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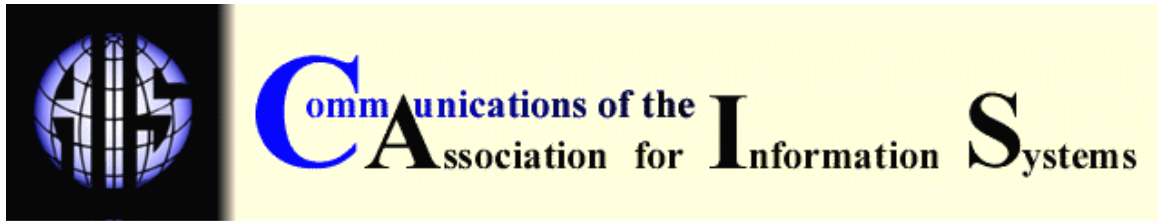
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PERVASIVE HEALTHCARE: APPLICATIONS, CHALLENGES AND WIRELESS SOLUTIONS

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ABSTRACT

A major challenge for healthcare is how to provide improved services to an increasing number of people using limited financial and human resources. Pervasive healthcare is considered a solution to many existing problems and a possible future of the current healthcare services. In simple terms, pervasive healthcare can be defined as healthcare to anyone, anytime, and anywhere by removing locational, time and other restraints while increasing both its coverage and quality. The broad definition includes prevention, healthcare maintenance and checkups, short-term monitoring (or home healthcare monitoring), long-term monitoring (nursing home), personalized healthcare monitoring, incidence detection and management, and, emergency intervention, transportation and treatment. These requirements could be effectively supported by universal, efficient and reliable access to healthcare services, providers, and biomedical information that is available at any time. In this paper, several pervasive healthcare applications and related challenges are discussed. An integrated wireless architecture that is designed to use the capabilities of current and emerging wireless and mobile networks for location management, intelligent emergency system, patient monitoring, and mobile telemedicine applications is presented.

Keywords: pervasive healthcare, mobile and wireless networks, wireless architecture, location management

I. INTRODUCTION

The introduction of information and telecommunications technologies in healthcare environment led to an increased accessibility to healthcare providers, more efficient tasks and processes, and a higher quality of healthcare services [Kern and Jaron, 2003]. These improvements became possible as an increasing number of healthcare providers use hand-held and mobile devices networked by wireless LANs or wide area public wireless networks to reach patients, access medical information and electronic records, and provide a range of healthcare services. However, several difficult challenges in healthcare delivery still exist worldwide. These challenges include a significant number of medical errors resulting in thousands of premature deaths and hundreds of thousands of injuries [IOM, 2000], which could be reduced by having anytime anywhere access to

patients' records. Healthcare providers are subject to considerable stress. Worldwise, healthcare services in rural and underserved areas are a major challenge [Suzuki and Doi, 2001]. Combined with the increasing cost of healthcare services[1], policy makers, healthcare providers, hospitals, insurance companies and patients face daunting problems. For several reasons, the number of seniors and retirees in developed countries increased sharply [Forum, 2005]. Similar geriatric trends are expected in developing countries where better medical care combined with reduced economic stress is increasing the number of people living significantly longer than ever before.

A major challenge is how to provide better healthcare services to an increasing number of people using limited financial and human resources. Pervasive healthcare is considered a solution to many of these problems and a possible future of healthcare services. In simple terms, pervasive healthcare can be defined as:

> *healthcare to anyone, anytime, and anywhere by removing locational, time and other restraints while increasing both the coverage and quality of healthcare.*

The broad definition includes prevention, healthcare maintenance and checkups, short-term monitoring (or home healthcare monitoring), long-term monitoring (nursing home), personalized healthcare monitoring, incidence detection and management, and, emergency intervention, transportation and treatment. These requirements could be supported effectively by universal, efficient, and reliable access to healthcare services, providers, and biomedical information anytime through mobile devices. Although many high-end and complex healthcare procedures and processes will not be well served by using mobile and wireless technologies in the near future, some benefits in terms of information anytime anywhere can still be derived.

II. CURRENT USES AND PROBLEMS OF WIRELESS SYSTEMS IN HEALTHCARE

Currently, the use of wireless technologies in healthcare is limited. Although healthcare professionals are increasingly encouraged to use hand-held devices to access patient records, write electronic prescriptions, send reminders to patients, and enter diagnosis and billing codes for healthcare services, few healthcare professionals have the training, orientation, or time to adapt to hand-held devices with their complex inputs, difficult and unreliable applications, and fear of information loss. Furthermore, many hospitals and healthcare providers prohibit the usage of (and even actively jam) wireless devices within their buildings in fear of interference to more critical medical devices. Although most healthcare providers and hospitals believe the potential of mobile and wireless technologies, several obstacles remain to be overcome. The real obstacles are:

- lack of comprehensive coverage of wireless and mobile networks,
- reliability of wireless infrastructure, and
- general limitations of hand-held devices.

