Using wireless technologies in healthcare

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Abstract: With an increasingly mobile society and the worldwide deployment of mobile and wireless networks, wireless infrastructure can support many current and emerging healthcare applications. However, before wireless infrastructure can be used in a wide scale, there are several challenges that must be overcome. These include how to best utilise the capabilities of diverse wireless technologies and how to effectively manage the complexity of wireless and mobile networks in healthcare applications. In this paper, we discuss how wireless technologies can be applied in the healthcare environment. Additionally, some open issues and challenges are also discussed.

Keywords: mobile and wireless networks; location management; intelligent emergency system; patient monitoring; telemedicine; healthcare applications; ad hoc wireless networks.

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1 Introduction

The introduction of telecommunications technologies in the healthcare environment has led to an increased accessibility to healthcare providers, more efficient tasks and processes and higher quality of healthcare services (Kern and Jaron, 2003; Wells, 2003; Lin, 1999; Zhang *et al.*, 2000; Lee *et al.*, 2000; Holle and Zahlmann, 1999). However, many challenges, including a significant number of medical errors (To err is human: building a safer health system, 2000; Hayward and Hofer, 2001) considerable stress on healthcare providers and partial coverage of healthcare services in rural and underserved areas, still exist worldwide (Singh, 2002; Parsloe, 2003). These challenges combined with an increasing cost of healthcare services, such as the cost of healthcare services reaching to 15% of the US Gross National Product (Kern and Jaron, 2003) and the exponential increase in the number of seniors and retirees in developed countries (Forum, 2005) have created several major challenges for policy makers, healthcare providers, hospitals, insurance companies and patients.

One such challenge is how to provide better healthcare services to an increasing number of people using limited financial and human resources. The current and emerging wireless technologies (Varshney and Vetter, 2000; Boric-Lubecke and Lubecke, 2002) could improve the overall quality of service for patients in both cities and rural areas. Also, these technologies can reduce the stress and strain on healthcare providers while enhancing people's productivity, retention and quality of life, and also reduce the overall cost of healthcare services in the long-term.

It is well known that many medical errors occur due to a lack of correct and complete information at the location and time it is needed, resulting in wrong diagnosis and drug interaction problems (To err is human: building a safer health system, 2000; Hayward and Hofer, 2001). The required medical information can be made available at any place and at any time using sophisticated devices and widely deployed wireless and mobile networks. Although, wireless technologies cannot eliminate all medical errors, some of the informational-errors can certainly be avoided by the anytime-anywhere access to medical information. Mobile and wireless technologies can be effectively utilised by matching infrastructure capabilities to healthcare needs. These include the following:

- The use of location tracking, intelligent devices, user interfaces, body sensors and short-range wireless communications for patient monitoring.
- The use of instant, flexible and universal wireless access to increase the accessibility of healthcare providers.
- The use of reliable communication among medical devices, patients, healthcare providers and vehicles for effective emergency management.

In the long term, affordability, portability, and reusability of wireless technologies for patient monitoring and preventive care will also reduce the overall cost of healthcare services (Varshney and Vetter, 2000; Boric-Lubecke and Lubecke, 2002; Pattichis *et al.*, 2002; Schepps and Rosen, 2002).

Before discussing our work, we briefly summarise the work done by others in applying mobile and wireless technologies to the healthcare sector. It has been noted that telemedicine is used in less than 10% of all healthcare services (Lin, 1999). Since about 50% of world population lives in rural areas in developing countries, this should be considered a partial success. As the deployment and usability of wireless infrastructure in rural areas increase, both real-time and store-and-forward type telemedicine applications could be utilised on a larger scale. For timely management of problem cases, telemedicine is used for real-time consultation between referring physicians and experts (Zhang *et al.*, 2000). A healthcare monitoring system and field trial for chronically ill patients using cable-TV infrastructure are described in Lee *et al.* (2000). The system supports ECG and BP information with video and audio communications among patients and healthcare providers.

