictured in Figure B.3 [28]. It is intended to be attached to a belt around the waist in a similar fashion to that of a pager. If the device receives an impact greater than a pre-determined threshold then it wakes-up and monitors the client's subsequent orientation and activity. The client is then given between half a minute to several minutes to recover from their fall before the device transmits a *fall_alarm*. A modular decomposition of the fall detector is presented in Figure B.4; and a high-level representation of the fall detection algorithm is presented in Figure B.5.

Figure B.3. Prototype fall detector.

By following the safety integrity guidelines presented in Table B.7, a body-worn smart fall monitor was rated as a class B telecare device. In order to ensure that the risks associated with the use of the device is as low as is reasonably practicable, a Failure Modes and Effects Analysis (FMEA) of the fall monitor was undertaken according to BS 8444, [212]. An example FMEA for the piezoelectric unimorph impact detector is shown in Table B.9. Example safety features considered as a result of this analysis included:

1. BIST for impact sensors.
2. Impact sensor redundancy (two orthogonal sensors).
3. Detection system to monitor device usage.
4. Detection system to monitor correct orientation of device upon installation.
5. Improved software-based false alarm rejection algorithm.
6. Use of fall prevention and secondary fall detection system for back-up (if part of an integrated system).

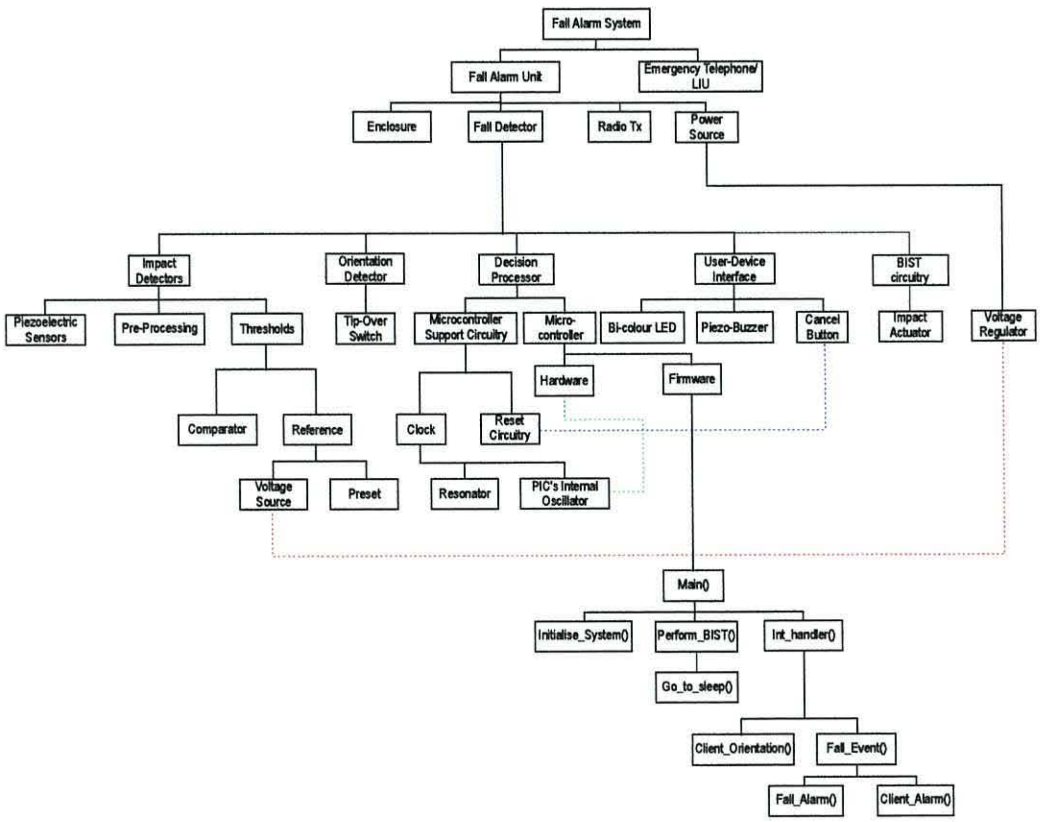

Figure B.4. Modular decomposition of Smart Fall Monitor.

