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Wireless Body Area Networks: Applications and technologies

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Abstract

The increasing use of wireless networks and the constant miniaturization of electrical invasive/non-invasive devices have empowered the development of Wireless Body Area Networks (WBANs). A WBAN provides a continuous health monitoring of a patient without any constraint on his/her normal daily life activities. Many technologies have proved their efficiency in supporting WBANs applications, such as remote monitoring, biofeedback and assisted living by responding to their specific quality of service (QoS) requirements. Due to numerous available technologies, selecting the appropriate technology for a medical application is being a challenging task. In this paper, the different medical applications are presented. The most common technologies used in WBANs are highlighted. Finally, a matching between each application and the corresponding suitable technology is studied.

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1. Introduction

Ubiquitous healthcare is an emerging technology that promises increases in efficiency, accuracy and availability of medical treatment due to the recent advances in wireless communication and in electronics offering small and intelligent sensors able to be used on, around, in or implanted in the human body. In this context, Wireless Body area networks (WBANs) constitute an active field of research and development as it offers the potential of great improvement in the delivery and monitoring of healthcare²². WBANs consist of a number of heterogeneous biological sensors. These sensors are placed in different parts of the body and can be wearable or implanted under the user skin. Each of them has specific requirements and is used for different missions. These devices are used for measuring changes in a patient vital signs and detecting emotions or human statuses, such as fear, stress, happiness, etc. They communicate with a special coordinator node, which is generally less energy constrained and has more processing capacities. It is responsible for sending biological signals of the patient to the medical doctor in order to provide real

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time medical diagnostic and allow him to take the right decisions.

As exposed in Fig.1, the WBAN common architecture consists of three tiers communications: Intra-BAN communications, Inter-BAN communications and beyond-BAN communications. Intra-BAN communications denote communications among wireless body sensors and the master node of the WBAN. Inter-BAN communications involve communications between the master node and personal devices such as notebooks, home service robots, and so on. The beyond-BAN tier connects the personal device to the Internet. Communications between different parts is sup-

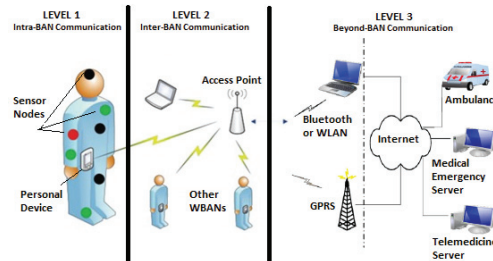


Fig. 1. General architecture for Wireless Body Area Networks

ported by several technologies, such as Bluetooth, IEEE 802.15.4. IEEE 802.15.6 was designed especially for WBAN applications while responding to the majority of their requirements. However, it looks less performing in some cases in comparison with other technologies supporting WBAN. Wi-Fi, Bluetooth and mobile networks can be solutions for implementing WBAN applications, since each technology offers specific characteristics, allowing it to meet the constraints of some applications⁴. In fact, WBAN applications cover numerous fields in order to improve the users quality of life. These applications can be categorized mainly according to whether they are used in medical field or in non-medical field. Non-medical applications include motion and gestures detection for interactive gaming and fitness monitoring applications, cognitive and emotional recognition for driving assistance or social interactions and medical assistance in disaster events, like terrorist attacks, earthquakes and bush fires. Medical applications comprise health-care solutions for aging and diseased populations mainly. Typical examples include the early detection, prevention and monitoring of diseases, elderly assistance at home, rehabilitation after surgeries, biofeedback applications which controls emotional states and assisted living applications which improve the quality of life for people with disabilities. Generally, body sensors used in health monitoring³ can be either : (a) Physiological sensors used to measure human body vital signals internally or externally, like body temperature, blood pressure or Electrocardiography (ECG); or (b) Biokinetic sensors able to collect human body movement based signals as acceleration or angular rate of rotation. To offer additional information about ambient temperature, environment pressure, light or humidity, ambient sensors can be combined to body sensors. In fact, since these sensors are in charge of monitoring the environment, they can provide valuable additional information for medical diagnosis and treatment, which is often the case in home environment⁸. However, the conception of WBAN applications should take into account many technical requirements, such as the motions and the temperature of the nodes, the node locations and the low node capacities in term of energy and processing. Other constraints tightly associated to wireless technologies, used for the communications between on-body and in-body nodes, must be taken into account, such as the short area range, the data rate, etc. ISO/IEEE 11073¹ specifies for some classes of medical applications the required data rates and latencies^{1, 21}. Besides, WBAN applications can involve additional requirements, tightly related to the medical application as well as the patient condition. For example, applications using implanted sensors should rely on mechanisms minimizing energy consumption in order to extend battery life; while achieving maximum throughput and minimum delay is a prerequisite for applications with high criticality, like operation of elderly heart patients. All these statements and requirements motivate us to study the different WBAN applications and to highlight the constraints to satisfy for the well functioning. We study also the different technologies used and try to associate the WBAN applications with the appropriate technologies in order to achieve the maximum of QoS. The rest of the paper is structured as follows. Section 2 describes the different

