

Implementation Issues for Mobile-Wireless Infrastructure and Mobile Health Care Computing Devices for a Hospital Ward Setting

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Abstract mWard is a project whose purpose is to enhance existing clinical and administrative decision support and to consider mobile computers, connected via wireless network, for bringing clinical information to the point of care. The mWard project allowed a limited number of users to test and evaluate a selected range of mobile-wireless infrastructure and mobile health care computing devices at the neuroscience ward at Southern Health's Monash Medical Centre, Victoria, Australia. Before the project commenced, the ward had two PC's which were used as terminals by all ward-based staff and numerous multi-disciplinary staff who visited the ward each day. The first stage of the research, outlined in this paper, evaluates a selected range of mobile-wireless infrastructure.

Keywords Healthcare · Mobile-wireless · Communications · Device · Infrastructure

Introduction mWard project

The hospital IT environment is often typically a legacy system that provides access to patient management infor-

mation and clinical results and is based on infrastructure such as desktop computers and wired networks, and legacy patient-record software. Legacy systems are large and difficult to modify and resist modification and evolution to meet new and constantly changing business requirements [1]. Many hospitals are locked into a cycle of dependence on legacy systems because limited funds often curtail the investment needed for comprehensive system design and integration. The health care industry, too, is unlikely to develop and deploy a large scale, national authentication infrastructure. Still, and there is some merit in leveraging existing hardware, software, and networks [2]. Some work has been reported on system integration for multi-platform medical computer systems [3]. Jasemian and Arendt-Nielsen [4] report on the design of wireless systems and explore factors to be considered when evaluating different technologies for application in a telemedicine system.

Our research was based at Southern Health, a public health service organization located in Melbourne Victoria, Australia. Southern Health provides services for more than 750,000 people, from children to adults, in Melbourne's south east. The research is based on the premise that the work of enhancing decision support for ward-based clinicians at the bedside somewhat relies on the use of mobile healthcare computing devices in a legacy environment to support clinicians with real-time access to network, communication and computer resources independent of location. Mobile healthcare computing devices (MHCDs) is a technical term defined by Lin and Vassar [5] as all mobile and handheld computing devices used in healthcare.

The aims of this paper are as follows:

- to describe a typical hospital wireless LAN infrastructure
- to describe the configuration of the mobile-wireless infrastructure and devices used in mWard's test LAN

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- to outline the technical information and implementation issues on the devices and infrastructure deployed and used in mWard's test LAN
- to describe the benefits and limitations of each component of a mobile-wireless infrastructure and devices
- to describe factors important to the end-user during the implementation process
- to conclude with suggestions of what improvements to mobile-wireless infrastructure and devices for a hospital ward setting are needed and where further research should be directed

The study is a pilot implementation and evaluation study. The design draws from organizational anthropology [6]. Ethnographic approaches to information systems research are slowly gaining recognition in disciplines outside the social science research [7, 8]. The approach offers one of the best ways to gather in-depth understanding as researchers tend to be on the site of study over an extended period [9]. Whenever realization of the full potential of the new/modified information system depends on the end-users' acceptance, a qualitative approach to the research design is preferred [10]. The take up ethnographic research is very popular in health services research [11].

The method of participant observation underpinned the data collection strategy. The researchers observed the interactions of ward staff with the technologies over a six month period. Detailed daily notes were written during the data collection period and these were summarized into a weekly journal which contained detailed descriptive information about the implementation issues on the wireless technologies deployed in the hospital ward. During the analysis phase, the researchers reviewed the weekly journal and summarised relevant data about implementation issues around technical aspects of system functionality in a hospital setting.

Participant observation is known to be effective for clinical informatics evaluation during formative and pilot stages as researchers gain insight into human interaction and system processes of the users' task requirements [12]. Factors that were important to the end-user during the implementation process were discovered using this method. Ethics approval was obtained from relevant institutional committees.

A limitation of the design is that factors are not conceptualized as discrete entities. For example, one of the factors discovered many times were flat batteries that hindered the functioning of the system. We did not count how many times residents reported flat batteries. Friedman and Wyatt [10] note that it is unrealistic to look for quantifiable changes in outcome until one has documented changes around structure and processes. In future studies we may look at quantifiable outcomes. We were able to observe how people engaged with the new technology in the context of the workplace. In this way we gained a

deeper understanding of issues in the context of the organizational environment.

