Review of Wireless Body Area Networks (WBANs)

B. Manickavasagam, B. Amutha and Priyanka Sudhakara

Abstract This comprehensive study guides the researchers to continue research in Wireless Sensor Networks and understanding of patient monitoring systems, protocold, and communication standards etc. This paper covers general wireless body area network (WBAN) architecture, methodologies, communication standards, and challenges to understanding. We summarize the frequency range, bandwidth, channel capacity, and bit rates of different communication standards and look at how to design sensor nodes and coordinator nodes for WBANs.

Keywords WBAN · Sensor network survey · WBAN standard
Vital parameters · WBAN survey · Patient monitoring system (PMS)

1 Introduction

Over the last one and half decades medical and personal monitoring systems research has grown rapidly. Nowadays, most people (both grownups and children) are affected by chronic diseases, but do not have the patience to continue their treatment in hospital due to the hospital atmosphere being offputting for most people. Researchers have identified these problems and are developing patient monitoring system (PMS) [1], which helps to keep the patients in their favored place (either the home or the workplace) with remote surveillance by a doctor or monitoring equipment. The sensor nodes of WBANs are placed or attached on the remote patient's body following either an on-body or in-body approach [2].

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Hence, patient's condition are monitored continuously if there is any change in their schedule based approach observation.

The rest of this paper is structured as follows. Section 2 explain vital medical signals and functionalities. Section 3 explain the WBAN architecture tier format. Section 4 describes the topology standards. Section 5 elucidates the IEEE wireless communication standard for sensor networks (SN). Section 6 contains the mode of WBAN communication, and Sect. 7 explains challenges facing WBAN.

2 Physiological Signals and Functionalities

Most WBAN systems use a combination of 2 to 5 vital signs to predict an emergency. They are temperature, measured in degrees Celsius (°C) or Fahrenheit (°F), blood pressure (BP) measured in millimeters of mercury (mmHg), heart rate (HR) measured in beats per minute (bpm), electrocardiography (ECG) and oxygen saturation levels (S_PO_2). In this section, we will discuss the above-mentioned parameters one by one.

2.1 Temperature

One of the basic vital sign is body temperature, or in other words, the body's capacity to generate heat; this temperature variation helps to find the initial stages of disease, for normal body temperature varies from 36.1 to 37.2 °C [3]. The temperature can be measured either by mouth (oral), rectal, skin or temporal (forehead), and ear (tympanic). It reflects the temperature of the body's core and underarm (axillary area) [4, 5].

2.2 Blood Pressure (BP)

Circulation of blood speed upon the blood vessels walls is termed blood pressure (BP). It is classified as systolic and diastolic. The heart contracts and pushes the blood to the rest of the body through arteries and this is known as systolic pressure, while diastolic pressure is the arterial pressure during the rest between heart beats. Normal human blood pressure is 120/80 mmHg (systolic/diastolic). Another form of calculation for blood pressure is mean arterial pressure (MAP) explained in Eq. (1) [6].

$$MAP = \frac{(2 \times diastolic\,Pressure) + Systolic\,Pressure}{3} \quad (1)$$

2.3 Electrocardiogram (ECG)

The passing of electrical impulse signals from the heart's sinoatrial node (upper right part of the heart or right atrium) called the SA node to rest of the heart. Human heartbeat rhythm produces four stage of signal waves, namely P-Waves, QRS Complex, T-Waves, and U-Waves.

- **P-Wave**: A signal passes from the SA node to the atrioventricular (AV) node. The other form of this process is called depolarization.
- **QRS-Complex**: The AV node passes the electrical impulse to the ventricle through AV bundles and branches.
- **T- Wave**: This represents ventricular repolarization
- **U-Wave**: This represents repolarization of the papillary muscle

2.4 Heart Rate (HR)

Another primary vital sign which helps to diagnose a disease is heart rate (HR). It varies depending on the stage of human, from birth to death. In our body there are four major locations to find the HR or pulse. These are the wrist, the inside of the elbow, the side of the neck, and the top of the foot. While measuring the pulse, some factors are considered and they are air temperature, body position, body size, and use of any medication. In [7] human heart rate variation and its effects are described, Fig. 1 shows the one heart beat's PQRSTU sign waveform and ECG graph and units are explained in Fig. 2.

