Wireless LANs in Healthcare Delivery

Ellen Marian O'Shea M.A., Dip Comp. Sc.

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Declaration

I declare that the work described in this dissertation is, except where otherwise stated, entirely my own work, and has not been submitted as an exercise for a degree at this or any other university.

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Summary

Clinical professionals by their very nature are mobile workers, who need instant access to up to date patient data at the point of care. It is to be expected therefore that mobile computers would be of benefit to health care workers. A review of international studies indicates that wireless LANs do indeed have the potential to deliver benefits to healthcare, and these benefits are in four main areas:

1. Improvement in clinical efficiency and productivity
2. Reduction of medical error
3. Increased user satisfaction
4. Enabling new applications not possible with a fixed IT infrastructure

This study was undertaken to examine the impact of wireless LANs in healthcare internationally and in the Irish context and investigate whether the benefits demonstrated internationally apply also to the Irish healthcare sector.

A survey was carried out to examine current wireless LAN penetration and future plans in a number of Irish hospitals, in order to establish the state of the art and look for emerging trends.

The pilot study examined the effects of wireless computers in an Irish acute hospital setting, and compared these with international findings, with particular reference to user satisfaction and efficiency. The size of the sample was too small to allow effects on patient safety to be examined. The study was carried out in two renal dialysis units, where nurses in one unit used fixed and wireless computers while nurses in the other unit used fixed PCs only. The study used a mix of qualitative (interviews with staff) and quantitative (clinical staff questionnaire) methods.

The study did not find evidence for an effect on efficiency due to the wireless computers. The results did however show increased user satisfaction among the wireless computer users, as measured by perceived accessibility of the system, quality of communication with patients and ability to access data at the point of care.

1. Introduction

1.1 Background

Wireless Local Area Networks (LANs) are already widespread in industry and being used more and more by businesses to provide their workforces with a level of mobility unattainable with fixed IT infrastructure. Studies by Intel have shown that wireless mobile computers can improve productivity and increase user satisfaction in the IT industry (Intel [39], [40]). In healthcare too, penetration of wireless LANs is increasing rapidly. In the U.S.A., spending on WLANs in healthcare is forecast to reach $71.4 million in 2005, rising to $75.8 in 2007 (Gartner [38]).

Clinical professionals by their very nature are mobile workers, who need instant access to up to date patient data at the point of care. It is to be expected therefore that mobile computers would be of benefit to health care workers. A review of international studies (Chapter 3) indicates that wireless LANs do indeed have the potential to deliver benefits to the healthcare industry, and these benefits are in four main areas:

1. Improvement in clinical efficiency and productivity
2. Reduction of medical error
3. Increased user satisfaction
4. Enabling new applications not possible with a fixed IT infrastructure

This study was undertaken to examine the impact of wireless LANs in healthcare internationally and in the Irish context and investigate whether the benefits demonstrated internationally apply also to the Irish healthcare sector. The acute hospital sector is focussed on as this is the most technology intensive part of the healthcare industry.

1.2 Objectives

The objectives of the study are to examine whether wireless LANS can bring the benefits demonstrated in international studies to Irish hospitals. Since no research has as yet been published on use of wireless computers in Irish healthcare, the study aimed to undertake a survey of Irish hospitals to determine the extent of wireless LAN usage, look for emerging trends and examine whether any new applications (benefit area four above) have been enabled. The study aimed to perform a case study to examine whether benefits found in international studies apply in Ireland. Two areas from the four benefit areas listed above were chosen to examine. These were efficiency and user satisfaction. Since the pool of Irish healthcare workers using mobile computers is as yet very limited, the sample size is too small to examine effects on medical error.

The objectives of the study are to

- Review the international state of the art to examine the impact of wireless mobile computing on the healthcare industry, and determine the major benefit areas
- Establish the Irish state of the art by undertaking a survey to find out the extent of the penetration of wireless LANs in the Irish healthcare sector, examine emerging trends and look for enabling of new applications.
- Perform a case study to determine whether the benefits of wireless mobile computers found in international studies apply also to the Irish context, with reference to efficiency and user satisfaction.

1.3 Overview of chapters

Chapter One introduces the subject of the study and gives an overview of the dissertation.

Chapter Two explains the key enabling technologies for commercial wireless networks.

Chapter Three presents a review of the state of the art. International studies of wireless LANs in healthcare are reviewed and the findings summarised.

Chapter Four surveys the current state of the art in Ireland and presents the results of a survey undertaken to investigate wireless LAN deployment in Irish hospitals.

Chapter Five introduces the case study, gives background information on renal dialysis, the medical devices and clinical software used and the two renal dialysis units where the case study took place.

Chapter Six describes the design of the case study.

Chapter Seven presents the results of the case study.

Chapter Eight discusses the results and compares them with international findings.

2. Enabling Technologies

2.1 Introduction

This chapter gives a brief explanation of the 802.11 standard, the technology used in industry standard wireless local area networks (WLANs). 802.11 is also known as WiFi.

2.2 The 802.11 standard

802.11 is the technology of choice for industry standard wireless LANs. 802.11 is part of the IEEE 802 family of networking standards (O'Hara and Patrick [7]). The 802 family defines a Logical Link Control layer, 802.2, and a variety of Medium Access Control (MAC) and Physical (PHY) layers. These include 802.11 and 802.3 (Ethernet) among others. The relationship between these standards and the Open System Interconnection (OSI) 7-layer model is shown in Figure 1.

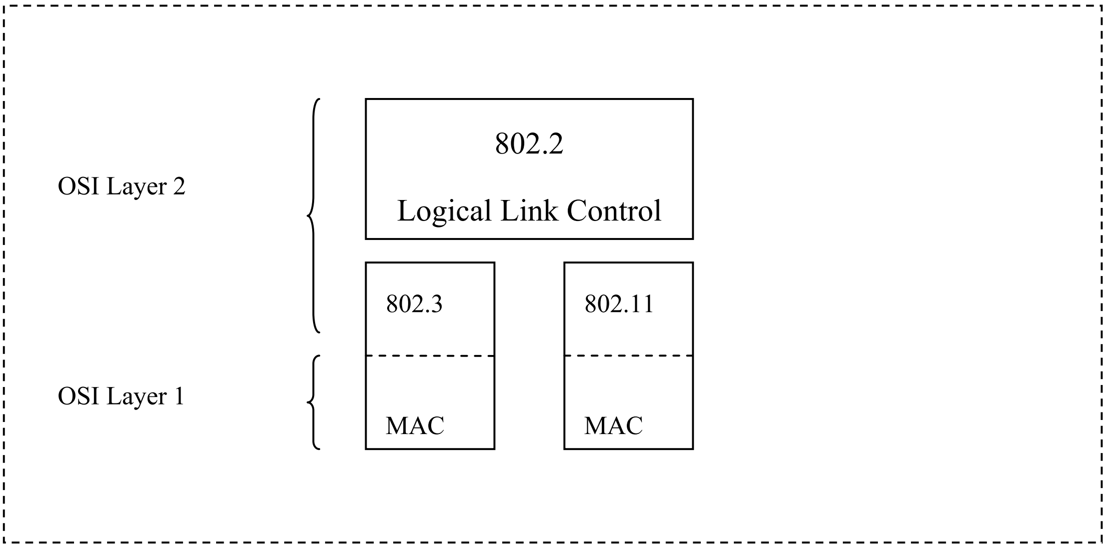

Figure 1 802.x and OSI

The Logical Link Control (LLC) provides a standard interface to higher layers of the OSI model. The 802 LLC and Medium Access Control (MAC) together correspond to the OSI Data Link Layer. All the MAC layer standards have the same interface to the LLC, which simplifies interworking between different MAC standards. 802.11 was designed from the start to look and feel like a 802.x wired LAN. It supports all the protocols and network management tools used on a wired network.

802.11 is also known as WiFi (Wireless Fidelity). The term WiFi is a registered trademark of the WiFi Alliance [5], an industry forum which provides interoperability testing and certification for 802.11x based products. WiFi denotes a product which has been certified by the WiFi alliance.

2.3 The 802.11x Family of Standards

The 802-11 standard was adopted in 1997, revised in 1999 (IEEE [1]). 802.11 defines a MAC and 3 Physical (PHY) layers in the 2.4 GHz band offering data rates of 1 -2 Mbps. 2 new PHYs were added in 1999. These are 802. 11a, which offers data rates of up to 54 Mbps in the 5 GHz band, and 802.11b, a higher rate PHY (up to 11 Mbps) in the 2.4 GHz band. A number of other extensions have been published since.

The commonest 802.11 standards in use today are 802.11b and 802.11g (IEEE [4], [3]). Most modern equipment is dual 802.11b/g. 802.11a is used for point to point wireless links, but is not commonly in use for standard user equipment. 802.11i was ratified in 2004 and offers enhanced security (IEEE [2]). See Table 1 for an overview of the various standards.

MAC variant	Description
802.11a	Operates in the 5 GHz band, offering data rates up to 54 Mbit/s, with an Orthogonal Frequency Division Multiplexing (OFDM) physical layer
802.11b	Extension to 802.11 PHY. Operates in the 2.4 GHz band. Data rate up to 11 Mbit/s
802.11e	802.11 extension for enhanced Quality of Service. QoS is required for

	transport of voice, video and audio streaming over 802.11
802.11i	Extension for improved security
802.11g	OFDM PHY. Similar to 802.11b, operates in the 2.4 GHz band, with data rate of up to 54 Mbit/s.

Table 1 The 802.11 family of standards

2.4 The 802.11 Protocol

802.11 is an elegant engineering solution to the problems posed by the wireless medium. The objective of the protocol is to deliver high throughput, reliable, continuous data delivery, equivalent to wired networks. It must also facilitate mobility and power saving. Wireless LANS face a number of unique challenges which the protocol is designed to overcome (O'Hara and Patrick [7]). These include:

- **Air interface**

A wireless LAN must deal with security concerns of data carried over the air interface. It must also handle the vagaries of radio propagation such as attenuation or reflection of the signal by objects in the environment, leading to differences in received signal strength.

- **Mobility**

Network nodes do not have a fixed address, and may move physically around the network. This gives rise to problems in routing traffic to and from the mobile stations, which the protocol must solve.

2.4.1 The 802.11 Architecture

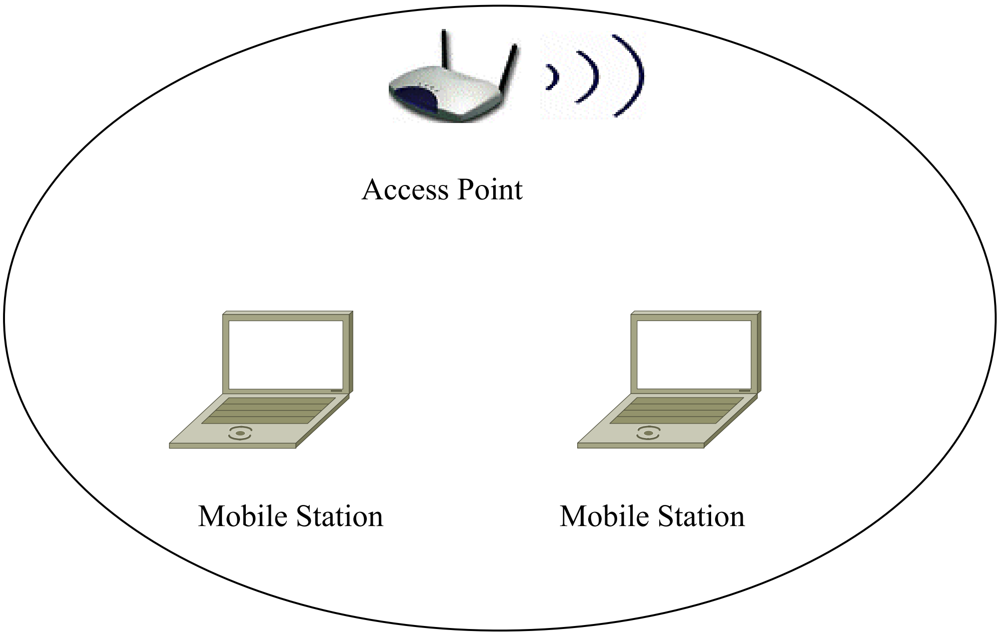

Figure 2 Basic Service Set

The main components of the 802.11 architecture (see Figure 2) are:

- Access Point (AP)
- Mobile Station (MS)
- Wireless medium
- Basic Service Set (BSS)
- Extended Service Set (ESS)
- Distribution System (DS)

Every mobile station and access point contains MAC and PHY layers and supports the services of authentication, deauthentication, privacy, and data delivery.

The Basic Service Set (BSS) is a set of stations that communicate. An infrastructure BSS always includes an AP. The AP provides a connection to the wired LAN and a relay function for the mobile stations. All mobile stations communicate via the AP. This consumes twice the bandwidth, but offers significant advantages e.g. power saving.

The Extended Service Set (ESS) facilitates mobility. The ESS is a set of infrastructure BSS's, where the APs communicate between themselves to forward traffic and facilitate movement of MS's from one BSS to another. They do this via the Distribution System.

The Distribution System (DS) is the backbone of the Wireless LAN. It may be wired or wireless. The DS is a thin layer in each AP. It determines whether traffic from the BSS is to be relayed to a local destination within the BSS, forwarded on the DS to another AP, or sent outside the ESS to the fixed infrastructure. Traffic from the DS is transmitted to the BSS. To the fixed network, the ESS and all MS's look like a MAC layer network where all stations are stationary. This hides the mobility of the Mobile Stations from the network outside the ESS. This allows network protocols with no concept of mobility to inter-operate with a WLAN which has Mobile Stations.

While the communication between APs is outside the scope of the standard, there is an inter access point protocol which has been developed by industry cooperation. There is however no guarantee that equipment from different vendors will inter-operate, a factor which network managers must bear in mind when purchasing equipment.

2.4.2 The MAC Layer

2.4.2.1 MAC Layer services

The MAC Layer provides the following services:

Station services

These services are provided in all APs and mobile stations.

- Authentication

  Used to confirm the identity of a station, thus allowing use of the network only to authorised users.

- Deauthentication

  Removes a previously authorised user from further use of the network.

- Privacy

  Provides Wired Equivalent Privacy (WEP)

- Data Delivery

  Provides reliable delivery of the data frames.

Distribution services

These services are provided to support the distribution system.

1. Association: The AP makes a logical connection to a Mobile Station (MS), so the AP can route data correctly to the MS and the AP can accept data from it. This service is invoked, when the MS joins the WLAN, on power up, or after being out of range. Association supports address filtering: the Station filters on the BSS ID as well as the destination address, to ensure it receives frames only from the BSS with which it is associated.

2. Reassociation: similar to association, but the message includes details of the AP previously associated with the MS. This service facilitates mobility throughout the ESS. It allows the new AP to contact the previous AP to collect any data frames waiting for delivery to the MS.

3. Disassociation: a MS may disassociate on power down or ejection of the wireless interface card, thus freeing up resources in the AP. An AP may use it to force the MS to associate, or when it can no longer provide services e.g. on power down.

4. Distribution: the AP uses this service to route frames correctly within the BSS, into the DS or to the fixed infrastructure outside the WLAN. This service determines whether the frame should be routed to another AP or to a portal.

5. Integration: this service connects the 802.11 WLAN to other LANs, wired or wireless. A portal performs the service. This is a service which translates 802.11 frames to frames for other networks and vice versa.

A Mobile Station may he authenticated by many APs, but can be associated with only one at a time. The MS must he authenticated before it can be associated. Only stations which are both authenticated and associated can receive or transmit data frames. Association and Authentication services facilitate mobility as the MS roams around the ESS. 802.11 provides the functionality of a wired LAN together with the benefit of mobility.

2.4.2.2 MAC Layer functions

The MAC faces a number of challenges

1. Ensuring Reliable Data Delivery. The wireless medium is inherently unreliable and subject to interference by other users e.g. microwave ovens.

2. Control of access to the wireless medium, preventing collisions which corrupt data and ensuring all stations have equitable access to the medium.

3. Data security : ensuring only authorised users have access and protecting data

4. Power management: mobile equipment is battery operated therefore strategies are needed to save power

5. Scanning to allow the MS to find the BSS

Reliable Data Delivery

The MAC uses the Frame Exchange Protocol to ensure data delivery. Each data frame sent by the source is acknowledged by the destination. If no acknowledgment is received, the frame is retransmitted. The frame and its acknowledgment may not be interrupted by other stations.

Access to the wireless medium

There are a number of problems which the MAC has to overcome to ensure equitable access to the wireless medium.

