Wireless technologies for telemedicine

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Wireless telemedicine is a new and evolving area in telemedical and telecare systems. Healthcare personnel require real-time access to accurate patient data, including clinical histories, treatments, medication, tests, laboratory results and insurance information. With large-scale wireless networks and mobile computing solutions, such as cellular 3G, Wi-Fi mesh and WiMAX, healthcare personnal can tap into vital information anywhere and at any time within the healthcare networks. The recent introduction of pervasive computing, consisting of radio frequency identification (RFID), Bluetooth, ZigBee, and wireless sensor networks, further extends the potential for exploitation of wireless telecommunications and its integration into new mobile healthcare delivery systems.

In this paper, snapshots of current uses and future trends of various wireless communications in the healthcare domain are highlighted. Special attention is given to the challenges of a telemedicine environment equipped with different wireless technologies and how the resulting issues might be addressed in medical services integration to provide flexible, convenient and economical medical monitoring, consultation and healthcare.

1. Introduction

Telemedicine is the use of modern telecommunications and information technologies to provide clinical care to individuals located at a distance, and to support the transmission of information needed to provide that care. It can be sub-divided into 'live' and 'store-and-forward' telemedicine. Live telemedicine requires the presence of both parties at the same time using audio-visual communications over high-bandwidth and low-latency connections. Almost all specialities of healthcare are able to make use of this kind of consultation, including psychiatric, medical, rehabilitation, cardiology, pediatrics, obstetrics, gynaecology and neurology, and there are many peripheral devices which can be attached to computers as aids to an interactive examination [1]. Store-and-forward telemedicine involves the acquisition of data, images and/or video content and transmission of this material to a medical specialist at a convenient time for assessment off line. Many medical specialities rely a great deal on images for assessment, diagnosis and management, and radiology, psychiatry, cardiology, ophthalmology, otolaryngology, dermatology and pathology are some of major services that can successfully make extensive use of the store-and-forward approach. In practice, however, a typical telemedicine interaction is likely to involve both store-and-forward and live interaction.

Both the traditional live and store-and-forward telemedicine systems provide an extension of healthcare services using fixed telecommunications networks (i.e. non-mobile). Various telemedicine solutions have been proposed and implemented since its initial use some 30 years ago in the fixed network environment using wired telecommunications networks (e.g. digital subscriber line) [2, 3]. Technological advancements in wireless communications systems, namely wireless personal area networks (WPANs), wireless local area networks (WLANs), WiMAX broadband access, and cellular systems (2.5G, 3G and beyond 3G) now have the potential to significantly enhance telemedicine services by creating a flexible and heterogeneous network within an end-to-end telemedicine framework. Given the advances of wireless technologies, many improvements in the quality, availability and effectiveness of telemedicine can be foreseen, with consequent impact on not only patient care but also the outcomes. In the future, integrating wireless solutions into healthcare delivery may well come to be a requirement, not just a differentiator, for accurate and efficient healthcare delivery. However, this raises some very significant challenges in terms of interoperability, performance and the security of such systems.

In this paper, the trend towards wireless telemedicine is examined by looking at how pervasive communications, ubiquitous computing, and context-aware mobile services come together to affect the telemedicine environment. This is followed by a description of a typical wireless telemedicine framework, the challenges foreseen, and the proposed approaches for meeting these challenges.

2. Wireless technology trends and their impact on telemedicine

There are a huge variety of potential telemedicine applications driven, in turn, by the huge and growing market size and the demographic shift in the average age of the population that will inevitably place an increasing burden on healthcare services around the world in coming years. However, the drivers towards the establishment of a more widespread telemedicine capability go beyond this demographic shift and include:

- critical shortages of medical staff in all developed countries, with US government projections indicating that there will be 114 000 unfilled registered nurse positions in the USA by 2015, while in the UK 21% of patients wait more than six months for in-patient care, and in Canada the wait is between 12 and 33 weeks — given the need for workflow efficiencies, interest in wireless medical telemetry systems, that are connected by local area networks (LANs), has proliferated [4],
- increases in chronic illnesses or medical conditions calling for continuous monitoring (e.g. diabetes, high blood pressure, at-risk heart patients, psychiatric conditions, depression),
- an increasingly complex medical environment in which errors which can contribute to increased hospital admissions [5],
- increased healthcare costs — higher hospitalisation rates and lengths of stay, increased levels of home healthcare,
- decreased access to healthcare providers.

