Patient monitoring using infrastructure-oriented wireless LANs

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Abstract: There is considerable interest in using wireless and mobile technologies in patient monitoring in diverse environments including hospitals and nursing homes. However, there has not been much work in determining the requirements of patient monitoring and satisfying these requirements using infrastructure-oriented wireless networks. In this paper, we derive several requirements of patient monitoring and show how infrastructure-oriented wireless LANs, such as versions of IEEE 802.11, can be used to support patient monitoring in diverse environments.

Keywords: patient monitoring; infrastructure-oriented wireless LANs; IEEE 802.11.

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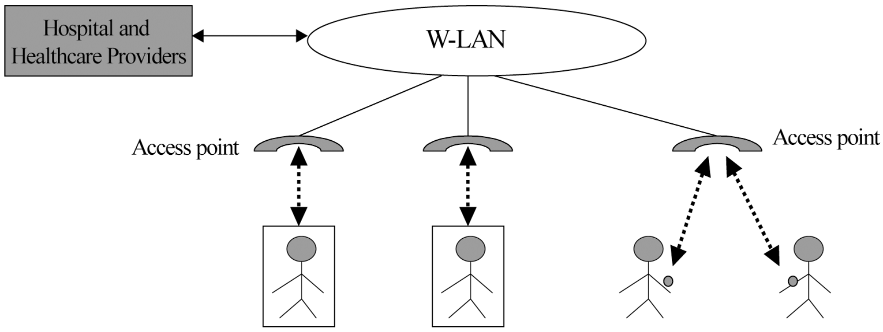
Biographical notes: Upkar Varshney is an Associate Professor of Computer Information Systems at Georgia State University. His interests include pervasive healthcare, mobile commerce and wireless networking. He is the author of 100 journal and conference papers. Several of his papers are the most cited references including most downloaded journal papers from ACM digital library (2004) and ACM/Kluwer MONET (2005). He has presented 30 tutorials and workshops at major conferences and has received several teaching awards. He is an Editor/Member of Editorial Boards for *IJMC*, *IJNM*, *IJWMC* and *CAIS*, and is also a Guest Editor of major journals including ACM/Kluwer MONET.

1 Introduction

The increasing cost of healthcare services, already at 15% of Gross National Product for the USA (Kern and Jaron, 2003), has created several challenges for policy makers, healthcare providers, hospitals, insurance companies and patients. A major and very important challenge is how to provide better healthcare services to an increasing number of people using limited financial and human resources. This challenge can be met by designing and deploying comprehensive patient monitoring solutions for both short-term home healthcare and long-term nursing home care for stationary and mobile patients. Before describing the proposed wireless local area networks- (WLANs-) based patient monitoring solution, we briefly overview some of the research work conducted in this area. This includes patient monitoring using cable TV network (Lee et al., 2000), an implementation of infrared and radio-based locator badges (Stanford, 2002), long-term health monitoring by wearable devices (Suzuki and Doi, 2001), a wireless telemetry system for EEG epilepsy monitoring (Modarreszadeh, 1997), a ring sensor for blood oxygen saturation monitoring (Rhee et al., 1998), a three-layer distributed sensor network (Bauer et al., 2000), a short-range Bluetooth-based system for digitised ECGs (Khoor et al., 2001), a hospital-wide mobile monitoring system using patients' devices (Pollard et al., 2001), a wearable stethoscope (Kyu and Asada, 2002) and real-time monitoring of patients in the home environment (Mendoza and Tran, 2002). Clothing-embedded transducers for ECG, heart rate variability and acoustical data and wireless transmission to a central server are proposed by Jovanov et al. (2002). A requirement model for delivering alert messages is presented by Kafeza et al. (2004). An implementation of WAP-based telemedicine system is described by Hung and Zhang (2003), where stored patient information is downloaded from a database to WAP-enabled device. The patient monitoring is neither real-time nor driven by patient conditions. A wireline standard network implementation of bedside patient monitoring is presented by Varday et al. (2002). Issues related to patient monitoring using wireless networks are discussed by Varshney (2004). The use of wireless sensors in minimally invasive and continuous health-monitoring systems is discussed by Boric-Lubecke and Lubecke (2002). A maritime telemedicine system with multi-lingual capabilities is described by Anogianakis et al. (1998). Several applications of wireless telemedicine systems including telecardiology, teleradiology and telepsychology are presented by Pattichis et al. (2002). The middleware requirements of pervasive healthcare have been identified as authorisation and authentication, adaptability, availability and modifiability (Raatikainen et al., 2002). A design approach for ECG data compression for a mobile telecardiology model is presented. Authors achieved a significant compression ratio and reduction in transmission time over GSM network (Istepanian and Petrosian, 2000). A telemedicine system that can 'bring' an expert specialist doctor to the site of the medical emergency, allow his/her to evaluate patient data and issue directions to the emergency personnel on treatment procedures until the patient is brought to the hospital, is presented by Pavlopoulos et al. (1998). Various issues in pervasive healthcare are discussed by Varshney (2003a–d). Personal health monitors based on a wireless body area network (BAN) of intelligent sensors are proposed for stress monitoring (Jovanov et al., 2003). Work on related issues include 'smart health wearable' research (Lymberis, 2003), interference for telemetry devices (Gieras, 2003), PDA as a mobile gateway (Jovanov et al., 2002), sensors in healthcare environment (Bhargava and Zoltowski, 2003), energy-efficient broadcasting for real-time transmission (Li and Wu, 2002) and security protocols for remote patients (Kara, 2001).