In terms of information systems, the following problems need to be resolved:

- Wireless and networking in hospitals
- Patient-device interfaces and
- Medical usability of sensors and mobile devices,
- Software and middleware for hiding the complexity of the underlying hardware and networks,

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[1] The cost of healthcare services reached 15% of Gross National Product in the U.S. or about $1.5 trillion [Kern and Jaron, 2003],

- Database design and availability for storing, accessing and updating patient records and past vital signs,
- Design and use of Internet-based portals for patient healthcare history,
- Insurance and payment models, and
- Management of pervasive healthcare systems, including privacy and security,

TECHNOLOGY ISSUES

The technology issues related to the introduction of wireless in healthcare include:

- networking support such as location tracking, routing,
- scalable architectures,
- dependability, and quality of access,
- 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.

MEDICAL ISSUES

The medical aspects are important in realizing a wide-scale deployment of wireless 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 are design of suitable healthcare applications, specific requirements of vital signs in healthcare environment, the 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 the usability of wireless-based solutions in healthcare.

The diversity of patients can range from uncontrollable energetic children, violent youth, and mid-life depressed or frail seniors. The requirements presented by these people to wireless networks vary significantly from keeping track of the behavior of children 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 limited functional intelligence or limited memory. Many of these patients also suffer from psychiatric disorders such as paranoia resulting in a suspicion towards wireless technologies, especially those requiring a patient to wear a locator or other device.

MANAGEMENT ISSUES

The management of pervasive healthcare could bring a mini-revolution in how wireless in the healthcare is implemented, offered, and managed. Management issues include:

- security and privacy in wireless healthcare (e.g., possible misuse of patient medical information),
- training of healthcare professional for pervasive healthcare,
- managing the integration of wireless solutions,
- increasing accessibility of healthcare services using wireless technologies,
- legal and regulatory issues, (e.g., liability and lawsuits in USA).

- insurance payments (possibility of insurance companies not paying or paying differently for treatment via mobile devices)
- cost, and
- the potential implications of HIPAA (Health Insurance Portability and Accountability Act of 1996). HIPAA is supposed to protect health information. A subject of controversy, it is interpreted differently by healthcare providers, insurance companies, and attorneys.

WIRELESS USABILITY AND INTEGRATION

Wireless-based devices must be designed to offer intuitive interfaces that can learn with and from individuals. Many less-technical-savvy population segments are willing to learn and use mobile and wireless technologies to allow them to live more independently [Mikkonen et al..2002]. The training of healthcare professionals to utilize mobile and wireless technologies effectively would be a less complex issue as an increasing number of health care professionals can use hand-held and wireless devices.

Certainly work is needed to address privacy and related concerns over wireless and mobile networks where security is still seen as insufficient. In the pervasive healthcare environment, the information on patient is likely to be stored and processed by his/her handheld devices and could be transmitted or routed by other devices. Although privacy safeguards of HIPAA could limit how and where patient information could be kept, but as long as such information is encrypted during transmission and is not accessed (but routed) by other devices, healthcare providers are likely to be considered HIPAA-compliant [HHS Office of Civil Rights 2003]. Considerable thought should be given to access control, encryption, and authorization requirements in the end-to-end communications involving private and public networks, including those using wireless links.

I next present several pervasive healthcare applications (Section III) wireless solutions (Section III), wireless networking architecture (Section IV), and location management support in Section V.

III. PERVASIVE HEALTHCARE APPLICATIONS

In the next two or three years, short-term 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, can be used to facilitate pervasive healthcare [Varshney, 2004]. With an increasing number and types of functions being added to hand-held devices, including cell phones and PDAs (Personal Digital Assistants), it is quite likely that in the next four to five years, these devices will be able to sense/observe one or more vital signs and transmit alert messages to hospitals, ambulances and healthcare providers for getting emergency services for their users, including mobile users such as those in vehicles. In addition to the use of wireless technologies in detecting emergencies quickly, more efficient vehicular routing and detailed information on nearby hospitals can be used to treat patients immediately and save many more lives. In addition to the current applications, new healthcare applications could become possible due to the wireless and mobile technologies (Figure 1).