Within this, the requirements for reliability, flexibility and portability make wireless technologies particularly attractive. The availability of pervasive communications, ubiquitous computing, and Web-based mobile applications, is already giving telemedicine a huge boost and together this family of technologies becomes a key enabler for wireless telemedicine, encouraging the use of high-bandwidth applications for clinic- and patient-based telemedicine services, as well as other low-bandwidth applications for the mass market. By providing portability and mobility, wireless telemedicine can allow the individual citizen to take greater care and responsibility for their own health. Consequently, substantial new markets are opening up in areas of sensor technology, integration of sensor technology into fixed and mobile consumer products, communications infrastructure (used in health maintenance and disease prevention), centralised diagnostic services (connecting the patient virtually to the service provider, reducing the need for travel), and unified medical databases.

2.1 Pervasive communications

Ad hoc networking and wireless communications technologies enable the communication of anything with anything else, not only between people but also between artefacts. With the various wireless technologies covering different niches, communications can be made available at any time, anywhere — like the air we breathe — and are well on their way to becoming pervasive.

The proliferation of radio frequency (RF) and microwave techniques over the last decades has resulted in the emergence of various low-cost broadband wireless solutions ranging from the last-metre connection of WPANs, to medium-range networking in WLANs (30 m to 100 m), and last-mile connection in cellular systems, wireless wide area networks (WWANs) or metropolitan area networks (WMANs). The last-metre access in a WPAN is accomplished by the introduction of IrDA, RFID, Bluetooth, ZigBee and ultra-wideband. This class of wireless technology is meant for cable replacement. With WLANs, Wi-Fi (IEEE 802.11a/b/g) is the dominant technology that allows users to access a data network at high speeds of up to 54 Mbit/s as long as users are located within a relatively short range (typically 30 m indoors and 100 m outdoors) from the access point (AP). Cellular systems and proprietary fixed wireless access systems have also been used for last-mile connection in the past. Wi-Fi mesh networks have emerged recently where nodes operate as a host and also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations. The dynamically self-organised and self-configured mesh networks result in low up-front cost, easy network maintenance, robustness, and reliable service coverage over extended areas.

The success of open-standard-based Wi-Fi WLANs has motivated the standardisation body, the IEEE, to develop IEEE802.16 and IEEE802.20 that can cover much greater distances with better quality-of-service (QoS) support than Wi-Fi. IEEE802.16, more commonly known as WiMAX, is a wireless metropolitan area network (WirelessMAN) technology that can provide backhaul connection to WLAN hotspots. It is regarded by many as a wireless alternative to cable and digital subscriber line (DSL) for last-mile broadband access. It facilitates connectivity between users without a direct line of sight (LOS) requirement and its coverage range is specified to be 50 km under LOS conditions.

The next-generation (NG) mobile communications, such as beyond-3G (B3G) and the fourth-generation (4G), will integrate existing wireless technologies, such as 3G, GSM, WLAN, Bluetooth, ZigBee, ultra-wideband, and other newly developed wireless technologies, into a seamless platform. NG services will be based on mobile triple-play (voice, video, data) with guaranteed QoS to support real-time multimedia applications such as citizen-centric healthcare systems. Another alternative for delivering high-speed communications to underserved areas is through satellite systems which have virtually worldwide coverage and a variety of data transfer speeds. However, satellite links have high capital and operational costs.