Hidden nodes

The problem of hidden nodes is overcome using the Request to Send (RTS) / Clear to Send (CTS) mechanism ([6], [1]). See Figure 3 below.

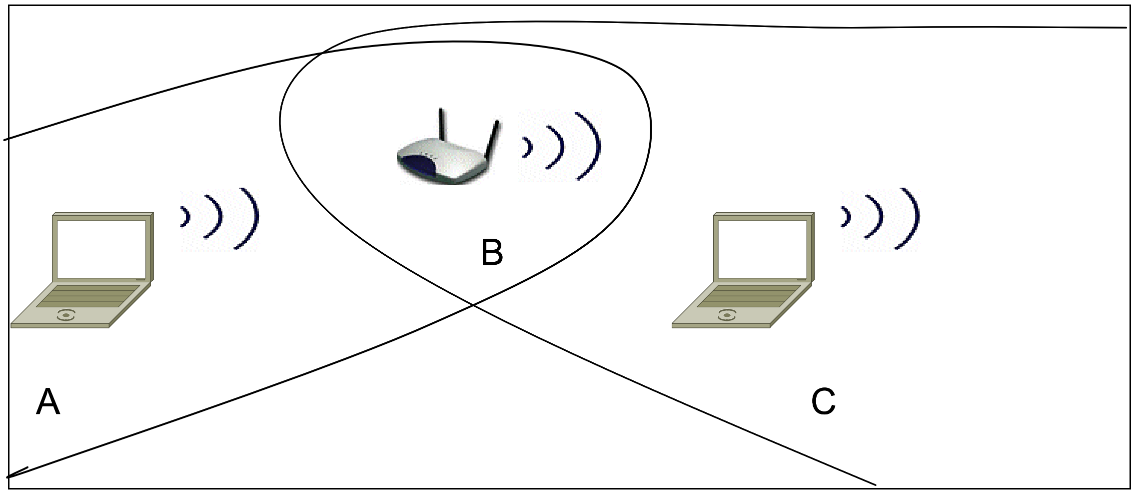

Figure 3 Hidden Node

Stations A and C cannot communicate with each other, but the AP (B) can communicate with both. A frame sent by A to B will not be heard by C, and C may interrupt transmission and corrupt the frame. A Sends a Request to Send (RTS) to B and B acknowledges with Clear to Send (CTS). A then sends its data frame, and B acknowledges it. C will hear the CTS, and will not attempt to access the medium until it hears the acknowledgment from B. Retry counters and timers limit the number of attempts to deliver a frame, to ensure the medium is not monopolised by an undeliverable frame.

Basic Access

The access method is Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), with binary exponential backoff. The station listens to the medium before attempting a transmission. If it detects a transmission in progress it will not attempt to transmit. This avoids collisions, which would corrupt the transmission. The listening station waits before retrying. The waiting period is determined by the binary exponential backoff algorithm. It will also increment a retry counter. This algorithm chooses a random number from a range called the contention window. The random number represents the time for which the medium must be idle before the station can reattempt transmission. The size of the contention window doubles for each transmission, until the maximum size is reached. The random nature of the time interval ensures all waiting stations do not attempt to transmit simultaneously once the medium becomes idle. Once the frame is successfully transmitted, the contention window is reduced to the minimum for the next frame. Because wireless devices generally cannot receive and transmit at the same time, the MAC uses collision avoidance.

Not all devices in a wireless network can communicate directly, therefore a Network Allocation Vector (NAV) is used. The NAV is the amount of time left before the medium becomes free. It is updated by the duration value that is transmitted in all frames, this value gives the duration required to complete transmission of the frame. The NAV is a virtual carrier sense mechanism which tells the station the medium is busy, when the physical carrier sense mechanism provided by the PHY does not detect a transmission.

Security

Security is a major issue for healthcare institutions who need to protect sensitive medical data. Concerns over security may be one of the reasons for the slow uptake of wireless LANs in the healthcare industry. The main security mechanisms implemented by 802.11 are MAC address filtering and Wired Equivalent Privacy (WEP).

Each network interface card in a mobile station has a unique MAC address which can be used to identify it. MAC address filtering can be employed to restrict access to stations whose MAC addresses have been registered with the Access Point. If the station's MAC address has not been registered with it, the AP will not allow it to associate.

Wired Equivalent Privacy (WEP) defined in the original 802.11 standard was intended to provide the same level of security as a wired connection. WEP provides two main security mechanisms:

- Authentication ensures only authorised users are allowed to access the network. A shared key is used to encrypt and decrypt a challenge text as proof that the stations have the same key..

- Encryption. WEP uses a shared key with the RC4 algorithm to encrypt and decrypt data. The same shared key is used for both authentication and encryption. The key may be 40 or 128 bits. It must be kept secret, and communicated to all stations. A set of up to 4 default keys may be defined, to be shared by all stations on a BSS or ESS. These allow all stations to communicate securely, however the keys are more widely distributed and so more likely to be revealed. The station chooses one of the keys for a transmission and indicates which one in the key ID field of the frame header.

WEP has been found to be vulnerable, and has been superseded by 802.11i [2]. WEP is vulnerable for a number of reasons ([10], [9]) . The Initialisation Vector (IV) used with the shared key to generate the RC4 key stream is relatively short (24 bits), so WEP eventually uses the same IV for different data packets. This can happen within an hour in a large busy network. This results in the transmission of frames having key streams that are too similar. If an eavesdropper collects enough packets based on the same IV, it is possible to determine the key stream or the shared key and decrypt the data.

The shared keys present another security problem because they are not changed often enough. 802.11 does not provide a function to support the exchange of keys among stations. As a result, the same keys may be used for long periods of time and this gives eavesdroppers an opportunity. Some vendors offer proprietary key distribution solutions to improve security.

WiFi Protected Access (WPA) was an attempt by vendors to address the security problems of WEP. WPA has now been superseded by 802.11i ([2]), which was ratified in 2004. The objective of 802.11i is to enhance the 802.11 security aspects ([8]). 802.11i introduces key management and establishment algorithms to manage security keys automatically as well as encryption and authentication improvements. The Temporal Key Integrity Protocol (TKIP) ensures that each station uses different key streams to encrypt the data. Unlike WEP, TKIP changes temporal keys every 10,000 packets. This provides a dynamic distribution method that significantly enhances the security of the network. In addition to the TKIP solution, the 802.11i standard includes the Advanced Encryption Standard (AES) protocol. AES offers much stronger encryption than RC4. An issue, however, is that AES requires additional hardware to operate. While the major 802.11 chipset vendors have included this hardware in their chipsets for some time, some users may need to replace existing equipment to implement AES ([8]).

Even if 802.11i or WPA is not used, WEP and the proprietary security measures offered by most manufacturers is sufficient to guarantee security and confidentiality of medical data. Technology exists to solve the security problem, and it need no longer be a concern for healthcare institutions wishing to install wireless LANs.

Power Management

Power saving is essential for battery operated mobile stations. Length of battery life is one of the most important parameters for users of such devices. Radios, especially when transmitting, are power hungry. 802.11 implements a power saving mechanism to allow the MS to turn off its receiver and transmitter to save power ([1], [7]) without losing messages. The MS must first inform the AP when it will enter power saving mode. The AP will then buffer frames for the MS while it is in power saving mode. The AP transmits a Traffic Indication Map indicating which stations have frames buffered in the beacon frame, which it transmits periodically. The MS must wake up at intervals to listen for the beacon. The intervals will be a predetermined multiple of the period between beacons. The MS therefore need only listen at intervals, and need only wake up fully if there is a message waiting for it. This mechanism reduces power consumption and lengthens battery life of mobile stations.

Scanning

The MS must find the BSS before it can join ([1], [7]). Scanning may be passive, where the MS listens for beacons and probe response frames, extracting the BSS information from them. It will listen on several channels to scan all BSS's within range. This method reduces power consumption but is slow. Active scanning minimises the time needed to find a BSS. The Mobile Station must know the network name (service set identifier) of the wireless network it wishes to join. The MS transmits a probe request on each channel. If there is a BSS with a service set identifier (SSID) which matches the one in the probe request, the AP will transmit a probe response.

2.4.3 The Physical layer

A variety of Physical (PHY) layers have been defined. These insulate the MAC from the underlying physical layer and handle all functions related to the wireless medium. All provide the same services to the MAC layer:

- Data transmission
- Data reception
- Clear Channel Assessment – physical sensing of the medium to determine whether it is idle or busy

2.5 Other Enabling Technology

2.5.1 Citrix Thin Client

Thin client computing [12] is popular in healthcare institutions and Citrix is the market leader ([11]). This section gives a brief overview of how Citrix thin client works.

Thin Client Technology or Server Based Computing enables any computer to access server based Microsoft Windows and Unix based applications. Citrix Thin Client technology is used to run applications over the network. The applications can be accessed from every desktop, and run directly on the server. This means there is no need to install the application on every desktop system. Only the screen, keyboard and mouse information are passed between the server and the client desktop system. Citrix Client software is required on the client device and this handles communication with the server.

Centralised management is a key feature of Citrix's server architecture. All user software and data can be stored on a centralised server without having to modify the client device. Many benefits can result from centralised management, including improved efficiency and cost savings.

A further advantage of thin client technology is that the client desktop or handheld can be smaller and cheaper. As all processing and file storage is on the server, there is no need for high specification processors or hard drives on the client. This means handheld clients can be made smaller and lighter, as well as cheaper.

Citrix provides secure remote access protected by 128-bit SSL (secure socket layer) encryption between the clients and servers. This is important for health care institutions to ensure protection of medical data.

3. Wireless Technology in Healthcare: The international context

This chapter examines the application of Wireless LAN technology in healthcare in the international context. A review of the literature is presented. The focus is on the acute hospital setting because this is the most technology intensive area of healthcare. We report on international studies which have examined the effects of wireless technology in healthcare. These studies have shown that wireless LANs may bring benefits in terms of four main areas:

- Improvement in clinical efficiency and productivity
- Reduction of medical error
- Increased user satisfaction
- Enabling new applications not possible with a fixed IT infrastructure

The following review of international studies is therefore presented with respect to findings in each of these areas. In addition a summary of findings in relation to the characteristics and suitability of different types of wireless client are included, as choice of wireless client is an important factor affecting usability of the wireless LAN.

3.1 Improving Efficiency

Healthcare is consuming a large part of the budgets of many countries. The U.S.A spent 14.6% of GDP on healthcare in 2002, while Ireland spent 7.3% (OECD [13]). Figure 4 shows total healthcare expenditure in 2002 as a percentage of GDP for a number of OECD countries. Spending in all these countries was rising for the three years prior to 2002.

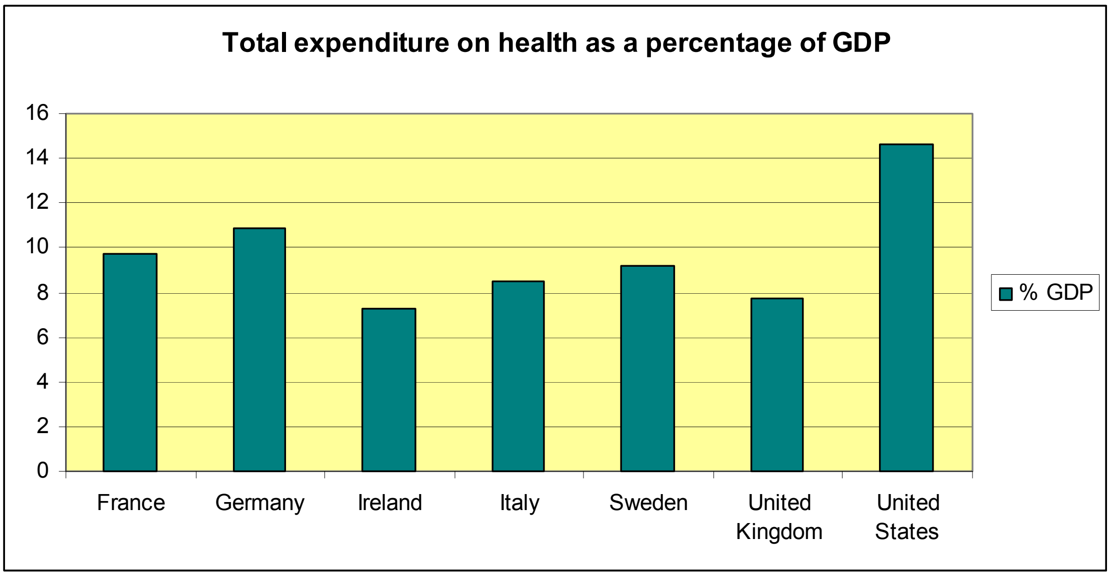

Figure 4 Total expenditure on health as a percentage of GDP in 2002 [13]

The percentage of elderly people in the population is rising in the U.S.A., U.K., Ireland and most western European countries (OECD [14]). Demand for healthcare is therefore likely to increase. If healthcare is not to consume an ever larger proportion of national resources, methods of increasing efficiency while continuing to deliver an acceptable quality of care must be found.

Studies from other industries have found wireless computers can lead to significant increases in efficiency. Intel [39], [40] reported a productivity improvement of 5% when their employees were given wireless laptops. Employees also changed their work habits to take advantage of the new technology and reported feeling more in control of their work. Studies of wireless computers in healthcare tie in with findings from other industries and have found wireless computers can lead to significant increases in productivity. A selection of studies is reviewed here which show how wireless computers can improve the efficiency of healthcare delivery.

Vendor studies such as the Jena [20] and Gemelli [37] hospital case studies as well as publicly funded research projects such as the Ward-In-Hand project [32] have found significant time savings when hospital staff were given wireless computers and properly trained in their use.

Ward-in-hand project

The Ward-In-Hand project [32] was EU funded and took place in three hospitals, in Italy, Spain and Germany. The project aimed to support the day-by-day activities of doctors and nurses within a hospital ward by providing a tool for workgroup collaboration and wireless access to the patient's clinical records. The project is based on accessing the information system from the patient's bedside through a handheld Personal Digital Assistant (PDA) client, connected via a wireless LAN. Once users became familiar with the systems, impressive efficiency gains were recorded. When a comparison with the time necessary to compile paper records was made, it was found that Ward-in-Hand allowed a time saving of up to forty percent .

Jena University Hospital, Germany

A case study reported by Intel at Jena University Hospital, Germany [20] shows how wireless PDAs could save time for nursing staff. Previously, nursing staff at Jena hospital had to enter and access patient data at the fixed ward PCs. The hospital wanted to reduce the administrative burden on the nurses to give them more time for patient care.

All nurses were equipped with PDAs, connected via wireless LAN to the hospital network. Data is displayed in a web browser on the PDA. No data is stored on the PDA and changed data is uploaded immediately to the server.

Nurses can now record data as care is being given. Since they can enter and retrieve data from anywhere on the ward, they no longer have to make trips to the ward PC. The reduction in administrative time was substantial. Nurses saved up to two hours per shift, leaving them more time for looking after their patients.

Gemelli Hospital, Rome

A study reported by Gartner [37] took place in Rome's Gemelli hospital. Here, all clinical staff in a forty bed trial ward were given personal PDAs. These devices were used to access patient records at the bedside. They were also used to collect data at the bedside and input it into the patient record database. This replaced the previous two step process where staff collected patient data on paper and input it later to a fixed PC. Staff could also use the PDAs to order examinations online. The results found that while collecting data at the bedside took much the same time, nurses saved time from not having to go to a fixed PC, and possibly having to queue for it, to enter data. The time saving was estimated at fifteen minutes per patient. Examination requests were received sooner in the relevant departments, allowing more of them to be processed the same day, rather than having to wait for the next day. This resulted in an estimated one day reduction in average length of stay from seven days to six days.

Conclusion

Wireless computers can deliver significant efficiency improvements and enhance the productivity of clinical staff.

3.2 Reducing error

This section considers the problem of medical error and how wireless technology could help to reduce it.. The National Institutes of Health [21] studied the incidence of medical error in U.S. hospitals. Studies by Upperman et al [22] and Jacobs [24] have shown that wireless computers used with a Computerised Physician Order Entry (CPOE) system can help reduce error and improve patient safety. Rothschild [25] in a review of published CPOE studies using fixed PCs considered that use of wireless computers would further improve the ability of CPOE systems to reduce error.