To measure the effectiveness of telemedical services, a four-phase evaluation framework based on technical performance to medical outcome in therapeutic effectiveness and diagnostic accuracy is proposed in Holle and Zahlmann (1999). The evaluation also includes economical aspects for telemedical systems. The use of wireless sensors in minimally invasive continuous health-monitoring systems is discussed in Boric-Lubecke and Lubecke (2002). A maritime telemedicine system with multilingual capabilities is described in Anogianakis *et al.* (1998). The system uses satellite and ground-based networks for supporting audio and video-conferencing, multimedia communications and flat-file and image transfer. Several applications of wireless telemedicine systems, including telecardiology, teleradiology, and telepsychology, are presented in Pattichis *et al.* (2002). An implementation of pervasive computing technologies in an assisted care facility[1] can be found in Stanford (2002).

Using network sensors and databases, facility staff members are alerted when residents need immediate care. Using combined infrared and radio-based locator badges, which also act as keys, the system alerts the staff if a resident wanders out of a certain area (Stanford, 2002). The middleware can play an important role in healthcare as it can hide the lower level networking details from the upper-layer applications. The middleware requirements of pervasive healthcare have been identified as authorisation and authentication, adaptability, availability and modifiability (Raatikainen *et al.*, 2002). We believe that the requirements could also include scalability, implementability and usability. For long-term health monitoring and easy retrieval of information, a wearable healthcare assistant can be used (Suzuki and Doi, 2001). This notebook computer-based system records physiological and contextual information. The assistant can sense pulse waves, user's actions and postures. It can also capture contextual photos and continuous voice. A high-pressure (stressful) state is detected from the high pulse-rate by using the context information. The information is stored and retrieved on a website and requires modification for fitting on smaller hand-held devices. As the patient information must be protected due to legal, ethical and privacy concerns, some work has been done in selective information sharing, where a set of rules are specified for restricting access to patient healthcare information (Zhang *et al.*, 2002). Using existing security protocols, such as IPsec, a protection system for remote patients is discussed in Kara (2001). To adapt mobile devices and services for elderly, some preliminary work has been done (Mikkonen *et al.*, 2002). The authors found that the elderly are ready to begin using wireless and mobile technologies as long as these truly facilitate independent living.

The location issues are addressed in Varshney (2003a; 2003c). Some works on delivering patient data across an enterprise are presented in Lin and Vassar (2004). The trust issues are discussed in Wickramasinghe and Mishra (2004). The use of internet GIS technology for public healthcare is suggested in Ptochos *et al.* (2004). The level of utilisation of mobile devices in a nursing home is examined in Chau and Turner (2004). Some development issues for wireless systems for healthcare are presented in Gururajan and Vuori (2003). The security impact of WAP on e-health is presented in Tan *et al.*

(2003). The design and implementation of a wireless prescription system is included in Zeadally and Pan (2004). The use of mobile internet-based solution for problem drinkers is presented in Cheng and Arthur (2002). Mobile data healthcare systems are presented in Sakarya (2002). The use of a survey to derive requirements and challenges in mobilising medical information and knowledge is suggested in Han *et al.* (2004). The design and implementation of mobile virtual communities is described in Leimeister *et al.* (2002). Several general issues in PDAs, hand-held devices and wireless healthcare can be found in Fontelo and Chismas (2005). The use of a certain hand-held device in clinical emergency environment is presented in Michalowski *et al.* (2004). The cost and acceptance issues in mobile healthcare are evaluated in Wu *et al.* (2005). The experiences in using mobile information systems by physicians are included in Harkke (2005). A list of critical factors in acceptance of mobile nursing technologies is identified in Li *et al.* (2005). A discussion of development and evaluation of mobile decision support system can be found in San Pedro *et al.* (2005). The transcoding of biomedical information resources for mobile devices is described in Parmanto *et al.* (2005). The access to medical literature using handheld devices is described in Fontelo *et al.* (2005).

The above review of wireless in healthcare illustrates several issues. These are the following:

- The introduction of wireless technologies is very preliminary as even healthcare requirements and challenges have not been identified.
- The unique capabilities of wireless and mobile infrastructure have not been utilised.
- The applications and solutions are limited to using a single type of wireless network, thus restricting the access and coverage.
- The introduction of wireless and mobile technologies is very fragmented and limited to a few simple cases.