Description of ward setting

Figure 1 shows the physical layout of the ward. The diagram highlights, using circles, the office of the registered medical officers (RMOs) and staff base (or nurses' desk); each area has a stationary, networked desktop computer. Also highlighted is the wireless-networked switch which is an important component of the mobile-wireless infrastructure.

Mobile-wireless infrastructure and devices

Typical hospital LAN with mobile-wireless equipment

Figure 2 is a schematic diagram showing a typical hospital LAN and a proposed range of commercially available mobile-wireless infrastructure and devices. The mobile-wireless infrastructure components are highlighted in the top three rectangles. They include a wireless switch, single-port power injectors and wireless access ports. The mobile-wireless devices are highlighted by the single rectangle at the bottom of the schematic diagram. They include a PDA, digital telephone and laptop. The wireless switch is usually connected by category five data cables to single-port power injectors that are, in-turn, connected by similar data cables that connect and power the wireless access ports. The actual authorised wireless connection occurs between the wireless access ports and each of the wireless devices.

mWard's test lan

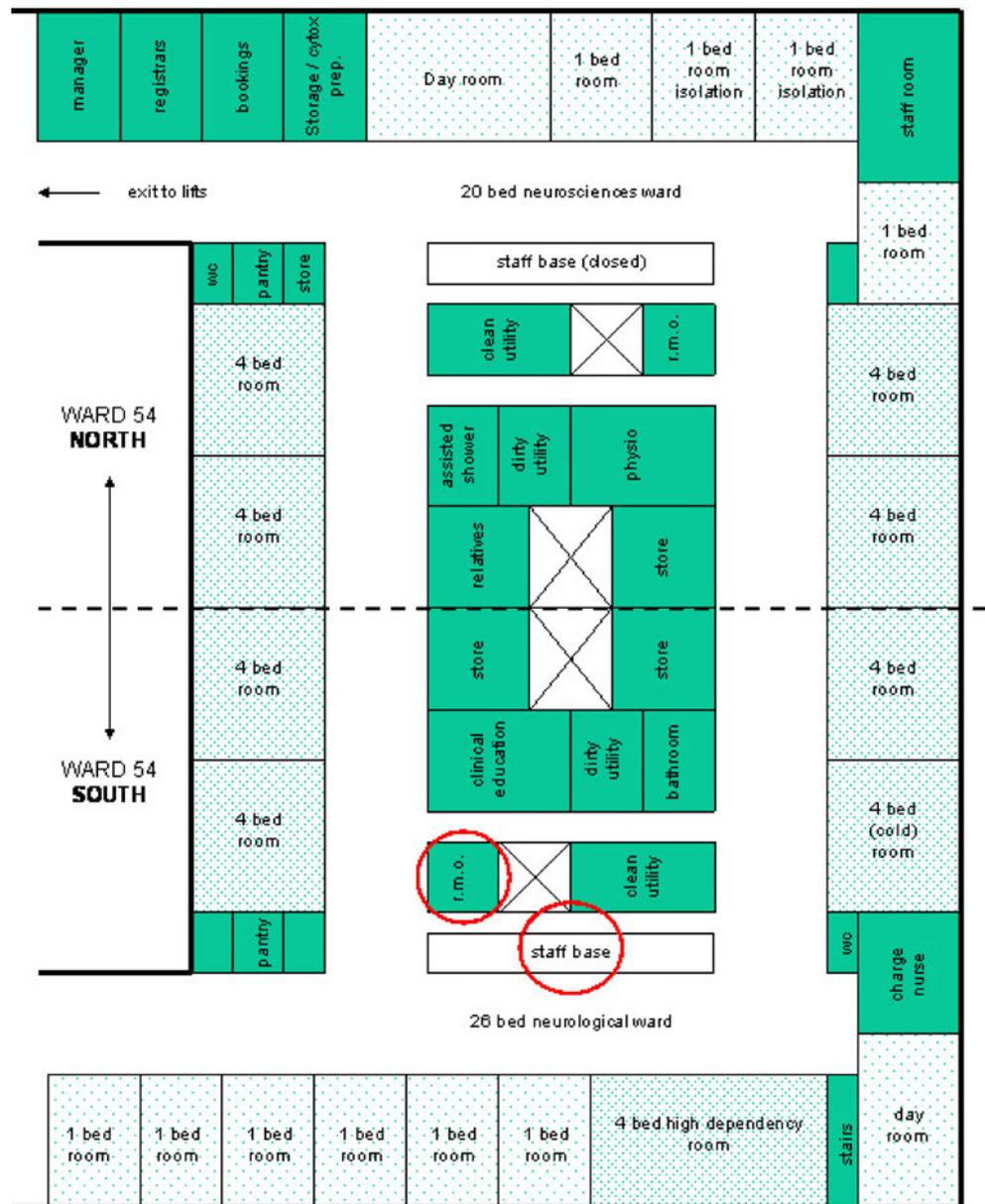
mWard implemented a test LAN using a similar mobile-wireless infrastructure with devices as shown in Fig. 2. It complemented the existing hospital LAN. mWard's key partners and associates provided a selected range of new mobile-wireless infrastructure and devices to help build a test LAN. The mobile-wireless infrastructure and devices were installed, configured and maintained by these key partners and associates.