The National Institutes of Health report

Medical error is a serious and growing problem. A study by the National Institutes of Health [21] estimates that medical error accounts for between forty four thousand and ninety eight thousand deaths annually in American hospitals. Even at the lower estimate, deaths due to preventable adverse events exceed the deaths attributable to motor vehicle accidents, breast cancer or AIDS. The NIH found that the proportion of hospital admissions experiencing an adverse event is between two point nine and three point seven percent. Of these, preventable adverse events due to error were between fifty three and fifty eight percent. The costs of preventable adverse events are considerable. Additional health care costs were estimated at $17 billion. Total national costs (including lost income, production, disability) were estimated at four percent of U.S. national health expenditure in 1996.

The NIH study points out that error rates in medicine are relatively high compared to other industries. They consider healthcare to be a complex and tightly coupled system, as defined by Perrow (1984), especially in the Operating Theater, Intensive Care Unit and Accident and Emergency department. A complex system is prone to unexpected and complex interactions between processes. Tightly coupled systems are centralised, with high dependencies between the steps of a process. This allows little opportunity for recovery once a fault occurs. Healthcare is both complex and tightly coupled and may therefore be classified as an industry prone to accidents.

When large systems fail it is generally due to multiple faults occurring together. Latent errors are failures built into the system, present long before active error arises. These built in failures are difficult to see, they may be hidden in computer systems or layers of management, or people may become used to working around the problem. Responses to failure tend to focus on active errors. This is not an effective way to make systems safer as safety is a characteristic of systems, not of their components.

Other industries such as aviation have successfully reduced their error rates. The NIH considers healthcare could do the same, and give some guidelines as to how this could be achieved. Two of these recommendations are

- Improve access to accurate timely information
- Information on patient, medication etc. should be available at the point of care

These are two areas where wireless computers are ideally placed to increase safety. Because computers are connected wirelessly to the hospital network, users have access to up to date information. Mobile computers give access to information where it is needed, at the point of care.

Cincinnati Children's Hospital Medical Centre

Cincinnati Children's Hospital Medical Centre (Jacobs [24]) implemented a hospital wide CPOE system after a study showed a significant level of prescribing errors. Seven percent of those errors contained potential for adverse effects on patients, ranging from a need for increased monitoring to permanent harm. Verbal care orders comprised twenty two percent of total orders and were a frequent source of error. Transcription errors accounted for fifteen percent of adverse or potentially adverse drug events.

Wireless connectivity via WiFi was considered essential to supporting clinical workflow. WiFi infrastructure was deployed in all wards and used with a variety of client devices including mobile carts, laptops and tablet PCs. The wireless PCs allowed the portability required for continuous order input during ward rounds, and allowed point of care access to patient data in close proximity to the patient an family.

Ninety percent of orders are now entered directly into the system. The system has built in decision support and pre-defined order sets specific to each clinician's specialty. As a result of CPOE orders are complete, legible and unambiguous. The CPOE is integrated with clinical documentation, thus eliminating transcription errors. Because clinicians are using wireless devices during their ward rounds, they are entering orders earlier in the day, contributing to earlier discharge of patients. The hospital achieved a thirty five percent reduction in medication errors. Order transmission to the pharmacy was reduced by one hour, improving the overall medication time cycle by fifty two percent. Better compliance with prescribing standards and increased user satisfaction were also observed.

Children's Hospital of Pittsburgh

Upperman et al [22] reported on a hospital wide CPOE system implementation in a pediatric setting. Both fixed and wireless computers were used [23]. The wireless computers were on mobile carts (COWs) that can roll on ward rounds. The pediatric population poses a unique set of risks predominantly because of the wide variation in weights. Overall, the hospital wide rates for adverse drug events (ADEs) in a paediatric hospital is estimated to be about ten percent.

Pre- and post- CPOE results were measured and compared. Verbal order regulatory compliance increased from 80% to 95%. Transcription errors were eliminated. The study found no significant difference in ADEs overall, the rate remained at around 3%. However there was a significant decrease in harmful ADEs. These decreased from the pre CPOE level of 0.05 ± 0.017 per 1000 doses to 0.03 ± 0.003 per 1000 doses in the post CPOE period ($P = .05$). The authors considered that these gains were because of rules that are built into the system that remind or warn the clinician about unfavorable clinical parameters in the patient's status.

Critical Care

Rothschild [25] conducted a survey of published CPOE studies, many of them in intensive care. The survey found that CPOE significantly reduces error during medication prescribing. Inclusion of Decision Support Systems during medication ordering not only reduces medical errors, but also increases the efficiency of healthcare delivery and the use of evidence-based clinical guidelines. While the studies reviewed used fixed computers, Rothschild considered that wireless communications and use of PDAs or tablet computers can be expected to further augment the potential of CPOE to reduce error.

Conclusion

CPOE systems using both wired and wireless computers reduce error. No studies to the best of our knowledge have specifically compared the incidence of medical error in wireless versus non-wireless CPOEs. There may be an effect on error due to bringing C (DSS) closer to the point of care with wireless computers, but this has not, as far as we know, been tested.

3.3 User Satisfaction

Despite the proven benefits in reducing error, deployment of CPOE has met with a number of failures. For example the Cedars-Sinai Medical Center in Los Angeles [26] turned off its computerised physician order entry system. Physicians complained that rather than speeding up and improving patient care, it actually slowed down the process of filling their orders. No computer system can be deployed successfully if the users refuse to accept it. The studies considered here show how wireless computers can support CPOE by helping integrate it into the clinical workflow, thus increasing user satisfaction and the chances of successful deployment.

In an evaluation of CPOE studies, Handler et al [28] point out that while medication error is an important issue, diagnostic error may be an even greater problem, particularly in Emergency Departments with a high volume of patients. CPOE / DSS systems that demand time from physicians have the potential to decrease medication error at the expense of increasing diagnostic error, resulting in an increase in the overall likelihood of error. Integration into the clinical workflow is key to getting the benefits of CPOE without introducing negative effects. For effective integration into clinical workflow, DSS and CPOE must be widely available, and at the point of care. Mobile wireless technologies are an essential component of this widespread availability. Handler et al conclude that without wireless technology to provide ubiquitously available hardware and software resources for CPOE, efficiency will suffer, clinicians will become frustrated, patient safety may be threatened, and implementations are likely to fail.

The California Healthcare Foundation [27] points out that CPOE is more than a technology – it is a clinical process facilitated by technology. They cite a number of studies, where wireless was a major factor in successful CPOE implementation. In Sarasota Memorial Hospital, Florida, remote access and wireless laptops increased acceptance by adapting to the way physicians work, i.e., providing access to automation wherever physicians are working, as opposed to making them change their workflow and come to the automation. In Montefiore Medical Centre, New York, the transition from paper order forms to CPOE was eased by use of wireless laptops that allow physicians the flexibility to enter orders while they do their rounds or after rounds are completed. They have been very successful and widely used. In the Ohio State University Medical Centre, Columbus, CPOE was introduced in the surgical transplant unit. The addition of wireless technology that allows physicians to enter orders online from the patient's bedside using a dedicated laptop computer increased the speed and accuracy of order completion, benefiting both patients and physicians.

Conclusion

A key advantage of wireless computers lies in increased usability and integration of CPOE with the clinical workflow, thus saving time and increasing user acceptance.

3.4 Enabling new applications

Wireless technology has the potential to enable new applications which are not possible with fixed PCs. Combining wireless with indoor positioning systems (IPS) technology has great potential for creating new applications. Indoor Positioning Systems locate people and objects inside buildings where the global positioning system (GPS) does not work well [33]. They have been developed using a variety of technologies based on radio, infra red or a combination. These systems open up new possibilities for creating location-aware services and context sensitive medicine.

IPS systems based on WiFi use existing wireless LAN infrastructure, and are thus more cost effective. Systems based on other radio technology or infra red require special proprietary infrastructure.

Heartlands Trial

Heartlands Hospital, Birmingham, trialled a new system in its surgical day-care ward ([29], [33]). The system uses WiFi based IPS technology from Ekahau [36] to track the patient's surgical journey and automatically displays all information relevant to a patient on wireless PDAs and tablet PCs at each point on the journey. Each patient is fitted with a WiFi tag for location tracking. When the patient arrives in an area, the location of the patient automatically triggers the display of the patient's current location and medical records on monitor screens and PDAs in theatres, anaesthetic rooms, nurses' stations. This ensures that all doctors, nurses and anaesthetists view the same information simultaneously and know where the patient is at all times – minimising errors that often occur due to logistics. The system replaces the operating theatre's paper-based process for managing patients. Previously, an operating list was generated on paper. As changes were made in the operating schedule, the list had to be updated, reprinted and distributed, often up to three times a day. This process caused delays and opened opportunities for human error. The digital operating list is easily updated and shared among practitioners using wireless PDAs and PCs. The system also time stamps each stage of the patient care process, enabling administrators to analyse how long each stage takes and evaluate where and why there may be time lags in the process. The system is expected to facilitate more efficient operating list handling and process improvement.

IPS Trials at MGH

An IPS recently tested at Massachusetts General Hospital ([35], [33]) accurately and reliably located patients and clinicians in time and space. Active radio tags are worn by patients and surgical staff and attached to medical equipment. Radio signals transmit from the tags to special receivers connected to the hospital's LAN and then to Web-based location software, which determines the location of the tag. This identity, location and time data are shared with hospital information systems. The data can be used to trigger pre-determined notifications, for example, a message to the surgical team that the patient is ready or an alert that the wrong patient is in an operating theatre. The system delivered a saving of about 30 hours of operating theatre time across all the covered operating theatres. The wireless technology used is a proprietary system from Radianse [35]. This system has cheaper tags but more expensive infrastructure than WiFi, as special receivers must be installed.

Conclusion

Wireless computers combined with Indoor Positioning Systems open up possibilities for new applications. However this area is currently cutting edge research. Neither of the studies reviewed has reported results yet. It is too early to evaluate what the impact of these new applications may be, but this is an area worth further research.

3.5 Choice of Client Devices

A brief survey of wireless clients is included here as the choice of client can influence usability of the system and user satisfaction. Mobile devices have some drawbacks in comparison with fixed PCs. They are battery operated and the battery life is limited currently to three or four hours, not long enough to cover a typical shift. In addition, screen size may be small and some devices such as PDAs and tablet PCs do not have keyboards.

Some international findings on various types of client are presented here which will be useful later for comparison with findings from the Irish case study reported in chapter 7. A variety of wireless client devices were used in the studies already reported in this chapter. Bullard [47] used mobile carts, also known as Computers on Wheels (CoWs). These are wireless laptops attached to wheeled carts with external batteries to provide the power supply. CoWs solve the problem of short battery life by using external long life batteries, but were found to be cumbersome and difficult to manoeuvre. The Jena [20], Ward in Hand [32] and Gemelli studies [20] used PDAs. In Cincinnati [24] a variety of devices (mobile cart, laptop, tablet PC) were used.

Review by Fischer et al

In a review of the literature on handheld computers in medicine, Fischer et al [17] found PDAs to be convenient and functional in a number of areas. Because of their small size they are easily carried in a pocket or briefcase and convenient to use for access to information at the point of care. However they have limitations when it comes to entering data. Fischer quotes other studies offering evidence for the usefulness of PDAs in a number of areas. These included:

- Cardiology

  A reported study showed PDAs can be safely used for interpretation of Electrocardiograms (ECG). Cardiologists made the same diagnosis when viewing the ECG on a PDA as they did when viewing the ECG on paper.

- Paediatrics

  Another study showed that paediatricians using PDAs at the point of care were more likely to adhere to clinical practice guidelines.

Santa Catarina University Hospital, Brazil

Medical images such as ultrasound, X-rays, Computed Tomography (CT) scans and Magnetic Resonance Imaging (MRI) are frequently used to aid diagnosis of many illnesses. While a Picture Archiving and Communication System (PACS) makes imaging data available in digital format from fixed workstations, this information is not readily available at the point of care. Andrade et al ([15], [16]) describe a system for accessing medical imaging data at the bedside, in a pilot study at the University Hospital of the Federal University of Santa Catarina, Brazil. Wireless enabled PDAs were connected to a central database via a wireless LAN and used to make imaging data available anywhere within the hospital. The PDAs were connected via the WLAN to a DICOM server, which manages a database of imaging data stored in DICOM format. Despite the small size of the PDA screen, and the need for compression of images, image quality was satisfactory. JPEG compression was used to reduce download times. This study shows that PDAs are satisfactory for display of medical images at the point of care.

Conclusion

PDAs are very useful for data access at the point of care because of their small size which allows them to be easily carried in a pocket. Despite the small size of the screen they are useful for accessing patient data including images. However PDAs are of limited use for entering data. Tablets and laptops are portable but have problems with short battery life, size and weight. CoWs overcome the problem of short battery life but are large and cumbersome.

4. Wireless Technology in Healthcare: The Irish Context

This chapter and the following chapters examine wireless technology in the Irish healthcare context. This chapter reports on the current state of the art and emerging trends in Irish wireless LAN deployment.

While very few Irish hospitals so far have installed a wireless LAN, it is likely Ireland will follow the trend seen elsewhere [38] and increase spending on wireless LANs. Increasing numbers of hospitals are deploying or have plans to deploy wireless LANs, therefore it is timely to study this technology in the Irish context. There are as yet no published studies of wireless LANs in the Irish Healthcare context. A survey was therefore undertaken to examine current wireless LAN deployment and future plans in a number of Irish hospitals. The aim of the study was to establish the state of the art and look for emerging trends.

This chapter examines Irish public health policy in relation to wireless LANs, presents a study of the state of the art in Ireland, and reviews an Irish project which enables new applications using wireless LANs and Indoor Positioning Systems.

4.1 Public Health Policy

The Health Service Executive (HSE) is supportive of wireless LAN technology. The HSE Information and Communications Technology (ICT) policy document [30] presents a clear vision of the place of wireless technologies in Irish healthcare. It states

> *"Online access to ICT services that support clinical processes will be available in real time through wireless-enabled devices at the point care is delivered, whether in a surgery or clinic, at a bedside or in the person's home"*

The strategy section of the document further states:

"The pace of development may also give rise to significant technological opportunities that may remove significant obstacles to development. For example, as wireless communications mature and become safer for use in hospitals and within communities, they will facilitate great advances in communications without needing the otherwise significant investment and delay in implementing wire-based systems. In addition, the significant advances being made in multi-media expert systems, integrated diagnostic and therapeutic systems, robotics and decision-support facilities may significantly change the ways in which clinical care is practised"

The National Health Strategy aims to achieve this vision within a 10-year timeframe. It is therefore to be expected that with HSE support at the highest level wireless LAN deployment will increase from its current low level, in line with international trends.

4.2 Study Design

In order to establish trends in the deployment of wireless LANs, interviews were conducted with IT staff in four Irish hospitals: St. James' in Dublin, the Adelaide, Meath and National Children's Hospital (AMNCH) in Tallaght, Midlands Regional Hospital (MRH) in Tullamore and University College Hospital Galway (UCHG). This is not an exhaustive list of hospitals deploying, or planning to deploy, wireless networks. These were picked as a representative sample, for which data are available. The interviews followed a structured format with a predefined list of questions. Interviewees were also asked whether any of the information given was confidential. No information designated as confidential has been reported here.

Questions

1. Wireless Infrastructure

    - How many access points?

    - Who is the equipment vendor?

- How is the wireless network connected to the fixed network?

2. Client devices

    - Which client devices are used? E.g. tablet / pocketPC / CoW etc.
    - Which operating systems are used?

3. Deployment

    - How many wards are covered?
    - Has the infrastructure been deployed and tested already?

4. Security

    - What security measures are used?

5. Applications

    - Which applications are used with the wireless LAN?
    - Who are the main users?
    - Are any other applications planned to use the wireless network?
    - How have users reacted to the application?
    - Has a trial been carried out?

6. Issues

    - Are there any issues with the client devices e.g. size, weight, battery life?

4.3 Results

This section reports on the results of the survey.

4.3.1 St. James' Hospital

St. James' is a large Dublin teaching hospital which has recently (December 2004) installed a wireless LAN. The LAN has been installed primarily for SAP inventory management purposes. There are as yet no clinical applications.

4.3.1.1 Infrastructure

The fixed LAN has a one Gigabit backbone with over one hundred switches, delivering one hundred Mb/s to the desktop. Over two thousand fixed devices are connected. The wireless LAN currently being rolled out is based on 802.11 b/g technology from Cisco. The WLAN is connected to the fixed network via 2 Virtual LANs (VLANs). There are sixty access points. Initially ten client devices will be served.

4.3.1.2 Client Devices

The only client under consideration for clinical applications is a specially designed, medical grade laptop on a trolley (Computer on wheels or CoW) with 23 hour battery power packs and a 17 inch display. It could be wheeled around wards and operating theatres.