¹ ISO/IEEE 11073: International Organization for Standardization/ Institute of Electrical and Electronics Engineers 11073: Personal Health Data (PHD) Standards.

categories of WBAN applications. Section 3 reviews the different technologies used in WBANs while presenting their key characteristics making them appropriate in some WBAN scenarios. Section 4 exhibits the specific requirements for each category of medical applications and discusses the most appropriate technologies able to satisfy its prerequisite requirements. The final section concludes our work.

2. WBAN applications

WBANs support a number of innovative and interesting applications. These applications include several areas such as smart health care, assisted elderly living, emergency response and interactive gaming. As noted previously, many researches classified WBAN applications as medical and non-medical application^{1, 2}. In¹, the authors distinguished between in-body and on-body applications, for medical ones. In this section, we present an overview of the main categories of medical applications; their technical QoS requirements will be discussed in section 3.

2.1. Telemedicine and remote patient monitoring

The rising healthcare costs and the aging of the world population contribute to the advancements in telemedicine network for the delivery of several healthcare services. Telemedicine enables the remote delivery of patient care using integrated health information systems and telecommunication technologies and allows scientists, physicians and other medical professionals around the world to serve more patients. In fact, thanks to signals that body sensors provide, gathered information can be effectively processed to obtain reliable and accurate physiological estimations and to allow distant doctor to have real time opinions for medical diagnosis and prescription. Such smart health care system can provide applications for diagnostic procedure, maintenance of chronic condition and supervised recovery from a surgical procedure. Patient monitoring applications generally control vital signals, and provide real time feedback and information helping the recovery of the patient³. In such situation, we can keep the patient under doctor monitoring under natural physiological states without constraining their normal activities and without injuring him high cost. Daily-life activity monitoring monitors the activity during daily life of patients with some specific diseases; while in-hospital monitoring focuses on cases in which patients have to stay in a hospital for intensive care and observations, sometimes for a prolonged period. Meanwhile, several medical parameters are continuously recorded. Post-surgery in-home recovery monitoring deals with patients in their post recovery period after a medical operation/surgery and a recovery period spent in hospital. A WBAN can provide continuous measurements of the physiological parameters and allow better revealing organ failures and faster detecting emergency situations. Such remote monitoring system will be safer, more convenient and cheaper. In this field, many works have been proposed in literature. Some of them tried to design a generic framework able to support the majority of cases⁵, while others tried to study specific diseases. Cardiovascular diseases²³, diabetes¹⁴, cancer detection, parkinson¹³, asthma, Alzheimer and artificial retina are some examples of specific remote patient monitoring applications²¹.