In-situ equipment

The following wireless infrastructure components incorporated several levels of security access and were installed into the ward to create the test LAN:

- wireless switch (WS5,000)
- wireless access ports (AP100)
- single-port power injectors (AP-PBIAS-T-1P-48)

Fig. 1 Neuroscience ward



The following mobile-wireless devices were supplied to the ward for testing:

- wireless laptops (EVOOn1000c)
- trolleys (to hold the wireless laptops)
- wireless PC Tablet (Versa T400)
- wireless ruggedised Pocket PC PDA (Personal Digital Assistant), (PPT8800w)
- wireless DEC telephones (Netlink i640 and e340)

The existing hospital LAN and wireless switch, as shown in Fig. 3, and the single-port power injectors, as shown in Fig. 4, form part of the mWard mobile-wireless infrastructure.

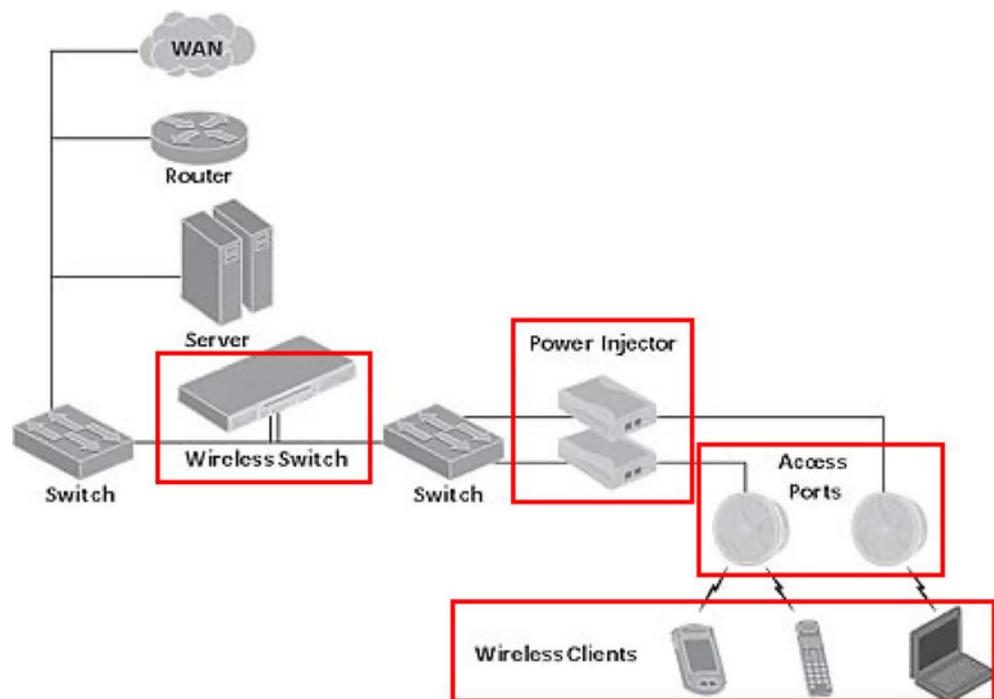
Description of mWard’s mobile-wireless equipment

In the following subsections each item of the infrastructure and devices are listed with a description of the technical information and implementation issues. Such issues are one aspect of a framework proposed by Martins and Jones [14] to analyse the features of MICT in health care.

