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PROSPECTS AND CHALLENGES OF WIRELESS TECHNOLOGIES FOR TELEMEDICINE NETWORK INFRASTRUCTURE

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ABSTRACT

The present view of medical environments where isolated networks are used for IT and medical applications is changing toward an integrated heterogeneous network scenario that can support a wide range of applications. Broadband Wireless Access technologies will play a fundamental role in enabling such integrated environment that is expected to support both medical and nonmedical applications. The ultimate goal is to exploit Bluetooth (WPAN), Wi-Fi (WLAN), and WiMAX technologies, as well as other wireless networks, such as 3G cellular systems and satellite networks, to support highly efficient medical care delivery, anytime and anywhere. This paper discusses some scenarios where Bluetooth, Wi-Fi, WiMAX, and 3G cellular technologies can be used to provide an integrated and ubiquitous network in medical environments. We also identify some issues of different medical applications when operating in integrated environment.

Keywords: Bluetooth, Wi-Fi, WiMAX, Satellite, Telemedicine, heterogeneous Wireless Network.

I. INTRODUCTION

Telemedicine is a rapidly developing application of clinical medicine where medical information is transferred via telephone, the Internet or other networks for the purpose of consulting, and sometimes remote medical procedures or examinations. Telemedicine may be as simple as two health professionals discussing a case over the telephone, or as complex as using satellite technology and video-conferencing equipment to conduct a real-time consultation between medical specialists in two different countries. Telemedicine generally refers to the use of communications and information technologies for the delivery of clinical care. Care at a distance is an old practice which was often conducted via post; there has been a long and successful history of in absentia health care, which-thanks to modern communications technologies- has metamorphosed into what we know as modern telemedicine. Recent advances in wireless technologies have opened up new possibilities that can revolutionize traditional health care delivery. Wireless connectivity provides the infrastructure and the mobility support for ubiquitous real time patient monitoring [1] and

tracking systems for emergency response [2]. The references [3-6], are few examples to show wireless technologies can be applied in medical environments to provide ubiquitous network that can be exploited to improve health care efficiency and deliver medical services to broader range of users.

The integration of Bluetooth, Wi-Fi and WiMAX technologies, which usually support higher data rates with smaller coverage range can be used to provide connectivity to medical and non-medical applications in scenarios such as hospital and medical clinics, and even at home or residential care centers. Unlike in the past where separate wireless spectra were used for medical and nonmedical applications, there is the need to use wireless technologies as a common communication infrastructure for administrative, entertainment, voice, video services, and medical applications, due to the fact that: legacy systems operating in narrow frequency bands as the Wireless Medical Telemetry Services, cannot support the increased bandwidth and quality of service (QoS) requirements of different medical applications; wireless systems operating in unlicensed frequency bands, such as Bluetooth, Wi-Fi and WiMAX are becoming more and more popular and elegant with increasing presence in remote areas, hospitals and homes; and they have cost saving potentials. Exploiting Wi-Fi, WiMAX and satellites for medical applications involves several challenges. Some of the issues were largely avoided in the past by customizing wireless devices for medical and non-medical applications separately and setting network parameters accordingly. Although providing different levels of service has been discussed in the context of generic applications, in which bandwidth and delay are usually the main requirements, the life-critical nature of some medical applications brings into the picture new constraints (e.g., high reliability, availability and very, low data source) that need to be taken into account in the design of wireless systems.

The outline of this paper is as follows. In section two, we provide an overview on WPAN (i.e., Bluetooth, UWB, Zigbee), WLAN (i.e.,Wi-Fi) and WMAN (i.e.,WiMAX) technologies, including that of satellite and 3G networks (i.e., WWAN) that are potential candidates for supporting medical applications in integrated environment and their applications to improve health care efficiency. Section three and four discuss on some prospective and different medical scenarios and identify the communication requirements of the medical applications. While section five highlights the prospects/opportunities of various wireless technologies and the challenges relevant to the medical environment and applications. The paper ends with a conclusion.