PERVASIVE HEALTH CARE SERVICES

Pervasive healthcare services would allow patients to be monitored in any location anytime. Using his/her medical history and current conditions, one or more actions can be taken including sending an alert message to the nearest ambulance or a healthcare provider using location-tracking capabilities of one or more wireless networks including satellites (for outdoor tracking) and cellular/wireless LANs (indoor). Intelligence in the form of context awareness can be built in pervasive services to avoid "false-positive" alerts. To overcome a lack of coverage from infrastructure-oriented wireless networks, such as wireless LANs, the devices (or sensors) on patients' can form an ad hoc wireless network for transmission of emergency signals to healthcare provider(s). The support for emergency messages requires high levels of message delivery and minimum delays and message corruption.
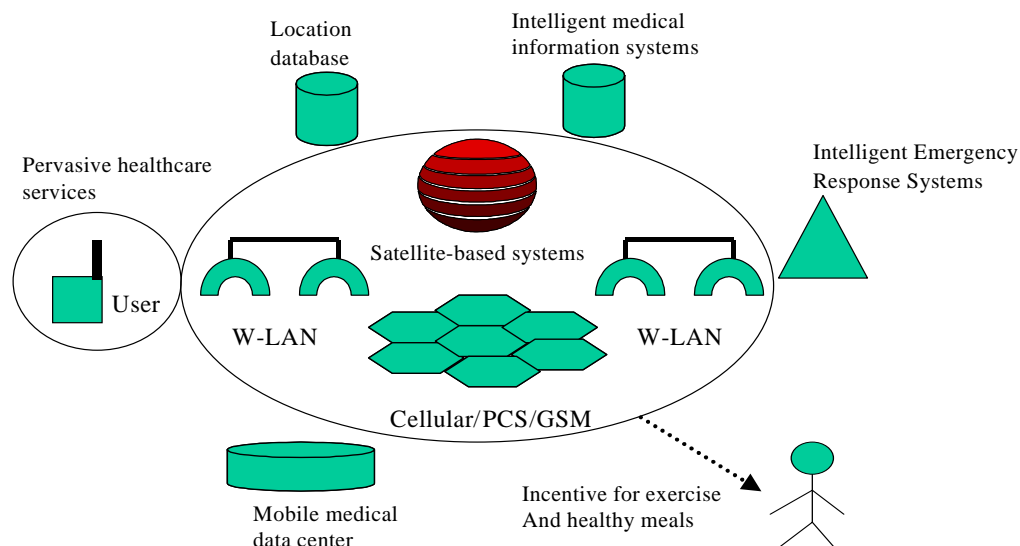
W-LAN: Wireless Local Area Network,
PCS: Personal Communications Systems,
GSM: Global System for Mobile communications

Figure 1. Several Current and Emerging Pervasive Healthcare Applications

The patient devices would normally be in range of an infrastructure-based network wireless LANs. However, when not covered these devices could form an ad hoc wireless network. The information on vital signs of a patient from sensors can be transmitted to another nearby patient and forwarded, thus increasing the chance that vital signs are picked up by healthcare professional on his/her device. Using one or more routing schemes, emergency messages can be transmitted to healthcare professionals (Figure 2). More details on ad hoc networks for patient monitoring can be found in Varshney, [2004].

UBIQUITOUS HEALTHCARE INFORMATION

Ubiquitous information would allow a patient or healthcare provider to access current and past medical information. This information would help reduce a patient's anxiety about certain conditions or medical tests. For healthcare providers, being able to access current and complete information anytime anywhere would result in reduced number of medical errors. A possible scenario is to store, medical information on a user's mobile device and update it as necessary. Information such as allergies and existing medical conditions would be used in delivering urgent and medical care correctly. Currently, work is going on to design and build "health" portals where healthcare information may be stored, accessed and updated. The use and access of such portals with hand-held device is expected to start in 2006-2007 and could become common in the

Di: devices/sensors on patient,
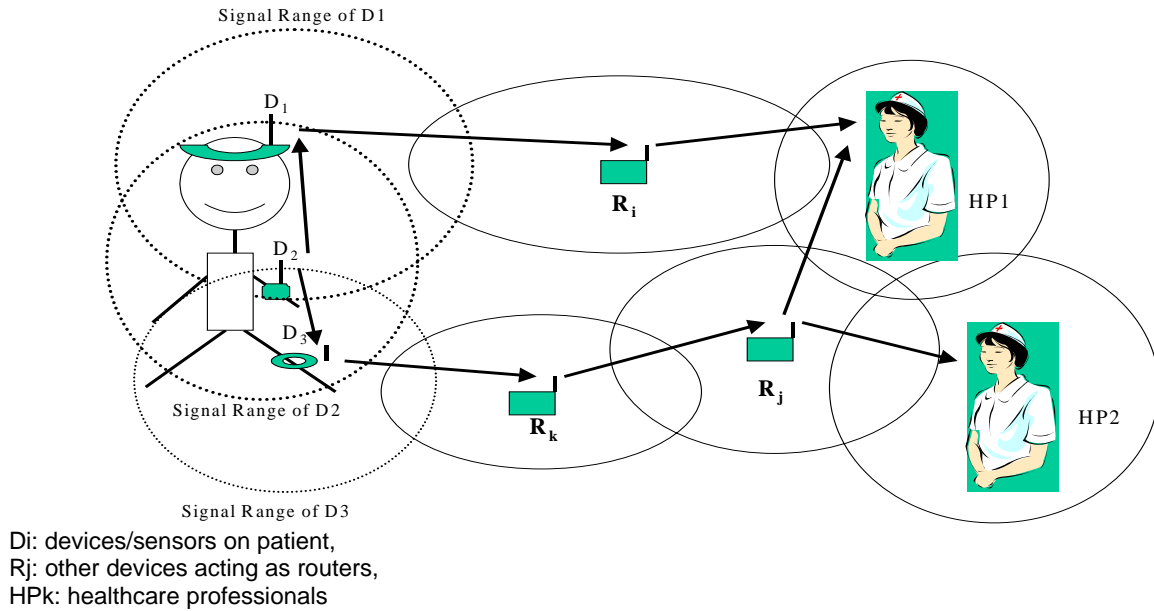Rj: other devices acting as routers,
HPk: healthcare professionals