Wireless switch (WS5000)

The wireless switch (WS5000), shown in Fig. 5, sends and receives data to the mobile-wireless equipment via the wireless access ports, the single-port power injectors and

Fig. 2 Hospital LAN with mobile-wireless infrastructure and devices (adapted) [13]



the wired hospital network. The wireless switch uses wireless or radio-frequency (RF) signals across the 900 MHz, 2.4 GHz and 5 GHz frequencies. It complies with the Institute of Electrical and Electronic Engineers (IEEE) wireless standards of 802.11a, 802.11b, 802.11 g [15]. The new generation of wireless switches now offer centralised LAN management, end-to-end scaled security, and lower total cost of ownership and scalability [15]. In other words, wireless switches can now centralise all management of the wireless LAN through one piece of equipment and interface. It provides several levels of security across the network. The number of wireless access ports can be increased to meet user demand and the wireless LAN is reliable.

Implementation issues

The wireless switch is both an administration centre for the wireless LAN as well as a transport hub between mobile-wireless devices and the hard-wired hospital network for routine data packets. It is housed in a secured computer cabinet on the ward. The project industry partner maintains the equipment and the hospital's computer services department maintains the LAN interface. The switch provides excellent wireless coverage across the ward with no apparent 'dead spots'. The wireless access speed of the switch matches current industry standards of between 11 Mbps (for 802.11b) and 54 Mbps (for 802.11 g). If the wireless switch fails the entire wireless network would cease to function.

Technical Information

Equipment	Wireless Switch (WS5000), 1 no.
IEEE Network Standards	802.11a, 802.11b, 802.11 g
Network Equipment	-
Network Protocol	TCP/IP
Data Encryption	WEP 128 bit
Power Source	Hospital mains with battery backup
Software	Web-browser interface under Microsoft Windows and/or a command-line interface under Unix/Linux.

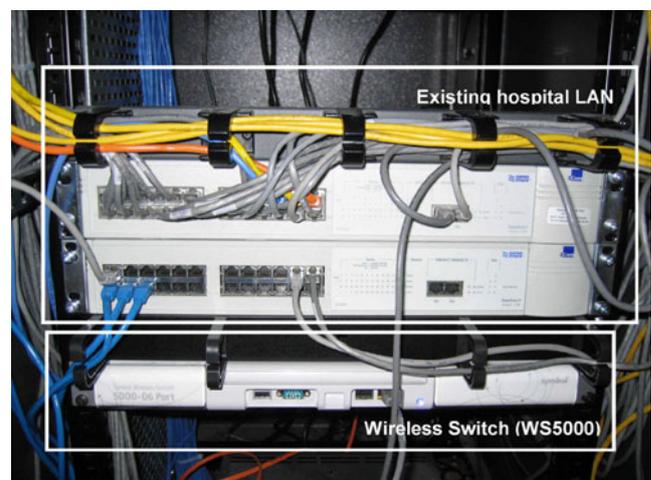


Fig. 3 Existing hospital LAN and wireless switch (WS5000)

Wired port power injectors (AP-PBIAS-T-1P-48)

Figure 6 shows the port power injectors (AP-PBIAS-T-1P-48) that are in use on the ward.

