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ABSTRACT

Patient monitoring is a major part of many healthcare services. It can reduce the number of un-necessary hospitalizations, while increasing the access to healthcare to those who really need these services. Wireless and mobile technologies are finding a role in patient monitoring in several different environments: homes, hospitals, and nursing homes. However, due to several limitations including unpredictable and spotty coverage of users by wireless networks, the quality and reliability of patient monitoring have not been highly satisfactory. In this paper, we present a patient monitoring solution using ad hoc wireless networks, which can be formed dynamically among mobile and wearable devices. This allows transmission of vital signs under normal and emergency situations. To make patient monitoring by ad hoc wireless networks a reality, we present a wireless architecture, discuss routing of emergency messages, and bring together many related technical and non-technical issues. The proposed patient monitoring solution is also designed to be reliable and implementable in the near-term.

Keywords

Patient monitoring, mobile and wireless networks, ad hoc wireless networks, wireless architecture.

INTRODUCTION

The increasing cost of healthcare services, such as the cost of healthcare services reaching to 15% of Gross National Product for U.S. (Kern and Jaron, 2003) has created several challenges for policy makers, healthcare providers, hospitals, insurance companies and patients. A major challenge is how to provide better healthcare services to an increasing number of people using limited financial and human resources. This will require reducing the number of un-necessary hospitalizations while offering healthcare services to those who really need these. This can be achieved by deploying a comprehensive patient monitoring involving homes, hospitals, and nursing homes. The patient monitoring includes both short-term (home healthcare monitoring) and long-term (nursing home monitoring). The patients in these environments will be either stationary or mobile. The current patient monitoring solutions do not support mobile users well as these were primarily designed for stationary users such as those in a bed. The current and emerging wireless technologies (Varshney and Vetter, 2000) are suitable for monitoring mobile as well as stationary patients in indoor and outdoor environments in cities and rural areas. The advances in wireless and mobile technologies, such as the ability to store a significant amount of information on a mobile device, radio-enabled watches, and a grid of body sensors, will facilitate both the quality and usefulness of patient monitoring. A possible scenario is to store, and update as necessary, comprehensive medical information on a user's mobile device. This will allow critical information such as blood group, allergies, and existing medical conditions to be used in delivering urgent and suitable medical care. In the near future, hand-held devices, including cell phones and personal digital assistants, will sense one or more vital signs and transmit alert messages to hospital, ambulance and healthcare providers for getting emergency services for the car driver going through a massive cardiac arrest. Patient monitoring by mobile and wireless technologies can reduce the stress and strain on healthcare providers while enhancing their productivity and reducing work-related stress. In the long-term, affordability, portability, and re-usability of wireless technologies for patient monitoring and preventive care will also reduce the overall cost of healthcare services. In this paper, we address the issue of patient monitoring using mobile and wireless networks. Before, describing the proposed solution, we present the current patient monitoring research and its limitations.

The Current Status and Limitations of Research in Patient Monitoring

There has been some work in patient monitoring and we briefly summarize the details. A healthcare monitoring system and field trial for chronically ill patients using cable-TV infrastructure is described in (Lee, Shen, Lin, Chang, and Chen, 2000).

The system supports ECG and BP information with video and audio communications among patients and healthcare providers. An implementation of pervasive computing technologies in an assisted care facility (www.elite-care.com) can be found in (Sanford, 2002). Using network sensors and databases, staff members are alerted when residents need immediate care. Using combined infrared and radio-based locator badges, also acting as keys, the system alerts the staff if a resident wanders out of a certain area (Sanford, 2002). 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, postures and 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 handheld devices. Using existing security protocols such as IPsec, a protection system for remote patients is discussed in (Kara, 2001). A wireless-based telemetry system for EEG epilepsy monitoring using 902-928 MHz (Industrial Scientific and Medical Band) was developed for patients who could wear this as a headband and could be 150 ft away (Modarreszadeh, 1997). A ring sensor worn by patients includes LEDs and photo-detectors where the technology of pulse oximetry is implemented for blood oxygen saturation monitoring (Rhee, Yang, Chang and Asada, 1998).