2.WIRELESS TECHNOLOGIES OVERVIEW

2.1 Wireless Personal Area Network (WPAN)

WPANs support limited range wireless connectivity. Short-range WPANs can be exploited in medical scenarios to connect wearable telemetry sensors around the patient to a bedsides monitor or a PDA that can act as bridges to the integrated network, as shown in Figure 2. Other applications for WPANs are to replace wires while interconnecting medical equipment. IEEE standards for WPANs are being developed under the 802.15.1/3/4 groups. Personal networks are used to connect various devices in a small area. Today, the most known of WPAN is Bluetooth/IEEE 802.15.1 [3]. Others known WPAN technologies are: one allowing a high data rate UWB/IEEE 802.15.3, and the other Zigbee/ IEEE 802.15.4, allowing low cost, low power device interconnections.

2.1.1 Bluetooth. The technology, firstly developed by the Sweden Ericsson makes it possible to make a master device communicate with 7 other slave devices. It is mainly designed to replace the wires which connect devices and peripherals. It is possible to constitute a maximum of 10 groups (80 devices in theory) in the same area. This kind of connection is dedicated to replace point-to-point connections or to interconnect two devices (personal assistant, telephone, micro-computer). Today standardized under the name IEEE 802.15.1, allows data rates up to 3Mb/s with up to 100 meters range. Bluetooth operates in the 2.4GHz ISM band and uses Frequency Hopping Spread Spectrum technology at the physical layer to provide data up to 2Mbps [3].

2.1.2 Ultra Wide Band (UWB). The new Ultra Wide Band standard uses a great part of the spectrum to exchange data. The UWB is standardized under the name IEEE 802.15.3 and makes it possible to transmit several hundreds of Mb/s on a few tens of meters (when 6 UWB systems are interacting together in the same area, with a 50 Mb/s maximum capacity each) [4]. WPANs based on UWB are attractive because:

1. They allow more devices to share limited spectrum.
2. They save power by transmitting only a fraction of the time and at lower power.
3. QoS requirements are met easily when excess bandwidth is available.

2.1.3 Zigbee. A network to mainly transmit commands but no important data streams. It is a low-data-rate WPANs which is designed to provide connectivity between low power devices to be used for applications such as sensor networks. Two physical-layer options are defined, both based on direct sequence spread spectrum. There is one air interface defined for 815 and 915MHz bands that supports data rates of 20Kbps (Europe) and 40Kbps (United States). The other interface is defined for 2.4GHz band and supports a raw data rate of 250Kbps There are two versions of Zigbee: a) IEEE 802.15.4 which allows to communicate at 250 Kb/s up to 10 meters to interconnect a maximum of 255 devices (2,4 GHz unlicensed band); (b) IEEE 802.15.4a which is limited at 20

Kb/s but allows an increased range until a maximum of 75 meters to interconnect up to 65,000 devices (900 KHz band) [5]. Zigbee is particularly adapted to the communication from object to object which does not require great data rates but whose cost must allow its integration in a great number of devices.

2.2 Wireless Local Area Network (WLAN)

These last years, the explosion of Wi-Fi devices made possible the discovery of the wireless network world. In the WLAN field, only HIPERLAN II tries to compete with it. The Wi-Fi standard family allows wireless network on short distances. These standards are sometimes associated with directional antennas to establish point-to-point connections. WLANs based on the IEEE 802.11 standard [6] are expected to be a major component to enable an integrated hospital and home networks. The 802.11 WLANs operate in the ISM (industrial scientific and medical) bands, with several flavors of physical layer available. The 802.11b and 802.11g operate in the 2.4GHz band and have data rates up to 11 and 54Mbps operating in the 5GHz bands. In fact, there exist several types of Wi-Fi networks:

1. IEEE 802.11: first standard of the series with frequency hopping spread spectrum with data rate 2 Mb/s);
1. IEEE 802.11b: theoretical data rate 11 Mb/s - range of 100 m to a maximum of a few hundreds meters- 2,4 GHz unlicensed band. This standard allowed the rise of wireless networks these last few years;
2. IEEE 802.11a: theoretical data rate 54 Mb/s (but decrease with distance faster than 802.11b). It's of about thirty meters range and in 5 GHz band;
3. IEEE 802.11g: theoretical data rate 54 Mb/s - range of a hundred meters - 2,4 GHz unlicensed band;
4. IEEE 802.11n: theoretical data rate 320 Mb/s about thirty meters range - uses two bands 2,4 and 5 GHz. QoS is included in the standard 802.11n.

Extensions:

5. IEEE 802.11e: QoS extension;
6. IEEE 802.11f: extension for managing handover (moving from one cell to another without drop);
7. IEEE 802.11i: security extension.

