Wireless Body Area Networks: A Review with Intelligent Sensor Network-Based Emerging Technology

Shabana Mehfuz, Shabana Urooj and Shivaji Sinha

Abstract The increasing interest and the constant miniaturization of intelligent wireless sensor based devices have empowered the development of Wireless Body Area Networks (WBANs). Recent evolution in wearable and implantable sensors and rapid growth in the low power, energy efficient and short range wireless communication technologies are enabling the implementation of WBANs. The design of these networks requires the new protocols with respect to those used in general purpose wireless sensor networks. This survey paper aims at reporting an overview of the concept of WBANs with applications, characteristics, hardware design issues and supporting short range radio technologies and standards. A brief overview of the existing and past projects is also discussed. Finally, this article highlights some of the design challenges and open research issues that still need to be addressed to make WBANs truly ubiquitous for a wide range of applications.

Keywords Body sensors · Health care · On body communication · Propagation channel · Ultra wide band (UWB) · Wireless body area networks

1 Introduction

Body area networks (BANs) are a new kind of personal area communication networks consists of smart sensors placed inside, on or around the human body, typically consists of a collection of low-power, miniaturized, lightweight devices

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with wireless communication capabilities. WBANs enable different applications, especially in healthcare monitoring and hence new possible market with respect to Wireless Sensor Networks (WSNs). On the other hand, their design issues are affected by several challenges for new paradigms and protocols in the proximity of a human body [1].

Body Area Network is formally defined by IEEE 802.15 as, “a communication standard, optimized for low power devices and operation in the vicinity of or inside a human body to serve a variety of applications including medical, consumer electronics or personal entertainment and other”. It focuses on communication in the human body area that is the immediate environment around the human body which includes the nearest objects that may be part of the body [2]. Basic requirements of a WBAN are listed below

- Limited coverage range (<0.01–2 m).
- Extremely low power consumption in sleep mode.
- Support of dynamic data rate ranging from 1 Kb/s to several Mb/s.
- QoS support for critical physiological data.
- Low latency over multi-hop network architecture.

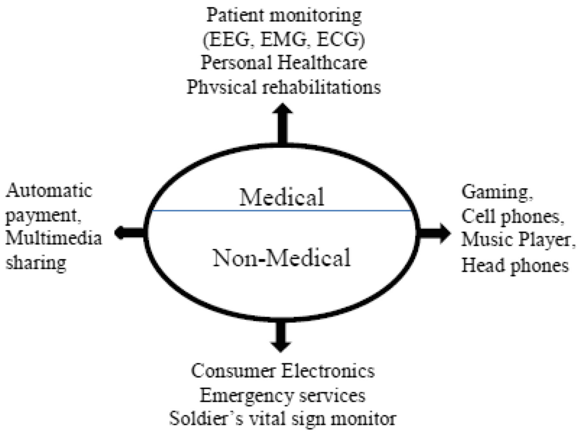
2 Application of WBAN in Health Care

There are different categorizations for application and usage models of body area networks. WBANs will play an important role in real time monitoring enabling ubiquitous:

- Medical health care services, e.g. Medical check-up
- Physical rehabilitations
- Physiological monitoring of vital parameters.

The tiny biosensors can collect various real time vital health parameters including blood pressure, SpO2, electroencephalogram (EEG), electrocardiogram (ECG), carotid pulse, glucose rate, body temperature. The BAN is also used in other non-medical areas such as military, sport, and entertainment. IEEE 802.15.6 categorizes WBAN applications in medical and non-medical (Consumer Electronics) as can be seen in Fig. 1. The WBAN can also be used in entertainment applications such as microphones, MP3-players, cameras, head-mounted displays and advanced computer appliances. They can be used in virtual reality and gaming purposes, personal item tracking, exchanging digital profile or business card and consumer electronics [3].

Fig. 1 BAN application categorization



3 Characteristics of WBAN

Unlike conventional wireless sensor networks (WSNs) and Adhoc networks, WBANs have their own typical characteristics. The following points distinguish WBANs from Wireless Sensor Networks (WSNs) and also create new technical challenges [3].

3.1 Architecture

A WBAN consists of only two categories of nodes; sensors in or on a human body and router nodes around WBAN wearers or second tier radio devices equipped on the wearers, functioning as an infrastructure for relaying data [4].

3.2 Density

When more nodes are required for a specific application, they are added accordingly in Body Area Networks. So the density of nodes is low in WBAN as compared to Wireless Sensor Networks (WSN).

3.3 Data Rate

Since WBAN is a heterogeneous network, which requires monitoring of periodical physiological activities, so require relatively stable data rate.

3.4 Power Supply and Demand

For the data acquiring, processing, and further transmission, WBAN requires suitable energy supplies. Implanted body sensor devices in the human body are powered by batteries, which are sometimes not possible to replace; thus, techniques like Wireless RF energy harvesting or body motion based energy harvesting must be required.