A three layer distributed sensor network for patient monitoring and care is proposed in (Bauer, Sichitiu, Istepanian, and Premaratne, 2000). The envisioned network has a leaf node layer (consisting of patient sensors), an intermediate node layer (consisting of the supervisory processor residing with each patient) and the root node processor (residing at a central monitoring facility). The capability of dealing with the bandwidth bottleneck at the wireless patient-root node link and the processing bottleneck at the central processor or root node of the network are also addressed. A system based on Bluetooth collects short and long-term digitized ECGs together with relevant clinical data for the management of patients in 10-20m range (Khoor, Nieberl, Fugedi, and Kail, 2001). A hospital-wide mobile medical monitoring system involving telemetry devices attached to patients to acquire, store and process continuous data about their state of health is proposed in (Pollard, Rohman, and Fry, 2001). It allows the medical staff to examine real-time graphical information and make comparisons with historical data and parameters may be set to cause an automatic alert to portable devices held by appropriate staff if a patient requires urgent observation. A wearable and battery-less stethoscope where the transceiver antenna can be worn outside the clothes and the reader unit can be clipped on a belt is proposed in (Kyu and Asada, 2002). The system can be used to capture human body sounds such as respiratory sounds for the purpose of continuous monitoring of patients with asthma or other pulmonary diseases. An integrated system for real-time remote acquisition of cardiac and other physiologic information from patients in the home environment is proposed in (Mendoza and Tran, 2002).

Transducers for measurement of electrocardiogram (ECG), heart rate variability (HRV), acoustical data are embedded into patient clothing for unobtrusive monitoring for early, sensitive detection of changes in physiologic status. The information is wirelessly transmitted to a central server located elsewhere in the home for signal processing, data storage, and data trending. Software-based algorithms detect out-of-normal or alarm conditions for HR and weight as defined by the healthcare provider. Several important issues in "smart health wearable" research are discussed in (Lymberis, 2003) including biomedical sensors, scenarios of use (linked to the business scenarios), data security and confidentiality, risk analysis, user interface, medical knowledge/decision support, dissemination, user acceptance and awareness, business models and exploitation. The use of protected frequency bands for medical telemetry will guard medical telemetry from the potential interference of other telemetry devices (Gieras, 2003). A Wireless Distributed Data Acquisition System is presented for prolonged, synchronized, health/stress monitoring using mobile client devices and mobile gateways. The personal digital assistant (PDA) is used as a mobile gateway to collect data from individual monitors and collected records are synchronized with existing records on the tele-medical server. Each client device uses flash memory as a temporary storage until the reliable connection with a mobile gateway is established (Jovanov, O'Donnel, Morgan, Priddy, and Harmigo, 2002).

The security and safety issues in medical environment, the technology, types, and characteristics of sensors, and research issues in smart antennas, denial of service, fault tolerant authentication, privacy issues, and energy considerations are discussed (Bhargava and Zoltowski, 2003). A study of fault-tolerant and distributed network protocols that support reliable, energy-efficient broadcasting for real-time multimedia transmission in multi-hop mobile ad hoc networks is presented in (Li and Wu 2002). The work focuses on finding a minimum-energy broadcast tree that is rooted from a given sender node and reaches each destination node. Moreover, the scheme is resilient to mobility and scales well since each node makes its decision based on its local information only. To support reliable, cooperative broadcast services, several node failure recovery cases have also been discussed.

The above review of wireless in the patient monitoring raises several issues:

1. The introduction of wireless technologies in patient monitoring is very preliminary as patient monitoring requirements and challenges in different environments have not been identified.

2. The unique capabilities of wireless and mobile infrastructure for patient monitoring have not been utilized.
3. The applications and solutions for patient monitoring are limited to using a single type of wireless network, thus restricting the access and coverage.
4. The introduction of wireless and mobile technologies in patient monitoring is very fragmented and limited to few simple cases.

Requirements of Patient Monitoring

The coverage of existing infrastructure-oriented wireless and mobile networks, such as cellular networks and wireless LANs, is spotty due to time and location-dependent channel quality and signal attenuation resulting in dead spots. There have been attempts to improve the coverage by several technical enhancements including overlapping base stations, however parts of any building or hospital have unreliable coverage. There is no data available on the extent of this problem, however it has been observed that spotty coverage exists within buildings, especially in the isolated areas. The use of ad hoc wireless networks can significantly improve the wireless coverage of the patients.

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. 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 hand-held or wearable wireless devices. In addition to end devices, patient monitoring will require comprehensive and high-speed access to wireless networks, reliable and scalable wireless infrastructure, secure and fast databases, and utilization of network intelligence and information. 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. 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.

