Emerging Wireless Technologies In E-Health

Trends, Challenges, and Framework Design Issues

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Abstract— **In healthcare the importance of obtaining the right information, at the right time, irrespective of time and location dependency is very critical. Healthcare personnel need to access real-time medical data such as patient clinical histories, laboratory results, treatments, chronic diseases, medication, and insurance information. Therefore, healthcare is the most apt domain for the application of ubiquitous technologies. Ubiquitous healthcare aims at creating an environment where healthcare is available to everyone, everywhere through the use of technologies that would not only be pervasive but also be assimilated flawlessly in the daily lives. With large-scale wireless networks and mobile computing solutions, such as cellular 3G, Wi-Fi mesh, WiMAX, Bluetooth, RFID, and Wireless Sensor Networks, healthcare personnel can tap into vital information anywhere and at any time within the healthcare networks. Ubiquitous healthcare, although promising, there are myriad challenges associated with realizing its vision. This paper highlights some snapshots of current uses and future trends of various wireless communications in the healthcare domains, addresses their applications for e-health, states the challenges faced in a ubiquitous healthcare environment equipped with different wireless technologies, and how the resulting issues might be addressed by developing a framework that provides a flexible and convenient medical monitoring, consultation, and healthcare.**

Keywords- m-health; telemedicine; e-health; wireless communications; RFID; Ubiquitous Computing; WSN

I. INTRODUCTION

Time and space are the most important barriers among healthcare providers and their patients. Patients are often physically remote to appropriate healthcare providers either in rural areas, accident scenes, on their way to a hospital, in a flight, etc. With the introduction of high bandwidth telecommunication technologies, time and space barriers are broken, and it is now possible to deliver audio, video, and data in real-time whenever and wherever needed [1].

Applied to healthcare, wireless technology has many advantages like providing data accuracy, reducing medical errors, and generally improving patient care. The benefits of this application can be illustrated in different examples. Healthcare professionals can obtain patient information from any given location because they are connected wirelessly to the hospital's information system. They can access patients' lab results, pharmaceutical information, histories, and insurance information. This will enhance medical resources, and improve the quality of patient care. Some handheld wireless devices can also be used for healthcare at home; for example to effectively monitor diabetes [1].

Telemedicine/e-health refers to the use of modern telecommunications and information technologies to transmit the necessary clinical information to deliver remote healthcare to individuals located at a distance. Telemedicine can be divided into 'live' and 'store and forward' telemedicine. *Live* telemedicine concerns the use of audiovisual communications over high bandwidth and low latency connections, and requires the presence of both parties at the same time. This can be used by almost all specialties of healthcare such as cardiology, psychiatric, pediatrics, neurology, etc., and there are many devices that could be used with computers to aid in an interactive examination. *Store and forward* telemedicine relies on the acquisition of data, images, and video content and their transmission to a professional, for an offline assessment. Many specialties rely on this type of telemedicine especially the ones concerned with radiology; such as cardiology, ophthalmology, dermatology, and pathology. A typical telemedicine interaction is likely to involve both types of telemedicine [1].

Mobile telemedicine is a new and evolving area of telemedicine, which exploits the recent developments in mobile networks for applications in telemedicine. The use of recent wireless communications systems, such as Wireless Personal Area Networks (WPANs), Wireless Local Area Networks (WLANs), WiMAX broadband access, and cellular systems (2.5G, 3G and beyond 3G) has significantly enhanced telemedicine services through the creation of a flexible and heterogeneous network, and improved the quality, availability, and effectiveness of telemedicine. The integration of emerging wireless solutions into healthcare has become a requirement for an accurate and efficient healthcare delivery; however it raises very significant challenges in terms of interoperability, performance, and security [1].

As reported by the U. S. Institute of Medicine, at least 98,000 people in the United States die every year because of medical mistakes and hospital infections. Some of the medical mistakes involve errors related to prescription of medicine, such as prescribing the wrong drug, loosing patient's medical history, and loosing medical records of patient's allergies and diseases [2].

In this paper the trend towards wireless telemedicine/e-health is examined by looking at how existing mobile technologies, pervasive communications, ubiquitous computing, and context-aware mobile services come together to affect the telemedicine environment in section I. Section II gives an overview of the challenges foreseen in wireless e-health. Section III provides a description of a typical wireless

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telemedicine framework and the proposed approaches for meeting these challenges, followed by conclusions and future work in section IV.