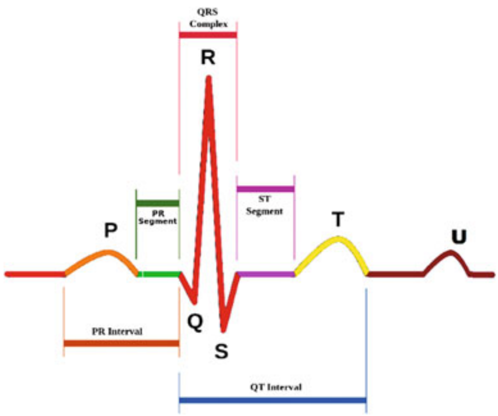

Fig. 1 Electrocardiogram waveform of one heart beat

2.5 Oxygen Saturation (S_PO_2)

This is a method used to find the oxygen level in our body, in other words finding the amount of oxygen-saturated blood hemoglobin in each pumping of blood from each heartbeat. A level of greater than 90% (96–100) of oxygen present in our blood hemoglobin is considered as a normal healthy S_PO_2 level for a human [8, 9].

3 WBAN Architecture

WBANs are categorized into a 3-tier architecture format. These tiers are sensor unit or sensor nodes (SN), gateway or coordinator unit (CU), and doctor's zone, as shown in Fig. 3. Depending upon the application, WBAN may be classified into another three types, namely in-body, off-body, and on-body communication [2, 10, 11].

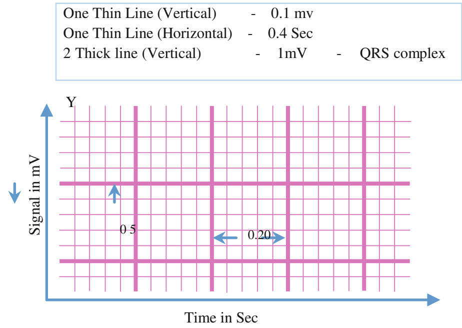

Fig. 2 Sample electrocardiogram graph

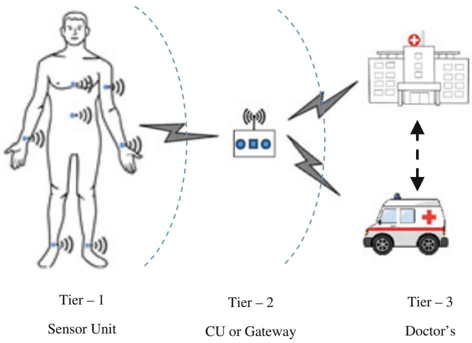

Fig. 3 WBAN architecture

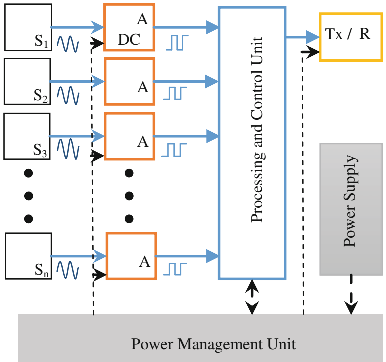

Fig. 4 Sensor unit components

3.1 Sensor Unit

Each sensor unit has different sensor combinations. It acquires or gathers biological signals from the human body. These signals are digitized through an analog-to-digital converter (ADC) and transmitted to a sink node through the processing and transceiver unit. A low voltage battery power supply is required for this entire process and it is managed by a power management unit [11] shown in Fig. 4,

where, S1, 2, 3, … n: sensors, Tx/Rx: transceiver and ADC: analog to digital convertor.

All sensor units transmit data to the sensor unit head present on the same floor or directly transmit to the gateway or coordinator present in tier 2 through near field communication (NFC).

3.2 Coordinator Unit

This unit acquires the all sensor node (SN) raw vital signals [12], processes them and sets the priority level based upon human vital sign thresholds [13]. It transmits the information to tier 3 through wi-fi, mobile communication (GPRS, 3G, 4G), and WiMAX. If a vital sign exceeds the threshold, an alert message is immediately sent to the doctors as well as to an ambulance unit. The coordinator acts as the decision maker for creating priority signals and sending them to the alert notification and immediate diagnosis system (IDS) to avoid unexpected situation.