This landscape, of pervasive wireless communication, allows low-rate healthcare applications using WPAN systems to be deployed at low cost without the compatibility, portability and mobility issues created by wired interfaces, and to provide universal and untethered access to key information. On the other hand, high-speed wireless networks will enable and support bandwidth-hungry telemedicine applications that used to be feasible only on wired communication networks [6]. Chu and Ganz have, for example, proposed a mobile teletrauma system [7] that assists healthcare centres in providing pre-hospital trauma care. Wireless communications networks also have a role to play in enabling many potential telemedicine projects that have been hampered by the lack of appropriate telecommunications facilities in rural and under-developed areas that do not have cable wiring or other kinds of high-bandwidth telecommunications access. Such broadband wireless access networks also open up possibilities for continuing education and training for isolated or rural health practitioners, as exemplified by the LINCOS project [8].

2.2 Ubiquitous computing

Ubiquitous computing integrates computation into the environment and is realised through a number of inexpensive, lightweight and miniature sensors. In the healthcare environment these can perform long-term, unobtrusive and ambulatory health monitoring. Wireless diagnostic devices will become smaller, cheaper and less power hungry, making it possible to obtain health-related information from wearable, embedded or ingestible sensors [4, 9—12]. Progress in multimethod location finding will allow devices to report their whereabouts. The evolution in standards for identity tagging will allow every object to be given a globally unique reference. This will lead to the creation of low-power, self-organising 'mesh networks' to convey data from various sensors to the edges of LANs, and onwards to the global Internet. As such, a wearable wireless body area network (WWBAN) [13] is formed by the physiological sensors that monitor vital signs, environmental sensors, and a location sensor, to provide instantaneous health status to the user.

The rapid growth of wireless technologies has created extensive competition within the consumer market, resulting in a veritable explosion of lightweight, portable devices such as personal digital assistants (PDAs), tablets, notebook PCs, etc, that shows no sign of relenting. Coupled with the pervasive communications mentioned above, healthcare personnel can use these mobile devices to access vital signs information, review patient data and update patient charts [14]. When integrated into a broader telemedical system with sufficient volume of patient records, this has the potential to bring about a revolution in medical research through data mining of the collected information, though this in turn may create a significant computational challenge.

The forms of monitoring envisaged include temperature, heart rate (HR), electrocardiography (ECG), respiration, oxygen saturation by pulse oximetry (SpO_2), blood pressure and location. The conditions which can be monitored using this data include, for example, cardiovascular diseases, respiratory problems, post-operative complications, patients in transit to hospital, etc. The data sets recorded can be processed to detect events that indicate possible worsening of the patient's clinical situation, or explored to assess the impact of clinical intervention. The main implications of ubiquitous computing in telemedicine are:

- supports mobility and continuity in medical monitoring and treatment,
- ability to place a wide range of monitors in a home environment [15, 16],
- improved patient satisfaction through on-line viewing and self-management of the healthcare process,
- improved quality of patient care by reducing medical errors through automated order entry and alerting systems,
- remote access provisioning to medical facilities and specialists.

2.3 Context-aware mobile services

Context awareness enables the devices that have information about the circumstances under which they operate to react accordingly. A context-aware mobile service will utilise the intelligent agent technology, Semantic Web Service co-ordination and peer-to-peer computing to adapt to the constraints of mobile devices and wireless communication paths. This will provide a seamless healthcare service where users could easily access the various medical applications at any time and anywhere.

CASCOM (Context-aware Business Application Service Co-ordination in Mobile Computing Environments) [17] has demonstrated how a medical emergency assistance service could manage the on-the-fly co-ordination of pervasive health care services. For instance, a traveller who encounters a sudden medical problem will be directed to an appropriate healthcare institution which allows his/her medical records to be accessed to avoid redundant or unnecessary examinations and even advise on the treatment cost. As for the remote medical supervision, the intelligent and infrastructure agents could perform data processing, detect critical situations and determine proper actions to be taken. Moreover, such a system is still able to operate locally under intermittent connectivity. In addition, this system extends a one-to-many communication which allows healthcare personnel to construct virtual grouping of similar patients.

The convergence of mobile communications and context-aware mobile services supports informed decision-making in highly dynamic clinical environments, allowing doctors, nurses, emergency medical technicians and therapists to track down critical medical information immediately. The mobile service enables access to patient histories, laboratory data, radiological imaging, medication schedules and precriptions, at emergency rooms, elevators, satellite clinics, emergency vehicles and ambulances, and other more remote sites.