Technical Information

Equipment	Single-Port Power Injectors (AP-PBIAS-T-1P-48), 3 nos.
IEEE Network Standards	802.3
Network Equipment	-
Network Protocol	TCP/IP
Data Encryption	-
Power Source	Hospital mains with battery backup
Software	-

Implementation issues

The wired port power injectors are located between the wireless switch and wireless access points. Their primary function is to power the wireless access points via the wireless switch using data cables-and are housed in a secure computer cabinet on the ward. The project industry partner maintains the equipment and disaster recovery is based on the hospital’s computer services guidelines and mWard

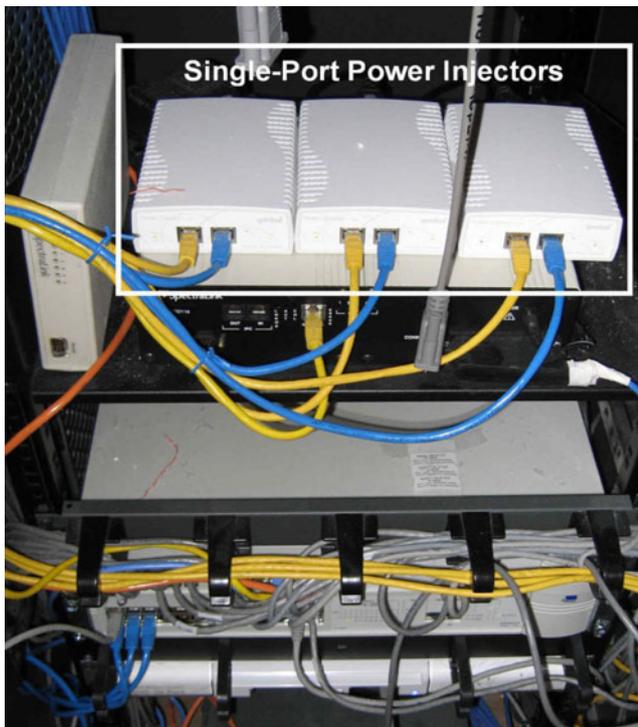


Fig. 4 Wired single-port power injectors

Fig. 5 Wireless switch (WS5000) uses centralised network management [15]



requirements. The single-port power injectors are convenient for powering the wireless access points and save the need for a separate power supply for each access point. If the single-port power injector fails then the wireless access port it is powering would cease to function and part of the wireless network would cease to exist.

Wireless access ports

The access ports (AP100) use IEEE 802.11b wireless LAN connectivity. The wireless access ports can be installed on desktops, walls, and above or beneath ceilings where its LED lights are easily visible to provide easy operating feedback [17]. AP100 has an “integrated (internal) 3.5 dBi omni-directional cross-polarized diversity antenna that provides the strongest wireless coverage possible” [17]. AP100 receives its firmware from the WS 5000 Wireless Switch and this means that the “cumbersome, time consuming and error prone process of loading traditional access point firmware is eliminated” [17]. Figure 7 shows the wireless access port with above-ceiling mounting piece (small round white disc) that is no bigger than an Australian 50 cent coin, which is approximately 10 centimetres in diameter.

Figure 8 shows the wireless access port mounted above the ceiling with the ceiling piece visible for easy viewing of status.

Technical Information

Equipment	Wireless Access Port (AP100), 3 nos.
IEEE Network Standards	802.11b
Network Equipment	-
Network Protocol	TCP/IP
Data Encryption	-
Power Source	Single-Port Power Injectors
Software	-

Implementation issues

The wireless access port provides the direct wireless-wired interface, using RF to transmit and receive data packets, and is located between mobile-wireless devices and the wireless switch. It is concealed in the corridor ceiling. The project industry partner maintains the equipment and disaster recovery is based on the hospital’s computer services guidelines and mWard requirements.

Wireless laptops (EVOv1000c)

Figure 9 shows the wireless laptops (EVO n1000c) that are in use on the ward.

Technical Information

Equipment	Wireless Laptop (EVO n1000c), 2 nos.
Pentium M, 1.8 GHz, 256 MB Ram, Hard disk drive 27.9 GB	
IEEE Network Standards	802.11b, 802.11 g
Network Equipment	3Com PCMCIA Wireless Access Cards
Network Protocol	TCP/IP
Data Encryption	WEP 128 bit
Power Source	Internal battery and hospital mains with battery backup
Software	MS Windows XP-SP1
Novell and Windows Network Authentication	
Reflections Software (Pathology via MS IE)	
Picture Archiving and Communication System (PACS) by GE Centricity (X-ray via MS IE)	
Patient Master Index via Homer System (PMI) (Patient information via MS IE)	

Implementation issues

The wireless laptops provide the ability to input, store, retrieve and view, in real-time, ‘unlimited’ patient information using a web-based interface at a patient’s bedside. They are located between the user and a wireless access point. The hospital computer services department maintains the equipment and disaster recovery is based on the hospital’s computer services guidelines and mWard requirements. Users include medical practitioners, nurses and allied health staff.