It can be observed that there has been some progress related to patient monitoring using wearable devices and short-range communications. As an increasing number of patients will wear or use communications devices, a comprehensive patient monitoring solution can be developed using infrastructure-oriented WLANs (Figure 1). The quality and reliability of patient monitoring can be improved by using a grid of WLANs. This will allow that the patient devices will be covered by one or more WLANs. The information on vital signs of a patient can be transmitted to base stations and will be picked up by healthcare professional on his/her device.

Figure 1 Monitoring using WLANs



The paper makes the following contributions:

1 generation of patient monitoring requirements (Section 2)

2 design of a patient monitoring solution using infrastructure-oriented wireless networks (Section 4)

3 identification of several open issues in patient monitoring (Section 5).

2 Patient monitoring requirements

With an increasingly diverse healthcare environment, deriving and combining requirements of patient monitoring involving fixed and mobile patients in indoor and outdoor environment is a difficult task. However, general requirements of patient monitoring can be presented and discussed (Table 1) under patient, network and healthcare provider categories.

Table 1 General requirements of patient monitoring

	Challenges	*Comments*
Patient-related	Transmission of vital signs (BP, heart rate, temperature, glucose level, oxygen saturation and EKG) Frequency of transmission (normal range, above or below normal, significantly above or below normal, high rate of change) The number of size of devices, and usability issues	1 The number and frequency of vital signs must be determined 2 Each individual user may require different size/type of devices
Network-related	Interference and reliability of information transfer Formation of networks on and among patients Routing of patient information Performance (delay, traffic) issues Scalability and network management issues	1 Requires network infrastructure to be dependable and available 2 Requires complex routing protocols 3 Requires sophisticated network management protocols

Table 1 General requirements of patient monitoring (continued)

	Challenges	*Comments*
Healthcare provider-related	Number of patients per provider and cognitive overload Confidentiality and privacy of patient information Liability issues Cost and re-imbursements	1 How much information can be routed to a healthcare provider must be resolved 2 Complex legal and business challenges must be handled

2.1 Patient-related requirements

The patient monitoring requirements include periodic transmission of routine vital signs and transmission of alerting signals when vital signs cross a threshold, patients cross a certain boundary or device battery drops below a level. These could include blood pressure, heart rate, temperature, ECG, EKG and other health-related information. Also, the followings must be measured and monitored:

- skin breakdowns
- abnormal gait and balance (to reduce the number of falls)
- motor activity, agitation
- current location
- cigarette smoke
- amount of moisture in clothes.