2.3 Wireless Metropolitan Area Networks (WMAN) and 3G mobile networks

Wireless networks adapted for covering cities and villages arrived few years after the Wi-Fi standards. They are:

2.3.1 WiMAX (World Interoperability for Microwave Access). The 802.16 IEEE standard technology that has the potential to replace all forms of telecommunications. The IEEE 802.16

WiMAX standard is being based on global interoperability including ETSI HIPERMAN, IEEE 802.16d-2004 for fixed, and 802.16e for mobile high-speed data[7,8]. Both the fixed and mobile standards will include licensed (e.g. 2.5, 3.5, and 10.5 GHz) and unlicensed (e.g. 2.4 and 5.8 GHz) frequency spectrum; however, the frequency range for the fixed standard covers 2-11 GHz while the mobile standard covers below 6 GHz. Depending on the frequency band, it can be Frequency Division Duplex (FDD) or Time Division Duplex (TDD) configuration. WiMAX will support line-of-sight (LOS) at a range up to 50 km (30 miles) and non line-of-sight (NLOS) typically up to 6-10 km (4-6 miles) for fixed customer premises equipment (CPE). The data rates for the fixed standard will support up to 75 Mbps per subscriber, peak, in 20 MHz of spectrum, but typical data rates will be more like 20-30 Mbps. The mobile applications will likely support 30 Mbps per subscriber, peak, in 10 MHz of spectrum, with 3-5 Mbps, typical. The base station will support up to 280 Mbps to meet the needs of many simultaneous users. Applications for fixed WiMAX (802.16-2004) include wireless E1 enterprise backhaul and residential 'last mile' broadband access, while applications for mobile WiMAX (802.16e) include nomadic and mobile consumer wireless DSL service.

WiMAX applications include: connecting Wi-Fi hotspots with each other and to other parts of the Internet; providing a wireless alternative to cable and DSL3 for last mile (last km) broadband access; providing high-speed data and telecommunications services; providing a diverse source of internet connectivity. Security is more improved and quality of service guarantee, but signal strength decreases proportional to the increase in distance from the base station. There is both flexibility and cost effectiveness, that makes the technology suitable for remote areas. On flexibility, WiMAX can be deployed in any terrain across all geographical areas.

2.3.2 Third Generation (3G). The 3rd generation wireless requirements are defined in the International Mobile Telecommunications "**IMT-2000**" project developed by the International Telecommunication Union (ITU). The IMT-2000 project that defined requirements for high-speed data transmission, Internet Protocol (IP)- based services, global roaming, and multimedia communications. After many communication proposals were reviewed, two global systems emerged; wideband code division multiple access (WCDMA) and CDMA2000.

- UMTS (WCDMA). A 3rd generation digital cellular system that uses radio channels that have a wider bandwidth than 2nd generation digital cellular systems such as GSM or IS-95 CDMA. WCDMA is normally deployed in a 5 MHz channel plan. The Third Generation Partnership Project (3GPP) oversees the creation of industry standards for the 3rd generation of mobile wireless communication systems (WCDMA). The

key members of the 3GPP include standards agencies from Japan, Europe, Korea, China and the U S. The 3GPP technology, also known as the Universal Mobile Telecommunications System (UMTS), is based on an evolved GSM core network that contains 2.5G elements, namely GPRS switching nodes. This concept allows a GSM network operator to migrate to WCDMA by adding the necessary 3G radio elements to their existing network, thus creating 'islands' of 3G coverage when the networks first launch.

- CDMA2000.A family of standards that represent an evolution from the IS- 95 code division multiple access (CDMA) system that offer enhanced packet transmission protocols to provide for advanced high-speed data services. The CDMA2000 technologies operate in the same 1.25 MHz radio channels as used by IS-95 and offer backward compatibility with IS-95. The CDMA2000 system is overseen by the Third Generation Partnership Project 2 (3GPP2). The 3GPP2 is a standards setting project that is focused on developing global specifications for 3rd generation systems that use ANSI/TIA/EIA-41 Cellular Radio Intersystem Signaling.