Citrix thin client (see section 2.5) will be used to run applications over the network.

4.3.1.3 Deployment

Coverage extends to all of the new hospital including wards and stores. The operating theatres are lead lined, necessitating an Access Point in each theatre where coverage is desired.

4.3.1.4 Security

The WLAN is divided into a public (to the air interface) and a private (to the main network) side. There is a dedicated subnet on the private side, with static Internet

Protocol (IP) addresses assigned to clients. The connection to the WLAN on the private side is managed by two machines, which can be monitored and secured.

Client devices are connected to the hospital network via Secure Socket layer (SSL) over Virtual Private networks (VPN). MAC address filtering is used, with MAC address authentication using a RADIUS server. The service set identifier (SSID) is also used. Authentication of the user is performed by the fixed network over SSL, using Windows NT user authentication.

Wired Equivalent Privacy (WEP) is not used, owing to the difficulty of administering keys on the client devices.

4.3.1.5 Applications

The WLAN is being installed initially for use with SAP for materials management. Wireless handhelds will be used for remote order entry, stocktaking etc.

Clinical uses being considered are

- Access to PACS. This would be via a COW which would be used in wards and operating theatres for viewing X-rays and other digital images.
- Use in A&E for access to patient records.

4.3.1.6 Issues

A number of issues present perceived obstacles to widespread deployment of WiFi enabled handheld devices in the hospital.

Power management Power consumption is a major issue. A PDA or laptop battery will only last 3-4 hours in constant use. A power supply which will last for an entire 8 hour shift is considered necessary for practical use.

Medical grade WiFi enabled handhelds must be medical grade. For use in the operating theatre this is a major issue, as the devices must be capable of meeting standards for disinfection. Medical grade devices are difficult to source and expensive.

For the reasons outlined above, the only client devices currently being considered for clinical use are the CoWs with 23 hour power packs. While these are portable to an extent, they do not allow realisation of the full benefits of wireless technology.

PDAs are not under consideration because of their limited functionality. This could be overcome by offering web-based services to PDAs. However there are no plans at present to do this, as the development work required on the intranet side would be considerable.

4.3.2 AMNCH

AMNCH is one of the main Dublin teaching hospitals. They have installed a wireless LAN in order to run TEAMS, Tallaght Education and Audit Management System, an integrated CPOE and clinical audit system.

4.3.2.1 Infrastructure

The WLAN uses Cisco AP1200 Access Points. The APs are connected directly to the fixed network. All mobile devices are on their own Subnet and roaming is supported.

4.3.2.2 Client devices

The client devices are APLUX A5 size Tablet PC thin clients. There is no hard drive. WiFi functionality is not built-in – an external Cisco WiFi network interface card is used. Battery life is around three hours with WiFi enabled. Since the devices are used intermittently, the batteries can be charged up between uses, so battery life is not perceived as an issue. Booting is fast, it takes between ten and fifteen seconds to boot up and display the login screen.

Service delivery is via Citrix MetaFrame on the server to the remote desktop thin client on the tablet.

4.3.2.3 Deployment

The AMNCH WLAN is a pilot system which has been running for a year. There are six or seven AP's in use at present. The WLAN is live, operational and resilient in two Wards. Rollout to A&E and three or four other wards is planned and is an immediate priority, as a number of current projects depend on it. Rollout to all wards is planned tentatively. The equipment is available, electrical and building work are the constraints. The pilot is funded by the hospital.

4.3.2.4 Security

A proprietary security mechanism supplied by Cisco is used to secure the wireless network. Users are authenticated using normal Windows authentication procedures.

4.3.2.5 Applications

The WLAN installation was driven by user need. These needs were primarily

- Bedside review of lab results
- Bedside access to patient records
- Fast and convenient lab test ordering
- Clinical Audit
- Capture of diagnostic data for the Hospital Inpatient Enquiry system (HIPE). This is a system used to capture casemix data for budgetary and benchmarking purposes.

The WLAN is used to view patient records and radiology results, in the same way as any other networked machine. Teams is used to interface with the lab. Teams is the main application used at present. Possible future applications being considered are for handling nurse dependency and nurse rostering.

4.3.2.5.1 TEAMS

Overview

TEAMS is currently the only application running on the WLAN. TEAMS includes a custom application to interface with the lab. TEAMS was developed by hospital IT staff working with a software vendor. The purpose of the TEAMS system is to allow doctors to immediately, effectively and efficiently record patient diagnoses on the spot, while they are actually with the patient. Key project objectives are to reduce the amount of time that medical staff will spend on this activity, and to enhance the accuracy and completeness of the information being captured.

The anticipated advantages and benefits of the TEAMS system are:

- Captured data and information is available in real time, rather than weeks later.
- As a direct result of the data being entered in a timely manner, it should be more accurate as it is entered while current in the users mind.
- Clinicians spend less time away from the bedside. Less time is lost looking up records and more time is spent receiving professional training at the bedside.

Technical Architecture

The system is implemented using Java Server Pages (JSP) and Tomcat on a Linux Server, with an Oracle database. Doctors access the system on their Tablet PCs over a wireless LAN connection as they visit patients. The application is java based.

TEAMS is accessed on client PCs (desktop, laptop or tablet) via a suitable standards compliant (HTML 4.0 or later, CSS2) browser such as Microsoft Internet Explorer V6.0.

Functions

The main functions are

- Access to patient records, radiology results and lab results
- Capture of diagnoses and procedures at the bedside. The user selects the diagnosis or procedure from a drop-down menu. The system codes it in International Classification of Diseases 9 (ICD9) format and inputs it to the patient record. The system also generates an automatic discharge summary and copy of the discharge letter for the General Practitioner (GP).
- Ordering of drugs and lab tests
- Capture of morbidity data for clinical audit

User Interface

The user interface consists of a number of drop-down menus. The menu hierarchy ([57]) is shown in Figure 5.

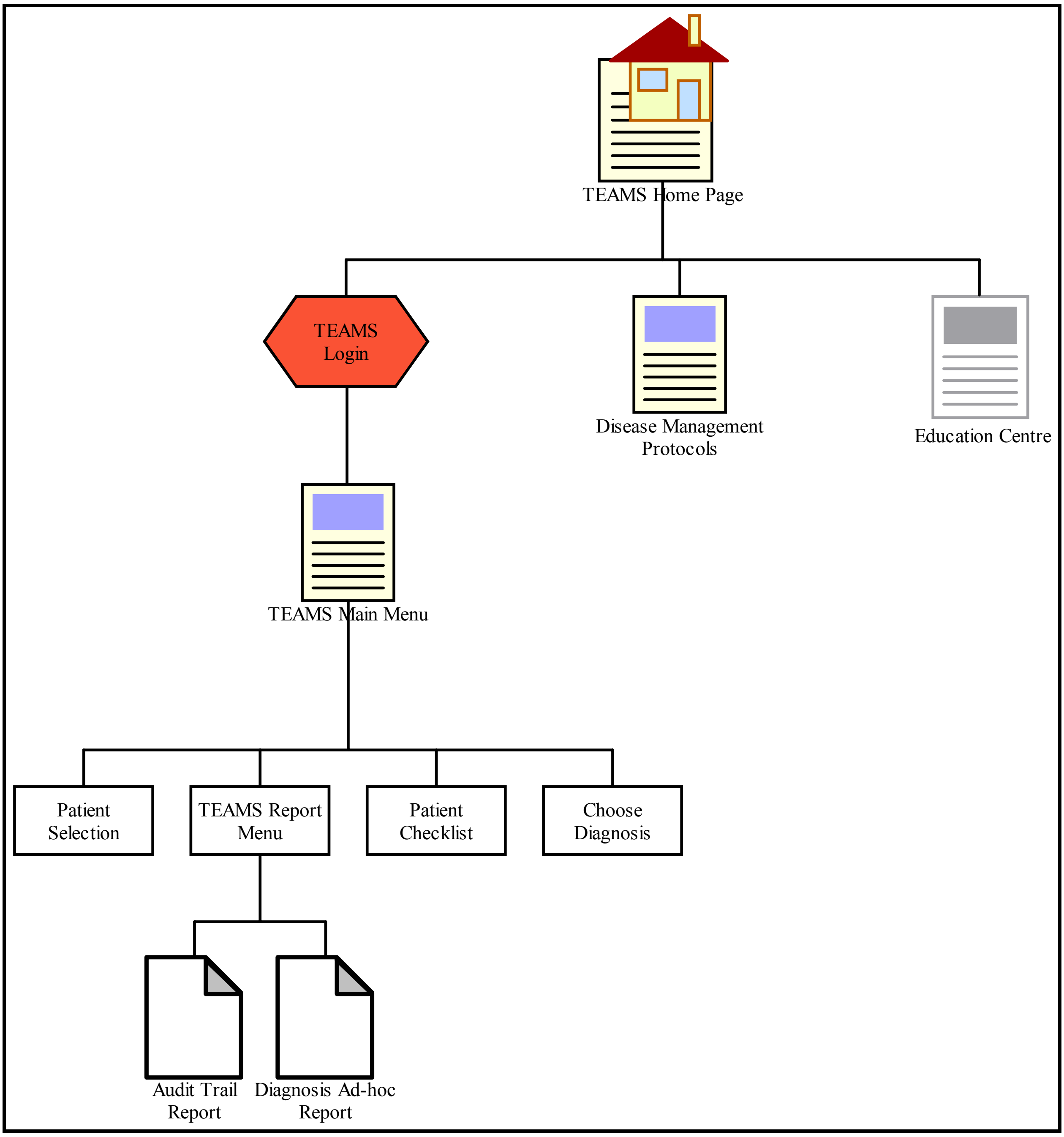

Figure 5 TEAMS Menu Tree

User reaction

The users are doctors and consultants. The system is not currently used by nurses. Doctors on two wards are using the WLAN and TEAMS daily, to access patient records, radiology results and lab results, and to order lab tests. Feedback has been very positive, though there have been teething troubles while the application was under development. TEAMS is mature now, and doctors want to move beyond the pilot.

Perceived Benefits

- Greater efficiency in clinical processes and reduced opportunity for error, e.g. losing handwritten lab test orders.
- Prescriptions are more complete
- Diagnoses and procedures are coded in International Classification of Diseases 9 (ICD 9) ready for input to the Hospital Inpatient Enquiry system (HIPE). An electronic interface to HIPE is a possible future extension.
- More complete and accurate collection of diagnostic data. Since part of the hospital's budget is based on casemix, capturing all diagnoses and procedures is important.
- More accurate collection of clinical audit data, leading to better clinical audit.
- Less time lost looking up patient records. This can now be done at the bedside, instead of having to go to a fixed PC, and possibly have to queue for it. Doctors spend more time with the patient and getting training at the bedside.

- It is not feasible to put a fixed PC at every bedside. Wireless handhelds can be brought to the bedside and once available open the way to further applications in the future.

The evidence for the benefits is based on user reports and a questionnaire given to users by the IT department..

4.3.2.6 Issues

Weight of the client devices is a problem - the tablets are considered too heavy by clinical users. The target weight is less than nine hundred grams. IT staff are continuing to look for alternatives.

Because the Tablets are turned off when not on the network and for recharging, there is an issue with downloading updates and new applications.

While user feedback is very positive, no formal cost/benefit analysis has been undertaken. While it is hoped to roll out the WLAN and TEAMS to the rest of the hospital, the business case has not yet been made.

4.3.3 Midlands Regional Hospital, Tullamore

Midlands Regional Hospital (MRH) Tullamore provides acute hospital services for the Midlands region. A new hospital is due to open in Tullamore in 2006. The Digital hospital project is a major initiative to make this the first public paperless hospital in Ireland [49]. The hospital has plans for an electronic patient record which will provide patient data when and where needed, in the community or in hospital. The overall concept is to achieve a 'Digital Care Network' which will be patient centred. This means structuring business processes and information and communication technology to enable the best quality of health and social care to the individual. The Digital Care Network will provide an integrated care record with a unique patient identifier. This project will involve partnerships with major multi-national technology companies.

4.3.3.1 Infrastructure

There is one Access Point in the renal dialysis unit, a Cisco AP1200 11g. Connection to the fixed network is via a Cisco LAN network switch.

4.3.3.2 Client Devices

The clients are four Tablet PCs, Fujitsu Siemens Stylistic ST 5020, with Intel Centrino and Pentium M. The tablets are thin clients, running Windows XP with Citrix client and Internet Explorer.

4.3.3.3 Deployment

Currently only the renal dialysis unit is covered. This is a new unit, opened in February 2005, which was wireless from beginning. Tullamore have ambitions plans for the new hospital. The Digital Hospital Project is a major initiative to make this the first public paperless hospital in Ireland. The wireless network was installed as part of this project. In the new hospital the electronic patient records system from iSoft will run on Wireless clients. There will be a new Laboratory Information System (LIS) and new Picture Archiving and Communications System (PACS), with bedside access from fixed and wireless computers.

With this in mind the Renal Dialysis IT system was developed using the latest secure wireless and mobile technologies to achieve the first unit to be paperless. It is intended to serve as a model for the future working environment in all areas of providing health care.

Future plans include: Wired / wireless Internet access for patients. Overnight dialysis at home, linked by internet. Diabetic patient monitoring. The Digital Care Network will extend care into the community, allowing remote monitoring of patients.

4.3.3.4 Security

Wireless Protected Access (WPA) and MAC address filtering are used to control access and protect data. Group policies are implemented to further protect the tablet PCs.

4.3.3.5 Applications

The nurses in the renal dialysis unit use the tablets to access a commercially available clinical application for management of renal dialysis. This application allows monitoring of all patients on dialysis machines and automatic recording of data from the machines. The users are the renal unit nurses.

As the case study was conducted in Tullamore, further details are left to later Chapters.

4.3.3.6 Issues

User feedback is very positive. The system is easy to use. Users would like the tablets to be smaller and lighter. Nurses tend to go to fixed PCs for inputting large amounts of data as the tablets have soft keyboards only. Nurses avoid queuing for fixed PCs, and can access patient data at the bedside. This increases accuracy of recording and they can look up data while talking to the patient.

4.3.4 University College Hospital Galway

University College Hospital Galway (UCHG) is the main teaching hospital in Galway. They have not yet installed a wireless LAN and are currently in the planning stage.

4.3.4.1 Infrastructure

The equipment vendor has not yet been chosen.

4.3.4.2 Client Devices

UCHG are considering PDA / smartphone client devices, running PocketPC. They will be issued to all clinical staff in the trial areas. These devices have been chosen for their convenience in terms of small size and light weight, so are easy to carry. They can also be used as communications devices for voice communications and alarms and alerts. UCHG have not yet decided whether to use tablets as well.

4.3.4.3 Deployment

The system will be deployed in the vascular / cardiology department. It will be piloted initially in the vascular ward, and will be rolled out later to the rest of the vascular and cardiology department, including operating theatres. UCHG expect to have the trial set up by the beginning of 2006.

4.3.4.4 Security

Security mechanisms are not yet decided on.

4.3.4.5 Applications

The department has a clinical software application for cardiology. They want to be able to access this on the PDAs.

4.3.4.6 Issues

No issues have arisen as yet.

4.3.5 Summary

Hospital	**Infrastructure**	**Clients: Hardware**	**Clients: Software**	**Security**	**Applications**
St. James	Cisco	CoWs	Windows XP Citrix thin client	SSL, VPN, RADIUS, MAC address filtering, Windows user authentication	No clinical applications
AMNCH Tallaght	Cisco	Tablet PC Aplux A5 size	Windows XP Citrix thin client	Vendor proprietary system	TEAMS
MRH Tullamore	Cisco	Tablet PC Fujitsu Siemens Stylistic ST 5020	Windows XP Citrix thin client	WPA, MAC address filtering	CADia renal dialysis clinical software
UCHG Galway (planned)	Not decided	PDA/smartphone	PocketPC	Not decided	Cardiology clinical software

4.4 Discussion of Results

A number of trends can already be identified, from the small number of deployments.

Thin Client Technology

Thin Client is the technology of choice for the wireless clients. St. James, AMNCH and MRH Tullamore have all chosen Citrix Thin Client. The wireless computers are thin clients with no hard drive. This has the advantage that all applications run on a network server. The client accesses the application via a web browser or via the Citrix Thin Client. No data is stored on the client, making it easier to protect confidential data. Maintenance is easier as there is no need to install applications on the client.