Another major issue is how frequent monitoring of vital signs should be done. There is also an issue of what information needs to be sent and in what representation. The amount and the frequency of information that needs to be transmitted is another challenge. For some patients, certain vital signs need to be transmitted every few minutes, while for others continuous monitoring every few seconds is necessary. For all patients, any major changes in the vital signs should be transmitted immediately. Also, vital signs may be compared with some previous values to detect changes in values or patterns. In wireless environment, it could be better to transmit differential changes since the last time or a reference value to reduce the amount of information. This would also increase the chances of reception by others.

As patient monitoring by wireless and mobile networks include the use of wearable, portable or mobile devices, many usability issues including user comfort and trust must be addressed. The diversity of patients including those suffering from mental illnesses is likely to make patient monitoring by wireless networks a challenge because of possible paranoia related to handheld or wearable wireless devices. The usability and portability of wearable devices for patient monitoring must also be addressed to match the limitations and strength of the patients. A level of trust from patients is also necessary for the success of patient monitoring. An example of a difficult situation involves some people with mental illnesses that are inclined to think that some controlling entity is monitoring them all the time. Such patients are likely to be quite difficult in agreeing to be monitored by wireless networks. Other difficult cases could involve uncontrollable energetic children, violent youth and frail seniors. The challenges are different as some of these patients will not allow any devices to be attached to them or may have serious doubts about the use of technology in general. One is the diversity of environments and patients requiring monitoring. The length of monitoring could also be variable such as short-term monitoring in hospitals and long-term monitoring in nursing homes.

2.2 Network-related requirements

The patient monitoring will require comprehensive and high-speed access to wireless networks, reliable and scalable wireless infrastructure, secure and fast databases and utilisation of network intelligence and information. An increasing number of patients will be wearing portable or mobile devices that would have access to public or private wireless networks. To improve the quality and reliability of patient monitoring, these devices could be designed to operate in ad hoc wireless mode. Also with a lack of coverage and variable fluctuating coverage by infrastructure-oriented wireless networks in some spots combined with patients in locations not reachable by others, an increased reliability of monitoring and higher chances of transmission of alert signal can be achieved with the use of ad hoc wireless networks. Owing to power and size requirements of these devices, the range of transmitted signal is likely to be small. Further, the range is likely to be affected both by the frequency of operation and the nature of spectrum used (licensed versus unlicensed). For the monitoring of patients who are not covered by an infrastructure-oriented wireless network, the cooperation of others with wireless devices in an ad hoc configuration will be utilised.

Patient monitoring should include location tracking where after a healthcare provider has received a message, the patient's location will be needed to send the necessary help. The patient monitoring could include the use of one or more location tracking schemes including those using Global Positioning Satellite system. The user devices will be equipped with location-tracking functionality. The proposed solution has been designed not to be dependent on GPS due to one-way nature and poor indoor coverage from GPS and also due to the availability of several other location-tracking systems available today including radio frequency identification (RFID).

The patient monitoring solution should include interference and conflict management that could occur with flooding of user information. The use of priority can be used in deciding the transmission and reception order.

2.3 Healthcare provider-related requirements

One major issue in patient monitoring is the number of patients per healthcare professional and potential cognitive overload that may occur with frequent messages from patient monitoring system. This is an important issue as the chances of medical mistakes could increase if a healthcare professional experiences cognitive overload.

Confidentiality and privacy issues are important and must be addressed. The information from device to device will be encrypted in the proposed solution to achieve a certain level of privacy. In the near future, some work must also be done on addressing how to satisfy one or more provisions of HIPAA regulations on moving patient information from place to place.

Another important issue is that the proposed solution will create the possibility that a certain healthcare personnel could receive information on more patients than they are directly responsible for monitoring. It is very likely that the amount of information will increase, resulting in potential cognitive overload. More work is needed in identifying the increase in the information overload for healthcare personnel and ways to reduce it to a more acceptable level. The network routing could be modified to match patient information to a certain personnel using information from the database. There are also some issues related to liability if the personnel that received information about some one else's patient and did not take suitable action.

One major open issue is the total cost of the system. It is difficult to determine the total cost at this point; however, a detailed cost-benefit study is needed that must include the cost of enhancing wireless devices with routing capabilities. The implementation of the proposed architecture including cost sharing will differ substantially in many countries. For example, in the USA, multiple wireless service providers, regulatory bodies and insurance companies will be involved, while in many developing countries, a single entity such as the government could undertake the whole process. There may also be a need for additional training for system operators, healthcare professionals and patients.