In this paper, we discuss and illustrate how mobile and wireless technologies can be applied for location management, intelligent emergency system, patient monitoring and mobile telemedicine applications. The contributions of this paper include:

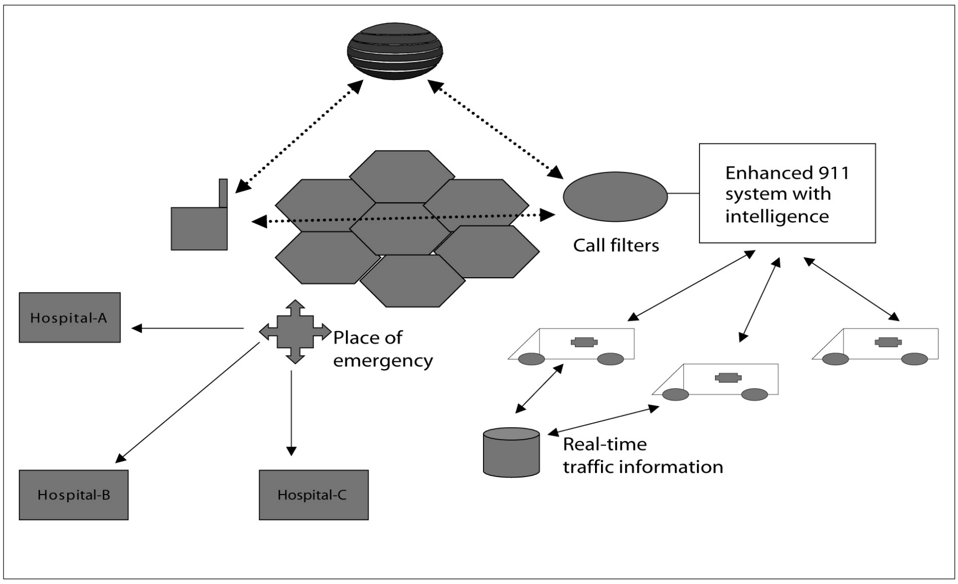
- identifying healthcare applications with the most potential for wireless technologies
- deriving requirements and networking infrastructure for several healthcare applications.

The paper is organised as follows. An intelligent emergency management system is presented in Section 2 and a deployment of wireless in patient care and monitoring is shown in Section 3. The use of mobile and wireless technologies in telemedicine is discussed in Section 4. The use of wireless technologies in the future healthcare environment is presented and discussed in Section 5. Finally, concluding remarks and open issues are presented in Section 6.

2 Intelligent emergency response and management system

The proposed architecture supports an intelligent emergency response and management system using the information from mobile and wireless networks. The information include the locations of emergencies derived from location tracking of enhanced 911 calls. Such information can be used to filter emergency calls by matching time, location and description of events as patterns (Figure 1). This could reduce the overload on emergency call systems (such as the emergency 911 service in USA), where for some systems it is routine to receive hundreds of cellphone calls for the same incident. This is wasteful because multiple ambulances may be dispatched to handle the same emergency and thus delay similar service if another incident takes place. The information from wireless networks can also be used to find the best routes by using real-time traffic information and allowing intervehicular communication to update the traffic routing information. This could be combined with finding the closest hospital(s) with the needed care and also for checking the availability of hospital space. If the information derived from the sensors on the bodies of people involved in emergencies can be processed, it may be possible to implement a prioritised healthcare delivery mechanism in the routing of emergency vehicles. These intelligent additions would improve the overall efficiency of the emergency management system, allowing it to maximise the number of emergency cases it can handle with a limited budget and people. The proposed changes can also result in saving many more lives while keeping the quality of service for others at a high level.