3.5 Latency, Reliability and Security

Because the medical information possesses confidential character, high reliability, low delay and stringent security mechanisms are required in WBANs mechanisms are required in WBAN to protect patient information.

3.6 Network Topology

In WBAN, it is more variable due to body motion, while very likely to be static in WSN.

4 Wireless Body Area Networks Architecture

The Body Area Network (WBAN) is a human centered communication network as shown in Fig. 2. The network consists of three types of nodes. The Sensor nodes consist of implanted and body surface nodes. These nodes collect vital parameters of the human body, such as ECG, EEG and EMG [5].

This information is transmitted to either intermediate router node or to an external coordinator node. The intermediate router node exchanges the data and control messages between the sensor and coordinator node. The Coordinator node is an external node which acts as a gateway for higher layer applications [3].

5 Hardware and Devices

A body sensor node consists of two parts; the physiological sensor and the radio platform as shown in Fig. 3.

The function of body sensor is to convert human's physiological energy to analog signals. Sensors are in direct contact with the human body surface or even

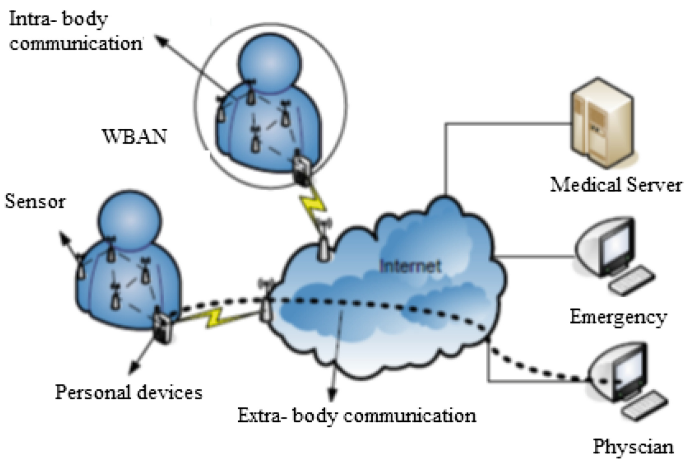


Fig. 2 WBAN application architecture of medical healthcare

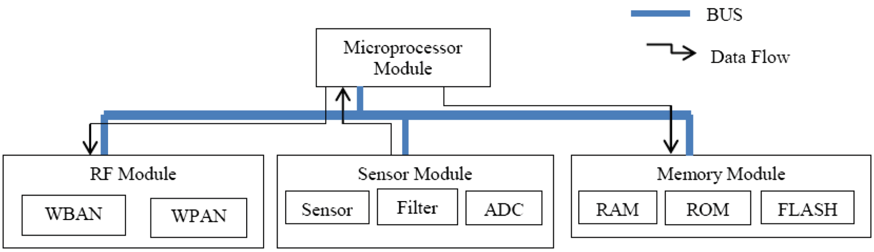


Fig. 3 Modules of sensor node platform

implanted inside the body, their size, quality of materials and physical compatibility is very important to human tissues. Short range radio technologies transmit the sensed data. The Table 1 compares the different radio interfaces in which overall IEEE 802.15.4 is widely adopted [2].

Table 1 Comparison of body sensor wireless platforms

Model	Wireless standard	Frequency (GHz)	Data rate (Kbps)	Outdoor range (m)
UWB	IEEE 802.15.6	3.1–10.6	10,000	<30
MicAz	IEEE 802.15.4	2.4	250	75–100
Imote2	Bluetooth	2.4–2.4835	250	30
ZigBit	IEEE 802.15.4	2.4–2.4835	250	3,700
BT node	Bluetooth	2.4	300	50
Mica2	IEEE 802.15.4	0.868/0.916	38.4	>100

6 Frequency Dependent Characteristics of Body

When the human body is exposed to an electromagnetic field, its characteristics are treated at the tissue level. Electrical properties of the human body are characterized by the cell membrane and the conductive intracellular fluid at the tissue level. When the human body is exposed to an electromagnetic field, its characteristics are treated at the tissue level. The human body has very unusual electromagnetic property values. The properties, electric permittivity and electric conductivity are not well known and depend on the activity of the person. These properties have been extensively studied in the last fifty years from 10 Hz to almost 10 GHz [6]. Since biological tissues, mainly consist of water, they behave neither as a conductor nor a dielectric, but as a dielectric with losses. The attenuation of transmitting power in the human body is due to absorption by body tissue, which is frequency dependent. At low frequency, the skin depth is large and therefore the electromagnetic wave can go into the depth of the human body.