Figure 2. Patient Monitoring Using Sensors and Ad Hoc Wireless Networks

following two to three years. Patients would use hand-held devices to upload the necessary medical and insurance information at the doctor's office, thereby reducing the amount of effort to enter detailed information. Downloading reduces the chance of entering incorrect information either by the patient or human receptionist, thus eventually reducing the number of medical errors.

DYNAMIC MANAGEMENT OF MEDICAL INFORMATION

Such management could allow a patient to restrict who can access his/her medical information and for how long. Any information stored by wireless or healthcare providers could be made secure and privacy concerns can be addressed by using opt-in and opt out. The patient would be able to change the access restriction to medical information using mobile devices anywhere anytime.

MOBILE HEALTHCARE DATA CENTER

This application would be used, where a large amount of stored healthcare data is to be stored, accessed, analyzed, and updated. The data can be made available to authorized "mobile decision makers" for making healthcare decisions. Such data can also be used by pharmaceutical companies to analyze and report quickly any problems with their existing drugs in the market. Another possibility is to use such data in projecting current and future demands for different medical drugs. By making data available to healthcare researchers without identifying the patients, the potential cost of conducting certain types of medical research could be reduced. Many different types of research can be conducted using this data including the incidence of different diseases, survival rates, and any changes in treatments. Individual patients would be allowed not to disclose their healthcare data, even in an anonymous format.

MOBILE TELEMEDICINE

Mobile telemedicine can expand the reach and coverage of telemedicine, which has been in operation for about thirty years [Pattichis et al. 2002]. Telemedicine was designed to remove the constraints of location. Mobile telemedicine could remove constraints on both location and

time. Mobile telemedicine will also benefit significantly from many of the pervasive healthcare applications described in this section. With an increasing bit rate of wireless networks such as those of 3G networks with support for video-conferencing, mobile telemedicine could be widely deployed in the next two or three years. It may still be few more years before handheld devices will meet the resolution requirements of some of the medical imaging applications in the telemedicine environment.

OTHER APPLICATIONS

Many more extreme examples of pervasive healthcare could include pervasive "life-style incentive management", where a small mobile micro-payment can be made every time a user exercises or eats healthy food. Payment may be a more effective incentive than the proposed "fat tax", under consideration for charging fast food items to recover the healthcare cost due to obesity. This interesting idea is likely to face several obstacles including difficulty in practical implementation and complex management.

Another application would involve detecting of some vital signs by the hand-held devices. With its analysis of known allergies and medical conditions, the device could alert healthcare emergency system (such as enhanced-911 in the U.S.). Healthcare emergencies can also be managed better by using intelligent emergency call management and routing for emergency vehicles. This data could be combined with locating the closest hospital(s) with the needed care and availability of hospital space.

The current and emerging mobile healthcare applications place several requirements on wireless and mobile infrastructure. These requirements include ubiquitous and high-speed access to wireless networks, location tracking and monitoring abilities, dependable and scalable wireless infrastructure, secure and fast databases, and utilization of network information.

IV. WIRELESS SOLUTION TO PERVASIVE HEALTHCARE

The current and emerging wireless technologies [Varshney and Vetter, 2000] could improve the overall quality of service for patients in both cities and rural areas, reduce the stress and strain on healthcare providers while enhancing their productivity, retention, and quality of life, and reduce the overall cost of healthcare services in the long-term. Many medical errors occur because of a lack of correct and complete information at the location and time it is needed, resulting in wrong diagnosis and drug interaction problems [IOM,2000]. The required medical information can be made available at any place any time using sophisticated devices and widely deployed wireless and mobile networks. The mobile and wireless technologies can be used effectively by matching infrastructure capabilities to health-care needs. These include:

- 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; and
- reliable communication among medical devices, patients, health-care providers, and vehicles for effective emergency management.

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.