Figure 1 An intelligent mobile emergency response system

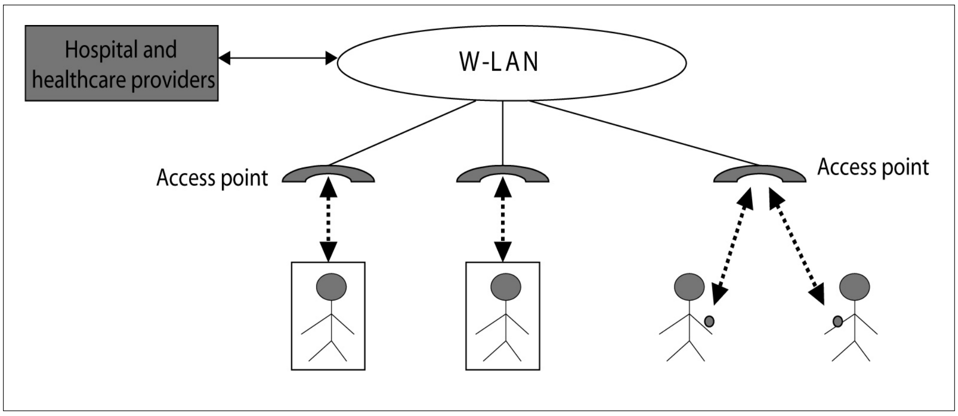


The requirements of intelligent mobile emergency response system include supporting intervehicle communications for incident management and finding best-current-route for vehicles. These can be supported by creating ad hoc wireless networks among emergency vehicles. However, issues on how to maintain communications among vehicles moving at high speeds and short contact time for communications must be addressed. The quality of communications channel at high speed and the amount of spectrum necessary for intervehicle communications must also be considered. It is also possible that communications among the emergency vehicles can be facilitated by emergency call systems. However, the network coverage and processing requirements could affect the scalability of such mediated communications. Other requirements include location tracking of incidents and automatic filtering of same incident-call by matching location, time and description of incidents. In terms of traffic, the sessions are likely to be short. Therefore, unicast communication for callers and multicast for emergency vehicles must be supported. The specific networking requirements include location management for calling parties, incidents and emergency vehicles. Also, wireless infrastructure must be dependable and support real-time communications among vehicles. The additional requirements are significant levels of intelligence in the emergency system and wireless networks and scalability of the system as the number of users, incidents, calls and vehicles are increased.

3 Wireless patient monitoring and requirements

Many healthcare applications require reliable monitoring of patients such as those in a hospital or nursing home. Although it is fairly simple to monitor patients using one of several wireless LANs (Local Area Networks) in and out of a facility (Figure 2), the coverage of wireless networks is not comprehensive on every square metre of a facility. This could result in time and location-dependent dead-spots with unpredictable wireless coverage. Currently in a typical nursing home in USA, a patient is observed by a nurse or staff one to few times an hour. However, if a patient is having a heart attack while being in the bathroom alone, the required help may not come in time.