3 Wireless LANs and protocols

WLANs have been designed to provide support for mobile computing in a small area, such as a building, hallway, park or office complex. These can be designed for both infrastructure (central access point covering users in an area) and ad hoc (peer-to-peer communications without an access point) configurations. The WLANs can provide wireless connectivity to hosts (computer, machinery or systems) that require rapid deployment in a local area environment. These hosts can be stationary, portable or mobile and may be handheld or mounted on a moving vehicle. The main attraction is the flexibility and mobility that is supported by a WLAN and the bandwidth considerations are secondary. Although the situation may change with widespread deployment of 802.11a and 802.11g, standards that allows up to 54 Mbps channel bit rate. The primary uses of WLANs have been LAN extension, nomadic access in hot spots and broadband access (2 Mbps or more per user) to the internet. We believe that future uses of WLANs would include patient monitoring services and location-based services.

3.1 Spectrum issues

One of the biggest issues for WLANs has been the spectrum availability. The use of ISM bands, primarily the 2400–2483.5 MHz band, has always been the first choice. This has led to the original 802.11, 802.11b and now 802.11g standards for WLANs. The original 802.11 standard also included infrared as one of the transmission method. As the ISM bands are designated for unlicensed commercial use and are widely used by ambulances, police cars, taxicabs and Citizen Band (CB) radios, there has been significant and varying levels of interference in some places from other users and also from many household and office devices operating in ISM bands, especially in 2.4 GHz. In addition to an increasing interference in this band, the demand for higher bit rates has also led to the consideration of other wider bands for wireless LANs. IEEE 802.11a is a standard in the 5-GHz band, but as all other versions of 802.11 in use are in 2.4 GHz, the backward compatibility has been an issue. The use of dual-band LAN cards is possible but has not become widespread. In addition to the amount of bandwidth available in a spectrum and the level of interference present, the choice of spectrum also affects power requirement and the range. For example, 5-GHz-based WLANs would require significantly more power than 2.4-GHz WLANs for the same range (coverage area), or will lead to reduce range for the same power. Many physical layer enhancements including coding and better antenna design, energy efficient LAN protocols can reduce, but not eliminate, power requirements at higher frequencies. In addition to multiple standards of IEEE 802.11, there are other standards for WLANs such as European HIPERLAN. Although designed for similar environment, these standards differ in frequency, bit rates, power requirements and coverage. For example, 802.11, 802.11b and 802.11g use 2.4 GHz, while HIPERLAN is for 5.15–5.30 GHz.

3.2 Multiple standards

Although original 802.11 allowed three different ways to transmit data over the wireless channel such as frequency hopping spread spectrum (FHSS), digital sequence spread spectrum (DSSS) and infrared, other versions have focused on a single method of transmission. For example, 802.11b only allows DSSS, while 802.11a uses orthogonal frequency division multiplexing (OFDM), a multi-carrier technique, where up to 52 carriers are used to transmit data from a single source to achieve 54 Mbps channel bit rate. A comparison of several different WLANs is given in Table 2 (Varshney, 2003a–d). As 802.11a uses different spectrum (wider and less crowded), one problem is that it is not 'inherently' backward compatible to 802.11b (although use of dual-band adapters allowing access to both 802.11a and 802.11b/802.11g could address this problem). 802.11a signals travel less distance with same power, thus requiring more access points to cover the same hot-spot area (thus, significantly affecting the economic survivability of carriers offering access in hot spots). IEEE 802.11g is a standard under consideration and will be backward compatible with 802.11b as it uses the same 2.4-GHz band and provides the higher bit rates of 802.11a.