PREVIOUS WORK

Preliminary work on wireless in pervasive healthcare appears in the literature. For example, Anogianakis et al.[1998] describe telemedicine using satellites and ground-based networks. Their maritime telemedicine work also includes multi-lingual capabilities and can support applications such as audio and video conferencing, multimedia communications, flat file and image transfer with low, medium and high data requirements.

Another area in pervasive healthcare includes several applications of wireless telemedicine systems including tele-cardiology, tele-radiology, and tele-psychology [Pattichis et al., 2002]. This paper also provides a snapshot of the application of wireless telemedicine systems as they have evolved over the last thirty years. Issues related to electronic patient records and emergency telemedicine are addressed.
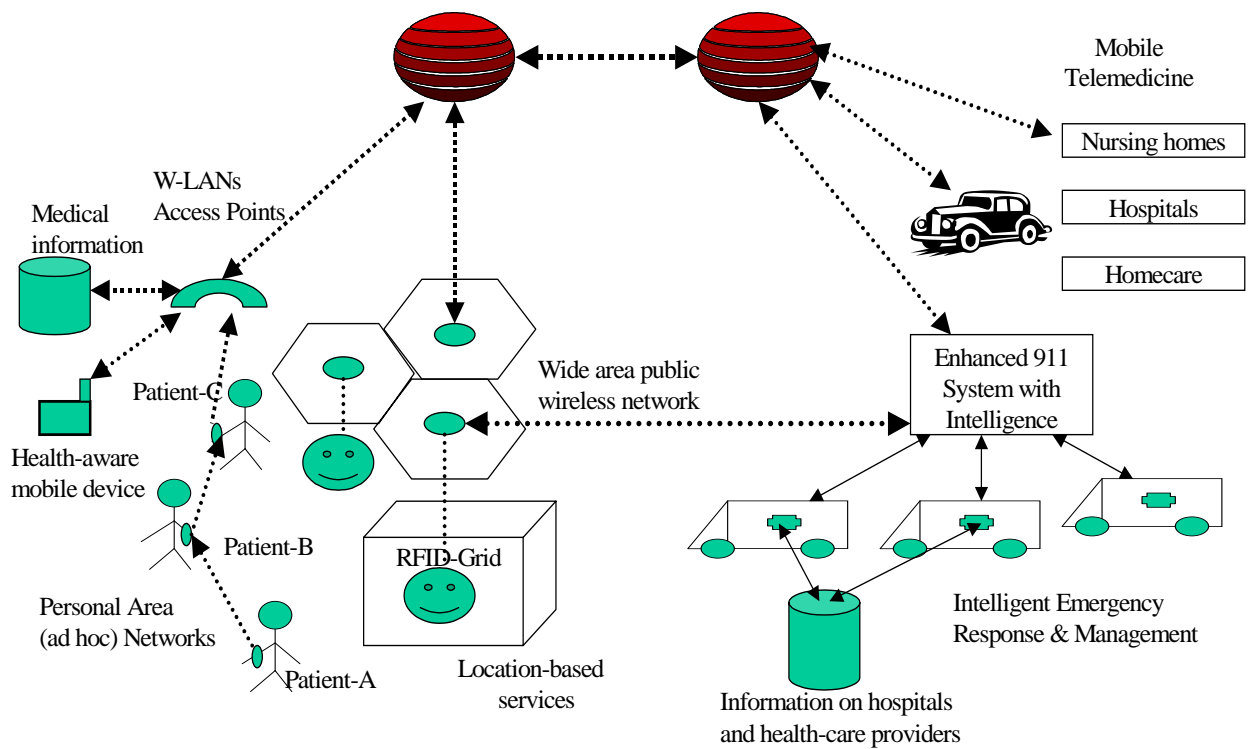
An implementation of pervasive computing technologies in an assisted care facility (www.elite-care.com) can be found in Stanford [2002]. Using network sensors and databases, facility staff members are alerted when residents need immediate care. Using combined infrared and radio-based locator badges, also acting as keys, the system alerts the staff if a resident wanders out of a certain area [Stanford, 2002]. The radio frequency system allows location tracking to about a 90-feet radius when infrared is not usable. The personalized system is designed to provide autonomy to residents of the assisted care facility living in a "smart" apartment complex. For long-term health monitoring and easy retrieval of information, a wearable healthcare assistant can be used [Suzuki and Doi, 2002]. 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. One feature involves detection of high-pressure (stressful) state from the high-pulse rate with the user's context information. The one problem with this system is that it requires a notebook to be carried.