Figure 2 Monitoring using Wireless LANs

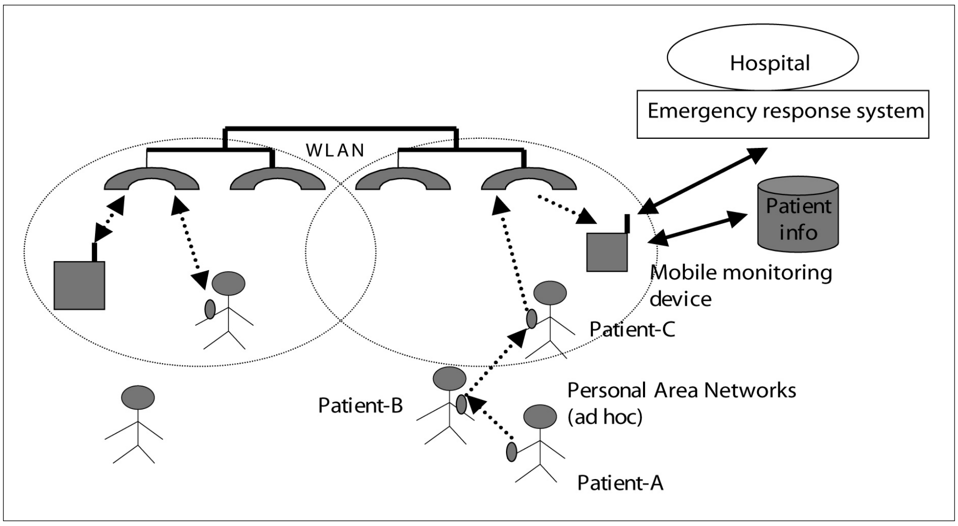


We propose a new architecture for patient monitoring where patients are equipped with small devices (such as a watch). These devices could normally be in range of an infrastructure-based network wireless LANs. However, when not covered by a wireless network due to coverage, battery power or obstructions, several of these devices could form an ad hoc wireless network. The information on vital signs of a patient can be transmitted from his/her device to another nearby patient and so on (Figure 3). This would increase the chance that such vital signs are picked up by one or more wireless networks or healthcare provider directly to his/her device.

This creation of ad hoc wireless networks among patients and devices to allow for movement of sensor information would require wireless routing and multicasting to allow for information to reach a healthcare provider. Unlike general-purpose wireless networks, the efficiency of networking operations is not the major criterion. The reliability, speed, and correctness of critical information must be supported.

The requirements of mobile patient monitoring includes the continuous monitoring for some patients and event-driven monitoring for others, frequency of monitoring, number and types of vital signs that must be monitored and transmitted, and size and frequency of messages to be transmitted. The specific networking requirements include universal access to wireless networks, location management, high levels of wireless network reliability, network scalability with an increased number of users and frequency of monitoring and support for prioritised transmission of vital signs of certain patients. The quality of service requirements are low delay and high probability of message delivery. The additional requirements include the security and privacy and the ways to support the usage cost of mobile patient monitoring systems. It is not clear how insurance companies would pay for patient monitoring services.

Figure 3 Augmenting wireless networking with human networking for reliable monitoring



4 Wireless and mobile telemedicine

Although in a limited scale, telemedicine, or the use of telecommunications technologies for medical diagnostics, treatment and patient care, has been in operation for several years (Varshney and Vetter, 2000). Currently, mobile devices such as PDAs with 802.11 wireless LAN access are being used to upload and download schedules for patients and doctors. In few places, doctors and nurses can access patient information on PDAs or hand-held devices and can also enter new information. People can be reminded of their appointments in their PDAs by displaying short text messages.

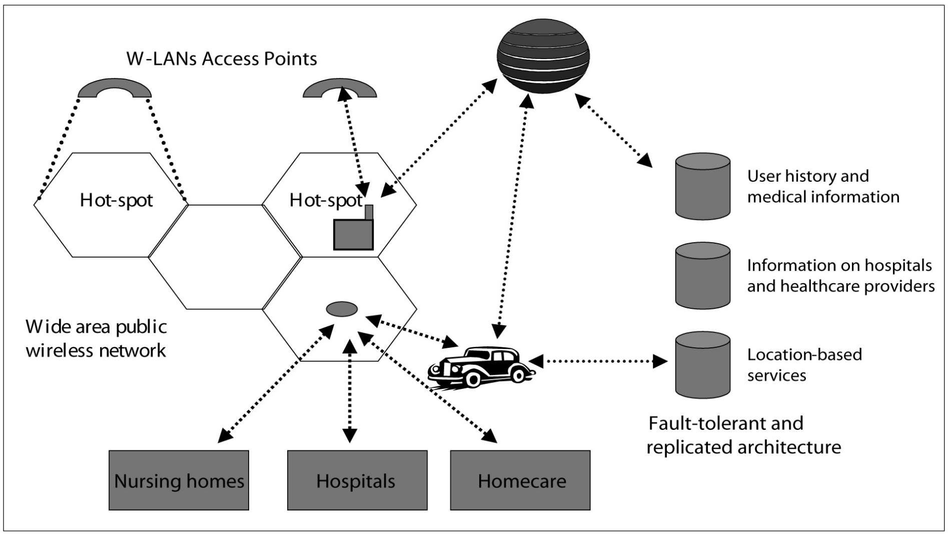
It is likely that mobile telemedicine services would be offered and used significantly. The reasons behind this optimism are the following:

- increasingly mobile savvy society with more than one billion hand-held devices worldwide

- deployment of wireless-based solutions in developing countries where 'wire-line' infrastructure is minimal or impractical
- portability and usability of mobile hand-held devices combined with an increasingly sophisticated workforce.