Mobile functionality is good when the laptop is on a trolley (see Fig. 10). Laptops provide good picture and



Fig. 6 Wired single-port power injectors [16]

Fig. 7 Wireless access port (AP100) with above ceiling mounting piece [17]



screen resolution and all programs that are available on the desktop computer are available on the laptop. Keyboards are similar to the desktop computer, but since they are wireless, no network cables are necessary. However, the laptops required a firmware upgrade to enable IEEE Network Standard: 802.11a, b and g.

The main disadvantage is that the battery life is approximately 2½ hours when batteries are new; batteries are not being recharged during or between shifts as staff forget to connect the laptops to mains electricity. The battery life of the mobile laptops does not last long enough for the shift of work and clinicians are too busy to re-charge them. Other needs are that staff need to learn to use either the touch pad or pointing device since there is no mouse available for security and cleanliness reasons; and there are problems with slow login to the hospital network.

Wireless DEC telephones (i640 and e340)

Figure 11 shows the wireless DEC telephones (i640 and e340) and cradles (left picture) and telephony gateway (black box, right picture) that is in use on the ward at MMC.

Technical Information

Equipment	Wireless DEC Telephone and cradle (Netlink i640 and e340) 2 nos. and 1 no. respectively
IEEE Network Standards	802.11b
Network Equipment	Wireless Access Card built-in
Network Protocol	TCP/IP
Data Encryption	WEP 128 bit
Power Source	Internal battery with recharger cradle
Software	-

Implementation issues

The wireless telephones allow nurses to contact medical staff internally at any time using digital technology. The project industry partner maintains the equipment and the hospital technology services maintain the interface with



Fig. 8 Casing to help mount the Wireless Access Port (AP100) above the ceiling—the ceiling piece is visible [17]

PABX. Disaster recovery is based on Southern Health’s computer services guidelines and mWard requirement. One walkie-talkie is available if DEC phones fail or are unavailable. Users include medical practitioners, nurses and allied health staff.

Each digital telephone has its own extension number and is linked to another telephone line (or “mate”) on the ward. The digital telephones will ring if their mate telephone lines are not answered in 15 or 20 s (approximately four to five rings). Coverage is good in the lift and toilets. The main disadvantage is that the battery life is 40 hours standby maximum when batteries are new. Batteries are not being recharged during or between shifts as staff forget to put them back into the cradles. Coverage is lost in and around the ward, as there are many blind spots. Also, if the ward staff were not trained properly to use the phones they will not use them.

Wireless personal digital assistant (PPT8800w)

Figure 12 shows a wireless Personal Digital Assistant (PDA, PPT8800w) that is in use on the ward.

Technical Information

Equipment	Wireless Personal Digital Assistant (PDA, Pocket PC PPT8800w), 1 no.
IEEE Network Standards	802.11b
Network Equipment	Wireless Access Card built-in
Network Protocol	TCP/IP
Data Encryption	WEP 128 bit
Power Source	Internal battery with recharger cradle
Software	MS Windows CE
Novell and Windows Network Authentication	
Reflections Software (Pathology via MS IE)	

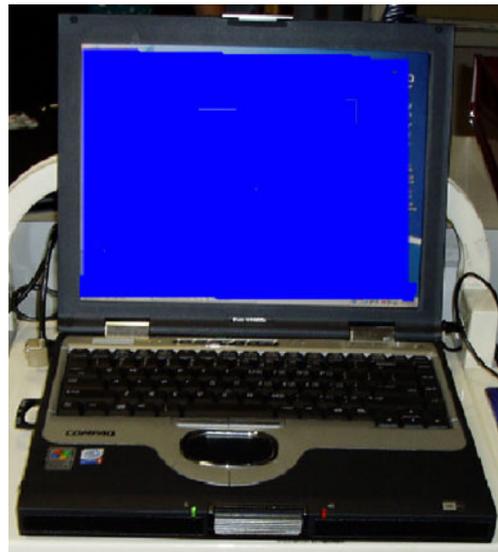


Fig. 9 Wireless Laptop (EVO n1000c)