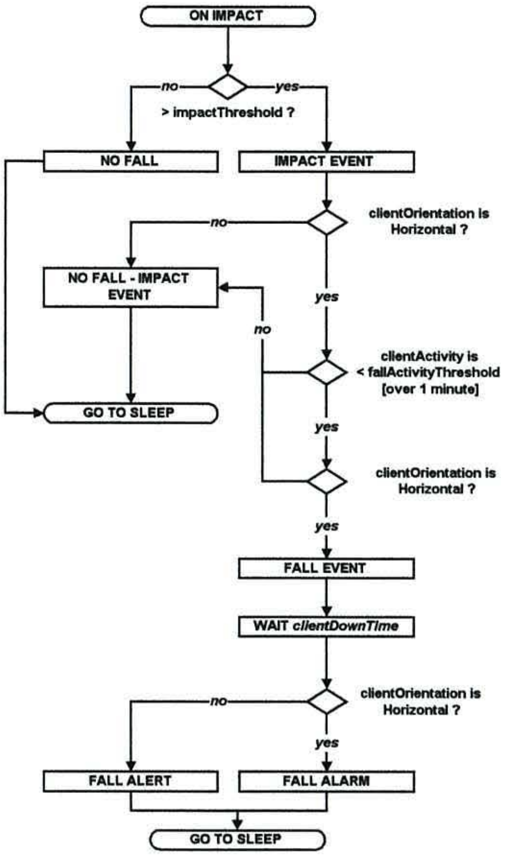

Figure B.5. Prototype high-level fall detection algorithm.

Table B.9. FMEA for Impact detector (piezoelectric unimorph).

Failure Mode	Possible Cause	Local Effects	System Effects	Remedial Action
Increased sensitivity	Faulty sensor; Manufacturing error;	May cause an increase in false alarms	System fail-safe	Test component thoroughly during manufacture; BIST – self calibrating impact threshold;
Decreased sensitivity	Freak failure Wear out Surface damage caused by: Excessive temperature variations; Electrostatic discharge; Excessive force on impact; Imminent lead failure; Detachment of sensor from enclosure;	May result in genuine falls not being detected	Possible system failure	Test component thoroughly during manufacture; Minimise opportunities for ESD both in manufacture and during operation; Ensure good and rugged bond between sensor and device enclosure.
No signal	Lead failure	Impact detection failure	System failure	Test component thoroughly during manufacture; BIST to predict failure.

The information made available through the use of a smart fall monitor is greater than just whether the client requires assistance following a fall. Other useful data should be made available if required. In particular, data may be made available to the CareWare module responsible for determining the client's fall prediction index. The monitoring methodology can therefore evolve from a reactive approach to a more proactive approach involving the prediction of future fall events. Fall-related event conditions of note are impact events, fall events (client has fallen, but recovers by themselves) and fall alarms (client falls and is unable to recover).