Table 2 Multiple versions of 802.11

WLANs characteristics	*802.11*	*802.11b*	*802.11a*	*802.11g*
Spectrum	2.4 GHz	2.4 GHz	5 GHz	2.4 GHz
Maximum physical rate	2 Mbps	11 Mbps	54 Mbps	54 Mbps
Layer 3 data rate	1.2 Mbps	6–7 Mbps	32 Mbps	32 Mbps
Transmission	Frequency hopping or direct sequence (FHSS or DSSS)	Direct sequence only	Orthogonal frequency division multiplexing	OFDM
Compatible with	None	802.11	None	802.11 and 802.11b

Table 2 Multiple versions of 802.11 (continued)

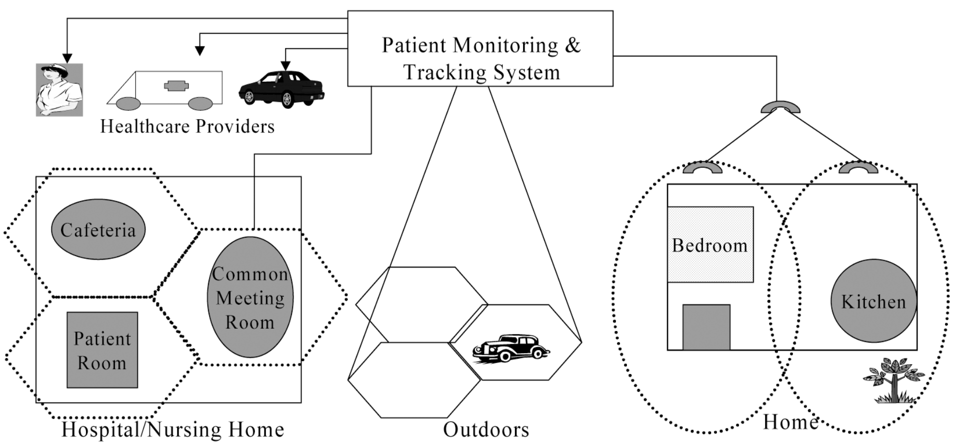
WLANs characteristics	*802.11*	*802.11b*	*802.11a*	*802.11g*
Major disadvantage	Limited bit rate	Bit rate not enough for many emerging applications	Smallest range of all 802.11 standards	Limited number of co-located WLANs due to limited spectrum
Major advantage(s)	Higher range	Widely deployed high range	Higher bit rate in a less crowded spectrum	Higher bit rate in 2.4 GHz spectrum higher range than 802.11a

Dual band adapters combining 802.11a and 802.11b have been available. IEEE 802.11g became a standard in mid-2003; however, many vendors have decided to go ahead and offered 802.11g-based systems in advance. For example, Apple is offering products with 802.11g support and adapters covering 802.11a, b and g together are becoming available now.

4 Patient monitoring using WLANs

Many healthcare applications require reliable monitoring of patients such as those in a hospital or nursing home. Currently in a typical nursing home in the USA, a patient is observed by a nurse or staff one to few times an hour; however, if a patient is having an heart attack while being in the bathroom alone, the required help may not come in time. To improve this situation, patient monitoring can be done using infrastructure-oriented wireless networks such as most of the existing and emerging WLANs (Varshney and Vetter, 2000). This will allow monitoring for mobile and stationary patients in indoor and outdoor environments (Figure 2).

Figure 2 Patient monitoring using infrastructure-oriented wireless networks



There are many major issues related to patient monitoring using infrastructure-oriented WLANs. These include the service area and signal reception, throughput and bit rates, number of patients that can be supported, colocated operation and interference issues, signal transmission from patients to access points, location accuracy, protocol and reliability of patient monitoring using WLANs. In the next few paragraphs, we discuss these issues one by one.

The service area of most access points in wireless LANs is limited to about 100 m, but is affected by mobility, obstacles and many problems. The range (or service area) is also affected by the frequency used in WLANs. The signal strength can be weakened by 30–90% as it passes through doors, walls and windows depending on the material and construction employed. Thus, these problems will reduce the coverage area of WLANs indoor. And, the outdoor coverage may be impacted by moving vehicles, other WLANs and trees. To increase the coverage of a WLAN, the number of access points can be increased, resulting in a higher initial cost. Another issue is the availability of wireless links between patients and access points. The link quality varies over space and time due to attenuation (power loss) caused to a signal as it passes through walls, doors, windows and humans. The power loss and/or interference can cause links to fail momentarily or completely. So, the full connectivity or 100% availability cannot be assumed even if everything else is fine. It is very difficult to measure the pattern of link availability as the movement of objects changes the interference type and level. Even when coverage exists, the links may be unusable due to one or more fading problems as links alternate between usable and unusable states.