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. Due 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 vs. un-licensed). For monitoring of patients who are not covered by an infrastructure-oriented wireless networks, the co-operation of others with wireless devices in an ad hoc configuration will be utilized. In this paper, we propose a wireless architecture for patient monitoring; discuss various aspects of our solution and present routing schemes to facilitating patient monitoring. The proposed solution will increase the access and quality of patient monitoring by using ad hoc networking and network intelligence.

PROPOSED SOLUTION FOR PATIENT MONITORING

Many healthcare applications require reliable monitoring of patients including those in a hospital or nursing home. Although patient monitoring can be done by using one of several wireless LANs (Figure 1), the coverage of wireless networks is not comprehensive on every square meter 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 on time.

It should be noted that there are many inherent problems in ad hoc wireless monitoring. These include possible routing difficulties due to changes in connectivity and user locations. These must be overcome for providing reliable transmission of patients' information periodically and specially when major changes take place. We propose that ad hoc networks can be formed by devices from patients for communications of vital signs, especially when significant changes take place. 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

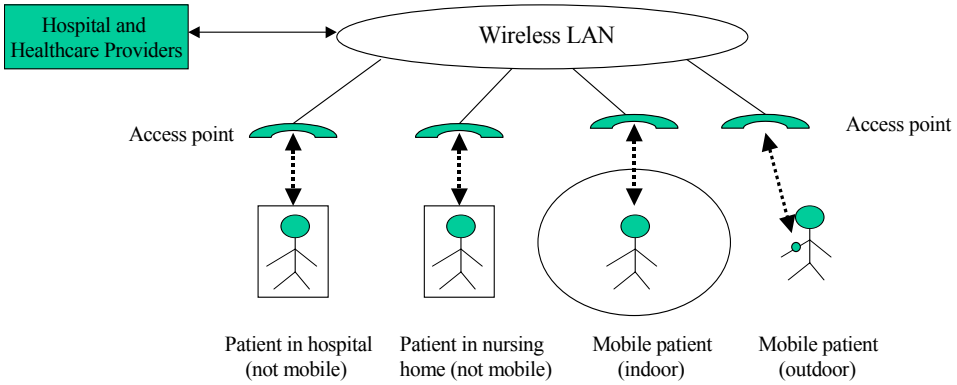

Figure 1. A Possible Architecture for Patient Monitoring using Wireless LANs

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. This would increase the chance that such vital signs are picked up by one or more wireless networks or healthcare provider directly to her device (Figure 2). 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 to a healthcare provider. Unlike general-purpose wireless networks, the efficiency of networking operation is not the major criterion, but the reliability, speed, and correctness of critical information must be supported.

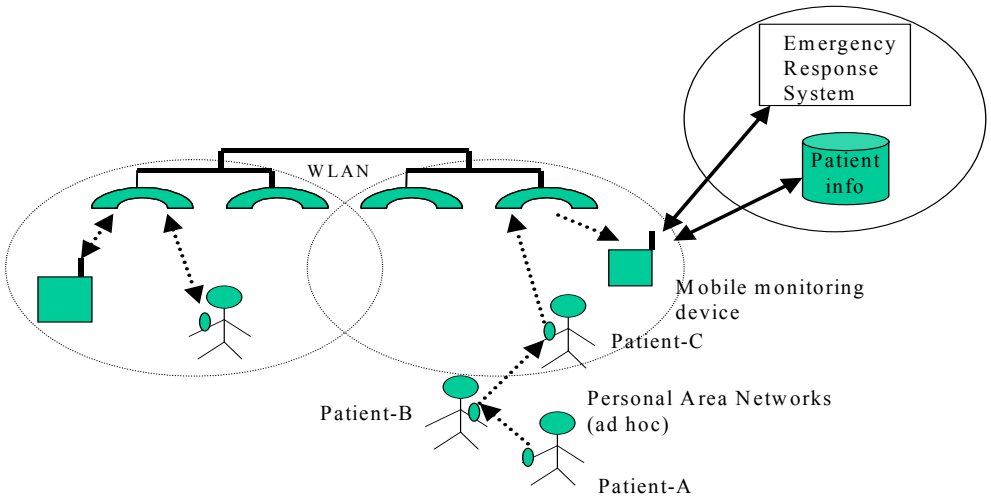

Figure 2. Augmenting Wireless Networking with Human Networking for Reliable Monitoring