Client Devices

Tablet PCs have been chosen in Tullamore and AMNCH. The Tullamore clients are full sized tablets. AMNCH are using A5 sized clients. Neither hospital is entirely happy with the clients. Size, weight and battery life are all issues for the users. Neither hospital is using PDAs. They are considered too small to display useful data. However international studies ([15], [16], [17]) have found that PDAs can deliver useful results, even for medical images. They have the advantage of being small and light enough to be carried in a coat pocket and have generally longer battery life. UCHG is planning to use a PDA/smartphone combination device. In view of the issues with Tablet PCs (size, weight and battery life), Irish hospitals should perhaps consider PDAs, at least for some applications.

Security

No discernible trend emerged in the area of security. A variety of methods are in use.

Technology Drivers

The AMNCH experience has 3 important lessons for progress in applying wireless technology to healthcare in Ireland.

1. **Application driven** The deployment of a WLAN was driven by user need for accessing records at the bedside, and for a particular application. This indicates that applications will drive deployment of technology, and not the other way round.

2. **Technology Champion** The main driver was a consultant who had experienced wireless technology in the U.S.A. This shows the importance of a technology champion among the user group

3. **Importance of the business case** The pilot has been funded by the hospital from its own resources; however rollout to the rest of the hospital depends on presenting a satisfactory business case. Hospital managers will not invest in technology unless they see a real return.

4.5 Enabling new applications

This section looks at an Irish project working in the area of enabling new applications using wireless LAN and Indoor Positioning System (IPS) technology. There are no reports in the literature of any other Irish research in this area. This project is ongoing and final results have not yet been published.

PRIMA, a Wireless Heart Monitor

The PRIMA project ([31], [33]) at NUI Galway and the Mater hospital Dublin has as its aim the remote monitoring and management of ambulatory patients. A typical application is management of patients with cardiovascular disease. The PRIMA ambulatory monitoring system uses standard WiFi technology to monitor patients recovering from cardiac surgery. Wireless sensors on the patient stream patient biosignals to the relevant applications on the server. The PRIMA patient sensor is integrated with a WiFi indoor positioning system (IPS) to facilitate accurate patient positioning within the coverage area. The patient's location is signaled by a WiFi tag attached to the patient.

The tag signals its location to a Positioning Engine on the server, which works out the actual location of the patient. The WiFi IPS and tags are supplied by Ekahau Inc. [36].

The system is being trialed in the Mater Hospital, Dublin. The main patient trials of the prototype monitoring system are now complete [34]. The positioning system has worked well. Initial target applications are step-down care of cardiac patients and in-transit or community based cardiac care.

5. The Waterford and Tullamore Case Study: Background

In order to examine the possible effects of wireless mobile computers in the Irish context, two renal dialysis units were studied, in Waterford Regional Hospital and Midlands Regional Hospital, Tullamore. These units were chosen because both used the same dialysis equipment and clinical software i.e. Fresenius dialysis machines, together with Finesse FinDB database and CADia clinical application software ([42]). However in Tullamore, nurses use wireless mobile computers while in Waterford nurses use fixed PCs only. It was anticipated that the clinical process would be similar, therefore the effects of the wireless computers would be relatively easy to determine.

This chapter gives background information on renal dialysis, the medical devices and clinical software used and the two renal units.

5.1 Renal Dialysis Overview

The major function of the kidney is to filter the blood to remove waste products, excess water and salts [41]. In so doing it regulates the fluid and electrolyte balance of the blood and produces urine. The urine is highly concentrated and carries the waste products and excess salt out of the body through the urinary tract. The kidneys regulate the blood pressure and regulate the balance between water and electrolyte concentration in the blood. In addition the kidneys regulate the pH of the blood. They produce Erythropoietin, which controls the production of blood cells in the bone marrow. Kidneys also influence the amount of calcium in the blood and the production of Vitamin D. When the kidneys are no longer functioning correctly, the body retains too much water. Toxins are not removed and can accumulate and damage other organs. Complications include bleeding stomach ulcers, heart rhythm disturbances or infection of the pericardium (heart lining). Blood pressure may increase. Calcium is lost from the bones. Anaemia may result from disruption to red blood cell production.

The purpose of dialysis is to replace the kidney functions by extracting water and toxins from the patient's blood. During haemodialysis, the patient's blood is removed through a vein and passed through an artificial filter outside the body. The filter membrane removes toxins while essential nutrients and red blood cells are left in the blood. Excess water is removed. The process is controlled by a dialysis machine which contains a filter, pump for the blood and a monitoring system to control the process. The machine may also administer drugs such as Heparin to prevent blood clotting during treatment. See Figure 6 for an illustration.

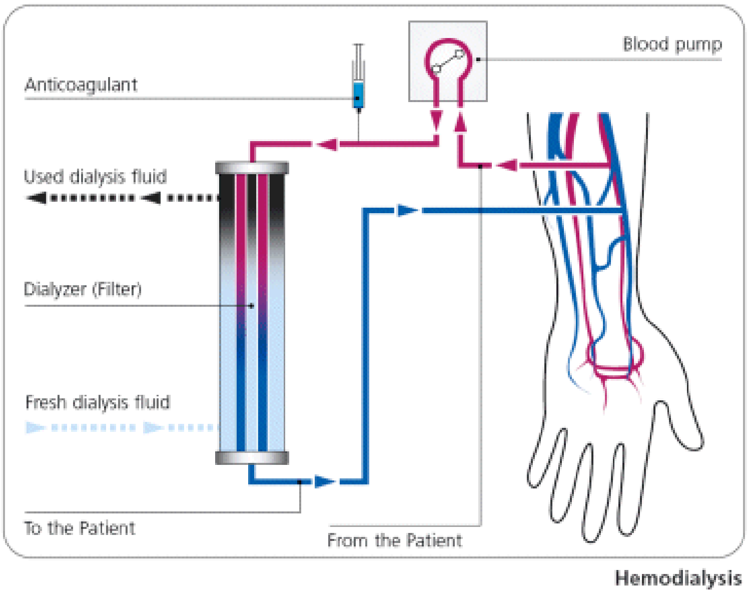

Figure 6 Renal Dialysis [41]

The blood is removed from a vein generally on the patient's forearm. A small operation is performed to establish a bypass between the vein and an artery to allow higher pressure and faster blood flow. This is called a shunt.

A patient's precise dialysis prescription varies according to the amount of water and toxins to be extracted in any given session. Before each session, patients are weighed. The difference between their target weight and their presenting weight determines the rate of dialysis (Ultra filtration rate). The patient is then connected to the dialysis machine by a nurse. The process of haemodialysis can destabilise a patient. The patient's blood pressure, pulse and blood volume must be monitored for general symptoms of destabilisation. A drop in any of these may indicate an adverse change in the patient's condition. At the end of a dialysis session, the patient is disconnected from the dialysis machine. The patient is weighed again to check that the prescribed dialysis goal was met. The nurse completes a post-dialysis assessment. Patients typically undergo dialysis for three or four hours three times a week.

5.2 Medical Equipment and Software

Both Waterford and Tullamore use Fresenius Dialysis machines from Fresenius [41] together with the FINESSE® system from Medvision ([42]) . Finesse is a system for connecting together the medical devices used in a dialysis unit. These are:

- Patient weighing scales
- Dialysis machines
- Blood pressure monitors
- Blood temperature monitors
- Blood volume monitors
- Electrolyte measuring instruments
- Blood gas analysers

Each patient is assigned a key which contains a chip. There are chip key readers on the weighing machines and dialysis machines. The key serves to identify the patient on the machine and match data from the machine with the correct patient record.

Finesse can be connected to the hospital network and to workstations, servers and mobile computers, see Figure 7 for an overview.

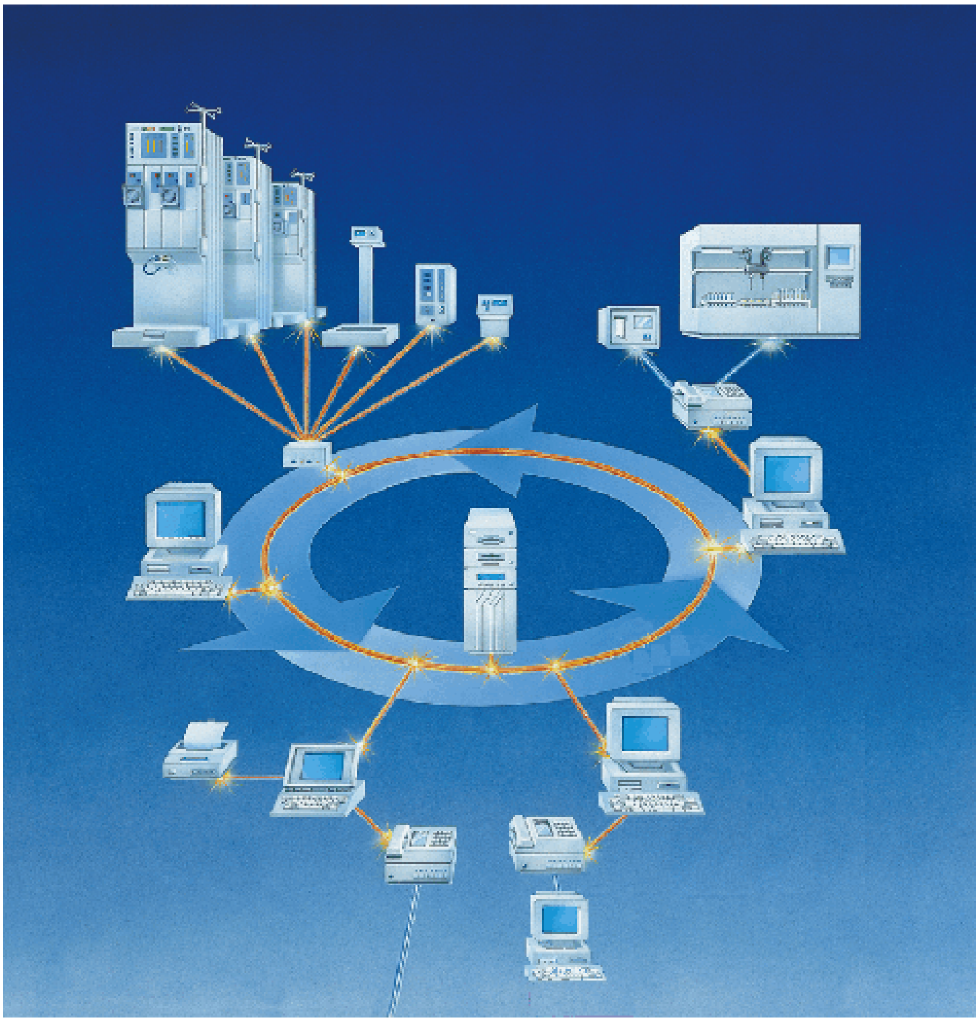

Figure 7 The Finesse system [42]

The FinDB database is part of the Finesse system. FinDB stores for each patient

- Basic demographic data
- Treatment – number and frequency of sessions, other details relating to treatment
- Patients dialysis and drugs prescription
- Data from past dialysis sessions. This information is stored to give a complete history of the patient's dialysis treatments.

Finesse CADia captures information from the dialysis machines and other medical devices connected to the Finesse system. CADia records the patient's dialysis session, presents the information on networked computers and automatically documents the session. CADia records the following data:

- Weight
- Ultra filtration rate
- Dialysis data (blood gas parameters etc.)
- Blood temperature
- Blood volume
- Blood pressure

Events and complications are entered manually by the nurse. CADia also stores a summary of the patient's last 5 treatments, this is used to judge fluid removal.

The dialysis machine monitors the patient and raises an alarm (visual and audible) if necessary. CADia flags alarms visually on networked computers. CADia is a data recording system, it is not relied on to monitor the patient. Patient monitoring is a function of the dialysis machine.

The information recorded by CADia can also be accessed directly on the dialysis machine. CADia downloads it to the computer network where it can be accessed from any networked computer. A screenshot of the CADia user interface is presented in Figure 8. After completion and signoff of the treatment, all information is downloaded to the FinDB database.

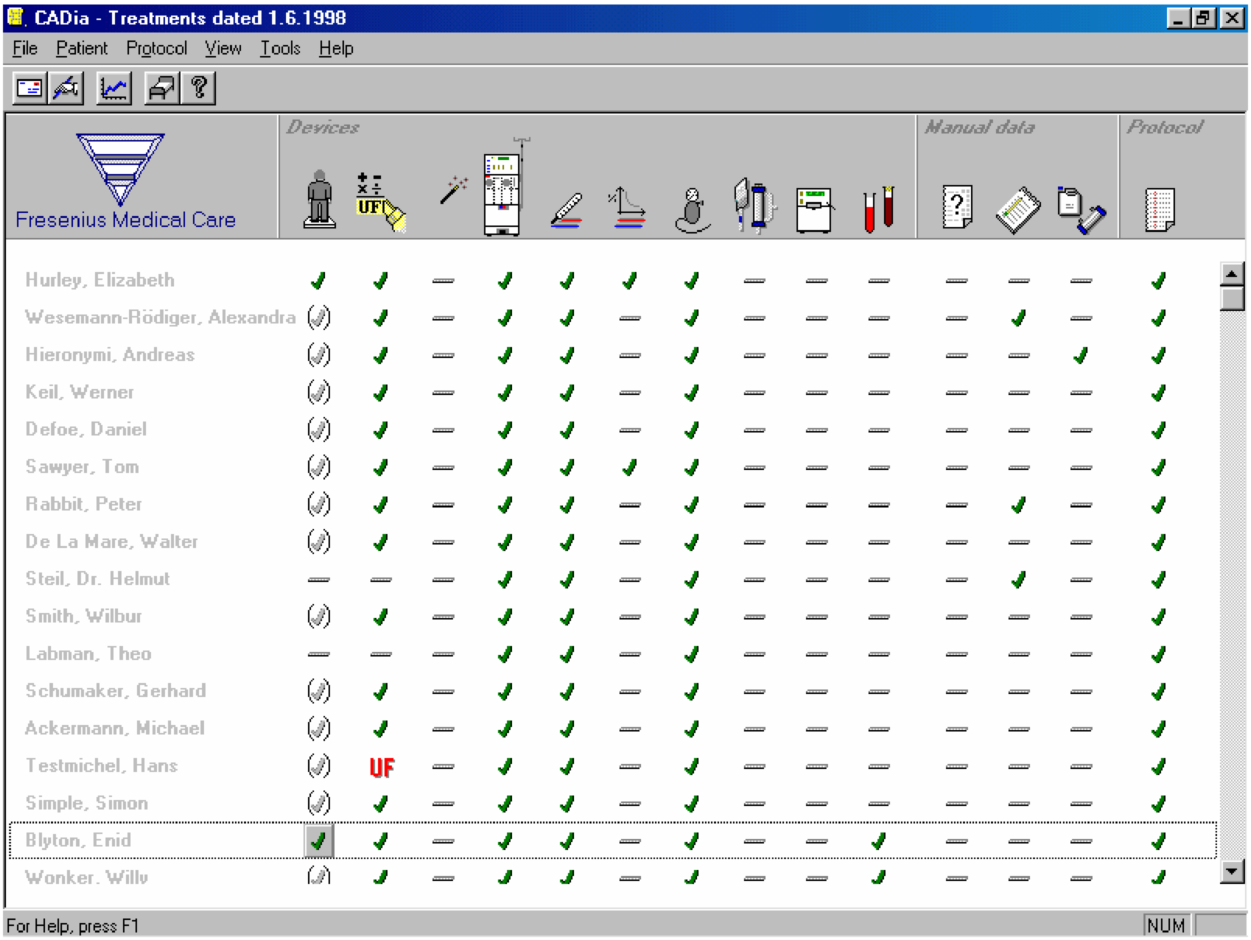

Figure 8 CADia screenshot [44]

5.3 The Waterford Renal Dialysis unit

The renal dialysis unit in Waterford has fourteen patient stations in use. The unit operates on a 24 hour basis, with patients coming in at two hour intervals. The unit treats sixty patients a day. A total of thirty eight nurses work in the unit, of which around a third are on duty at any one time. Four nurses are on duty at night. Nearly all patients are returning patients and attend on a regular basis. There are four PCs networked with Finesse via the hospital network, they are located in the two nurse's stations.

5.4 The Tullamore Renal Dialysis unit

Tullamore has six patient stations. The unit operates six days a week, with two treatment sessions per day, one in the morning and one in the afternoon. Nearly all patients are returning patients. A total of ten nurses work in the unit, of which three are on duty at any one time.

The renal unit has a wireless network, details are given in section 4.3.3. The wireless computers are Thin Client tablet PCs. There are four tablets, one for each nurse on duty plus a spare. There is one docking station which is used only for charging. There is also a fixed PC at the nurses' station.