The throughput, or actual number of bits that can be transmitted after subtracting overhead and retransmission, decreases with an increasing distance between patients and access points, so either a higher number of access points per WLAN or a higher bit rate WLAN should be employed. As given in Table 2, different WLANs will offer different throughput, which is about 30–40% lower than the maximum possible bit rate. The number of patients that can be supported by an access point will depend on the bit rate, frequency of monitoring and the amount of information per patient that needs to be sent every time.

One major issue in infrastructure-oriented WLANs is the need to allow colocated network operation where multiple WLANs may exist in the same or nearby location. Although colocated operation affects different WLANs differently based on the physical layer transmission and the choice of ISM band used, in general the throughput is reduced due to an increased ISM interference. No coordinating body exists yet to register your WLAN and claim a location. Also, due to reflection of a signal from other objects, the receiver gets multiple copies of a signal. These copies are slightly shifted in phase (time), so overlapping may occur, which makes it hard to decode a signal. The multipath interference is the biggest challenge to high-speed data communications as bits become smaller and even a slight shift of phase can cause significant interference. This is a problem for higher bit rate WLANs. Also, as ISM band is used in WLANs, interference from unlicensed spectrum radio, microwave ovens or radar transmitters may also exist affecting the usability and coverage of infrastructure-oriented WLANs for patient monitoring.

Another major issue is how would signals be transmitted from patients to wireless access points. This will depend on if patients can wear or carry devices with WLAN adapter cards that transmit signals to a base station. If not, then for every few patients, one device with adapter card can proxy and transmit signals to one or more access points.

This will be useful if patients wear devices with short range of signal transmission. The device usability and accessibility issues must be addressed along with size and portability of devices that must be carried.

Another issue related to patient monitoring using WLANs is the monitoring delays that may be created by access points and WLAN protocols. The delays occur as patients will have to wait for transmission and can be reduced selectively using prioritised transmission. It should be noted that almost all WLANs were designed for data-type traffic where delays were not critical. However, such problems will affect the quality of patient monitoring. The delays could rise substantially, if many more patients happen to be under the coverage of the same access point due to locational restrictions or due to mobility.

The patient monitoring system will support both fixed and mobile patients (and also patients that are fixed sometime and mobile sometime). The mobility of patients will create uneven number of users under different access points. This will affect both throughput and delays for patient monitoring. For such cases, prioritised transmission could be employed for patient with emergency signal. To support mobility, most wireless LANs use *synchronisation* (for finding and staying with a WLAN), *power management* (for periodic sleep, letting the station sleep without missing any message) and *association and re-association* (for joining a network, moving from one AP to another). The station scans all the possible frequency channels and looks for a beacon signal for the network it wants to join. It can re-associate with other network if needed.

Patient monitoring does require location management of patient in addition to the transmission of their vital signs over infrastructure-oriented WLANs. To support this, individual access points can maintain a list of currently supported patients. This would support location management with an accuracy equal to the size of its coverage. This may be enough for some applications; however, access points can combine other location management technologies such as RFID for better tracking of patients.

Most wireless LANs use Collision Sense Multiple Access with Collision Avoidance (CSMA/CA) as opposed to CSMA/CD where collision detection is required. The medium access control frame contains MAC control, destination MAC address, source MAC address, data and CRC for frame checking. In WLANs, different stations are required to wait different amount of time the channel is free before transmitting (so if you have to wait less, you in effect have a higher priority). The waiting time (or inter frame space) is dependent on what you have to transmit (such as ACK, CTS, poll response will be transmitted with higher priority or lower waiting time – called short inter frame space). This kind of reduced waiting can be used to support transmission abnormal or emergency signals.