- TD-SCDMA. On a global basis, it is likely that WCDMA and CDMA2000 will dominate the 3G market, however in China there is growing support for a homegrown standard known as Time Division Synchronous CDMA (TD-SCDMA). TD-SCDMA offers voice services and data services, both circuit-switched and packet-switched, at rates up to 2 Mbps. It uses a Time Division Duplex (TDD) technique in which transmit and receive signals are sent on the same frequency but at different times. The timeslots on the radio carrier can either be allocated symmetrically for services such as speech or asymmetrically for data services where the bit rates in the two directions of transmission may differ significantly.

2.4 Wireless Wide Area Network (Wwan)

Satellite allows access and connections with several countries and facilitates the access to the Internet in the non accessible rural zones as shown in Figure 1. According to the satellite altitude, networks can be defined as [9,10]:

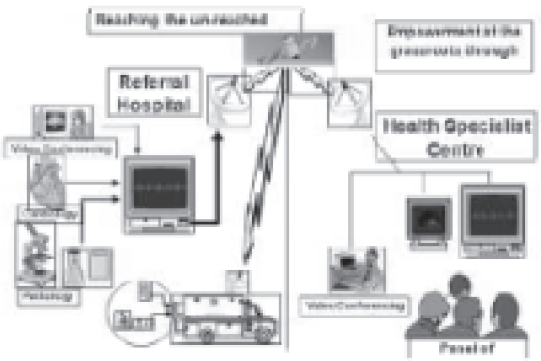

Figure 1. Telemedicine via satellite networks

1. **Geostationary satellites (GEO)**, located at 35,800 km of the ground, they remain in the same position in the sky. The satellites allow a bidirectional access using DVB-S standard downlink and more often DVB-RCS standard uplink. The equipment prices and bandwidth are variable according to technological use;
2. **Low orbit satellites (LEO),** require sending a "constellation" of the satellite in order to have a complete cover of the ground surface. After a difficult beginning of constellations of satellites, it found commercial applications such as telephony;
3. **Satellites in average orbit (MEO)**, this could in the long-term constitute a good compromise between the need for a reduced number of satellites and the proximity to the ground which allows less power consumption and reduced latency rate.

Table 1. Summary and analysis of broadband wireless technologies expected to support both medical and nonmedical applications in Telemedicine

zTechnology	Standards	Data rate	Frequency	Range	Mobility	Power consumptions
WPAN						Low power
Bluetooth	802.15.1	2Mbps	2.4GHz	100 m		<100mW
UWB	802.15.3	>50Mbps	3-10GHz	10 m	Very Low	<250mW
Zigbee	802.15.4	<250Kbps	2.4GHz	10-100m		1mW
WLAN						MediumPower
WiFi	802.11a	54Mbps	5.5GHz	30 m	Low	<1W
WiFi	802.11b	11Mbps	2.4GHz	100m	Low	30mW
WiFi	802.11g	54Mbps	2.4GHz	100m	Low	79mW
WMAN						Complex power control
WiMAX	802.16a	75Mbps	<11GHz	10Km	Not appl	
WiMAX	802.16e	15Mbps	<6GHz	50Km	Full	High power
WWAN						Complex power control
2G	GSM	2Mbps	900,1800MHz	3 to		
3G	UMTS	2Mbps	1800,1900MH	8Km NLOS	Full	
Satellite		2Mbps				High power

3. MEDICAL NETWORKING SCENARIOS

In this section and next, descriptions of some prospective scenarios and applications of wireless technologies to improve health care efficiency are done. Then we identify the communication requirements of the medical applications and describe some of the wireless technologies that can be applied in such scenarios. Categorization of the scenarios and applications from networking and requirements perspective are explained and we provide a simplified grouping, giving a broad picture of these technologies in health care environments.