2.2. Rehabilitation and therapy

The goal of rehabilitation is to allow patients to restore their functional capability to normal, through appropriate rehabilitative treatments after they were dismissed from hospital^{24, 25}. In fact, rehabilitation is a dynamic process which uses available facilities to correct any undesired motion behavior in order to reach an expectation (e.g. ideal position). To enable a person who has experienced a stroke to regain the highest possible level of independence so that she can be as productive as possible, the movement of patients, in a rehabilitation course, needs to be continuously monitored and rectified so as to hold a correct motion pattern. Consequently, detecting/tracking human movement becomes vital and necessary in a home based rehabilitation scheme. Sensor diversification, multi-sensor data fusion, real-time feedback for patients and virtual reality integration are examples of features that make rehabilitation a specific research area with specific constraints and requirements⁶.

2.3. Biofeedback

Self remote monitoring of human body is now possible, using WBANs to access data collected by the sensors. Sensors are implanted or placed in human body to monitor some behaviors or pathologies, and help patients to maintain

their health through biofeedback phenomena such as temperature analysis, blood pressure detection, Electrocardiography (ECG), Electromyography (EMG), among others. In this context, biofeedback refers to the measurement of physiological activity plus other potential useful parameters and feed them back to the user allowing him to learn how to control and modify his physiological activity with the aim of improving his health and performance^{18, 19, 20}. Biofeedback has been used since the early 1960s and has been shown to be useful in controlling emotional states and involuntary body functions, such as migraine and blood pressure. Biofeedback devices can include those that monitor breathing, heart function, muscle activity and brainwaves¹⁸.

2.4. Ambient Assisted Living

The aging population, the increasing cost of formal health care and the importance that the individuals place on living independently, all motivate the development of innovative-assisted living technologies for safe and independent aging. Applications in this field improve quality of life in order to maintain a more independent lifestyle using home automation¹⁵. In fact, assisted living facilities have emerged as an alternative housing facility for people with disabilities and elderly who are not considered independent but do not need around-the-clock medical care, as in nursing or retirement homes. An ambient sensor network can sense and control the parameters of the living environment and then delivers the body data to a central station, thanks to a continuous cognitive and physical monitoring. The health condition of these people can be estimated from their heart beat rate, blood pressure and accelerometer data. The system may be connected to a health care center for observation and emergency assistance, in case of strong changes in the observed parameters or deviations from the normal range²⁶.

3. WBAN technologies

WBAN may involve different technologies at different levels, as exposed in Fig. 1. In this section, we present a comprehensive study of the main proposed technologies for WBAN.

3.1. Bluetooth

Bluetooth technology¹² was designed as a short range wireless communication standard, intended to maintain high levels of security. Thanks to this technology, each device can simultaneously communicate with up to seven other devices within a single piconet, an ad hoc network including one device acting as a master and up to seven others as slaves for the lifetime of the piconet. Slaves have to synchronize by the system clock of the master and follow the hopping pattern, determined by the master. Besides, each device can belong to several piconets simultaneously, as they enter radio proximity of other master devices. The main attractive characteristic of Bluetooth is to allow a wide range of Bluetooth enabled devices to connect and communicate with each other, almost everywhere in the world. Another key feature is the ability of devices to communicate without need of line-of-sight positioning of connected devices. Thus, it is widely used for connecting a variety of personally carried devices to support data and voice applications. Bluetooth devices operate in the 2.4 GHz ISM band (Industrial, Scientific and Medical band), utilizing frequency hopping among 79 1 MHz channels at a nominal rate of 1600 hops/sec to reduce interference. The standard specifies three classes of devices with different transmission powers and corresponding coverages ranging from 1 to 100 m. The maximum data rate is 3 Mbps.