V. AN INTEGRATED WIRELESS ARCHITECTURE FOR PERVASIVE HELTHCARE APPLICATIONS

Figure 3 shows my proposal for an integrated wireless architecture for pervasive healthcare applications. The architecture is designed to be independent of a single wireless technology while allowing the use of several diverse mobile and wireless networks to support the requirements of healthcare applications. This architecture will evolve as the changes in wireless and mobile technologies take place with increased bit rate, coverage, and network reliability. The architecture is developed by using several unique capabilities and functionalities of the current and emerging mobile and wireless devices, networks, and middleware. These capabilities include access to multiple and diverse wireless networks, a range of location tracking, and ad hoc networking for increasing the access and quality of healthcare service. These functions can support several new healthcare applications, location tracking of patients and devices, intelligent emergency response system, and mobile telemedicine. The wireless architecture should reduce long-term cost of healthcare and would also result in an increased productivity of healthcare providers (Table 1).

Although I did not perform a cost analysis, the proposed wireless architecture should reduce long-term cost of healthcare and would also result in an increased productivity of healthcare providers. The following paragraphs describe details of the proposed architecture using several aspects such as coverage and scalability, dependability, suitability for healthcare applications, and modifiability.

The architecture is designed to provide wireless coverage in both rural and urban areas for both indoor and outdoor environments. This goal is achieved by using public wide-area cellular networks for urban coverage combined with wireless LANs for the congested indoor and outdoor urban areas (hot-spots). To provide healthcare services in rural areas that are not covered (or are partially or unreliably serviced) by wide area cellular networks, the architecture supports either or both of satellite and wireless LANs. This access to multiple wireless networks enhances both the coverage and the scalability of the proposed wireless architecture in terms of users, distance, and applications.

RFID= Radio Frequency Identification

Figure 3. An Integrated Wireless Network Architecture for Healthcare Environment

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A major challenge in supporting healthcare applications is how to ensure that wireless infrastructure is reliable and dependable. Even with significant advances, the reliability of wireless infrastructure is not yet at the same level as the "wire-line" infrastructure such as the public switched telephone networks (PSTN). 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 healthcare delivery. The architecture employs the following networking and system design techniques to improve both the availability and quality of wireless infrastructure for healthcare environment.

Table 1. Details of the Wireless Architecture for Pervasive Healthcare

Issues	Wireless Solution	Comments
Coverage and Scalability	Use of public wide area cellular networks for urban coverage combined with wireless LANs for the congested indoor and outdoor urban areas. For healthcare services in rural areas, use of either or both satellite and wireless LANs.	The access to multiple wireless networks enhances both the coverage and the scalability of the in terms of users, distance, and applications.
Dependable and Reliable Operation	Prioritized operation for healthcare services Improving access by using multiple wireless networks Deployment of fault-tolerant wireless infrastructure Replication of medical information	Designed to ensure that it is available and usable when needed, works as expected, and does not add errors of its own in the context of healthcare delivery
Suitability for healthcare applications	Designed by considering several requirements of healthcare environment including an increased access and quality of healthcare services. Supports short and long-term monitoring, non-emergency and emergency situations, and individualized healthcare delivery by using location tracking, ad hoc networking, and wireless network intelligence	The architecture will also support several new healthcare applications, location tracking of patients and devices, intelligent emergency response system, and more effective mobile telemedicine.
Practical & Implementable	Practical by using the capabilities of the current wireless and mobile networks. Immediate or near-term implementation of the architecture using off-the-shelf components, public and private wireless LANs with user devices, and public wireless infrastructure.	It can also utilize free wireless LAN service, existing wide-area cellular and other wireless service. The medium bit rate monitoring services can be implemented by sharing of wireless LAN capacity among friendly neighbors.
Expandable and Modifiable	Designed to be available, dependable and practical. Extendible for future use as the requirements change or new healthcare applications emerge due to both the high-level abstraction and design technique	It will easily support use Fourth Generation (4G) wireless networks allowing multi-network roaming.
Other considerations and limitations	Known weaknesses in wireless security (wireless LANs) The implementation of the architecture could differ substantially in different countries	Multiple wireless service providers, regulatory bodies, and insurance companies in USA, while a single entity (government) in many other countries.

1. Prioritized operation for Healthcare Services

Although it would be preferable to provide a complete separate network infrastructure for healthcare applications, the cost involved and sporadic patterns of usage make it more likely that the existing and emerging wireless networks will be used for healthcare applications. The proposed architecture effectively supports healthcare services by allocating higher priorities for emergency and crisis management combined with pre-emptive capability to terminate non-urgent user traffic over wireless networks.

2. Improving Accessibility by using Multiple Wireless Networks

The proposed architecture supports access to multiple heterogeneous wireless networks to increase the overall infrastructure availability for healthcare applications. This arrangement 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.

3. Deployment of Fault-tolerant Wireless Infrastructure

The wireless infrastructure dependability requirement is supported by fault-tolerant operation at device, access, and infrastructure levels. Fault tolerance requires that a user device be equipped with multiple network interfaces; however it provides highly dependable operation for both user devices and networks.