3. Challenges and solutions for wireless telemedicine

Figure 1 depicts the typical infrastructure and devices required to deploy wireless solutions in the healthcare sector. In this example, various medical sensor nodes attached to a patient in a hospital or home environment will form the WPAN for continuous monitoring, and send the collected data through the local gateway. Tablet computers, laptops and handheld scanning devices can be used within the coverage of the WLAN. Switches/routers are connected (wired) to a central database where healthcare personnel can access electronic medical records, timesheets, inventories, etc. Healthcare personnel in an ambulance will be accessing the hospital database using Mobile-Fi (upcoming 802.20), mobile WiMAX (802.16e-2005), or 3G evolutions that support mobility. The provision of wireless telemedicine ranging from WPAN, WLAN, WMAN to WWAN is not only a matter of technology but also encompasses medical, scientific, economic, social, political and legal issues. Here, three major challenges, namely interoperability and usability, coexistence and interference, and end-to-end QoS, are highlighted.

3.1 Interoperability and usability

Interoperability and usability are key to the success of integrating various wireless technologies into telemedicine applications. Coherent planning must take place from the outset, as the time to market (including clinical trials) can be long, typically 10 years from concept to exploitation. Manufacturers should be able to patent application concepts and architectures, while using open rather than proprietary communications standards to encourage the required interoperability

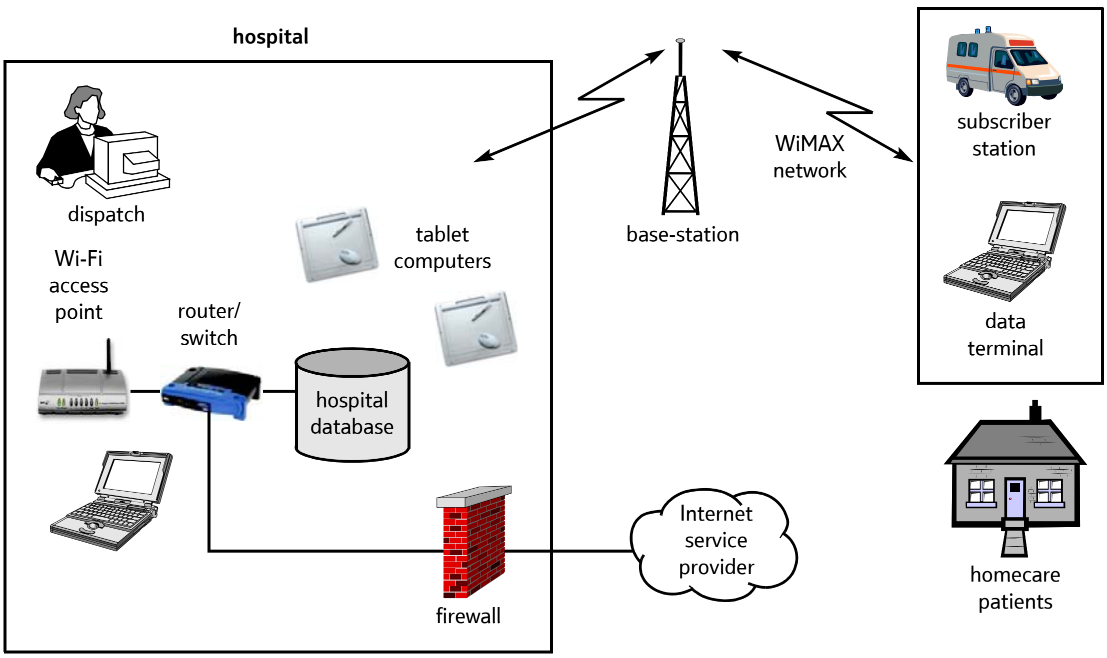

Fig 1 Technical environment for wireless solutions in healthcare sector.

and boost market take-up; for example, DICOM3, HL7, CorbaMed have all addressed storage, protection and encryption of patient data. However, there is still a lack of standardisation for data exchange, collaboration and negotiation protocols.