3.2. Bluetooth Low Energy

A derived option of the Bluetooth standard is the Bluetooth Low Energy (BLE)⁷, which was introduced as a more suitable choice for WBAN applications where less power consumption is possible using low duty cycle operation. Bluetooth LE was designed to wirelessly connect small devices to mobile terminals. Those devices are often too tiny to bear the power consumption as well as cost associated with a standard Bluetooth radio, but are ideal choices for the health-monitoring applications. Bluetooth Low Energy technology is expected to provide a data rate of up to 1 Mbps. Using fewer channels for pairing devices, synchronization can be done in a few milliseconds compared to Bluetooths seconds. This benefits latency-critical BAN applications, like alarm generation and emergency response,

and enhances power saving. Its nominal data rate, low latency and low energy consumption make BLE suitable for communication between the wearable sensor nodes and the access point (AP). Moreover, adaptive frequency hop spread spectrum allows BLE to co-exist with Wi-Fi. However, interference with other devices might be an issue as the technology operates in the 2.4GHz ISM band. Besides, Bluetooth is more advantageous in supporting applications with different data rates, network coverage and power requirements, it is most convenient for short-term high data rate applications in which two peer to peer devices are connected in an ad hoc configuration, such as between two personal servers of two WBANs or between a WBAN and a personal computer.

3.3. Zigbee and 802.15.4

ZigBee¹², defined by the ZigBee specification, is one of the wireless network technologies which is widely used from the low power environment. ZigBee is targeted at radio-frequency applications that require a low data rate, long battery life and secure networking, thanks to its 128-bit security support to perform authentication and guarantee integrity and privacy of messages. Through the sleep mode, ZigBee enabled devices are capable of being operational for several years before their batteries need to be replaced²⁶. ZigBee technology is separated into two parts. First, ZigBee alliance designates the application layers, defining the network, security and application software layers. Second, IEEE 802.15.4 standard defines the physical and medium access control layers, where access to wireless channel is through employing unslotted/slotted CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) mechanism for channel access and handling guaranteed time slot (GTS) allocation and management. ZigBee-based wireless devices operate in 868 MHz, 915 MHz, and 2.4 GHz frequency bands. Thus, one significant disadvantage of Zigbee for WBAN applications is due to interference with wireless local area network (WLAN) transmission, especially in 2.4 GHz where numerous wireless systems operate. Another disadvantage of Zigbee is related to its low data rate (250 Kbps), which makes it inappropriate for large-scale and real time WBAN applications. In fact, due to the low data rate, it is difficult to implement in hospitals or clinics (multiple patients); But, it is ideal for personal use (single patient).

3.4. IEEE 802.11

IEEE 802.11⁸ is a set of standards for wireless local area network (WLAN). Based on the IEEE 802.11 standards, Wi-Fi allows users to surf the Internet at broadband speeds when connected to an access point (AP) or in ad hoc mode. It is ideally suited for large data transfers by providing high-speed wireless connectivity and allowing video-conferencing, voice calls and video streaming. An important advantage is that all smartphones, tablets and laptops have Wi-Fi integrated; However, high energy consumption is an important drawback³.

3.5. IEEE 802.15.6

IEEE 802.15.6⁹ is the first WBAN standard that serves various medical and non medical applications and supports communications inside and around the human body. IEEE 802.15.6 standard uses different frequency bands for data transmission including: The Narrowband (NB) which includes the 400, 800, 900 MHz and the 2.3 and 2.4 GHz bands; the Ultra Wideband (UWB)⁴, which uses the 3.111.2 GHz; and the Human Body Communication (HBC) which uses the frequencies within the range of 1050 MHz. This standard is a step forward in wearable wireless sensor networks as it is designed specifically for use with a wide range of data rates, less energy consumption, low range, ample number of nodes (256) per body area network and different node priorities according to the application requirements. The channel access is handled using CSMA/CA or slotted Aloha access procedure. It provides flexibility in security features, since it defines three security schemes³. IEEE 802.15.6 standard can reach data rates up to 10 Mbps while being extremely low power. In addition, it can consider some movements of body (i.e., straight walking from one point to another), which is not suitable for emerging WBAN applications requiring scenarios such as sitting, laying, standing up, jogging, swimming and running. This standard can satisfy most of the WBAN applications throughput requirements by maximum achieving 680 Kbps. But, it is not able to meet the constraints of the emerging applications which require high quality audio or video transmissions.⁷.