4. Replication of Medical Information on Multiple Databases

To ensure the continued availability of medical information, medical and user information can be kept at multiple databases with redundancy (backup). Redundancy would allow fast access to critical information by accessing one of the closest databases. If a user goes outside his/her country or region, the access to such database may still add significant delays or in some cases may not be accessible. One minor issue is the impact of information update and the need for synchronization, which can be completed soon after an emergency or update is over. If databases provide conflicting information, then human intervention can be used to decipher the correct information.

The proposed architecture considers several requirements of the healthcare environment, including increased access and quality of healthcare services. The proposed architecture supports short and long-term monitoring, non-emergency and emergency situations, and individualized healthcare delivery by using location tracking, ad hoc networking, and wireless network intelligence. Using these functions, the architecture will also support several new healthcare applications, location tracking of patients and devices, intelligent emergency response system, and more effective mobile telemedicine.

The proposed architecture uses the capabilities of current wireless and mobile networks. As a result, immediate or near-term implementation of the proposed architecture is possible using off-the-shelf components, public and private wireless LANs with user devices, and public wireless infrastructure. The proposed architecture can also use free wireless LAN service, as provided by some city governments, existing wide-area cellular and other wireless service without any additional charges or modifications. The low to medium bit rate monitoring services can be implemented today by the sharing of wireless LAN capacity among friendly users living in a close vicinity. Therefore, it can be stated that the proposed architecture is implementable without waiting for future technologies or many resources.

As stated throughout this section, the architecture is designed to be available, dependable, and practical. In addition to these characteristics, the proposed architecture can easily be extended

for future use as the requirements change or new healthcare applications emerge. The high-level abstraction and design technique result in a flexible and modifiable architecture.

In the next few years, fourth generation (4G) wireless networks could emerge, allowing users to access multiple wireless networks without manually switching from network to network. This "intelligent" support for network roaming would be even more helpful as the device complexity would be reduced and users could focus more on the healthcare services and less on network access issues. The architecture would benefit from such advances from 4G wireless networks.

There are several other considerations that must be addressed before the proposed architecture can be deployed. These include several known weaknesses in wireless security, especially in wireless LANs; and the need for additional training for system operators, healthcare professionals and patients. The implementation of the proposed architecture could differ substantially in different countries. For example, in the US, multiple wireless service providers, regulatory bodies, and insurance companies would be involved, while in many developing countries, a single entity such as the government could undertake the whole process.

VI. PROVIDING LOCATION MANAGEMENT SUPPORT

Healthcare applications would benefit from the location tracking of patients and healthcare providers, devices, and supplies. It will be 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. Location management in healthcare environment is shown in Figure 4 using several components including GPS, cellular networks, wireless LANs, and RFID for location tracking of people, devices, and services at diverse location accuracy. The patients in a pervasive healthcare environment may also have sensors on their bodies, thereby creating intra-body and inter-body sensor networks. The sensors, due to their limited computing and communications power, are short range. Typically sensors are fixed (in a location or on patients) and not mobile, but are inter-connected in an ad hoc topology. One or more devices can aggregate the information from multiple sensors and transmit to one or more base stations in a wireless LAN or another type of wireless network as shown in Figure 4. An example of sensors in healthcare is project CodeBlue at Harvard [Harvard, 2005], where sensors are used for pre- and in-hospital emergency care and patient rehabilitation. Another example is tracking of patients in emergency room using RFID (Janz et al., 2005).
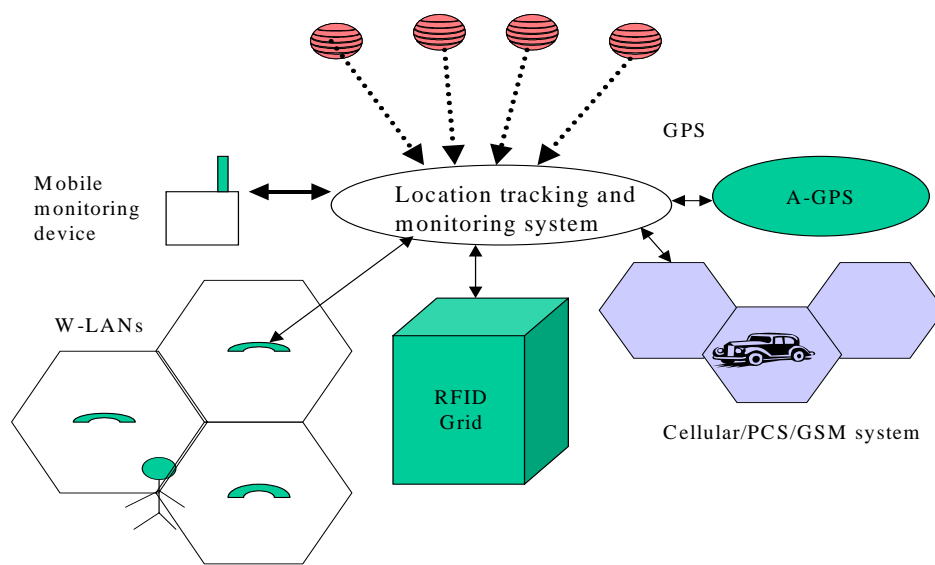