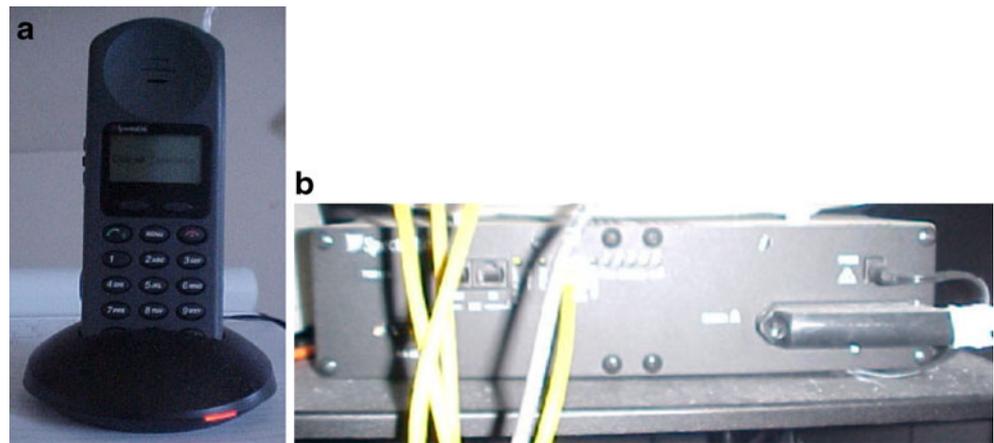
Implementation issues

The wireless PDA provides the ability to input, store, retrieve and view, in real-time, ‘limited’ patient information using a web-based interface and software (eg pathology lookup) at a patient’s bedside. It is housed in the Nurse Unit Manager’s office. Currently mWard uses PDA’s to display existing patient records from the hospital’s legacy database via Microsoft Internet Explorer. mWard does not yet capture



Fig. 10 Laptop on a trolley

Fig. 11 Wireless DEC telephone and cradle, and telephony Gateway (black box)



patient information on PDA's for downloading at a later period (as a replacement for current paper documents).

Clinicians reported that advantages of the PDA were that it feels comfortable to hold in the hand and that the attached rear elastic strap prevents the user from dropping the device if knocked from the hand. The PDA is ruggedised and designed to work even if dropped from a height of about 1 meter or less. The PDA has commercial grade quality casing and internal components. The PDA provides good screen resolution for pathology. No network cables are necessary and good coverage is available in and around ward. No blind spots have been identified. In case of a flat battery, the PDA's WLAN settings and MS Internet Explorer proxy settings can and are automatically reconfigured using a prewritten file which has been installed into the registry every-time the PDA is started or rebooted.

There is a spare slot on the PDA cradle to charge a spare battery while at the same time charging the PDA.

The main disadvantage is that the battery life was not explicitly specified by the manufacturer. Within the product specific documentation and on the website we were unable to find any reference to the predicted battery life of the product. We had to test the life of the battery to see how long it would last in the hospital environment. Batteries are not being recharged during or between shifts as staff forget to put the PDA back into cradles. Recharging lights on the cradle are not bright under fluorescent lights and it is difficult to see if the device is charging. There is limited pathology data available at present and the pathology lookup screen does not resize so staff cannot see all the information without scrolling left to right or up to down. Not all programs that are available on the desktop computer are available on PDA. Styluses are easily lost and generic replacements do not fit into the stylus storage slot on side of device. The device loses WLAN and MSIE proxy settings when the battery is exhausted.



Fig. 12 Wireless pocket PC-PDA (PPT8800w)



Fig. 13 Wireless PC Tablet showing a patient's chest x-ray

Training programs need to be designed and implemented. Clinical staff are professionals who may also be using a PDA at home or in other areas of their professional lives. Their PDAs may be technically acceptable for limited usage in a ward setting, but the demanding ward environment in a hospital requires a technically different PDA as described.

Wireless PC tablet (Versa T400)

Figure 13 shows a wireless PC Tablet (Versa T400) that is in use on the ward.