3.6. Other radio technologies

In addition to most common technologies used in WBAN application development, other radio technologies can be efficient. The Ultra Wideband (UWB) technology is used for short-range communication systems and provides a high bandwidth. Because of localization of users is particularly important for indoor localization in assisted living facilities and in hospitals, UWB provides the only reliable method of localization. However, due to its complexity, it is unsuitable for wearable applications. ANT protocol¹⁰ is another emerging standard for wellness and health monitoring applications. ANT is a low speed and low power protocol being supported by several sensor manufacturers. The Zarlink technology^{16, 12} is ultra-low power, which makes it suitable for medical implant applications requiring low frequency and low data rates. Rubee active wireless protocol¹² uses Long Wave magnetic signals to send and receive short (128 byte) data packets in a local network. Rubee does not require line of sight communication for its operation. Additionally, Rubee has the advantages of efficient transmission distance, high security level, ultra-low power consumption, stable operation providence and long battery lifetime, which make convenient for many WBANs applications such as patient monitoring and mobile healthcare.

4. Applications versus technologies

WBAN medical applications show great promise in improving the quality of life of people and satisfying many requirements of elderly people by enabeling them to live safely, securely, healthily and independently. Since wireless medium provides a very convenient way for information transmission, wireless technologies are involved in communication among sensors as well as between the base station and sensors. Although, the IEEE 802.15.6 is defined to serve various medical and non medical applications, most popular and commonly used standards are IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (widely referring to ZigBee) in some applications. In fact, other considerations must be taken into account, such as data rate, interference which is generated by the coexistence of different technologies working in the same place, etc³. An appropriate radio technology for WBANs can be decided upon based on the specific requirements of a WBAN application. In this section, we discuss the requirements of each category of medical applications related to the wireless technology, and point out the ones able to support and satisfy these requirements. The specific requirements of WBAN are mainly:

- 1)Reliability:** Data sent by WBAN sensors concern heath information for which high reliability is required.
- 2)Latency:** Some medical applications handling emergency data cannot tolerate long response time. Thus, real-time transmission with performance guarantee is required.
- 3)Security:** such systems handle personal and critical data; the security and privacy of such data are becoming important issues.
- 4)Power consumption:** Battery replacement in WBAN is easy and so there is less focus on power consumption, for some scenarios.

These requirements may differ while considering the different operational environments and characteristics of each WBAN application. In fact, applications for rehabilitation aim to capture movements and postures of patients for monitoring his motor activities during rehabilitation therapy. Possible clinical applications include cognitive rehabilitation such as cognitive impairment or brain injury treatments, as well as motor rehabilitation such as post-stroke rehabilitation, post-surgery rehabilitation, post-accident rehabilitation or post-disease rehabilitation. As many sensors are used, taking into account the proximity of the nodes on the body and interferences should be considered at network layers to provide reliable communication. Besides, to correctly get the phenomenon being monitored, sensors should be sampled at high frequencies. The system must show high accuracy in data collection and data processing in order to extract correct medical information. It should also support real-time communications with guaranteed delays to deliver real-time feedback to the patient during rehabilitation sessions to allow the patient to adjust his movements immediately. As the health of patients is involved, the system must guarantee the delivery of alerts, such as falls of elderly during exercising, within strict delay constraints. Energy concerns can be considered for elderly or impaired patients to avoid burdensome battery charging.