3.1 Hospital Integrated Network: We looked into an integrated hospital network infrastructure that supports different applications in a seamless way as shown in Figure 2. This network will not only be used by typical information technology applications (e.g., Web browsing, email, etc.), but also be shared by a new range of medical applications such as: medical IT (e.g., image and video transfer, patient record access); medical telemetry; remote control of medical devices, such as infusion pumps and ventilators; and real-time multimedia applications, such as voice and video conferencing used for entertainment and remote medical procedures. WiMAX, WLANs and WPANs will play a fundamental role in such integrated environment to enable seamless connectivity as shown in Figure 2. For instance, wireless telemetry sensors attached to the patient (mobile body WPAN as in Fig. 2) can send data to a PDA, forming a short range WPAN, and the PDA equipped with a WLAN interface can continuously transmit physiological data to a central control workstation, as the patient walks along the hospitals hall. This scenario corresponds with single/multiple ambulatory cardiac patient use case in [11]. Figure 2 also shows patients recovering in an intensive care unit (ICU) while having his/her physiological data captured by body sensors that sends this information through a WPAN to a bedside monitor. The images and videos generated by medical diagnosis devices can also be sent across the wireless network to update digital records that can be accessible remotely through the internet. This scenario corresponds with single cardiac patient use case in [11].In another example, during peri-operative/ICU or operation room (OR) care, a patient could be moved through several units within a hospital with continuous connectivity requirements for several different types of medical devices. The ultimate goal of all these is to have a ubiquitous and integrated hospital network to improve productivity, reduce errors, and save time, so that the clinicians could spend more time analyzing data and giving more attention to the patients.

3.2 Residential/Home-Care Network- As wireless services become ubiquitous and health-care costs grow, some non-critical medical services would be offered away from hospitals. For example, elderly care in homes. In this second scenario, wearable telemetry devices can be connected to a remote

emergency center through the internet. More advanced applications such as remote real-time consults can also be supported, provided that residential/home network and the Internet can guarantee the required QoS for such applications. This scenario corresponds with home monitoring of single cardiac patients and wellness monitoring of single elderly patients in home use case as in [11].

3.3 Anytime, Anywhere Health Care- In the third scenario, an integrated wireless network that provides pervasive seamless connectivity to patients and health-care professionals is envisiaged. This heterogeneous network would integrate satellites and cellular systems, WiMAX, WLANs, and WPANs. Additionally, it would provide the underlying data transport system for a wide range of medical applications, making health-care information accessible anytime, anywhere and with any device. This third scenario is in line with the m-Health scenario proposed in [9] and references therein, that combines mobile computing, medical sensors, and communication technologies for health care. Also, medical evacuation use case described in [11] corresponds with this third scenario.

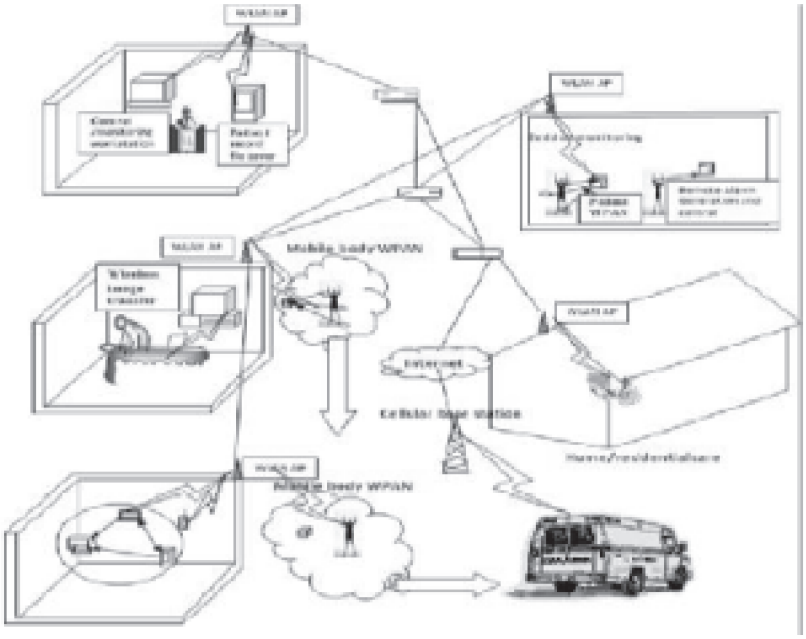

Figure 2. The integrated medical network scenarios in and away from a hospital.

4. MEDICAL APPLICATIONS AND REQUIREMENTS

The aforementioned scenarios in section 3 may include a great number of distinct applications. However, in order to study the practical issues imposed to the wireless technologies in such scenarios, we classify here the medical applications in categories, according to their requirements.

4.1 Office/Medical Information Technology- These are office oriented applications, such as email, Web browsing, file sharing, interactive access to patients' records, downloads of medical images and videos (e.g., X-rays, MRI, CT scans). Generally, these applications are bandwidth elastic and can recover from packet loss. For example, using transport layer protocols (e.g., TCP), and they are able to tolerate moderate delays. A patient's personal information must remain confidential, which imposes high security constraint.