Technical Information

Equipment	Wireless PC Tablet (Versa T400), 1 no.
Pentium III-M, 933 MHz, 256 MB Ram, Hard disk drive 17.4 GB	
IEEE Network Standards	802.11a/b
Network Equipment	Wireless Access Card built-in, Hardware On/Off Switch
Network Protocol	TCP/IP
Data Encryption	WEP 128 bit
Power Source	Internal battery and hospital mains with battery backup
Software	MS Windows XP-SP1 (Tablet PC Edition)
Novell and Windows Network Authentication	
Picture Archiving and Communication System (PACS) by GE Centricity (X-ray via MS IE)	

Implementation issues

The wireless tablet PC provides the ability to input, store, retrieve and view, in real-time, ‘limited’ patient information using a web-based interface and software (eg PACS digital x-ray images) at a patient’s bedside. It is located on a trolley in front of the nurses’ station. The industry partner maintains the equipment and computer services maintain the software. The disaster recovery procedure is based on the hospital’s computer services guidelines and mWard requirements. Users include medical practitioners, nurses and allied health staff.

The main advantages of the PC tablet are that doctors like its usability and professional appearance in front of colleagues and especially patients. Picture and screen resolution is good for viewing radiology and pathology

results. No network cables are necessary and there is good coverage in and around ward with no blind spots identified. Input device options include a keyboard and/or stylus. The user interface includes i) handwriting recognition, and ii) on-screen keyboard. Speech recognition software is also available. Patients and relatives feel a sense of inclusion in the treatment process when they are shown pictures of pathology.

As with the other devices, the main disadvantage is the limited battery life which is approximately 2.5 hours for new batteries. Batteries, as for the other devices, are not being recharged during or between shifts as staff forget to connect them to the mains electricity for re-charging. A new battery or another way to charge the batteries is needed. Data may be lost if batteries are changed while staff have software programs open with data un-saved. Not all programs that are available on the desktop computer are available on the PC Tablet. The PC tablets are sometimes difficult to hold as there is nothing on the back of PC tablet to assist with stability in the palm and forearm. The team are investigating installing elastic on the back of the PC tables to assist with stability in the palm and forearm. The aerial is easily lost and difficult to replace. The PC Tablet also gets very warm after running for as little as 10 to 15 minutes. The voice recognition software does not recognize accents other than Australian, American or English.

Discussion and conclusion

There has been a gradual increase in the implementation of mobile-wireless infrastructure and mobile health care computing devices for acute hospital ward settings. The devices to capture and manipulate data over wireless networks have the potential to deliver enormous benefits to clinically-based ward staff by improving access to data at the point of care, reducing costs, improving patient safety and improving response times (see for example, Sintchenko, Iredell, Gilbert and Coiera [18] and Thompson [19]).

Following our evaluation of mobile-wireless infrastructure and devices, we are conducting further research on the positive and negative workflow issues that clinical staff experience and are considering adaptations needed to better suit a hospital environment.

Implementation of mobile and wireless devices and infrastructure in a hospital environment where existing computer services don’t offer wireless or a wireless structured service is difficult and requires an incremental approach. Such challenges are well documented [14]. The wireless infrastructure we have installed has been fully operational for two months and emulates full desktop capability including use of a mouse, printing bar codes to the ward four laser printer and full access to Homer (a 20

year old and ‘obsolete’ patient administration system), pathology and radiology. We predict that effective use of the devices and higher adoption rates will be better when clinical staff gain greater benefit from applications that are functional at the point of care and are properly trained to use the technology in their work environment. Medical staff found the devices reliable, useful and easy to use but nurses in the ward may find the technology more acceptable when applications improve their experience of how such technology assists in delivering better and timelier health care for their patients. Our next phase of research will develop one or two manual improvements or practical applications to improve uptake and use of the technology. We plan to invest further funds to get better uptake of the technology and to expand the use of wireless in the ward setting.

We have highlighted some of the initial challenges arising during the implementation of a mobile-wireless infrastructure and mobile health care computing devices. Further research is needed on organizational, workflow process and technical guidelines to improve the use of mobile devices in a hospital ward environment.

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Footnotes

The public health organization where the study was conducted is identifying a new computer system and the current project will contribute to the configuration of the new system to some degree.