A possible scenario to extend telemedical services to a larger population is as follows. A geriatric psychiatrist who spends most of his/her time in an out-patient clinic prefers to go to a far away nursing home only if there are several patients for comprehensive evaluation. However, preliminary consultations with nursing home staff, patients and other doctors could be done by using hand-held devices and access to multiple wireless networks, allowing him/her to be in a car, office, airport, traffic jam or other places (Figure 4). Such a system will also enable an information-aware physician to download the detailed current patient information before arriving at a nursing home for seeing multiple patients. This would also allow him/her to either see more number of patients in his/her limited time. Thus, the physician increases his/her productivity and he/she is able to finish nursing home jobs quicker.

Figure 4 A mobile telemedicine system using multiple wireless networks



The characteristics and requirements of mobile telemedicine include long sessions for consultation, multilocation coordination, pervasive and ubiquitous access to patient data and information and ability to transmit significant data due to images, video and medical information. The specific networking requirements include dependable and reliable network architectures, universal access to wireless networks, real-time support for information upload, download and discussions, support for significant quality of service and continued access for long sessions. The additional requirements include security and privacy, mobile devices that can work with minimal input requirements and voice activation. It also includes and ways to support the installation and usage cost of mobile telemedicine systems. There are also issues of insurance payments for mobile telemedicine services rendered to patients, for potential mistakes, errors and liabilities.

5 Wireless technologies for healthcare

Many of the healthcare applications would benefit from the location tracking of patients and healthcare providers, devices and supplies. Location tracking can also be very helpful for finding people with matching blood groups, locating organ donors, providing post-op care for people and helping old and mentally challenged people in hospitals and nursing homes.

An integrated wireless architecture for location management could include GPS, cellular networks, wireless LANs and RFID. Each one of these networks and wireless technologies supports location tracking of people, devices and services in diverse locations accurately. Cellular networks can offer higher accuracy as Enhanced 911 (E911) infrastructure becomes increasingly available. It will allow network-based tracking with 100-metre precision and handset-based tracking with 50-metre precision for mobile users.[2] The accuracy achieved for portable and fixed entities is even higher. Major E911 schemes are Assisted and Differential Global Positioning Systems (A-GPS and D-GPS, respectively), Time Difference of Arrival (TDOA), Angle of Arrival (AOA) and Location Pattern Matching (LPM) (Djuknic and Richton, 2001). TDOA and AOA schemes locate a mobile device by processing the difference in signal arrival times at three or more antenna sites. This is called base station triangulation. Our architecture supports even higher location accuracy by combining small cells with base station triangulation.

Some of the cellular/PCS location schemes can be used in indoor location tracking. Since many indoor applications require higher location precision, smaller Wireless Local Area Networks (WLANs) and Personal Area Networks (PANs) can be used. The base stations are kept closer. These cooperate in the location tracking of radio-enabled devices, users, products and services. The radius of a cell can be determined as the minimum of location accuracy and the coverage of base stations.

Radio Frequency Identification (RFID) uses wireless links to uniquely identify objects or people using dedicated short-range communications (D'Hont, 2001). When a product or person with a tag enters the read zone of a reader, the address and data stored on the tag is read and can be sent to a server for location tracking purposes. Since RFID readers have limited coverage (5–10 feet), multiple RFID readers will be needed to cover the whole area (*e.g.*, a warehouse). The maximum distance between two neighbouring readers can be based on the range of readers and the location accuracy required (Varshney, 2003b).

Another interesting way to perform indoor location tracking is via the use of specialised location devices attached to products and people. One such example is the Locus that can be attached to clothes or portable devices (Koshima and Hoshen, 2000). Such location terminals can return signal strength data and IDs of base stations to a monitoring centre. Using this information, the user location can be computed with varying degrees of accuracy.