The Tullamore unit is new, it opened in February 2005. The unit was wireless from beginning. The dialysis management is paperless, though paper records are used for other aspects of the patient's treatment. The clinical process in the unit was developed by the nurses and is evaluated and updated on an ongoing basis.

6. Study Design

6.1 Rationale

International studies on wireless computers in healthcare, described in Chapter 3, showed positive effects in the areas of Efficiency, Patient safety, User satisfaction, and Enabling new applications.

The pilot study was undertaken to determine whether these international findings also apply in the Irish context. The study examines the effects of wireless computers in an Irish acute hospital setting, and compares these with international findings, with particular reference to user satisfaction and efficiency. The study focuses on these two areas, as the size of the sample was too small to allow effects on patient safety to be examined. The enabling of new applications has already been considered in Chapter 4.5.

6.2 Choice of pilot study location

The pilot study examined the effects of wireless computers by studying two renal dialysis units, one in Waterford Regional Hospital and the other in the Midlands Regional Hospital, Tullamore. Both units use the same dialysis equipment and clinical software package i.e. Fresenius dialysis machines [41], together with Finesse FinDB database and CADia clinical application [42]. In the Tullamore unit, nurses use wireless mobile computers while in Waterford nurses use fixed PCs only.

These units were selected for the study because both use the same dialysis machines and clinical software, while only one unit uses mobile computers. This makes it easier to compare clinical processes and nurses' attitudes to IT, and detect any possible differences attributable to the use of wireless computers.

6.3 Hypotheses

- That the use of wireless mobile computers increases the efficiency of clinical staff

- That the use of wireless mobile computers improves clinical user satisfaction

6.4 Methodology

Healthcare delivery is a complex environment where many factors influence the interaction of clinicians with clinical IT systems. Both qualitative and quantitative data are required to determine the major underlying factors and interpret results. The study therefore used a mix of qualitative and quantitative methods.

6.4.1 Qualitative Methods

Qualitative data was collected by interviews which were conducted in Waterford and Tullamore. Three interviews in total took place. Two interviews took place in Tullamore: the first interview was conducted with a senior nurse and a senior member of the Midlands Health Board IT department, The second interview, for the purpose of clarification of issues arising, took place with the senior nurse only. One interview took place with a senior nurse in Waterford.

The purpose of the interviews was to get an appreciation of the clinical process in each unit, how IT is used to support it, nurses' attitudes to the IT system and effects on productivity. In Tullamore, a further aim was to investigate how the nurses use the wireless computers and their effect on the clinical process.

The topics covered in these interviews were:

- Renal unit background
    - Number of patients, number of nurses
- Dialysis equipment
- IT system
    - Clinical support software

    - Number and location of PCs
    - Interface with hospital information systems
- Wireless system details (Tullamore only)
    - Wireless Infrastructure
    - Client Devices
    - Interface with clinical software application
    - Interface with hospital information systems
- Clinical workflow
    - Patient’s journey
    - Nurse’s workflow
- Role of IT in supporting the clinical process
    - How data is recorded and accessed
    - How nurses use the fixed PCs
    - How nurses use the wireless computers (Tullamore only)
- Nurses’ attitudes to IT system
- Nurses’ attitudes to wireless computers (Tullamore only)
- Effect of IT system on productivity
- Effect of wireless computers on productivity (Tullamore only)

- How wireless computers could be used, and what effects they might have, if they were available (Waterford only)
- Future plans

6.4.2 Quantitative Methods

A questionnaire was prepared to get quantitative data on efficiency and user satisfaction. Information from the first interview in Tullamore, as well as results of international studies, were used to guide selection of questions.

The questionnaire was given to nursing staff in both units. The purpose of the questionnaire was to ascertain the effects of the IT system and nurses' attitudes towards it. Nurses were also asked about their perceptions of efficiency. The questions were divided into 5 main sections, using a model proposed by Despont-Gros et al [45] for evaluating user interactions with computer systems. These were

- User characteristics
- Computer system characteristics
- Use/context/environment
- Process characteristics
- Impacts

The questions were derived from studies by O'Connell [46], Likourezos [48] and Bullard [47] and are listed below. A five point Likert scale was used for scoring.

User characteristics

Do you use a computer at home or work?

Do you use e-mail or internet at home or work?

Do you use a computer every day?

Would kind of computer user would you consider yourself to be:

Sophisticated user Unsophisticated user Neither

Computer system characteristics

It is easy to enter data into the patient record

It is easy to enter text into the patient record

It is easy to access data from the patient record

The Computer is convenient to use

Use/context/environment

The Computer is available when I need it

Patients make negative comments about the computer

The Computer is accessible in all locations where I need it

I am generally satisfied with the computer system

Wish I could just write on paper

I was adequately trained in the use of the computer

Process characteristics

The computer eliminates a lot of paperwork

The Computer improves the quality of documentation

The Computer improves workflow

The computer leads to increased use of clinical practice guidelines

Impacts

The Computer saves time

It takes me longer to finish my work

The computer reduces my risk of making errors

I am better able to monitor patient progress

I find the computer makes me more efficient

The Computer reduces communication with staff

The Computer reduces communication with patients

The computer has a negative impact on the nurse–patient relationship

In addition a number of questions were included to elicit attitudes to use of wireless computers, and to estimate how much time nurses spend accessing and updating patient records. The complete questionnaire is included in the appendix. A covering letter was sent with the questionnaire, also included in the appendix.

As no patient contact was involved, and contact was only with professionals who voluntarily agreed to participate, ethics committee approval was not required. Respondents were not asked to fill in their names on the form, therefore confidentiality was assured. Questionnaires were posted to the units, and collected personally by the author.

7. Results

In this section the qualitative and quantitative results are presented and discussed. The workflow is described in detail as differences here are important to interpreting both the questionnaire and interview results.

7.1 Interview Results

This section describes the results from the interviews. Information from the interviews was also used to document the workflow. The clinical process and patient's journey in Waterford and Tullamore are described in some detail, as this is important in interpreting the results of the questionnaire, especially in relation to efficiency. Any differences in workflow due to factors other than the use of wireless computers, must be carefully examined and taken into account before attempting to draw any conclusions.

7.1.1 Waterford Clinical Process and workflow

1. The patient signs in and collects the key. The keys are colour coded and each patient has his/her own key permanently assigned.

2. Patient inserts key in weighing machine, machine measures weight

3. Patient removes the key from the weighing machine and inserts it in the dialysis machine

4. The patient's weight is sent automatically from the weighing machine to CADia

5. The Nurse enters the patient's weight and dialysis parameters manually into the dialysis machine

6. The Patient is connected to the machine by the nurse

7. The dialysis session begins. The dialysis machine monitors the patient and records treatment data. CADia captures the information from the dialysis machine and

makes it available on networked computers. Any incidents requiring attention cause an alarm. Alarms are flagged by visual and audible alerts on the machine, and visually in CADia.

8. The Nurse visits the patient hourly for observation. Parameters are read from the dialysis machine and entered manually on a paper record.

9. The dialysis machine flags the end of the session with visual and audible alerts

10. The Nurse disconnects the patient from the machine

11. The Patient is weighed again

12. The nurse enters data on complications and events manually into CADia

13. The nurse enters the discharge weight manually into the paper record and signs off the treatment session on the paper record and on the PC. Data on the session is uploaded automatically to FinDB on signoff.

14. Patient returns key.

7.1.2 Tullamore Clinical Process and workflow

1. The patient signs in and collects the key. As in Waterford, each patient has his/her own key.

2. Patient inserts key in weighing machine, machine measures weight

3. Patient removes the key from the weighing machine and inserts it in the dialysis machine

4. The patient's weight is sent automatically from the weighing machine to CADia

5. Patient's prescription is downloaded automatically to CADia.

6. The Nurse enters the weight and dialysis parameters manually into the dialysis machine. The weight and parameters are available in CADia and can be accessed on the tablet.
7. The patient is connected to the machine by the nurse
8. The dialysis session begins. The dialysis machine monitors the patient and records treatment data. CADia captures the data from the dialysis machine and makes it available on networked computers, including the wireless tablets. Any incidents requiring attention cause an alarm. Alarms are flagged by visual and audible alerts on the machine, and visually in CADia. Patient monitoring is done by the machine. CADia records data but is not relied on for monitoring.
9. The dialysis machine flags end of session with visual and audible alerts
10. Nurse disconnects patient from machine
11. Patient puts key in weighing machine and is weighed again. Weight is recorded automatically in CADia
12. The Nurse enters data on complications and events manually into CADia
13. Patient returns key
14. Nurse signs off the treatment on the tablet or PC. Data on the session is uploaded automatically to FinDB on signoff.

There is no fixed time at which the nurse visits the patient. The nurse discusses any issues arising with the patient at the start of the session and may access information on past sessions using the wireless computer while with the patient. Alarms and alerts are flagged visually and audibly on the dialysis machines and are dealt with as they arise. Signoff can be done at anytime after the end of the session. Morning patients are signed off in the course of the afternoon and afternoon patients before the end of the shift. An automatic data collection process runs at night and collects data from any sessions which have not been signed off and uploads them to FinDB.

7.2 Effects of Mobile Computers

Nurses in Tullamore use wireless computers, while nurses in Waterford do not. This section looks specifically at the use of mobile computers in Tullamore, and also examines the opinions of the interviewee in Waterford on how mobile computers could fit into the workflow there.

7.2.1 Tullamore

The nurses in Tullamore have a wireless tablet PC each, on which they can access CADia and FinDB. The new unit was wireless from the beginning and is the first unit in Ireland to use the Finesse system with wireless.

The system is very easy to use. Nurses use the wireless computers to look up data, but tend to use fixed PCs to enter large amounts of data. The tablets are not small and light enough to be carried around continuously, which limits their usefulness. Data entry is cumbersome as there is no keyboard. The handwriting recognition function does not work well because there are multiple users. The docking station is used only for charging. Battery life is not long enough to cover a complete shift. When the batteries are low, the system shuts down. The nurses have to log in again and this is slow. Potential efficiency gains from the wireless computers are limited because of the size and weight, data entry and battery life problems.

The advantages of the wireless computers were identified as follows:

- The wireless computers are considered indispensable for looking up data at the patient's bedside, and while talking to the patient. Data on past treatments is consulted for about 50% of treatment sessions.

- Access at the bedside increases the accuracy of recording manually entered data and reduces the chance of having a parallel paper system.
- Nurses can access the patient's weight and dialysis parameters directly at the dialysis machine, for input into the machine. This saves having to make a trip to the fixed PC to look up the data.

7.2.2 Waterford

On asked if she thought wireless computers would be useful in her work, the Waterford interviewee felt they would and mentioned three areas in particular where she considered time could be saved:

- A wireless computer would be useful for looking at past sessions while with the patient. Previous sessions are looked up in more than 50% of sessions.
- Recording of observations: A wireless computer would be very useful and would save time for recording observations at the patient's bedside when the unit goes paperless.
- Sign-off: At the end of each session, several patients have to be signed off at once and nurses have to queue for one of the PCs. Nurses could use wireless PCs to sign off more quickly and without having to leave their own section.

7.3 Questionnaire results

Six completed questionnaires were collected from Tullamore, representing a response rate of 60%. Ten questionnaires were completed by staff in Waterford, a response rate of 26%. The raw data for sections one, three and four are presented in Table 2 and Table 3. Summary results for section 2 showing mean and standard deviation are presented in Table 4 and Table 5. Complete raw data is presented in the appendix.

Waterford results 1 = Strongly Disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly Agree U = Unsophisticated S = Sophisticated N =Neither n/a = not answered										
Questionnaire No.	*1*	*2*	*9*	*10*	*4*	*5*	*6*	*7*	*8*	*3*
Question										
Section 1										
Do you use a computer at home or work?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Do you use e-mail or internet at home or work?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Do you use a computer every day?	Yes	No	Yes	No	n/a	Yes	Yes	No	Yes	Yes
What kind of computer user would you consider yourself to be	U	U	N	U	N	U	U	U	U	U
Section 2										
I was adequately trained in the use of the computer	2	2	3	3	4	4	4	4	4	5
Section 3										
Do you use a wireless computer for access to patient records?	No	No	No	No	No	No	No	No	No	No
Could a fixed computer meet your needs for access to information at the patient's bedside?	No	No	Yes	Yes	Yes	Yes	No	Yes	n/a	Yes
Section 4										
How much of your time per shift do you spend accessing and updating patient records?	< 10%	10%-20%	n/a	20%-40%	20%-40%	< 10%	10%-20%	10%-20%	n/a	20%-40%

Table 2 Waterford results for sections one, three and four

Tullamore results						
1 = Strongly Disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly Agree						
U = Unsophisticated S = Sophisticated N =Neither n/a = not answered						
Questionnaire No.	***1***	***5***	***4***	***2***	***3***	***6***
Question						
Section 1						
Do you use a computer at home or work?	Yes	Yes	Yes	Yes	Yes	Yes
Do you use e-mail or internet at home or work?	No	Yes	Yes	Yes	Yes	Yes
Do you use a computer every day?	No	no	Yes	Yes	Yes	no
What kind of computer user would you consider yourself to be	U	U	N	U	N	N
Section 2						
I was adequately trained in the use of the computer	2	2	3	4	4	4
Section 3						
Do you use a wireless computer for access to patient records?						
	Yes	Yes	Yes	Yes	Yes	Yes
Could a fixed computer meet your needs for access to information at the patient's bedside?	Yes	Yes	Yes	Yes	Yes	Yes
Section 4						
How much of your time per shift do you spend accessing and updating patient records?	20%-40%	20%-40%	20%-40%	20%-40%	10%-20%	< 10%

Table 3 Tullamore results for sections one, three and four

Question	*Waterford all users*		*Tullamore all users*	
1 = Strongly Disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly Agree				
	Mean	*STDEV*	*Mean*	*STDEV*
I was adequately trained in the use of the computer	3.50	0.97	3.17	0.98
I am generally satisfied with the computer system	3.50	0.97	3.33	0.82
It is easy to enter data into the patient record	3.70	0.95	4.00	0.00
It is easy to enter text into the patient record	3.90	0.57	3.67	0.82
It is easy to access data from the patient record	3.50	0.85	2.67	1.03
The computer is convenient to use	3.70	0.82	3.50	1.22
The computer is available when I need it	3.40	0.97	3.67	1.03
The computer is accessible in all locations where I need it	3.10	1.29	3.67	0.52
The computer eliminates a lot of paperwork	3.00	1.33	2.67	1.03
The computer saves time	3.50	1.18	3.00	1.10
It takes me longer to finish my work	3.11	0.93	2.33	0.52
I find the computer makes me more efficient	3.20	0.79	2.67	0.82
I am better able to monitor patient progress	3.30	0.82	3.00	0.89
The computer improves workflow	3.40	0.84	2.67	0.82
Wish I could just write on paper	3.10	1.29	2.00	1.10
The computer leads to increased use of clinical practice guidelines	3.20	1.14	2.83	0.75
The computer reduces my risk of making errors	3.10	0.99	2.50	0.84
The computer improves the quality of documentation	3.50	1.08	2.83	0.98
The computer reduces communication with staff	2.30	0.82	2.67	0.82
The computer reduces communication with patients	2.22	1.56	2.00	1.10
Patients make negative comments about the computer	2.11	1.05	2.50	1.52
The computer has a negative impact on the nurse–patient relationship	2.78	1.20	1.83	0.75

Table 4 Mean and Standard Deviation for all users

Question	Waterford Trained users only		Tullamore Trained users only	
1 = Strongly Disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly Agree	Mean	STDEV	Mean	STDEV
I was adequately trained in the use of the computer	3.88	0.64	3.75	0.50
I am generally satisfied with the computer system	3.63	0.92	3.75	0.50
It is easy to enter data into the patient record	3.88	0.83	4.00	0.00
It is easy to enter text into the patient record	4.00	0.53	4.00	0.00
It is easy to access data from the patient record	3.63	0.74	3.00	1.15
The computer is convenient to use	4.00	0.53	4.25	0.50
The computer is available when I need it	3.63	0.92	3.75	0.50
The computer is accessible in all locations where I need it	3.13	1.36	4.00	0.00
The computer eliminates a lot of paperwork	3.25	1.28	3.00	1.15
The computer saves time	3.88	0.99	3.50	1.00
It takes me longer to finish my work	3.14	1.07	2.25	0.50
I find the computer makes me more efficient	3.38	0.74	3.00	0.82
I am better able to monitor patient progress	3.38	0.74	3.25	0.96
The computer improves workflow	3.63	0.74	2.75	0.96
Wish I could just write on paper	3.13	1.46	1.50	0.58
The computer leads to increased use of clinical practice guidelines	3.38	1.19	2.75	0.96
The computer reduces my risk of making errors	3.25	1.04	2.75	0.96
The computer improves the quality of documentation	3.75	1.04	2.75	0.96
The computer reduces communication with staff	2.25	0.89	2.75	0.96
The computer reduces communication with patients	2.29	1.70	1.50	0.58
Patients make negative comments about the computer	2.14	1.07	2.25	1.89
The computer has a negative impact on the nurse–patient relationship	2.88	1.25	1.75	0.50

Table 5 Mean and Standard Deviation for trained users only

7.4 Discussion of Results

In this section the qualitative and quantitative results are discussed. The quantitative results from the questionnaire are interpreted in the light of qualitative information from the interviews.