The major issue is the reliability of patient monitoring using WLANs. The reliability here is affected by several factors: coverage and signal strength, available bit rate and prioritised transmission, delay performance, and failure of access points and interconnection architecture. The first three factors are addressed in the preceding paragraphs, we should address failure of access points and interconnection architecture. To reduce the impact of access point failures, we propose that both overlapping and back-up access points be deployed. This will improve coverage in normal cases and continued coverage even when one or more failures occur. The access points can be interconnected in a grid of WLANs using mesh-based interconnection. The mesh, due to its rich interconnection pattern or high redundancy of links, is a highly reliable interconnection architecture.

The protocol for patient monitoring using WLANs should involve the following steps:

1 patient's devices to locate and join an access point

2 patient's device to measure vital signs (if above or below normal, transmit a signal to access point using higher priority. If matches a pattern or highly above or below normal, transmit an 'emergency' signal to the access point using highest priority)

3 access point to route the message to one or more healthcare providers along with past vital signs (from a database) and the current location of the patient.

Also, the number of patients that can be monitored under every access point can be limited to provide both improved and reliable patient monitoring services. These limits can be derived, differently for multiple versions of 802.11 WLANs (Table 2), based on the traffic generated (frequency of monitoring and packets per monitoring event) and the delay requirements.

5 Open issues

Before WLANs become widely adopted in patient monitoring environment, there are many limitations that must be overcome. Currently there are many limitations of wireless LANs. These deal with few security weaknesses and lack of multicast and locations management support as required for many emerging applications. More work is also necessary to address and evaluate the scalability of WLANs in terms of users and distance.

5.1 Security

There are several solutions for 802.11 security problems, one short-term and one long-term. Temporal Key Integrity Protocol (a patch for message integrity, rekeying, etc.) adds message integrity code (64 bits), packet sequencing and perpacket key mixing in addition to 128-bit codes. The long-term solution, termed Counter-mode CBC MAC Protocol (CCMP) with 48-bit IV and Advanced Encryption Standard (AES), is also under consideration as discussed by Winget and others. Another solution proposed by Kuo and others is to use virtual private networks (VPN) with an IPsec (Secure IP) tunnel. This would allow secure and continued access, but as all traffic must be processed by a VPN gateway, the scalability in terms of number of possible users that could be supported becomes an issue.

5.2 Multicast support

Patient monitoring would need group communication among users. The most efficient way to support this requirement is wireless multicast, where the information exchange among users is performed and membership of a group is maintained. As mobile users move to different locations or leave the group or new users join the group, the membership information is updated for network traffic routing. To support multicast-based patient monitoring in WLANs, the followings are necessary:

1 identifying the multicast requirements of patient monitoring and

2 modelling and evaluating the overhead caused due to protocol modifications.

5.3 Location management support

For patient monitoring, it may be necessary to get location information on patients and other entities. To support such applications, WLANs should provide location management services. In simple terms, WLANs can easily keep track of all users under an access point (base station). For a higher location accuracy, several smaller access points, sensors and RFID tags could be integrated with WLANs, and also other wireless networks that support location management can be utilised.

5.4 Future of wireless LANs in patient monitoring

There are many technological issues and business issues that will require attention. One is the bit rate per user that would need to be increased to support higher-end applications. To address the demands of future WLANs, IEEE High Throughput Task Force (802.11n) is considering ways to increase bit rates to 108 Mbps and possibly 320 Mbps (possibly available in 2005). The future of WLANs would depend on how both technology and business issues are addressed. The merger (or alliance) of WLANs in hot spots with wide area wireless networks would be another critical factor in the deployment and usage of WLANs in healthcare. In a large-scale deployment, the scalability of WLANs could become a challenge as both technical as well as business issues must be addressed. Another major issue is the possible inter-operation or merger of WLANs with wide area cellular/PCS networks.

6 Conclusions and future research

There is considerable interest in using wireless and mobile technologies in patient monitoring in diverse environments including hospitals and nursing homes. However, there has not been much work in determining the requirements of patient monitoring and satisfying these requirements using wireless networks. In this paper, we derive several requirements of patient monitoring and show how infrastructure-oriented WLANs, such as versions of IEEE 802.11, can be used to support patient monitoring in diverse environments. The future research should address how to improve the reliability of patient monitoring under varying coverage of WLANs, wireless link variations and access point failures.

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