II. Emerging wireless technologies and their impact on e-health

A. Existing mobile technology

1) Second generation (2G) and (2 G+) wireless networks: Most of the second generation (2G) networks are based on circuit-switched technologies developed in different parts of the world: GSM (Global Systems for Mobile Communications), Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Personal Digital Communications (PDC). 2G+ technology is packet based and was developed by system providers for increased data communication speeds; as high as 384 kbps. 2G+ systems are based on the following three technologies: the *High-Speed Circuit-Switched Data* (HSCSD), the *General Packet Radio Service* (GPRS), and the *Enhanced Data Rates for Global Evolution* (EDGE) [1].

2) Third generation (3G) wireless networks: Various 2G wireless systems have converged into a single global system including terrestrial and satellite components; which is named the third generation networks (3G). The 3G wireless technology unifies existing cellular standards and provides the following air interface modes: Wideband Code Division Multiple Access (W-CDMA), CDMA2000, and Universal Wireless Communication (UWC-136). *W-CDMA* requires a bandwidth between 5 and 10 MHz and is suitable for higher capacity applications. *CDMA2000* is backward compatible with the second generation CDMA IS-95 standard used in the US. *UWC-136* was designed and proposed by TIA to comply with the North American ANSI-136 TDMA standard.

3G wireless networks have two independent networks; a Radio Access Network (RAN) and a core network. The *core network* provides the same functionality as a GPRS system and a circuit-switched domain, and consists of a packet-switched domain which includes 3G Serving GPRS Support Nodes (SGSN) and Gateway GPRS Support Nodes (GGSN). The *RAN network* provides different types of core networks with independent access for mobile terminals, and different appropriate RAN services. The RAN consists of network elements known as Node B and RNCs (Radio Network Controllers). *Node B* is similar to the Base Transceiver Station of 2G wireless networks. *RNC* replaces the basic station controller and provides radio resource management, handover control, and connection support for circuit-switched and packet-switched domains. The RAN and core network elements interconnection is based on ATM as a layer 2 switching technology. Many of the 2G and 3G wireless networks components are shared, interconnected, and similar. However, there exist many differences between the core network, the radio portion and other areas of the two networks [1].

Other wireless technologies namely Wireless LAN (WLAN), Bluetooth, and Wireless Application Protocol (WAP) have become popular and used as an alternative for wired LAN. *WLAN* allows users to access a data network at speeds of up to 11 Mbps as long as users are located within a relative short distance from the WLAN base station/access point; 30-50 meters indoors and 100-500 meters outdoors. Typically a WLAN network consists of two main components; the WLAN access point which is a base station, and the WLAN access card which is the client interface that talks to the access point. WLAN operates in two unlicensed bands; 802.11b and 802.11g operate in the 2.4 GHz band, and 802.11a operates in the 5 GHz band. *Bluetooth* is a wireless technology that enables electrical devices, such as PDA's and laptops, to communicate in the license free 2.5 GHz ISM (Industrial, Scientific, and Medical) frequency band. Bluetooth is a low-cost, low-size, and low-power radio technology suited to the short range Personal Area Network (PAN). *MMDS* (Multi-Point Multi-Channel Distribution System), referred to as wireless DSL or broadband wireless, is a broadband wireless technology used for internet access. It operates in the United States and Canada at 2.5 GHz and in many international markets at 3.5 GHz. It can serve a radius of up to 35 miles, and provide a data throughput of 500 Kbps to 1 Mbps, ideal for small and midsize business customers as well as consumers. Implementation of MMDS is ideal in geographical areas where wire line technologies such as DSL are not available [1].

3) Fourth generation (4G) wireless networks: The goal of 4G is to provide a wide range of mobile devices that support global roaming, and to replace the current proliferation of core mobile networks with a single worldwide mobile network based on IPv6 and used to provide uniform control, video, packet data and voice services. 4G networks will include three basic areas of connectivity: PANS such as Bluetooth, WANs such as IEEE802.11, and cellular connectivity. The objective is to provide global connectivity and mobility among networks, and allow users to benefit from seamless multimedia services by accessing an IP based infrastructure through heterogeneous access technologies [3]. Using this vision of the 4G infrastructure based on IPv6, companies will be able to introduce new services [4]. Table 1 below gives a comparative view of technologies from 2G to 4G according to different features.