A wireless architecture for reliable patient monitoring is shown in Figure 3, where multi-hop wireless ad hoc networks are formed between patient and healthcare personnel. This is possible as many other co-operating devices act as routers for transmission of patient's information. The proposed architecture transmits signals in all directions and many possible paths are used to communicate patient information to one or more healthcare personnel. In case, no other devices can be found nearby to a patient, a stronger signal could be transmitted from patient's device to increase the chances of reception by one or more co-operating devices. There are many possible routing schemes that can be used in this architecture and are shown in Table 1. Multicast routing will involve designating some nodes or users as multicast routers who will route to a certain set of healthcare personnel. Hyper multicast will involve repeated transmission of information until an acknowledgement from

healthcare provider arrives or a certain amount of time passes. Flooding involves sending messages or information in all directions to all possible users and could result in very reliable delivery of information to an intended receiver. Hyper flooding takes this process even further where flooding is repeated several times. Each one of these schemes brings its own set of requirements including traffic and offers a certain range of probability for message reception. The selection of a certain routing scheme can be based on the current quality of wireless channel, level of interference, and traffic considerations.

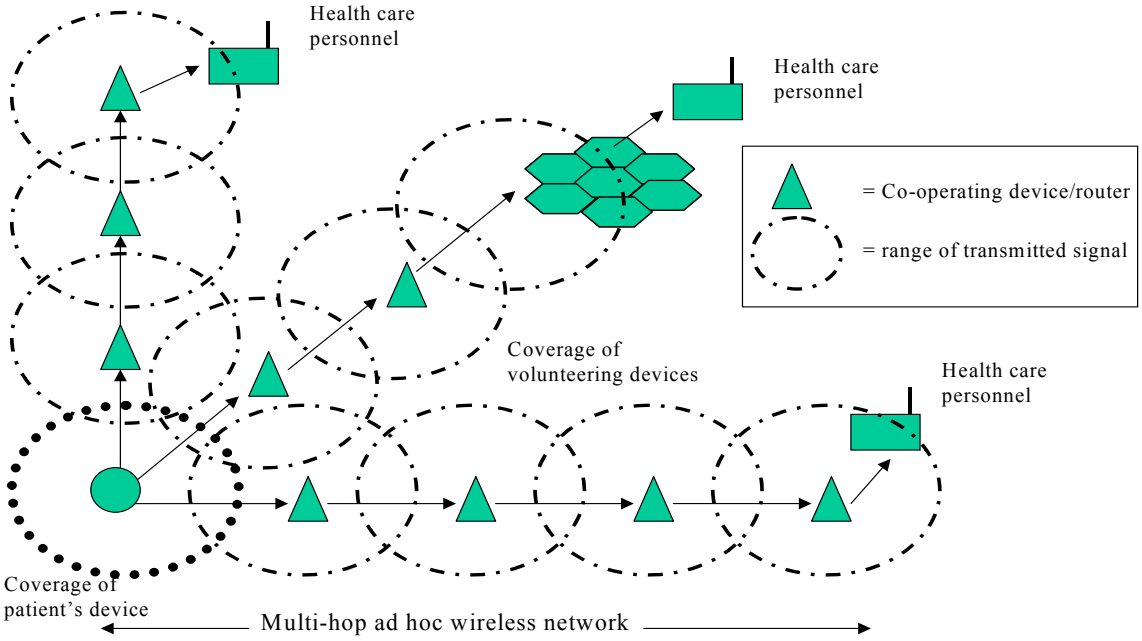

Figure 3. Possible Routing of Patient Information to Healthcare Personnel

Routing Scheme	Description	Comment
Regular routing	Patient information is routed to one and only one health care personnel	Most efficient routing Lower chances of message delivery
Prioritized routing	Patient information is routed to multiple healthcare personnel by allocating higher priority	Higher traffic Increased chances of message delivery
Multicast routing	Patient information is multicast to multiple healthcare personnel	Requires creation of multicast tree or structure (so some delays) Efficient routing Increased chances of message delivery
Hyper-multicast	Multicast process is repeated several times	Increased traffic Higher chances of message delivery
Flooding	Patient information is sent in all directions	Will result in significant traffic Higher chance of message delivery
Hyper-Flooding	The flooding process is repeated several times	Will result in very significant traffic Highest chance of message delivery

Table 1. Several Possible Routing Schemes for the Proposed Wireless Architecture

After discussing technical details of our patient monitoring solution, we now present many important related issues.