3.3 Doctor's Zone

This acts as the centralized node, all patient's vital sign information have stored in this location, which helps to manage the patient health details, complete and later diagnosis process, and remote patient's continuous monitor, and it also communicates with the emergency care unit (ambulance service) [11, 14].

4 WBAN Topology

4.1 Star Topology

Sensor nodes communicate to a hub, called the coordinator, or the cluster head of a particular patient's cluster group. In this approach all sensor nodes communicate to the CH within the transmission period without affecting the transmission cycle of other sensor nodes. All sensor nodes are receiving the duty cycle information from Cluster Head. Based on this information cluster group sensor nodes are transferring patient information to CH.

4.2 Mesh Topology

Mesh topology used in both sensor node to coordinator communication, and coordinator to data server communication. In scenario one, sensor nodes communicate to the coordinator through single hop or multihop communication. In scenario two, the cluster head sends the details to a data server or hospital by the shortest and most reliable transmission path in an effective way through multihop communication.

5 WBAN Communication Standard

WBAN utilizes three types of communication technologies, namely short-, medium-, and long-range transceivers. This range of communications utilizes IEEE 802 standard [15], and the following section explains major wireless communication standards and the specifications used for WBAN. Table 1 describes existing research work's communication topology, feature and standards.

Table 1 Existing research work and its methodology and communication standards

Ref. no.	Sensors	Topology	Impact	Standard
[1]	ECG, respiration, temperature, pulse	Point to point	–	IEEE 802.11 b
[3]	Temperature	Point to point	–	IEEE 802.15.4
[11]	Three-Lead ECG, S_PO_2 and heart rate	Cluster		
[16]	Simulation	Multihop	Reduces latency, energy efficient, packet loss rate	CSMA/CA
[17]	Realtime	Point to point	Fall detection, criticality identification	–
[37]	Simulation	Cluster and mesh network	Less time delay, energy consumption	IEEE 802.15.4
[18]	Simulation	–	Energy efficiency, data rate	IEEE 802.15.6
[19]	–	Multihop	Routing, energy efficiency	IEEE 802.15.6
[20]	–	–	Energy efficiency	–
[21]	–	Star topology	–	–
[31]	–	Star topology	–	–
[22, 23]	ECG, S_PO_2 Blood Pressure	Mesh topology	–	–
[24]	Simulation	Star topology	–	–

5.1 IEEE 802.11

IEEE 802.11 is a standard developed for local area networks (LAN), in 1997. The 802.11 physical layer supports frequency hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), and infrared (IR). FHSS and DSSS utilize the 2.4 GHz industrial, scientific, and medical (ISM) band [25]. This standard is offered for tier 2 components (see Fig. 3).

5.2 IEEE 802.15.1

From 1989 onward most PMS communicated through Bluetooth technology. Bluetooth technology operates in the 802.15.1 standard within a short range over the ISM band at 2.4 GHz. This communication range varies from 1 m to below 100 meters. The bandwidth is approximately 720 Kbps to more than 20 Mbps and consumes 1 mV for 10-m range communication. In [26], there is a discussion about utilizing Bluetooth communication technology for a patient monitoring system in a home environment in order to detect disease in its early stages.

5.3 IEEE 802.15.4

IEEE 802.15.4 is a standard developed for low-range communication purposes. It helps in industrial monitoring, natural disaster sites, agriculture, and home automation and networking. It also offers a dual physical layer (PHY) that utilizes the DSSS method for low-duty cycles and low-power operation purposes. One PHY operates in the 2.4 GHz ISM band with 250 Kb/s in global, while the other PHY operates in the 868/916 MHz band for specific operation. The 916 MHz band is used in the United States (US), and the 868 MHz band is used by European devices at 20 Kb/s and 40 Kb/s respectively [27, 28].