B. Pervasive communications

Wireless technologies are on their way of becoming pervasive; covering different niches and making communications available at anytime, anywhere. Various low-cost broadband wireless solutions have emerged over the last decades, due to the proliferation of Radio Frequency (RF) and microwave techniques, including Wireless Personal Area Networks (WPANs), WLANs, cellular systems, Wireless Wide Area Networks (WWANs), and Wireless Metropolitan Area Networks (WMANs) [5]. Other short range technologies such as Infrared Data Association (IrDA), Radio Frequency Identification (RFID), Bluetooth, ZigBee, and Ultra wideband were also introduced [6]. Wi-Fi (IEEE 802.11a/b/g) mesh networks, 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, have also emerged recently. These networks are characterized by a dynamic self-organization and self-configuration which result in low up-front cost, robustness, easy network maintenance, and reliable service coverage over extended areas [5].

TABLE I. COMPARATIVE VIEW OF 1G-4G TECHNOLOGIES [4]

Technology/ Feature	2G	2G+	3G	4G
Year of deployment	1980/1991	1985/1999	1990/2002	2000/2006
Data Bandwidth	14.4 kbps	14.4 kbps	2 Mbps	200 Mbps
Standards	TDMA, CDMA, GSM	GPRS, EDGE, 1xRTT	WCDMA CDMA-2000	Single unified standard
Technology	Digital cellular technology	Digital cellular technology	Broad bandwidth CDMA, IP technology	Unified IP and seamless comination of broadband, LAN/ WAN/ PAN and WLAN
Service	Digital voice, SMS	Higher capacity, packetized data	Integrated high quality audio, video and data	Dynamic information access, wearable devices
Multiplexing	TDMA, CDMA	TDMACDMA	CDMA	CDMA
Switching	Circuit	Circuit for access network & air interface; Packet for core network and data	Packet except circuit for air interface	All packet
Core Network	PSTN	PSTN and Packet network	Packet network	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and Vertical

IEEE802.16 and IEEE802.20 were developed by the IEEE to cover much greater distances with better quality of service support than Wi-Fi [5]. IEEE802.16, known as *WiMAX* is a Wireless Metropolitan Area Network (Wireless MAN) technology that can provide backhaul connection to WLAN hotspots, and is regarded by many as a wireless alternative to cable and digital subscriber line (DSL) for last-mile broadband access. WiMAX 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) of mobile communications; beyond-3G and fourth-generation integrate existing wireless technologies into a seamless platform. The services of these generations will support the transmission of voice, data, and video with a guaranteed Quality of Service (QoS), and support real-time multimedia applications such as citizen-centric healthcare systems.

This variety in pervasive wireless communications allows both low-rate and bandwidth-hungry telemedicine applications to be deployed without the portability, compatibility and mobility issues created by wired interfaces. They will also help implementing many potential telemedicine projects in rural and under-developed areas that do not have telecommunications access or cable wiring.

C. *Ubiquitous computing*

In healthcare, ubiquitous computing integrates computation into the environment through the use of wireless sensor networks (WSNs). Miniature sensors can perform long-term and ambulatory health monitoring, such as heart rate and blood pressure monitoring. The use of smaller, cheaper and less power hungry diagnostic devices, allows obtaining health-related information from wearable or embedded sensors. Also, some devices are equipped with location finding techniques that allow reporting their whereabouts. Therefore, a *Wearable Wireless Body Area Network* (WWBAN) can provide instantaneous health status to the user through the physiological sensors that monitor vital signs, environmental sensors, and location sensors [5, 16].

Coupling the pervasive communications mentioned above with the lightweight portable devices such as PDAs, tablets, notebook PCs, etc., healthcare personnel can access vital signs information, review patient data, and update patients' records seamlessly. The main benefits of ubiquitous computing integration in healthcare include, but are not limited to the following: mobility and continuity support in medical monitoring and treatment, patient status report through the placement of a wide range of monitors in a home environment, 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, as well as remote access provisioning to medical facilities and specialists [5].