ISSUES IN THE PROPOSED SOLUTION

There are many important issues in the proposed solution including how to increase the reliability of patient monitoring by the proposed solution and its suitability for patient monitoring.

Increasing the Reliability of Patient Monitoring

One of the major reasons behind using ad hoc wireless networks is to increase the reliability of patient monitoring. The reliability can be further improved by the following factors:

Maximizing the power transmitted to increase the range: by increasing the power transmitted, even for a short time, the range of the signal could increase significantly, thus increasing the chances of finding other co-operating devices (Figure 3) or a healthcare personnel.

Multiple retransmissions: by attempting to transmit emergency signals more than once, the overall probability of message reception would increase.

Access to multiple networks: the access to multiple wireless networks enhances both the coverage and the scalability of the proposed wireless architecture in terms of users, distance, and applications.

Increased number of co-operating devices: by increasing the number of co-operating devices, such as by convincing most people in the nursing home to wear one or more, the chances of message reception would increase. It is also possible that certain patients may wear multiple devices.

The presence of multiple heath care personnel: by increasing the number of possible destinations, the probability of message reception could be increased substantially.

Suitability of the Proposed Solution for Patient Monitoring

The proposed architecture is designed to ensure that wireless infrastructure is available and usable when needed, works as expected, and does not add errors of its own in the context of patient monitoring. The use of ad hoc wireless networks for patient monitoring could overcome wireless congestion, poor quality or un-usability of certain wireless links, coverage problems (such as dead-spots), and, time and location-dependent interference and fading problems. The architecture employs the following networking and system design techniques to improve both the availability and quality of wireless infrastructure for patient monitoring. The wireless infrastructure dependability requirement is supported by fault-tolerant operation at device, access and infrastructure levels. This requires that a user device be equipped with multiple network interfaces; however it provides fault-tolerant (highly dependable) operation for both user devices and networks. The proposed architecture is fairly practical as it is using the capabilities of the current wireless and mobile networks and patient devices. This allows for immediate or near-term implementation of the proposed architecture using off-the-shelf components, public and private wireless LANs with user devices, and public wireless infrastructure. The proposed architecture can easily be extended for future use as the requirements change or new healthcare applications emerge. This is possible due to both the high-level abstraction and design technique, which result in a flexible and modifiable architecture. The architecture is also designed to evolve with advances in mobile and wireless technologies.

Co-operation and Priority Issues

The proposed solution requires that many, if not all, devices must join an ad hoc network. Although it is not possible to force patients to enable their devices for ad hoc network access and routing, it can be stated that most patients will realize that by agreeing to become a hop for other patients' data they are also increasing their chances of getting help on time. To overcome limitations of users devices, a priority mechanism can be set for information transfer.

Support for Fixed Patients

The proposed solution is designed for both fixed and mobile users. It has been shown by (Varshney and Vetter, 2000) that mobility and wireless are not necessarily the same. A user could be fixed or stationary but can access a wireless network. In this sense, the proposed solution can be used to monitor patients that are not mobile such as those in hospital beds. The current patient monitoring systems that are designed for fixed or stationary users cannot conveniently support the same users when they become mobile. The proposed solution can be used for both types of users or users that are fixed for some time and mobile sometime. It can be used both as a primary solution for patient monitoring as well as extended solution to the existing wireless solutions.

Probability of Finding Suitable Device

The proposed solution is designed for patients that are fixed or mobile in indoor or outdoor environment. It will not work if a user is highly mobile and is unable to find some other device or willing person who can forward the patient information to another device. This situation can arise if a patient is highly mobile or in a very isolated area without other users or devices. We envision that majority of patients covered by our solutions will be inside or close to a hospital or nursing home. The support for global mobility of patients will be much more complex and can be addressed in the future research.

The role of GPS

Patient monitoring also includes location-tracking where after a healthcare provider has received a message, the patient's location will be needed to send the necessary help. The proposed solution includes 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).

Interference

The proposed solution will 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.

Open Issues in the Proposed Solution

There are many open issues and challenges related to patient monitoring that must be addressed. 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. 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.

Confidentiality & 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.

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 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.

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.

CONCLUSIONS

Wireless and mobile technologies are finding a role in patient monitoring in several different environments: homes, hospitals, and nursing homes. However, due to several limitations, the quality and reliability of patient monitoring have not been highly satisfactory. In this paper, we presented and discussed a patient monitoring solution using ad hoc wireless networks. We discussed wireless architecture, routing of patient information, and related technical and non-technical issues. Many open issues have also been identified and can be addressed in the future research.