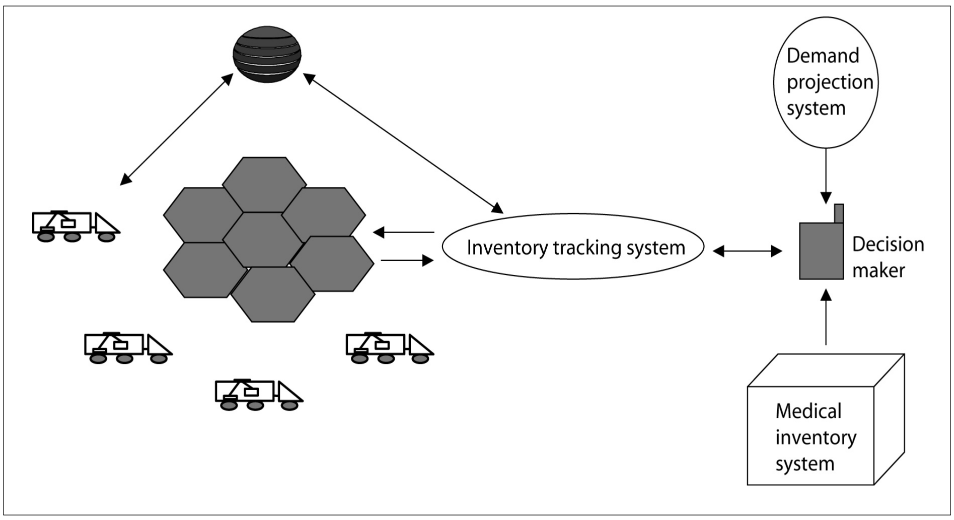
The outdoor tracking support for healthcare applications may be provided by either a cellular/PCS system or a satellite-based system such as assisted GPS. Nearly all the schemes used in cellular and satellite-based networks perform well in an outdoor environment. Even wireless LANs and RFID-based systems can support applications requiring outdoor location management. Many of the proposed outdoor schemes will encounter performance problems in indoor environment due to triangulation difficulties caused by weaker signals and line of sight requirements of satellite-based schemes.

Since many indoor tracking applications require higher location precision, smaller WLANs and PANs should be used for indoor location management. Indoor tracking for healthcare applications can be performed using specialised cells (where a base station can locate in a very small area, but where a significant number of base stations are required to cover the whole area), wireless LANs, ad hoc PANs and Radio Frequency ID (RFID).

The location precision requirement can be satisfied by using one of several wireless networks, which provide different levels of location accuracy. An extensive wireless coverage is achieved by providing indoor and outdoor coverage to fixed and mobile users in local as well as in wide area environments. Since this architecture supports the roaming of a user across multiple networks, location coordination is necessary among networks. Location tracking can also be performed using a WLAN or a PAN. These networks cover smaller areas (and fewer users). Therefore, a base station or a certain device can be programmed to determine if a certain device or user is located in the networks' coverage. This feature is applicable to both infrastructure and ad hoc versions. Location tracking involves mobile, portable or fixed entities. Mobile entities can be located within the accuracy of the location scheme of the wireless network(s) used. If mobile entities are part of an ad hoc wireless network, then a more specialised scheme (such as using GPS and a monitoring system) has to be used. Portable entities without regular wireless access can be tracked using radio frequency tags or specialised locator devices. Location information on fixed entities can be stored in a database and can be updated as necessary (Varshney, 2003b).

One example of how wireless location management techniques is used in healthcare is shown in Figure 5, where medical inventories are managed using a mobile hand-held device. As the quantity of the supplies decrease below a threshold, additional inventory is ordered and tracked using wireless networks. This system can be joined with a demand projection system for 'pro-active' inventory management. Such an intelligent mobile inventory system is likely to reduce the cost of inventory while increasing the chances of finding a certain item when needed. To allow multiple suppliers to compete for medical supplies, mobile auction type trading can be performed. This reduces the cost of supplies even further.

Figure 5 A mobile medical inventory management system



6 Open issues and conclusion

There are many open issues and challenges in using wireless technologies in healthcare that must be addressed. These include a lack of comprehensive coverage of wireless and mobile networks, reliability of wireless infrastructure, general limitations of hand-held devices, medical usability of sensors and mobile devices, interference with other medical devices, privacy and security, payment and many management issues in pervasive healthcare. We will attempt to group these issues and challenges under the following categories: technologies, medical and management.