D. *Context-aware mobile services*

Context awareness refers to a general class of mobile systems that can sense their physical environment, and adapt their behavior accordingly. Three important aspects of context are: where you are, who you are with, and what resources are nearby. It is used generally to include nearby people, devices, lighting, noise level, network availability, and even the social situation; e.g., whether you are with your manager or with a co-worker [7].

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 prescriptions, at emergency rooms, elevators, satellite clinics, emergency vehicles and ambulances, and other more remote sites. For instance, a traveler 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.

III. CHALLENGES AND SOLUTIONS FOR WIRELESS E-HEALTH

Wireless e-health encompass in addition to advancement in technologies such as WPAN, WLAN, WMAN and WWAN, other medical, social, scientific, political, and economic issues. Hereafter, the major challenges including electromagnetic interference, patients' radiation exposure to wireless signals, interoperability and usability, coexistence and interference, and end-to-end QoS for wireless e-health are highlighted.

A. EMI (Electromagnetic Interference)

The electromagnetic interference (EMI) from sources such as cellular phones and wireless handheld devices with the medical equipment in hospitals has been a timely topic. These sources of EMI can cause medical monitors and other hospital devices to malfunction [8]. The impact of medical equipment malfunction can range from death or mere inconvenience to serious problems. Efficiency is also reduced by EMI and some incidents can occur for e.g. nuisances when alarms go off. EMI occurs when electromagnetic waves emitted by one device interfere with the normal operation of another. Sensitive electronic components inside any equipment that relies on computer chips can be vulnerable to other electromagnetic energy. Nowadays, hospitals have complex pervasive wireless communication networks that deliver patient information whenever and wherever it is needed, which leads to more EMI problems because most medical devices used in hospitals were not built to function in such an electromagnetic environment. In particular, devices that are used to measure patients' health indicators are the most susceptible to interference mainly for two reasons; the human body and the connecting wires act as antennae, and these devices can measure very low-level signals [9].

Many new devices are "immunized" to EMI and designed to be more resistant to unwanted electromagnetic signals. However immunization is a major technological problem given that it should be applied to an extremely broad spectrum. Some standards were also established for Electromagnetic Compatibility (EMC) and immunity; however they do not offer a complete solution because they are only applied to new devices. Testing for EMC of the equipment currently in use is expensive and impractical, since it requires testing every medical device under simulated conditions for every possible rare event and set of operating conditions. As medical devices and wireless communication networks become an increasingly part of the healthcare environment, problems with EMI will continuously grow and will have to be dealt with by organizations [9].

B. Radiation Exposure to Wireless Signals

It is worth mentioning the effects of wireless signals on the human body. Several considerations need to be taken into account when considering the possible shortcomings of exposure to wireless transmitters. First, exposure guidelines vary with frequency. Second, power output of the transmitter and its distance from the body should be considered; handheld devices operate at a low power but are used very close to the body, however some mobile units, e.g. ambulance vehicle radios, operate at higher power levels but their transmitting antennas are located far from users. Specific Absorption Rate (SAR) is the most useful measure of a person's exposure to RF energy. It measures the power absorbed in the body using watts per kilogram of tissue. In order to keep SAR levels safe in the body, many organizations have established limits for human exposure to RF fields [9].

C. Interoperability and Usability

Interoperability and usability are key issues when integrating wireless technologies into e-health applications. Manufacturers should encourage the use of open standards rather than proprietary ones, in order to boost interoperability and market take-up. The lack of standardization of clinical medical communications processes may affect the completeness and accuracy of patient records both in hospital and in a remote environment. Among standardization bodies that have developed guidelines for wireless technology usage within healthcare environments, the IEEE1073 and the European Committee for Standardization (CEN) have created references to enable manufacturers to define a unified communications protocol that enables devices to work in different countries depending on available spectrum and local regulation [5].

New wireless devices used in healthcare have implemented usability in order to not affect the patient appearance and function. Therefore, tiny, lightweight and invisible devices have been produced such as biomedical sensors for breathing, temperature, and heart rate monitoring, wearable and subcutaneous biosensors for remote patient monitoring, and implanted patient-data RFID chips. The implementation of the latter has raised health risks, privacy, and security concerns [5].