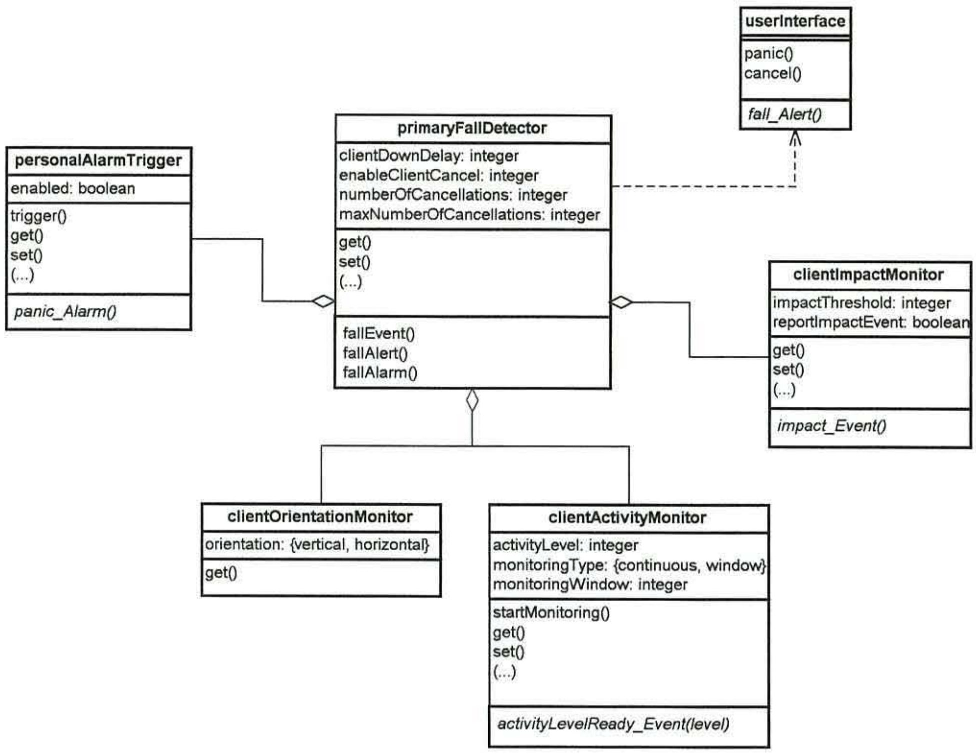

Figure B.6. An example of a primary fall detector.

Figure B.6 illustrates the classes required to implement a primary fall detector based on monitoring client orientation, impacts, and activity levels. It shows the inclusion of an integrated trigger alarm.

Secondary Fall Detection

The use of a body-worn fall detector may not always be relied upon. One of the problems with the wearable option is that the client is unlikely to wear the device to bed because it may prove uncomfortable and also because there is a significant possibility that the action of tossing and turning in bed may cause false alarms. The client is also unlikely to put on the unit when going for a shower, or when popping out of bed at night to visit the bathroom. If an integrated system is being used, then it is possible for the system to detect the client getting out of bed and of reminding him/her to wear the device. However, secondary (passive) systems are preferable under these circumstances to detect a possible client fall situation.

If the client is in an 'unstable' state in the same room for an abnormal length of time and the activity level in the room is low, then there is a possibility that the client may have fallen. Secondary fall prevention is useful as a backup mechanism to the primary method. Figure B.7 illustrates the devices and CareWare components required to collaborate in order to provide the secondary fall detection service described.

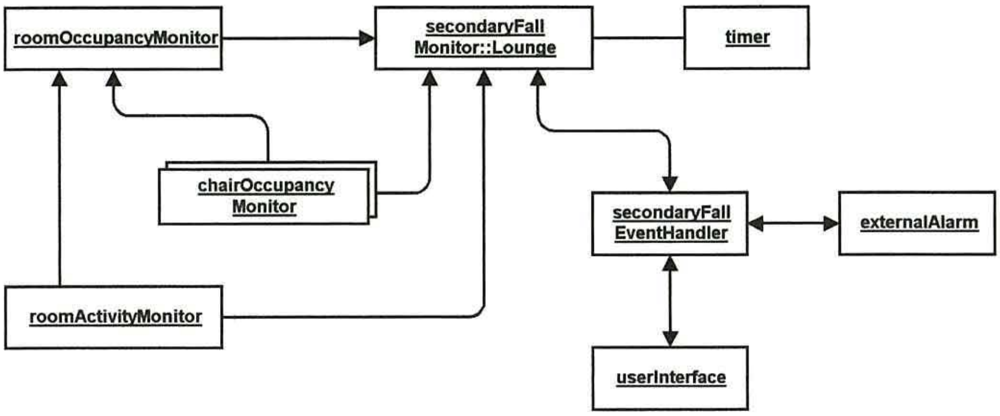

Figure B.7. Example of secondary fall detection.

B.5.4 Bedroom Fall Prevention System

Finally, prevention is much better (and cheaper) than cure, and so CarerNet also has the capacity to try to reduce the risk of a fall occurring in the first place. The *bedroomFallPreventionCareWare* is responsible for fading up a light source if the client gets out of bed (or if they sit up in bed) while the room is dark, Figure B.8.