7.4.1 Interview Results

7.4.1.1 Workflow

Nurses in Tullamore use wireless computers, while nurses in Waterford do not. However there are other major differences in workflow, even though the same clinical software is used. Understanding the workflow differences is important in understanding the results and evaluating the impact of the wireless computers. It is essential to examine the workflow carefully in order to disentangle the effects of the mobile computers. This section therefore analyses the workflow in some detail.

There is no manual recording of dialysis treatment information from the machines in the Tullamore unit and the dialysis management is paperless. In Waterford, the treatment information is read on an hourly basis from the machines and recorded on paper. In both units, the same information is recorded automatically by CADia, and is available on all PCs. In Waterford, CADia and FinDB are used only to lookup historical data and as a database for research. The reason for the paper recording in Waterford seems to be a concern for system reliability. In the event of a server crash, the paper records serve as a backup. Waterford do however plan to go paperless. Tullamore have shown that this is possible and technology exists to ensure system reliability and integrity of data. Tullamore estimate that nurses save between ten and fifteen minutes per treatment by using automatic data recording. At twelve treatments per day (six patients in the morning and six in the afternoon) this adds up to a substantial timesaving. This estimate is in comparison with a completely paper based system. In Waterford the hourly observations are recorded on paper, but CADia is used to record and download data on completed sessions. The system is not therefore completely paper based.

In both units, an automatic monitoring system is provided by the dialysis machines. The machine continuously monitors the patient, and if there is an incident requiring attention, such as a drop in blood pressure, this is flagged by visual and audible alerts on the machine. In Tullamore, there is no fixed routine for observing patients, instead they are attended to as the need arises. In Waterford, nurses physically go to each patient once an hour to check status and record data.

In both Waterford and Tullamore, nurses enter data on events and complications manually into CADia and signoff the patient's treatment session. In Waterford all patients must be signed off at the end of the session and this can cause bottlenecks as nurses queue for the PCs. In Tullamore, signoff can take place at any time after the patient leaves.

It seems likely from the above that Tullamore are achieving substantial timesaving from the CADia automatic recording feature and the dialysis machine automatic monitoring system. However an IT system will only deliver benefits if the benefits are actively managed and planned for. The benefits flow from the change in work practices which IT enables, rather than from the IT system per se (Tiernan and Peppard 2004 [50]). Tullamore is a new unit which aimed to be paperless from the start. The clinical workflow was planned by the nurses and is still evolving. There was no existing workflow which had to be accommodated, so a new workflow which took full advantage of the IT systems could be developed. There is heavy investment in IT for the new hospital, which is intended to be a showcase for digital technology in healthcare [49]. Issues such as system reliability are not a concern, so nurses can feel confident about relying on the system for patient care.

While it appears likely that Tullamore are achieving productivity gains, a study using observational techniques such as a time and motion study would be necessary to measure precisely the extent of the timesaving. The possible productivity gains identified above are due to differences in workflow and do not depend on the use of wireless computers.

7.4.1.2 Impact of Wireless Computers

Both Waterford and Tullamore interviewees identified similar advantages of wireless computers. Both considered access to data at the patient's bedside to be a key advantage, and both further identified the ability to look up records while talking to the patient as an advantage. Consultation of past treatment records occurs during about 50% of treatment sessions and is therefore a major component of the nurse's workflow. These results indicate that the wireless computers in Tullamore make the system more accessible to users and improve communication with patients.

Differences in workflow make it difficult to compare the clinical process in Tullamore and Waterford directly to establish any effect on efficiency attributable to the use of wireless computers. The wireless computers may have a small effect on efficiency in Tullamore. Nurses can look up the patient's weight and dialysis parameters on the tablets while inputting these data into the machine, and they can look up data on past treatments at the bedside. They would otherwise have to make a trip to a fixed PC. Potential efficiency gains may be limited by issues with the client devices themselves. They are too large and heavy to carry around continuously, and battery life is not long enough. They have no keyboard so nurses prefer to go to a fixed PC with a keyboard for manual recording of data. Potential efficiency gains may also be limited because the unit is small and the fixed PC's are readily accessible. When the unit moves to the new hospital the fixed PCs will be further away, and larger efficiency gains may then be realised from use of the wireless computers.

Waterford identified possible improvements in efficiency from the ability to record observations manually at the bedside, in place of the current paper recording system. However time could be saved simply by using the CADia automatic data collection, with or without wireless computers. It is also likely that Waterford would have the same issues with client devices as Tullamore, and that nurses would go to a fixed PC with a keyboard for manually entering data.

Waterford identified a further possible efficiency gain from streamlining of the patient signoff process. At the end of each session, all patients have to be signed off at once and nurses have to queue for one of the PCs. If they had access to wireless PCs they could sign off more quickly and without having to leave their own section. Tullamore found there was no need to sign patients off at a particular time and nurses could do it after the patient had left, thus eliminating bottlenecks for access to PCs. It seems likely the main potential for efficiency gains in Waterford comes from use of CADia automatic data collection and changes in workflow, rather than from deployment of wireless computers.

7.4.1.3 Conclusion

Overall the interview results indicated the major advantage of wireless computers lies in improving access to patient data at the bedside and improving communication with patients. Major gains from efficiency were not identified, though there may be a small effect. This is in contrast to international findings ([20], [32], [37]). Issues with the client devices (size, weight, battery life, lack of a keyboard) appear to be the main factors reducing the potential of wireless computers for delivering gains in efficiency. Efficiency gains may also be limited due to the small size of the Tullamore unit and ready availability of fixed PCs.

7.4.2 Questionnaire Results

It is difficult to draw statistical conclusions from such a small sample. It is therefore very important to use the qualitative data from the interviews to interpret the quantitative results. This section focuses only on the areas where differences seem to be significant.

Overall there was wide variation in the results. Answers to questions on user characteristics in Section 1 of the questionnaire did not seem to point to any factors influencing the results. It is worth noting that that none of the respondents regarded themselves as sophisticated computer users. The issue that did seem to differentiate users was training on the system. Two users in each unit considered they had not been adequately trained. Removing these users reduced the variation in results for most questions. See Table 4 and Table 5 where the mean and standard deviation is presented for all users, and for trained users only (i.e. excluding those who disagreed that they had been adequately trained).

The results from selected individual questions are presented and discussed below. The results of questions which seemed to differentiate most strongly between the two units were charted and are presented in Figure 9, Figure 10, Figure 11 and Figure 12. In all charts the two users who considered they had not been adequately trained are represented by the leftmost two data points. The results of some questions which would have been expected to show a difference, but did not, are also discussed.

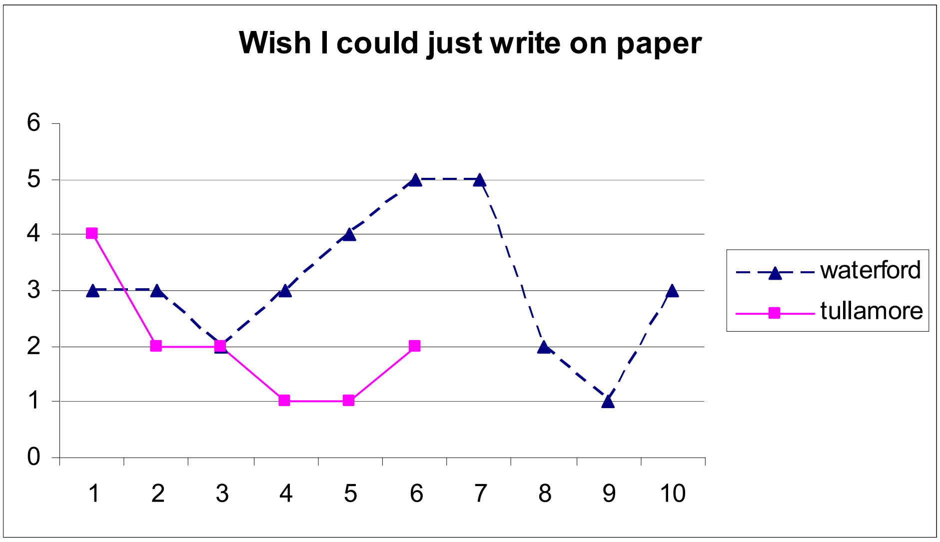

Figure 9

The statement analysed in Figure 9 relates to the perceived usability of the system. O'Connell (2004 [46]) found 8% and 14% of two sample populations agreed with this statement. The agreement rate in Waterford for trained users (three out of ten, discarding the neutrals, with a mean of 3.15 and standard deviation of 1.46) is quite high compared to O'Connell's finding. None of the trained users in Tullamore agreed (mean of 1.5, standard deviation 0.58). It is unlikely the wireless computers in Tullamore had any influence on this result, as mainly fixed PCs are used for data entry. It is more likely other factors are at work. There is a considerable amount of data recording on paper in Waterford, nurses may see the computer system as simply duplicating what is already on paper.

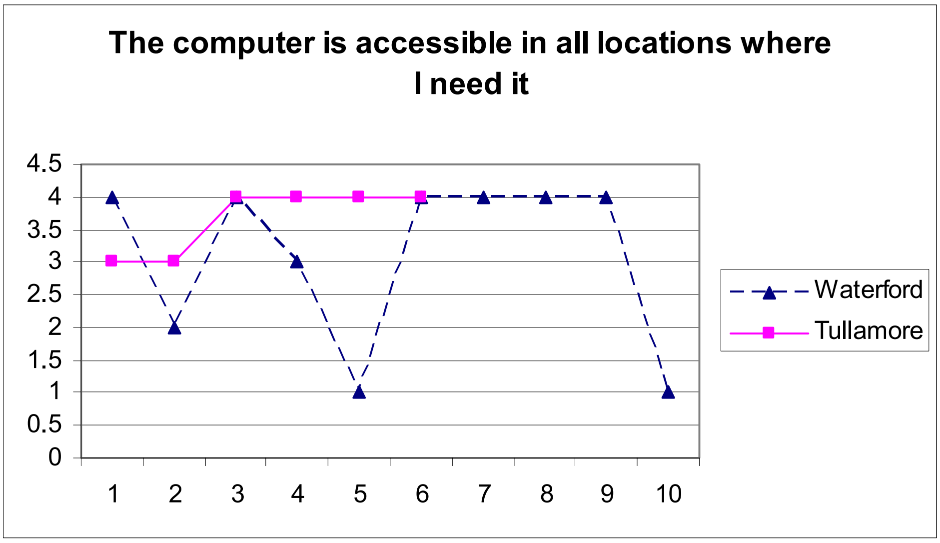

Figure 10

The findings in Figure 10 contrast with those of Bullard (2004 [47]), who found no significant differences in perceived accessibility between mobile and fixed PC users. However physicians in Bullard's study were using a cart on wheels to move the mobile computer around, and users found the cart to be a major impediment to use of the computer. 100% of trained users in Tullamore found the computer to be accessible in all locations where required (mean 4.0, standard deviation 0) while only 62.5% of trained Waterford users agreed with this statement (discarding the neutrals) (mean of 3.12, standard deviation 1.36). In view of the finding from the interviews that the mobile computers are used to look up data while at the patient's bedside, this can be considered to be an effect of the wireless computers.

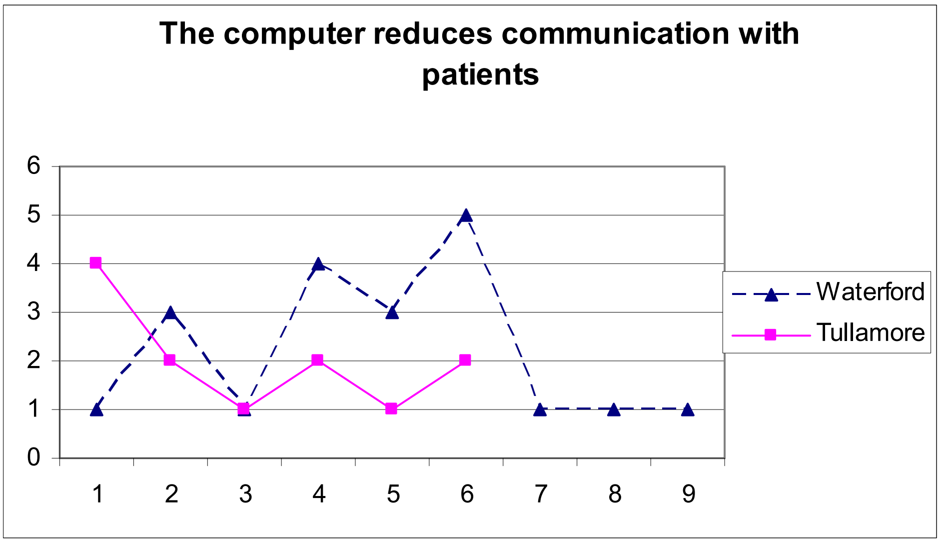

Figure 11

The data in Figure 11 show all trained Tullamore users disagreed (Mean 1.5, standard deviation 0.57735) that the computer system reduces communication with patients, while only 44% (Mean 2.29, standard deviation 1.7) of trained Waterford users disagreed. Bullard (2004 [47]) found no significant differences between mobile and fixed PC users in answers to this question.

Taken together with interview findings this is likely to be an effect of the mobile computers. Nurses are able to look up data on past treatments while talking to the patient in Tullamore, while in Waterford nurses have to leave the patient and go to a fixed PC.

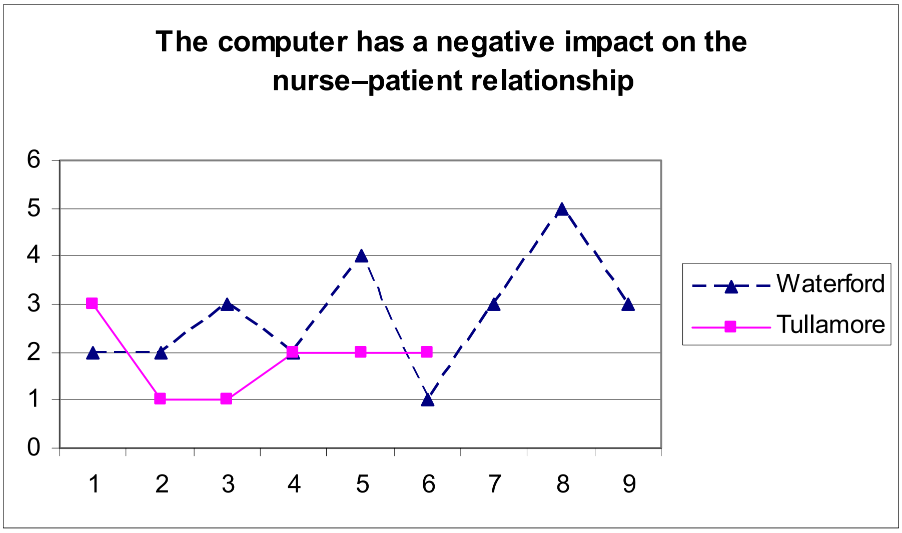

Figure 12

The findings presented in Figure 12 are similar to the results for the question on patient communication in Figure 11. All trained Tullamore users disagreed with the statement (Mean 1.75, standard deviation 0.5) while only twenty two percent (Mean 2.87, standard deviation 1.25) of trained Waterford users disagreed. As with the question on patient communication, this finding is likely to reflect the fact that nurses in Tullamore can discuss a patient's past treatments with the patient at the bedside, accessing the data on a mobile computer. This finding can therefore be considered an effect of the wireless computers.