Figure 4 shows the variation of electromagnetic properties for three representative tissues in the range 10 kHz to 1 GHz, blood (very high water content), muscle (high water content) and fat (low water content). Compared to classical dialectical materials, the dielectric permittivity is high. It is found that at 1 kHz, the relative permittivity of the blood is 435,000. With an increase in frequency, relative permittivity decreases. In the same way, the conductivity of the muscle varies from 0.3211 to 0.9982 in the 1 kHz to 1 GHz frequency band. The wetter a tissue is, the lossy it is; the drier it is, the less lossy it is. On the other hand, the permeability of biological tissues is that of free space [7].

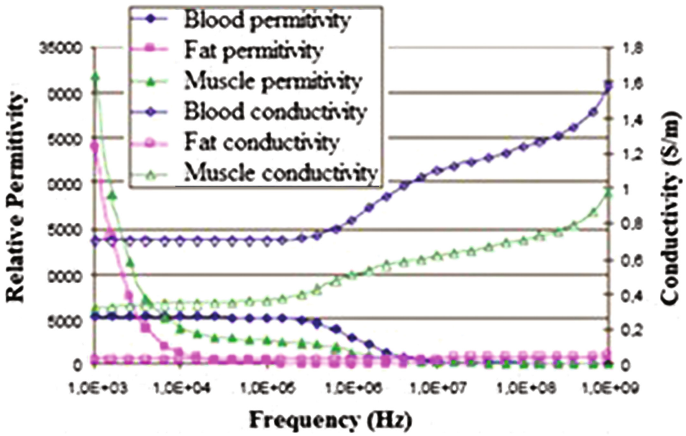


Fig. 4 Variation of electric properties with frequency for blood, fat and muscle tissues

7 Channel Modelling and IEEE 802.15.6 Physical Layer

In the past few years, researchers have characterized and model the propagation channel inside and on the body surface both through the measurement and simulation. Channel model is important for the development of

- More effective antenna with Low SAR with efficient coupling for to the dominant mode propagation
- Prediction of link performance for PHY layer.

WBAN is greatly affected by the amount of path loss that occurs due to different body channel impairments. It was found that the path loss depends on the separation between transmitter and receiver, location and height of antennas, propagation medium such as moist or dry air [12]. Equation (1) Suggests the path loss (PL) in [4, 8]

$$PL(d) = PL(d_o) + 10n\log_{10}\left(\frac{d}{d_o}\right) + \sigma_s \quad (1)$$

where, d_o is the path loss at a reference distance d_o, n is the path loss exponent, (n = 2 for free space) and σ_s is the standard deviation. Equation (2) gives the dependence of path loss of distance do as well as frequency f.

$$PL = 20\log_{10}\left(\frac{4\pi df}{c}\right) \quad (2)$$

where c is the light velocity.

The propagation of electromagnetic (EM) energy on the surface of the body or inside the human body has been investigated in [7]. The propagation around the human body is divided into

- Direct line of sight (LOS)
- Indirect or non-line of sight (NLOS).

In the former, the curvature effects on the body are not taken into account. While in the later, the effects of propagation from the front of the body to the side or the back of the body are evaluated. The simulation and experimental conclusions for propagation along the human body in the line of sight (LOS) channel model was studied in [7]. The studies were done for both narrowband and UWB signals. The path loss exponent n is calculated between 3 and 4, depending on the position of the nodes. The study in [9] shows that the antenna height impact on the path loss. The closer the antenna is to the body, the higher the path loss and a difference of more than 20 dB is observed for an antenna placed at 5 mm and 5 cm. The small size sensors and antennas will be close to the body which will result in a higher path loss [10, 11].

According to the Federal Communications Commission (FCC), Ultra Wide Band (UWB) technology has emerged as a solution for the wireless BANs. UWB refers to any radio technology having a transmission bandwidth exceeding the lesser of 500 MHz or 20 % of the center frequency. Due to low power spectral density emission and license free use in the 3.1–10.6 GHz frequency band, UWB is suitable for short range, RF emissions sensitive (e.g., in a hospital) indoor environment [13]. UWB transmitters are designed using simple techniques, although UWB receivers require complex hardware design techniques. It also consumes comparatively higher power. In order to achieve reliable, low power radio communication, a sensor node can be constructed using a UWB transmitter and a narrow band receiver.

Narrowband UWB pulses do not cause significant interference to other systems operating in the vicinity and do not represent a threat to patients' safety.

8 Research Challenges and Conclusion

In this survey paper, a comprehensive review of WBANs in terms of its applications, characteristics, network architecture, hardware requirement, physical layer modeling and recent low power, short range technologies is presented. As a complement to existing wireless technologies, the WBAN plays a very important role in interdisciplinary research and development. We truly believe that this survey can be considered as a source of inspiration for future research directions. Several open issues like Physical characteristics of sensors and effect of RF circuits, Biocompatibility, Security, Authentication and Privacy, Routing protocols still need to be addressed. In particular, for life-saving applications, thorough studies and tests should be conducted before WBANs can be widely applied to humans.

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