REFERENCES

1. Bauer, P., Sichitiu, M., Istepanian, R. and Premaratne, K. (2000) The Mobile Patient: Wireless Distributed Sensor Networks for Patient Monitoring and Care", *In Proc. IEEE EMBS International Conference on Information Technology Applications in Biomedicine,* Arlington, VA, 17-21.
2. Bhargava, A. Zoltowski, M. (2003) Sensors and Wireless Communication for Medical Care, *In Proc. 14th International Workshop on Database and Expert Systems Applications,* 956-960.
3. Gieras, I. A. (2003) The proliferation of patient-worn wireless telemetry technologies within the U.S. healthcare environment, *Proceedings of 4th International IEEE EMBS Special Topic Conference on Information Technology Applications in Biomedicine,* 295-298.
4. Jovanov, E. O'Donnel, A. Morgan, A. Priddy, B. Hormigo, R., (2002) Prolonged telemetric monitoring of heart rate variability using wireless intelligent sensors and a mobile gateway, *In Proc. of the Second Joint IEEE EMBS/BMES Conference, 2002 (24th Annual EMBS Conference and the Annual Fall Meeting of the Biomedical Engineering Society),* 1875-1876.
5. Kara, A. (2001) Protecting Privacy in Remote-Patient Monitoring, *IEEE Computer*, 34, 5, 24-27.
6. Kern, S. E and Jaron, D. (2003) Healthcare Technology, Economics and Policy: An Evolving Balance, *IEEE Engineering in Medicine and Biology Magazine*, 22, 1, 16-19.
7. Khoor, S., Nieberl, K., Fugedi, K., Kail, E. (2001) Telemedicine ECG-telemetry with Bluetooth Technology, *In Proc. Computers in Cardiology 2001,* Rotterdam, 585-588.
8. Kyu J. C. and Asada, H. H. (2002) Wireless, Battery-less Stethoscope for Wearable Health Monitoring, *In Proc. the IEEE 28th Annual Northeast Bioengineering Conference,* Philadelphia, PA, 187-188.
9. Lee, R-G., Shen, H-S., Lin, C-C, Chang, K-C. and Chen, J-H. (2000) Home Telecare System using Cable Television Plants-An Experimental Field Trial, *IEEE Transactions on Information Technologies in Biomedicine*, 4, 1, 37-44.
10. Li F. and Wu, K. (2002) Reliable, Distributed and Energy-efficient Broadcasting in Multi-hop Mobile Ad Hoc Networks, *In Proc. 27th Annual IEEE Conference on Local Computer Networks,* 761-769.
11. Lymberis, A. (2003) Smart Wearables for Remote Health Monitoring, from Prevention to Rehabilitation: Current R&D, Future challenges, *Proceedings of 4th International IEEE EMBS Special Topic Conference on Information Technology Applications in Biomedicine,* 272 – 275.
12. Mendoza, G. G. and Tran, B. Q. (2002) In-home Wireless Monitoring of Physiological Data for Heart Failure Patients, *In Proc. of the Second Joint IEEE EMBS/BMES (24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society) Conference*, 1849-1850.
13. Modarreszadeh, S. (1997) Wireless, 32-channel, EEG and Epilepsy Monitoring System, *In Proc. 19th Annual IEEE International Conference on Engineering in Medicine and Biology*, Chicago, IL, 1157-1160.
14. Pollard, J. K., Rohman, S. and Fry, M. E. (2001) A Web-based Mobile Medical Monitoring System, *International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 2001,* Crimea, 32-35
15. Rhee, S., Yang, B.-H., Chang, K., and Asada, H. H. (1998) The Ring Sensor: A New Ambulatory Wearable Sensor for Twenty-four Hour Patient Monitoring, *In Proc. 20th Annual IEEE International Conference on Engineering in Medicine and Biology,* Hong Kong, 1906-1909.
16. Stanford, V. (2002) Using Pervasive Computing to Deliver Elder Care, *IEEE Pervasive Computing Magazine*, 1, 1, 10-13.
17. Suzuki, T. and Doi, M. (2001) LifeMinder: An Evidence-Based Wearable Healthcare Assistant, *Proceedings of the ACM CHI Conference*
18. Varshney, U. and Vetter, R. (2000) Emerging Wireless and Mobile Networks, *Communications of the Association for Computing Machinery (ACM),* 43, 6, 73-81.