Standardisation of clinical medical communications processes is needed for intercommunication between medical devices and clinical information systems. Lack of such connectivity will hamper the completeness and accuracy of patient records during the monitoring process whether in hospital or in a remote environment [18]. The IEEE1073 group is developing guidelines in wireless technology usage for medical device communications within various healthcare environments. A close harmonisation with other standardisation bodies, such as the European Committee for Standardisation (CEN), to create a single set of international references, will enable manu-facturers to define a unified communications protocol, thus enabling devices to work in different bands in different countries, depending on local regulation and spectrum availability.

The Telemedicine Alliance (TMA), a partnership of the European Space Agency (ESA), the International Telecommunication Union (ITU) and the World Health Organisation (WHO), formulated a vision for eHealth by 2010, and has successfully completed its second phase project called TMA-Bridge — a bridge towards co-ordinated eHealth implementation in Europe, focused on eHealth interoperability and mobility aspects of European citizens — delivering a set of relevant reports and recommendations to the European Commission. The strategic plan recommends action from three levels of influence — political, organisational and social, and technical — which could facilitate cross-border health services. Such an initiative could potentially be extended to facilitate global interoperability of telemedicine systems and services.

The key to usability is devices that do not affect the appearance and function of the user. Hence miniaturisation of biomedical sensors will be needed to produce devices that are tiny, lightweight and 'invisible'. There are alternative approaches, however, and recently a number of companies have introduced 'healthware' in garment form to monitor breathing, temperature and heart rate. In the meantime, healthcare providers and researchers are evaluating various wearable or subcutaneous biosensors for remote patient monitoring. The use of implanted patient-data RFID chips may appear to be a natural extension of the latter. However, this possibility is already causing concern in terms of health risks, privacy and security. The Food and Drug Administration (FDA) of the United States spells out potential health risks associated with RFID implant devices such as adverse tissue reaction, migration of the implanted transponder, compromised information security, electrical hazards, etc. The privacy issues (i.e. that individual data could be easily accessed through an electronic scanner) are well known and have been extensively discussed. In this respect, wireless technologies exaggerate the dilemma for eHealth. Personal data is very sensitive but rapid access can be critical to life. This forms the complex and contradicting requisites of maximum privacy coupled with simple and speedy operation. Research directed towards the development of technical solutions to fulfil these requirements will underpin the practicable, versatile, universal and unfettered use of telemedicine.

3.2 Co-existence and interference

Wireless telemedicine will need to work over multiple or heterogeneous network services, i.e. pervasive computing where information can be sent to users through different types of network (e.g. WPAN, WLAN, WiMAX, 3G, B3G, etc). The flexible and adaptive integration of heterogeneous wireless networks is one of the most challenging tasks where handover, location, mobility, and resource management need to be addressed and planned carefully. As different requirements and constraints are imposed by the various telemedicine applications, and use-case scenarios prohibit the development of a single fits-all wireless technology, several radio options will have to be employed in order to support different applications and requirements in the formation of ubiquitous healthcare communities.

As multiple wireless access technologies sharing the same radio spectrum will be utilised simultaneously in the same space, the interference level between them has been raised as a major concern for such important and possibly life-critical applications. Evaluations from Golmie et al [19] indicated that Bluetooth protocol specifications (e.g. seven slaves in a Bluetooth piconet), and the interference between piconets, have limited the use of Bluetooth for medical sensors. On the other hand, IEEE802.15.4 technology faces the problems of limited bandwidth (e.g. highest data rate of 250 kbit/s on each of 16 channels in the 2.4 GHz band) and MAC protocol design (e.g. a high probability of packet collision when multiple sensor nodes access a single access point and co-channel interference when all the channels are in use) where very specific topologies need to be designed to support the high sensor density area. In the case of telemedicine, conventional interference mitigation practices, such as power control, multiple-input multiple-output (MIMO) techniques, and antenna beam-forming, may not be applied directly without modifications. For example, power control and antenna beam-forming techniques that are commonly used in cellular systems may not be used directly as the rapid changes of effective isotropic radiated power (EIRP) may cause significant electromagnetic interference (EMI) to the surrounding sensitive medical measurement, recording and display devices. Meanwhile, certain computationally intensive MIMO techniques (especially iterative-based algorithms) may not be suitable for use in wireless sensor nodes of limited processing power. In addition, the use of multiple antennas for reception or transmission may not be practical due to the limited physical size of medical devices.