Neither Waterford nor Tullamore users seemed to agree that the computer saves time or eliminates paperwork. The mean responses were slightly positive and close to neutral for both questions (see Table 4 and Table 5). Users in Tullamore reported spending more time per shift accessing and updating patient records than users in Waterford (see Table 2 and Table 3). 66% of Tullamore users reported spending 20%-40% or their time on this activity, while only 33% of Waterford users did. This is surprising, given the use of automatic data recording and the elimination of manual recording on paper in Tullamore. The interview data from Tullamore indicated substantial timesaving. Paper is not completely eliminated in Tullamore, as CADia manages the dialysis session only, and there are still paper records for other aspects of patient care. Nurses in Waterford may see the hourly recording of data as a separate activity and may not consider it part of accessing and updating patient records. These results may simply reflect different user expectations and experiences. Efficiency is difficult to measure accurately from user reports alone. Intel [56] found that user reports are not an accurate measure of timesaving, and that users generally tend to overestimate time savings. Observational techniques would yield a more accurate measure of efficiency, and should be used in any follow-up research in this area. It is difficult to draw any firm conclusions about efficiency from the questionnaire data alone.

While all users in Tullamore felt a fixed PC would meet their needs for accessibility at the bedside, this would mean a fixed PC at every bedside. This is an expensive solution, and would also give rise to issues with logging in to the PC on each visit to the patient. Wireless computers would appear to offer a better solution for accessibility at the point of care.

7.4.2.1 Conclusion

There was no evidence from the questionnaires for an effect on efficiency due to the wireless computers. The interviews indicated there may be a small effect, but it may be too small to measure given the limited size of the sample and the techniques used (i.e. self report rather than observational techniques).

The wireless computers did appear to increase user satisfaction, as measured by accessibility of the system, communication with patients and ability to access data at the point of care.

8. Discussion

The key advantage of wireless computers in Tullamore appears to be the ability to access patient data at the bedside. This is indicated by the interviews and supported by the questionnaire results. Data on past treatments is accessed in 50% of cases. The ability to look this up at the bedside and while talking to the patient improves the quality of patient care, as indicated by nurses' response to questions on the quality of communication and the relationship with the patient. These results also point to increased nurse satisfaction, as nurses using wireless computers considered the system to be more accessible.

Bates (2003, [52]) points out that accessibility of data at the point of care is a key requirement for improving safety in medicine. By improving accessibility the mobile computers in Tullamore are probably improving patient safety. Jacobs (2004 [24]) and Upperman et al (2005 [22]) showed use of wireless computers could improve patient safety in a paediatric setting. Rothschild (2004 [25]) in a review of studies in a critical care setting considered that wireless computers would further increase the improvements in patient safety afforded by use of CPOE in critical care.

Handler et al [28] and The California Healthcare Foundation [27] point out that user satisfaction is an essential element of successful eHealth implementations. Both conclude that wireless computers can help to increase system usability and thereby increase user satisfaction. The finding that nurses in Tullamore report increased accessibility of computers, a measure of overall system usability, is in agreement with these findings.

Wireless computers were not found to have a significant effect on efficiency. This is in contrast to a number of international studies (Basso [37], Intel [20] and Ancona [32]). Potential efficiency gains may be limited by issues with the computers themselves. Tullamore nurses found the wireless computers are not small and light enough to be carried around continuously. This is also an issue which came up in AMNCH (section 4.3.2). Efficiency is difficult to measure accurately from user reports alone. Observational techniques would yield a more reliable result (Intel [56]) and should be used in any future studies aimed at measuring efficiency.

Battery life is an issue in both AMNCH and Tullamore. Ideally batteries should last for a complete shift, but the current state of battery technology limits battery life to 4-5 hours.

Data entry is an issue in Tullamore. The handwriting recognition function does not work well because there are multiple users using each tablet. The soft keyboard was found very cumbersome and almost never used. Nurses generally seemed to prefer using a keyboard, and consequently went to the fixed PCs for entering data. Data entry was not flagged as an issue in AMNCH. This may be because the TEAMS application uses drop down menus for data entry. In Tullamore nurses need to record information on complications and events in text format. A possible solution to the data entry problem would be to provide a docking station with a keyboard at each patient station. These are relatively inexpensive and would solve both the data entry and battery life problems.

Slow login on the tablets was another issue which came up in Tullamore. These are probably due to extra security for wireless devices. Use of biometric data for login could make this procedure faster and more convenient for the user. Many tablets (e.g. the Motion M1400 [53]) are equipped with a fingerprint reader.

The debate on the ideal client for healthcare has been going on for some time. Many manufacturers e.g. Motion Computing [53] are producing tablets for the healthcare market. However this format is not yet proven. It is worth noting that Dell, the market leaders in PC manufacturing, have yet to produce a tablet. Experience at Tullamore indicates the tablet format has some shortcomings, in at least some healthcare settings. eHealth Insider reports on user experiences with both Tablets and PDAs, with no clear conclusion as to which is best ([54]), and highlighting drawbacks of both. AMNCH and Tullamore both consider the PDA screen is too small meet their needs for data display. Size and weight is a crucial issue, as the client has to be small and light enough to carry around comfortably. The consensus from both AMNCH and Tullamore is that the ideal wireless client is A5 size and weighs less than a kilo. This ideal device is not yet on the market.

Some studies (Intel [20], Andrade [16]) were conducted with wireless PDAs and found them to be satisfactory. PDAs have the advantage of being small and light enough to be carried in a pocket. However the screen is very small and this limits their usefulness. Galway have decided on a PDA/smartphone device. Experiences of users with these devices will be very interesting and would be a worthwhile subject for further research.

8.1 Conclusion

This case study has shown that wireless computers can improve user satisfaction in an Irish context. The key advantage of mobile computers appears to be the ability to access patient data at the bedside and while talking to the patient. Nurses using wireless computers reported improved communication and a better relationship with the patient. The nurses also found the computer system to be more accessible. These findings indicate that wireless computers can improve the quality of patient care and increase clinical user satisfaction. User satisfaction is essential to successful eHealth implementations. There may also be an improvement in patient safety, as accessibility of data at the point of care is a key requirement for improving safety in medicine (Bates 2003 [52]).

The study did not find a significant effect on efficiency. This may be partly due to issues with the client devices, and partly due to ready availability of fixed PCs, which limits the gains to be made. It may also be due to limitations of the study itself, as observational techniques were not used.

Close attention must be paid to the choice of client devices in order to realise all the benefits of wireless computers. Size and weight, ease of data entry and battery life are all issues which need to be taken into consideration, and which are not satisfied by any devices currently on the market. Users clearly preferred a keyboard for manual entry of data. Further study to determine client device requirements would be beneficial. It is likely that different healthcare settings will have very different requirements for client devices. The experiences of UCHG Galway with the implementation of PDA/smartphone devices will be very interesting and worthy of further research.

8.2 Limitations

The pool of Irish healthcare professionals using wireless computers is currently very small. This case study was conducted with a very small sample, in one healthcare setting (renal dialysis) and with one category of clinical user (nurses). Observational techniques were not used. Further study is needed with a larger sample, in a variety of care settings and with a variety of clinical users. Observational techniques such as time and motion studies should be used to measure effects on efficiency. Further research on client devices is necessary to determine the optimum combination of features for different healthcare settings and categories of user.

Use of wireless computers is only beginning in Irish hospitals. However it is likely Ireland will follow trends in the U.S.A and increase deployment of wireless networks in the coming years. Research on the likely benefits and how best to realise them is essential to making the most of what will be a substantial national investment in IT.

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Appendix A. Covering Letter

My name is Marian O'Shea and I am a post graduate student at the Department of Health Informatics, Trinity College Dublin. I am conducting research into use of computers in renal dialysis units. As part of the study I am asking nursing staff in 2 hospitals to fill in a questionnaire on their use of computers at work. It should take you maximum 10 minutes. The results of the study will be written up but the identity of all participants will be protected. You are welcome to check this at any time. The research will be submitted as part of the requirements for the M.Sc. in Health Informatics from TCD. If you would like to see the results of the study, I will be happy to supply them on request by email. I can be contacted at 087 9553233 or marianoshea@eircom.net

I will collect the completed questionnaires on Thursday July 21st.

Thank you very much for agreeing to participate in this study.

Appendix B. Questionnaire

Section 1

This section asks some general questions about your use of computers. Please answer yes or no as appropriate.

Do you use a computer at home or work?	Yes / No
Do you use e-mail or internet at home or work?	Yes / No
Do you use a computer every day?	Yes / No
What kind of computer user would you consider yourself to be (circle one): Sophisticated user Unsophisticated user Neither	

Section 2

The questions in this section ask about your use of the computer system in your place of work. Please circle the number which most closely agrees with your opinion.

1 = Strongly Disagree

2 = Disagree

3 = Neither agree nor disagree

4 = Agree

5 = Strongly Agree

Your comments are very welcome, please add them if you wish in the space provided.

1.	It is easy to enter data into the patient record	1 2 3 4 5
2.	It is easy to enter text into the patient record	1 2 3 4 5
3.	The computer reduces communication with patients	1 2 3 4 5
4.	The computer is convenient to use	1 2 3 4 5
5.	The computer speed is fast	
6.	The computer is available when I need it	1 2 3 4 5
7.	Patients make negative comments about the computer	1 2 3 4 5
8.	The computer is accessible in all locations where I need it	1 2 3 4 5
9.	I am generally satisfied with the computer system	1 2 3 4 5
10.	It is easy to access data from the patient record	1 2 3 4 5
11.	I was adequately trained in the use of the computer	1 2 3 4 5
12.	The computer eliminates a lot of paperwork	1 2 3 4 5
13.	The computer improves the quality of documentation	1 2 3 4 5
14.	Wish I could just write on paper	1 2 3 4 5
15.	The computer saves time	1 2 3 4 5

16.	The computer leads to increased use of clinical practice guidelines	1 2 3 4 5
17.	It takes me longer to finish my work	1 2 3 4 5
18.	The computer reduces my risk of making errors	1 2 3 4 5
19.	I am better able to monitor patient progress	1 2 3 4 5
20.	I find the computer makes me more efficient	1 2 3 4 5
21.	The computer reduces communication with staff	1 2 3 4 5
22.	The computer improves workflow	1 2 3 4 5
23.	The computer has a negative impact on the nurse–patient relationship	1 2 3 4 5
Your comments are very valuable. If you wish to add extra information or clarify any of your answers, please do so here. Use the back of the page if you need more space.		

Section 3

This section asks some questions relating to use of fixed and wireless computers. A fixed computer is a computer which remains in one place and is connected by wires to the hospital computer system e.g. a desktop PC at the nurse's station. A wireless computer can be carried around in the hand and is connected by wireless to the hospital computer system e.g. a tablet PC.

Do you use a wireless computer for access to patient records?	Yes / No / Sometimes
Could a fixed computer meet your needs for access to information at the patient's bedside?	Yes / No
If your answer to the previous question was no, please explain why. Please use the back of the page if you need more space.	

Section 4

How much of your time per shift do you spend accessing and updating patient records? Please circle the closest estimate.

Less than 10%   10% - 20%   20% - 40%   40% - 60%   More than 60%

Thank You

Appendix C. Questionnaire Results

Tullamore results						
Questionnaire No.	1	5	4	2	3	6
Section 1						
Do you use a computer at home or work?	Yes	Yes	Yes	Yes	Yes	Yes
Do you use e-mail or internet at home or work?	No	Yes	Yes	Yes	Yes	Yes
Do you use a computer every day?	No	no	Yes	Yes	Yes	no
What kind of computer user would you consider yourself to be	U	U	N	U	N	N
Section 2						
I was adequately trained in the use of the computer	2	2	3	4	4	4
I am generally satisfied with the computer system	3	2	3	4	4	4
It is easy to enter data into the patient record	4	4	4	4	4	4
It is easy to enter text into the patient record	4	2	4	4	4	4
It is easy to access data from the patient record	2	2	2	4	2	4
The computer is convenient to use	2	2	4	5	4	4
The computer is available when I need it	2	5	3	4	4	4
The computer is accessible in all locations where I need it	3	3	4	4	4	4
The computer eliminates a lot of paperwork	2	2	2	4	4	2
The computer saves time	2	2	2	4	4	4
It takes me longer to finish my work	3	2	3	2	2	2
I find the computer makes me more efficient	2	2	3	4	3	2
I am better able to monitor patient progress	3	2	4	4	3	2
The computer improves workflow	2	3	2	4	3	2
Wish I could just write on paper	4	2	2	1	1	2
The computer leads to increased use of clinical practice guidelines	3	3	3	4	2	2

The computer reduces my risk of making errors	2	2	3	4	2	2
The computer improves the quality of documentation	2	4	2	2	3	4
The computer reduces communication with staff	3	2	3	2	2	4
The computer reduces communication with patients	4	2	1	2	1	2
Patients make negative comments about the computer	3	3	1	5	1	2
The computer has a negative impact on the nurse–patient relationship	3	1	1	2	2	2
Section 3						
Do you use a wireless computer for access to patient records?						
Could a fixed computer meet your needs for access to information at the patient's bedside?	Yes	Yes	Yes	Yes	Yes	Yes
Section 4						
How much of your time per shift do you spend accessing and updating patient records?	20%-40%	20%-40%	20%-40%	20%-40%	10%-20%	< 10%

1 = Strongly Disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly Agree
U = Unsophisticated S = Sophisticated N =Neither n/a = not answered

Table 6 Tullamore results raw data

Waterford results										
Questionnaire No.	1	2	9	10	4	5	6	7	8	3
Section 1										
Do you use a computer at home or work?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Do you use e-mail or internet at home or work?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Do you use a computer every day?	Yes	No	Yes	No	n/a	Yes	Yes	No	Yes	Yes
What kind of computer user would you consider yourself to be	U	U	N	U	N	U	U	U	U	U
Section 2										
I was adequately trained in the use of the computer	2	2	3	3	4	4	4	4	4	5
I am generally satisfied with the computer system	4	2	4	3	2	4	4	4	5	3
It is easy to enter data into the patient record	4	2	4	4	4	4	4	4	2	5
It is easy to enter text into the patient record	4	3	4	4	4	4	4	4	3	5
It is easy to access data from the patient record	4	2	4	3	2	4	4	4	4	4
The computer is convenient to use	3	2	4	4	4	4	4	4	5	3
The computer is available when I need it	3	2	4	4	2	5	4	4	3	3
The computer is accessible in all locations where I need it	4	2	4	3	1	4	4	4	4	1
The computer eliminates a lot of paperwork	1	3	4	3	2	4	1	4	3	5
The computer saves time	2	2	4	4	2	3	5	4	5	4
It takes me longer to finish my work	3	3	3	3	2	4	n/a	3	2	5
I find the computer makes me more efficient	3	2	3	3	2	4	4	4	4	3
I am better able to monitor patient progress	4	2	3	3	2	4	4	4	4	3
The computer improves workflow	2	3	4	4	2	4	3	4	4	4
Wish I could just write on paper	3	3	2	3	4	5	5	2	1	3
The computer leads to increased use of clinical practice guidelines	2	3	4	3	1	4	3	4	5	3

The computer reduces my risk of making errors	3	2	4	3	2	4	2	3	3	5
The computer improves the quality of documentation	2	3	4	3	2	5	3	4	4	5
The computer reduces communication with staff	2	3	3	3	2	3	1	2	1	3
The computer reduces communication with patients	1	3	1	4	3	5	1	n/a	1	1
Patients make negative comments about the computer	1	3	2	3	n/a	4	2	2	1	1
The computer has a negative impact on the nurse–patient relationship	2	n/a	2	3	2	4	1	3	5	3
Section 3										
Do you use a wireless computer for access to patient records?	No	No	No	No	No	No	No	No	No	No
Could a fixed computer meet your needs for access to information at the patient's bedside?	No	No	Yes	Yes	Yes	Yes	No	Yes	n/a	Yes
Section 4										
How much of your time per shift do you spend accessing and updating patient records?	< 10%	10%-20%	n/a	20%-40%	20%-40%	< 10%	10%-20%	10%-20%	n/a	20%-40%

1 = Strongly Disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly Agree
U = Unsophisticated S = Sophisticated N =Neither n/a = not answered

Table 7 Waterford results raw data

Glossary of Terms

AP	Access Point
BSS	Basic Service Set
CoW	Computer on Wheels
CPOE	Computerised Physician Order Entry
DS	Distribution System
ESS	Extended Service Set
IT	Information Technology
LAN	Local Area Network
LIS	Laboratory Information System
MAC	Medium Access Control
MS	Mobile Station
PACS	Picture Archiving and Communications System
PC	Personal Computer
PDA	Personal Digital Assistant
PHY	Physical Layer
WiFi	Wireless Fidelity
WLAN	Wireless LAN