4.2 Real-Time Noncritical Applications- These include real-time medical image transfer, video conference for remote consultation, and Voice over IP (VoIP). Although these applications can support data loss, they are delay sensitive and have confidentiality constraints. Ubiquity is also required, as the patient/clinicians must be able to maintain their connectivity while moving.

4.3 Real-Time Critical Applications- This category includes the monitoring of patients physiological function (e.g., cardiac signal monitoring). Typically, these applications require low bandwidth connectivity, but are highly sensitive to data loss and delay, since they are life critical. Therefore, reliability and mobility support are basic requirement.

4.4 Remote Control Applications- This category includes remote control of medical instrument, such as infusion pumps that control drug delivery and ventilation that supports physiological function. These applications require intermittent connectivity with very low bandwidth as well as very high reliability and no data loss.

5. PROSPECTS AND CHALLENGES

This paper in the last three sections has discussed extensively the various wireless technologies and has also described some prospective medical network scenarios. The paper classified the application in categories according to their various requirements. Table 2 below now summarize in tabular form some of the opportunities and challenges relevant to each technology in enabling a common communication infrastructure for administrative, entertainment, voice, video services, and medical applications in an integrated medical network environment.

CONCLUSIONS

Telemedicine allows physicians, nurses, and other medical professionals to offer a variety of medical services to remote patients. In turn, patients can contact and remain under close medical supervision without physical presence of

the healthcare practitioners. It can furthermore, be applied in a multitude of medical settings and contexts which include patient care, research, training, diagnostics, healthcare administration, exchange of information pertinent to medical case management, analysis of non-invasive films (x-rays, MRIs, MRAs, etc.), and the education of health professionals between hospitals and medical schools.

Wireless connectivity will enable applications to improve health-care delivery in many different scenarios. WWAN, WMAN, WLAN and WPAN technologies are the enablers for an integrated communication infrastructure at medical environments that can improve efficiency and reduce errors and cost. In this paper, we identified some future integrated scenarios where these wireless technologies provide a network infrastructure shared by medical and nonmedical applications with different requirements, as well as discussed the prospects and challenges involved in enabling such integration. The solutions to these challenges are not trivial, however, it's mainly due to the life critical nature of some medical applications that do not tolerate high delay, data loss, and the fact that wireless technologies would be required to support heterogeneous applications simultaneously in a shared environment.

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BIOGRAPHY

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Wireless Technology Standard	Advantages and Opportunities Relevant for Medical Environment (PROSPECTS)	Main Issues Relevant to Medical Applications (CHALLENGES)
WWAN /3G /Satellite	- Provide infrastructure for outdoor patient monitoring and emergency systems [1-2] Can enable the anytime, anywhere, health care Services. - Can reach out to the rural and remote medical care units. Support patient monitoring and control of medical devices beyond the hospital	Roaming support and integration with WLAN No QoS support. Coexistence with other technologies in the ISM bands and roaming support,
WMAN **WiMAX/ 802.16a/e**	An alternative to extend and enhance system coverage and capacity [7,8]	QOS provisioning for critical medical applications. Roaming support and integration with other networks
Legacy WLAN **WIFI/ 802.11**	Can support an integrated medical environment Can support voice and IT applications Low cost and high popularity Mobility support inside medical facilities	No QoS support. Coexistence with other technologies in the ISM bands. Power consumption. Roaming support, and Security.
WLAN 802.11e	Can provide guaranteed QoS. Can provide probabilistic QoS that can be used for real time critical applications.	Provisioning of guaranteed QoS under EDCA mode. Coexistence with other technologies in the ISM bands. Power consumption for battery operated devices. Fast roaming support, and Security.
WPAN 802.15.1/Bluetooth	Low power and low cost technology for short range connectivity Can support voice and monitoring applications	QoS provisioning for critical medical applications Coexistence with other technologies in the ISM bands. Roaming support and integration with WLAN, and Security
High data rate WPAN/UWB	Can provide the required QoS support for different applications including real time and IT applications	Roaming support and integration with WLAN Coexistence with other technologies in the ISM bands, and Security
Low data rate WPAN	Low power and low cost solution for monitoring and remote control applications	QOS provisioning for critical medical applications. Coexistence with other

Table 2. Wireless technologies and open issues relevant to medical applications