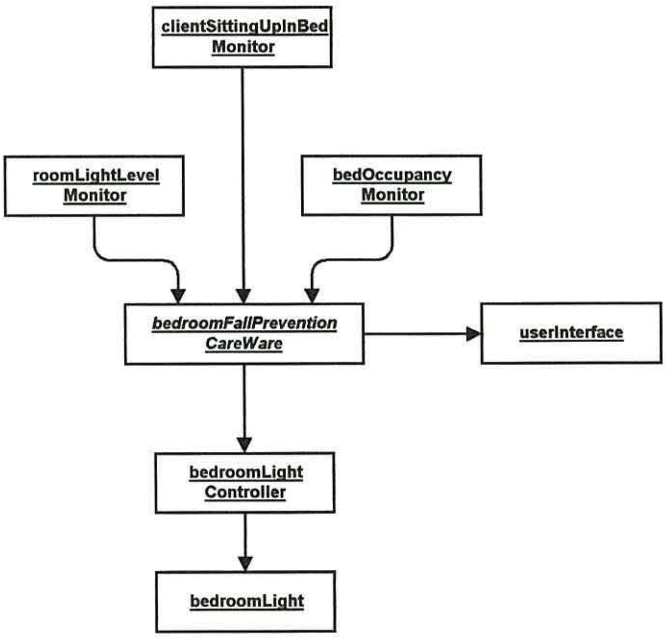

Figure B.8. bedroomFallPreventionCareWare 'collaboration' diagram.

It relies on bed occupancy data from the *bedOccupancyMonitor* and light level data from the *roomLightLevelMonitor*. Its outputs link in with the *bedroomLightController* which is an *analogueController* and the local user interface. The latter may be useful for clients suffering with dementia who may benefit from a spoken message providing advice (e.g. in this instance reminding them of the time if it is too early to be getting up).

B.6 Conclusions

This Appendix has provided an overview of some of the work performed in relation to safety and risk-related issues in telecare.

Telecare systems will enable the remote management of risk in the community, enabling many individuals to remain at home safe in the knowledge that they have a safety-net if anything were to go wrong. In order to assure a safe and reliable risk-management service, however, the actual components that make up the telecare system: people, hardware, firmware, and software, must also be safe and reliable. Suitable measures must be taken at the design-stage to build-in resilience to individual failures such that systems will generally fail-safe and follow a graceful degradation. Above all, the system must be made aware of any failures and the optimum way to achieve this is to build-in techniques of allowing the system to monitor its own 'health'. The CarerNet model, with its local intelligence, distributed smart sensors, and multiple monitoring systems (some with use of built-in self-test (BIST)) is well-placed to support the self-checking of data and hardware required to ensure system integrity.

The case study illustrated at many levels how potentially hazardous situations can be controlled with intelligent system behaviour brought about through an *integrated systems approach*.

Appendix C

Conference & Seminar Attendance

C.1 Conferences Attended

- Presented at the 18th Annual International Conference of the IEEE Engineering in Medicine & Biology Society, Amsterdam, 31st Oct - 3rd Nov, 1996.
- Presented at the 19th Annual International Conference of the IEEE Engineering in Medicine & Biology Society, Chicago, USA, 30th Oct - 2nd Nov, 1997.
- Presented at the 20th Annual International Conference of the IEEE Engineering in Medicine & Biology Society, Hong Kong, 29th Oct - 1st Nov, 1998.
- Attended *PREP '99 Postgraduate Research in Electronics, Photonics and Related Fields*, 5th – 7th January, UMIST, Manchester. (Competed in, and won 'Design a Device' competition with a smart fall monitor)
- Presented and organised workshop entitled "Technologies to support people with dementia living in their own homes" at *Dementia Care 2001*, University of Wales, Bangor, 27th June 2001.

C.2 Seminars Attended

- Presented at "*New Ways to Make Health and Personal Social Services More Accessible*", Institute of Medical and Social Care Research, University of Wales, Bangor, May 13th, 1998.
- Attended "*The Technical Future for Sheltered Housing*" The Strathallan Thistle Hotel, Birmingham, Wednesday 10th June, 1998.
- Attended "*Telephones, Alarms and Other Telecommunications for Older People: Future policy, Provision and Practice*" COST 219/ KCL Age Concern Institute of Gerontology, S.O.A.S., University of London, Wednesday 17th June, 1998.
- Attended "Towards a Better Older Age?" Age Concern North Wales Central, North Wales Conference Centre, Llandudno, Tuesday November 16th, 1999.
- Attended "People at Home and In Touch" hosted by Durham County Council Social Services Department, County Hall, Durham, 12th June 2001.

C.3 Colloquia Attended

- Attended "*Technologies Supporting the Remote Delivery of Health and Care Services*" IEE Computing and Control Division Colloquium, Professional Group C10 (Consumer and Domestic Systems), Savoy Place, London, Wednesday 19th February, 1997.

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