5.4 IEEE 802.15.6

The final version of IEEE 802.15.6 was released in 2012 to handle the main issues in WBAN, like quality of service (QoS), low energy communication, maximum data rate, high reliability, lower error rate, etc. It supports ultra wide band (UWB), human body communication (HBC), and narrow band (NB) physical frequencies for communication with three different level of security mechanism. These are level 0: communication of unsecured, level 1: only authentication process, and level 2: encryption with authentication. IEEE 15.6 standard properties like, different communication frequencies, channel capacity, data rate and bandwidth capacity, which are all explained in references [29, 30].

6 Communication Scenarios

Sensor nodes communicate to a sink node or hospital server in different circumstances through the sensor network coordinator, and vice versa. The following subsections explaining the different communication scenarios.

6.1 Communication Based on Threshold Values

In this scenario the coordinator converts the analog vital signals into digital data which are acquired from the SN and have been compared with a normal patient's health information. This normal health information is obtained form different patients' health histories by a stochastic method, i.e. patients' gender, age, home environment, job, and any regular activities they carry out. After comparison, if the situation is critical then the coordinator sends the data to the data center, DZ, and the nearest care taker for immediate remedy or any other services required [31]. It is normal for the coordinator to send the details to the data center for future analysis of the patient.

6.2 Communication Based on Scheduling Algorithm

Using this scenario, the SNs' gateway transmits patients' vital information at a particular time interval which has been allotted by one of the controllers. Sender transferred the packets to sink and if it gets back acknowledgement from sink then the particular sender goes to sleep mode till next slot that particular goes to the sleep mode till next scheduling slot. In some critical situations the SNs' coordinator broadcasts the emergency beacon message to the other coordinators to update the scheduling algorithm [31]. Once emergency data have been transferred to the DZ, the entire network resume the previous scheduling approach.

7 Power Consumption

7.1 Energy Efficient Method

While communicating, sensor nodes consume more power in the first three layer levels, namely level 3: network layer (NWK), level 2: medium access control (MAC), and level 1: physical layer (PHY) [32]. To avoid more power consumption in the PHY, sensor networks are capable of transmitting data in the ultra-low power radio frequency band and adopt the periodic scheduled transmission tactic for data transmission instead of continuous transmission except in circumstances of critical and chronic disease monitoring. Radio turn off in no packet transmit and receive time and wake up whenever packet wants to transmit or receive depending up on scheduling or MAC slot allocation and communication scenarios (Sect. 6). Using this tactic we can reduce the energy consumption of sensor networks'. Network layer manages end to end delivery and packet routing, it selects the low cost shortest path for source and destination communication process. Due to this shortest path selection, we can reduce the packet delay, packet loss and more power consumption. In case, network layer selects the same path for n no of nodes communication at a time it leads to packet error. For example, during transmission it is not possible to ignore even one packet failure because in medical applications both reliability and QoS are important factors. Hence, the sensor node retransmits the packet to the sink node. If it's one hop or P2P communication then it affects only a particular sensor, but in the case of multihop communication it will reduce the lifetime of the entire network. In [33–35] authors are explained the energy efficient based data transmission methodologies and channel allocation strategies.

7.2 Self-powering Method

A normal human body generate heats at 20 mW/cm^2 [32]. This will vary depending on the climate, human activity, and clothing material [36]. Using a thermoelectric generator, we can convert human body heat to electrical energy. In [33], a thermoelectric energy harvester attached to a shirt, generated electricity in three situations, which are sitting in the office, outdoor bike parking and outdoors. The generated electrical power was approximately 1 mW @ 24 C, 1mW @ 17 C and 4 MW @ 17–19 °C respectively. Apart from this method, we can generate electricity using air flow, pressure, and vibration.

8 Routing

To increase network lifetime, QoS, reliable communication, and to avoid high traffic congestion, routing plays the main role. Routing is the functionality of network layer it guides to which way the information wants to send from source to destination in the efficient method. Based on the critical situation, sensor network power level, network traffic, communication range, reliability, and network cost, the network layer chooses the best route path for packet transmission [37]. Table 1 summarizes the few existing WBAN-aided PMS and their methodology, standard protocol, and topology.

9 Conclusion

In this review paper, we discussed WBAN architecture framework and its functionalities, how communication occurs between them, and the different communication standards developed and incorporated into PMS and WBAN architecture. Basic vital signs are explained along with their variations that can be used to predict a remote patient's health condition.

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