D. Co-existence and Interference

Many challenges are facing the flexible and adaptive integration of heterogeneous wireless networks, such as WSN, WPAN, WLAN, WiMAX, 3G, B3G, etc., in telemedicine, and need to be addressed and planned carefully. These challenges include but are not limited to handover, resource management, location, and mobility. Therefore several radio options have been employed to meet the different ubiquitous healthcare applications requirements [5]. The interference level between multiple wireless technologies that are sharing the same radio spectrum and used in life-critical e-health applications, has been raised as a major concern in e-health. Some of the conventional interference mitigation practices, such as MIMO techniques, antenna beam-forming, and power control, need to be modified before application to telemedicine due to the sensitive medical data and measurements used, wireless sensor nodes limited processing power, and limited physical size of wireless devices. The co-existence and interference issues as well as the impact of use of ultra-wideband within the e-health environment must be fully investigated as more wireless technologies are introduced in the same RF band [5].

E. End-to-End QoS

QoS is the ability to guarantee a certain level of performance to a data flow (bit rate, delay, jitter, packet dropping probability, and bit error rate), and to provide a different priority to different applications, users, or data flows. In the future, the user experience with mobile devices will be enhanced due to the introduction of new features such as location-based technologies, context awareness technologies, high resolution display screens, and support of QoS. QoS provisioning in wireless medical networks is becoming a need, due to the stringent requirements and real-time nature of medical data. Patient's measurements should be delivered quickly and reliably in an emergency care service; also mobility should be supported in case of an ambulance moving through different e-health domains, using different e-health applications [10].

Currently, QoS in terms of high throughput and low delay is supported only by cellular networks. However, the use of cellular communication devices in healthcare introduces a number of EMI problems. Low cost Wi-Fi mesh networks have been used to support a number of telemedicine applications that require high bandwidth transmission. However, the Wi-Fi mesh networks performance in terms of throughput and delay degrades significantly as long as the users are getting away from the gateway, due to the multi-hop principle used by this type of networks. WiMAX was suggested to be used as one of the transport channels between the mesh nodes in order to solve the degradation issues of Wi-Fi mesh networks. WiMAX and IEEE802.20 (Mobile Broadband Wireless Access) are expected to facilitate mobility support for more telemedicine applications and services [5].

F. Standardization

Patient monitoring in e-health requires the use of multiple monitoring devices and thus compatibility among these devices. The lack of technological standards would neither allow devices to communicate effectively, nor data to be stored and managed in different types of repositories. An international family of norms has been developed to standardize communications between health devices, the International Organization for Standardization (ISO)/IEEE 11073 PHD (X73PHD). X73PHD allows the most suitable technology to be used by the devices depending on the application context while meeting certain minimal requirements. X73PHD maintains a range of selection of technologies, which helps easing integration and improving the health applications' technical features [11].

IV. E-HEALTH FRAMEWORK DESIGN CONSIDERATIONS

A framework for supporting an e-health application should consider the challenges stated above as well as current and future wired and wireless architectural needs. The framework should be built based on a modular approach that takes into consideration standards for interoperability, and support for security, privacy, multiple operating systems, multiple hardware platforms, multiple data formats, scalability, multiple wired and wireless communications protocols, and multiple application interfaces [12, 13].

The framework should consider the use of standardized data formats such as XML, ASCII, etc., in order to achieve a class of *interoperability* between disparate systems, applications, and transactions. It should be *scalable* both as a standalone solution and when implemented as a subset of an existing enterprise solution. Services of the framework should adapt and conform to available computing resources of the execution platforms be it a handheld device, a mobile phone or a personal computer. The framework should provide services and support to ensure a level of *high availability*. This is feasible by the use of checks and balances that utilize real time resources to ensure information, application and platform availability with redundant, fail safe options. The platform should provide *security* through encrypting/decrypting, and authenticating sensitive information using standard solutions derived from algorithms such as SSL, RSA, and 3DES. It should ensure the level required to meet necessary security levels using available approved standards. The framework should support the *Privacy Act* and inform users about some technologies that raise privacy issues such as RFID, where relevant. It can provide users with several options to implement privacy such as disabling tags, encrypting tags, and authenticating readers. The framework should support existing technology industry standards, as well as standards on security, privacy and interoperability [12], and consider *potential information overload*. It should be designed to take into consideration the receipt of vast amount of patients' data, and include linking remote monitors to special-purpose services that manage data on behalf of doctors, configure electronic medical records so they automatically receive information from remote monitoring devices, and process data locally and only inform doctors with concise summaries or alerts [13].