Biofeedback offers also to users the ability to constantly monitor health parameters such as body/ intra-body temperature, heartbeat rate, arterial blood pressure, in an unobtrusive and efficient way. Monitoring biomedical human

parameters is critical to ensure normal human life and behavior. Thus, capturing these parameters has to be the most accurate and reliable as possible. Even, when the application feeds this biological information back to the user, the wireless technology adopted must take into account the intrinsic characteristics of such medium, such as interferences. Such application should take a special attention on sensor node energy constraints. In fact, sensor size constraints limit battery capacity and if a sensor stops working, a health parameter is lost. Besides, these physiological applications require designing solutions to address new challenges in efficiency, cost and user interface. For such application, it is imperative to transform raw sensor data in meaningful data for both patients and medical staff. Many provided solutions rely on Bluetooth enabled mobile devices, such as a Smartphone. Other approaches use a handheld device (such as a personal digital assistant (PDA)) to communicate with the sink node, allowing patient mobility. Current PDAs have computing power to process some data, while feature several gigabytes of flash storage. The proposed integrated system is centered on a feasible wireless architecture through both wireless and Bluetooth communications. Bluetooth is used for short-range connectivity between wearable sensors and a PDA, for patient feedback. The collected patient data will be managed by a micro database on a PDA and wirelessly transferred to a remote server via WLAN, for further treatment by medical staff if required.

An ambient Assisted Living (AAL) system²⁶ can provide healthcare monitoring and e-health services. Assisted living promotes independence and dignity (aging in place) while reducing medical costs. Smart Homes equipped with several acoustic, vibration and vision-based sensors can help monitor patient activity and lifestyle. Since the information transmitted in AAL systems is very personal, the security and privacy of such data are important issues. Thus, information exchange needs to satisfy confidentiality, integrity, and availability requirements. The IEEE 802.15.6 standard can be used to achieve efficient and secure communication, since it defines three security levels (Level 0 for unsecured communication, level 1 for authentication only and level 2 for both authentication and encryption). In case of emergency, guarantee for real time data is required. Telemedicine field also handles sensitive and important data, since it is related to human life. In-time detection of medical emergencies based on real time monitored patients physiological data, guarantee when sending such sensitive healthcare data must be satisfied in terms of transmission parameters and latency over a wireless network. For example, Wi-Fi cannot provide timing guarantees on packet delivery, while beacon-Enabled ZigBee can provide real-time communication by supporting GTS. However, Zigbee slow rate can be considered as a shortcoming. Table 1 resumes the specific requirements for each category of medical applications and the appropriate technologies used.

Table 1. Applications and QoS requirements

Application	Examples	QoS Requirements				Technologies used
		Reliability	Latency	Security	Power consumption	
Telemedicine	Remote Health monitoring	*	*			Bluetooth
	Emergency rescue	*	*		*	IEEE 802.15.6
	Chronic diseases monitoring	*	*	*	*	ZigBee
	Prevention and detection of diseases	*		*		WiFi
	Daily-life activity monitoring		*	*	*	RFID
	Post-surgery in-home recovery monitoring	*	*			ANT
Rehabilitation	Daily life and rehabilitation	*	*		*	ZigBee WiFi
Assisted living	Assisted living for elders	*	*	*		IEEE 802.15.6
	Treatments of peoples at home	*	*	*		ZigBee
Biofeedback	User biofeedback activity	*			*	ANT Bluetooth ZigBee

5. Conclusion

In this article, we review the major applications of WBAN and highlight their QoS requirements. The aim is to provide suitable and appropriate wireless technologies for such networks. For this purpose, a list of communication

technologies has been presented. An appropriate radio technology for WBANs can be decided upon based on the specific requirements of a WBAN application and at which level of the architecture it will be deployed. In a generic WBAN architecture, we can consider 1) intra-BAN communications between body sensors and a master node, where energy, latency and throughput concerns may be involved. 2) Inter-BAN communications between the master node and one or more access points (APs), where collisions and interferences can easily occur over a shared channel. Possible wireless technologies for inter-BAN communication include: WLAN, Bluetooth, Zigbee, cellular, and 3G, etc. 3) Beyond-BAN communications are required to enable authorized healthcare personnel (e.g., doctor or nurse) to remotely access patients medical information by means of cellular network or the Internet.

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