Figure 4. An Integrated Tracking and Monitoring System

GPS AND A-GPS

Satellite-based systems such as GPS (Global Positioning Satellite-system) can be used for location tracking. In this system, 24 satellites broadcast coded location information, which is then received and processed by GPS receivers to determine their locations. The location precision achieved is in the range of a few to several hundred meters. To reduce the complexity of user devices Assisted GPS (A-GPS) system could be used (Figure 4). In A-GPS, the processing or decoding of locational information from GPS satellites is shared between hand-held devices and base stations of cellular networks. This assisting by base stations leads to the name Assisted-GPS. Assistance reduces both the complexity of user devices and the processing delays before locational information can be derived. However additional complexity is introduced in base stations (or cellular wireless networks). To improve location accuracy even further, differential GPS systems can also be deployed. Details on GPS use can be found in [Pick, 2004].

CELLULAR AND WIRELESS NETWORKS

In cellular, Personal Communications Systems, and Global System for Mobile Communications (GSM), location tracking involves updating once the user moves to a different location area (Figure 4). In general, the network knows the location of users with accuracy equal to the size of the location area. The architecture achieves even higher accuracy by using a smaller location area with a reduced cell size and number of cells. If "immediate" tracking is needed with near-zero response time or when a user is inactive or is in an area out of the network coverage,, the network can return the last known location of the user. Even higher precision of location could be supported by the emerging Enhanced 911 (E911) infrastructure that will allow network-based tracking with 100-meter precision and handset-based tracking with 50-meter for mobile users [Varshney, 2003]. 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), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and Location Pattern Matching (LPM) [Varshney, 2003]. TDOA and AOA schemes locate a mobile device by processing the difference in signal arrival times at three or more antenna sites, termed base station triangulation. The architecture supports even higher location accuracy by combining small cells with base station triangulation.

WIRELESS LANS, PANS, AND RFID

The cellular/PCS location schemes can also be used in indoor location tracking. Since many indoor applications require higher location precision, I propose that smaller wireless local area networks (WLANs) and personal area networks (PANs) be used. In the architecture (Figure 4). Base stations are kept closer and co-operate in 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.

RFID (Radio Frequency Identification) uses wireless links to identify objects or people uniquely using dedicated short-range communications [Varshney, 2003]. 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 coverage is limited (5-10 feet), the architecture includes a multi-dimensional grid of RFID readers to cover the whole area (such as a warehouse). This geometry would detect both horizontal and vertical location of components, products and people with RFID tags. The maximum distance between two neighboring readers can be based on the range of readers and the location accuracy required [Varshney, 2003].

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. Even wireless LANs and RFID-based systems could support applications requiring outdoor location management.

Since many indoor tracking applications require higher location precision, smaller wireless local area networks (WLANs) and personal area networks (PANs) should be used for indoor location management. Indoor tracking for healthcare applications could be performed using specialized cells (where a base station can locate in a very small area, but a significant number of base stations are required to cover the whole area), wireless LANs, ad hoc personal area networks (PANs), and Radio Frequency ID (RFID). It should be noted that RFID-based systems have very short range if passive tags are used. Additional power is obtained by higher cost if active RFID tags must be used for increased range.

Several potential security and privacy problems must be resolved because important healthcare and personal information can be copied by a nearby RFID reader used by information thieves. There is also a potential for duplication of tags to receive "un-entitled" health benefits.

V. CONCLUSIONS AND FUTURE

With increasing cost of healthcare combined with an increased number of patients and retirees, it is imperative that technological improvements for existing healthcare systems be seriously considered, especially when it is clear that additional financial and human resources are unlikely to become available anytime soon. The significant and on-going advances in wireless and mobile technologies can support the vision of pervasive healthcare by improving and expanding the coverage of existing services. The increasing use of hand-held devices by healthcare professionals combined with increasingly available wireless networks, will lead to an increased deployment of pervasive healthcare services.

In addition to significantly improved access to pervasive healthcare, considerable cost savings can be achieved to bring the total cost of healthcare services to a more manageable level. In this paper, I discussed pervasive healthcare and related information systems and networking issues. Several current and emerging pervasive healthcare applications were presented as was an integrated wireless architecture to support these applications.

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EDITOR'S NOTE: The following reference list contains the address of World Wide Web pages. Readers who have the ability to access the Web directly from their computer or are reading the paper on the Web, can gain direct access to these references. Readers are warned, however, that

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