The technology issues related to the introduction of wireless network technologies in healthcare includes networking support such as location tracking, routing, scalable architectures, dependability and quality of access. These issues also include how to provide patient monitoring in diverse environments (indoor, outdoor, hospitals, nursing homes, assisted living), continuous vs. event-driven monitoring of patients, use of mobile devices for healthcare information storage, update and transmission, sensing of vital signs and transmission using cellular networks and wireless LANs, formation of ad hoc wireless networks for enhanced monitoring of patients, managing healthcare emergency vehicles and routing and network support for mobile telemedicine.

The medical aspects are very important in realising a wide-scale deployment of wireless network technologies in healthcare. The issues of how patient care is delivered, how medical information can be represented and requirements of diverse patients must be addressed. Many important issues include the design of suitable healthcare applications, specific requirements of vital signs in healthcare environment, diversity of patients and their specific requirements, representation of medical information in pervasive healthcare environment (multimedia, resolution, processing and storage requirements), role of medical protocols, improved delivery of healthcare services and usability of wireless-based solutions in healthcare. The diversity of patients can range from uncontrollable energetic children, violent youth and midlife, depressed or frail seniors. The requirements presented by these people to wireless networks vary significantly from keeping track of the behaviour of kids to how to avoid wandering and getting lost for dementia patients. It will be a major challenge to involve people with mental illness to use wireless infrastructure due to their limited functional intelligence or their very limited memory (such as those suffering from dementia). Many of these also suffer from psychiatric disorders such as paranoia resulting in a suspicion towards wireless technologies, especially those once requiring a patient to wear a locator or other device.

The management of pervasive healthcare could bring a mini-revolution in terms of how wireless network technologies in the healthcare environment is implemented, offered and managed. There are many challenging and diverse management issues that must be addressed including the security and privacy in wireless healthcare, training of healthcare professionals for pervasive healthcare, managing the integration of wireless solutions, increasing coverage of healthcare services using wireless technologies, legal and regulatory issues, insurance payments and cost aspects and potential implications of HIPAA (Health Insurance Portability and Accountability Act of 1996). The usability and integration of wireless-based solutions in healthcare is another challenge. The devices must be designed to offer intuitive interfaces that can learn with and from individuals. It has been shown that many less-technically savvy population segments are willing to learn and use mobile and wireless technologies for allowing them to live more independently.

The training of healthcare professionals to effectively utilise mobile and wireless technologies would be a less complex issue as an increasing number of those are using hand-held and wireless devices. Another major issue is how to reduce the cost of delivering healthcare services to as many people by using wireless infrastructure. Other challenges in the large-scale introduction of wireless infrastructure in healthcare are legal and regulatory issues such as the issues of liability and lawsuits in the USA and possibility of insurance companies not paying or paying differently for treatment via mobile devices. Another major issue is the privacy and the possible misuse of patient medical information. In the USA, a major regulation termed HIPAA (Health Insurance Portability and Accountability Act of 1996), which have been designed to protect such information, has received some controversy and has been interpreted differently by major players, healthcare providers, insurance people and attorneys. Some work is needed in addressing privacy and related concerns over wireless and mobile networks where security is still seen as insufficient.

The role of wireless infrastructure in healthcare application is expected to become more prominent with an increasingly mobile society and with the deployment of mobile and wireless networks. The work on wireless network technologies in healthcare has been in its initial stages and many requirements have not been addressed. In this paper, we discuss and illustrate how mobile and wireless technologies can be applied for location management, intelligent emergency system, patient monitoring and mobile telemedicine applications. The contributions of this paper include the following:

- identifying healthcare applications with most potential for wireless technologies
- deriving requirements and networking infrastructure for several healthcare applications
- design of wireless infrastructure for current and future healthcare applications.

We have also identified a large number of open issues and challenges that must be addressed before wireless technologies can be applied on a wide scale within the healthcare environment.

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Notes

1 www.elite-care.com

2 FCC Enhanced 911, www.fcc.gov/e911