Applied to healthcare, FlexRFID middleware architecture, as described in [14], could be integrated with e-health applications as shown in Fig. 1. This integration ensures the e-health framework design considerations mentioned above.

The FlexRFID middleware will ensure the enforcement of applications' rules, such as security and privacy, through the use of the business rules management module (Fig. 1), in which applications can specify their preferences and rules upon registration time with the middleware [15]. FlexRFID will take care also of interconnecting different ubiquitous devices, processing the raw data collected from the devices, integrating this processed data with existing medical records, generating the adequate events, and inferring decisions to be applied by the various connected e-health applications; such as medical asset management, patient medical/caring management, drug/medical stock management, etc. An example of a medical process will be defined, and its corresponding application will be integrated with the middleware in a real-life case study. The flexibility of the FlexRFID middleware will allow the use of various hardware automation devices, the management of interoperability, availability, and performance of these devices, as well as the delivery of the processed data to the chosen e-health application depending on its preferences.

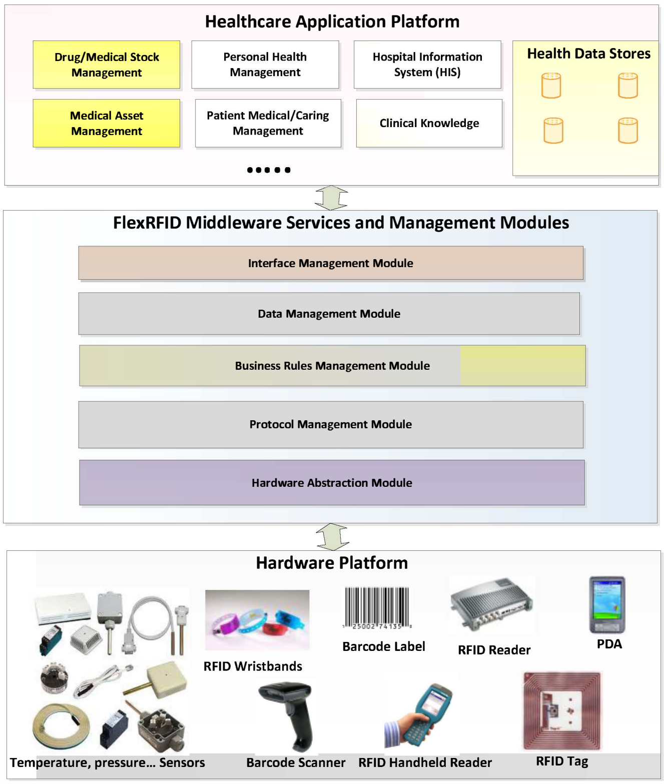

Figure 1. FlexRFID in a healthcare environement

V. CONCLUSION AND FUTURE WORK

The common goal of designing and implementing telemedicine solutions is to provide patients suffering from chronic diseases with mobile services that enhance their quality of life, support, and optimize their treatment in case of emergency. A conclusive system for improving the efficiency of healthcare should be designed taking into consideration the use of wireless communication networks, local intelligence in the form of a powerful mobile information unit, and connection to a global network. Wireless technology in e-health is heavily driven by technological advancements and trends such as pervasive communications, ubiquitous computing, and context-awareness. This paper provides a snapshot of these trends that will be used to facilitate various telemedicine scenarios and provide better healthcare for patients, and states some of the issues and challenges related the wireless technologies' implementation in healthcare, such as interoperability and usability, co-existence and interference, and end-to-end QoS. A range of coordinated actions should be taken by the different stakeholders in order to improve the existing healthcare systems and build upon them to realize the wireless connectivity. An open technical framework taking into consideration the design issues of interoperability, scalability, high availability, security, privacy, and support for standards should be created. Special attention must also be given to the standardization issue in order to promote improvements in healthcare quality through the adoption of clinical applications and information exchange based on standards. Also, it is important to face the public with convincing messages about the advantages of using wireless technologies in telemedicine, so that patients will be encouraged to access their own health information and trust the wireless e-health services. Our future work consists of integrating the FlexRFID middleware with an existing healthcare application, and developing a real case study for this integration using multiple devices, hardware configurations, and applying different business rules.

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