Another study of the co-existence of IEEE802.15.4 (WPAN) and IEEE802.11b (WLAN) shows that WLAN traffic suffers from about 50% of packet loss while WPAN experiences up to 90% packet loss. Although the WPAN and WLAN interference problem could be solved by static network planning and optimisation, such as non-overlapping channels selection, it is not always possible due to various network scalability and management issues. Thus, potential solutions, such as heterogeneous network radio resource management, dynamic frequency selection, and vertical handover, should be studied to mitigate the interference problems. The co-existence and interference issues must be fully assessed as more wireless technologies are introduced in the same RF band, especially the licence-exempt spectrum. Further, the impact of the use of ultra-wideband within the wireless telemedicine environment should be investigated.

3.3 End-to-end QoS

Currently, cellular networks are the only metro-area mobile communications system that supports QoS in terms of high throughput as well as low delay (communication latency). However, the use of cellular communications devices in the vicinity of medical equipment still introduces a number of non-trivial EMI problems [20]. The proliferation of low cost Wi-Fi mesh networks in a number of cities, e.g. Taipei [21], has opened the door for the use of Wi-Fi to support a number of telemedicine applications that require high-bandwidth transmission. Generally, a Wi-Fi mesh network operates on the multihop principle without the need for high transmission power. However, its performance, in terms of throughput and delay, degrades significantly as users are located at an increasing number of hops away from the gateway. In order to solve the degradation issues, recent studies have focused on the use of multi-radio technologies (using different RFs for communications between the nodes and devices), as well as WiMAX as one of the transport channels between the mesh nodes. Meanwhile, the emergence of mobile WiMAX and IEEE802.20 (under standardisation) is expected to facilitate even more affordable telemedicine services and applications with mobility support (Wi-Fi mesh networks do not support mobility in principle).

QoS support for end-to-end communications does not guarantee good support for telemedicine applications without the presence of a suitable display for mobile devices. Devices capable of supporting broadband communications combined with additional features, such as location-based technologies and high resolution display screen, will further enhance the user experience. Although continuous research work has been undertaken on improving the resolution of mobile devices, context-aware technologies could be introduced to utilise whatever high resolution devices can be found in the vicinity instead of solely relying on the display of the mobile device. The lesson learned from the success or failure of new technologies is that timely availability of consumer devices with simple and convenient interfaces will be the key to future service development, revenue generation, and the establishment of a market-leading position.

4. Conclusions

This paper gives a snapshot of some completed, ongoing and emerging applications of wireless information technology in healthcare systems. It is shown that wireless telemedicine technology is heavily driven by emerging technological trends such as pervasive communications, ubiquitous computing and context-aware mobile services. These trends will facilitate various successful wireless telemedicine scenarios, provided that additional effort is put into solving issues such as interoperability and usability, co-existence and interference, and end-to-end QoS. Integration of the latest wireless technologies into telemedicine applications will enable better healthcare service for the consumer.

However, it is important to note that it is not possible, or even desirable, to dramatically transform the conventional healthcare system in the blink of an eye. Existing systems need to be improved and built upon, and the task of realising wireless connectivity in healthcare will need a variety of stakeholders to take a range of closely co-ordinated actions. They must create an open technical framework for connectivity, address financial barriers, and engage the public.

Special attention must also be given to the development of financial and other incentives as well as related processes, such as standards certification, to promote improvements in healthcare quality through the adoption of clinical applications and information exchange based on standards. In addition, it is also important to reach out to the public with a consistent set of messages to be used by government, healthcare professionals and consumer leaders to promote the advantages of wireless technologies in telemedicine as well as to encourage patients and consumers to access their own health information.

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