Review of wireless body area networks: protocols, technologies, and applications

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ABSTRACT

Nowadays, technology plays a vital part in our daily lives. Especially in medicine, such as consultations, examination, and operation, these processes are necessary and must be utilized accordingly. Medical checkups are required to ensure the patient's wellbeing. However, many people suffer from severe health conditions and are not always able to leave the house for examination. They are also not aware of potential risks within their body and therefore, don't feel the need to be examined. With the rise of new technological advantages, new solutions are being presented to tackle those issues. In the field of wireless sensor networks (WSNs), the wireless body area network (WBAN), alongside with its features and functionalities, can be regarded as one of the potential innovations for medicine, military, sport, and entertainment. With its tiny sensors, as well as with its plethora of applications, the WBAN is an excellent choice for remote medical surveillance and treatment. Furthermore, various routing protocols can provide proper solutions, depending on the application needs. However, challenges, such as energy efficiency, and security. are being further developed to improve the needs of its demands. This review is an overview of WBAN technologies, protocols, applications and potential challenges.

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1. INTRODUCTION

The constant improvements and discoveries in technology, as well the growing interest in development, lead to a noticeable increase of implementation of new innovations in several sectors of our daily lives. Sectors, such as industry, science, commerce, engineering, even military, and of course medicine have benefited immensely from these new technologies [1]. Specifically, in the field of wireless sensor networks (WSNs), such as the wireless body area network (WBAN), has there been a great enhancement for these sectors since these types of networks enable a constant and real-time surveillance and thus allows a greater accuracy in data evaluation. Areas, such as wireless health management systems (WHMSs) in particular, gained a tremendous amount due to possibility of being able to detect and, if necessary, treat acute and chronic diseases at an early stage [2], [3].

This review will focus on the WBAN alongside with its applications, which are used in WHMS. One of the big challenges of today's society is the increase of elderly people in relation to the younger demography, while healthcare facilities, with their human and financial recourses are quite limited. Thus, a solution is required in order to avoid an overload and consequential break of the healthcare system [4]. With an electronic healthcare system, using WBAN as its infrastructure, many issues can be successfully countered. Patients are able to be released earlier from hospitals, and thus relieving hospitals, since they can be monitored at home remotely [5]. Medical staff can then access the patient's physiological data from any station, which has access to the system. This method is drastically reducing the total cost for healthcare systems as well as increasing the accuracy of the patient's data, since they can be monitored over an increased amount of time [6]. Furthermore, in case of an emergency, medical staff will be able to respond faster since they will be alerted in a timely manner. All these factors will result in an overall improvement of the quality of life [2], [7], [8]. Furthermore, when WBAN is set as the network of choice, challenges, such as the right decisions regarding energy consumption vs quality of service (QoS), must be made. This review will have a closer look at the WBAN regarding its architecture, layers, routing protocols, the communication technology, applications, as well as energy efficiency. Furthermore, its performance, security, and QoS.

2. RELATED WORK

In recent years, WBAN has significantly increased in importance and popularity. This is evident by the amount of research that has been conducted in various fields of WBAN. Furthermore, WBAN offers a wide range of research opportunities, from its hardware design and specifications to its architecture, its protocols, security, energy efficiency, QoS and its vast types of applications. Research by Punj and Kumar [9] who focused on network architecture for WBAN applications in terms of data collection, data transmission, such as communication, energy, routing protocols and aggregation, as well as data analytics. Research by Aishwarya [10] did an analysis on the architecture, types, applications and drawbacks. The research of Hajar *et al.* [11] focuses on the security and privacy of the wireless area body networks. According to Hasan *et al.* [12], the main attention was in the architecture, technologies, challenges and different aspects of WBAN, as well as the architectural limitations of existing WBAN communication frameworks and possible future development of research incorporating software defined networking (SDN), energy harvesting (EH) and blockchain technology.

According Shokeen and Parkash [13], on the other hand researched the significant characteristics, issues and challenges specifically in medical applications. Research by Yaghoubi *et al.* [1], security challenges, sensor network architecture and functions, and communication technologies as well as mechanisms for increasing security and decreasing energy consumption are addressed. Research by Tavera *et al.* [14] are considering the computational and mathematical methods in medicine in regard to its regulations, requirements, applications, and challenges. Another research done by Kaur and Kang [15] was dedicated to a specific routing protocol algorithm, which was choosing a node based on its trust level. If a node was defined as malicious, the algorithm chose a different path instead. Research by Saleh *et al.* [16] is about privacy preservation and its security concerns. According to Adarsh and Kumar [17], smart e-healthcare scenarios that utilize advancements in the field of wearable medical sensors and efficient body area networks were researched. Especially challenging issues, such as energy, and time-efficient routing protocol were a priority. Additionally, they conducted a comparison of several communication technologies for body area networks.

According to Qu *et al.* [7], the focus was on the analysis of the routing protocol, as well as the classification and comparison of possible advantages and disadvantages of existing routing protocols. Abidi *et al.* [18] proposed a routing protocol, which is able to transfer data with a low energy consumption, rate as well as enabling a longer lifetime of the system via multi hop communication. Rady *et al.* [19] introduced a survey on hierarchical based routing protocols for mobile WSN (MWSN), which outlined classification of specific routing strategies in hindsight of mobility. Research by Zhong *et al.* [20], an extensive investigation was conducted concerning sensor technology for the collection of physiological data to the wireless transmission technology for the transmission process, for example frequency bands, and channel models. Additionally, an application specific integrated circuit (ASIC) based wireless area network plan is presented to improve its security and privacy with an ultra-low energy consumption rate.

Ananthi and Jose [21] conducted a methodological approach regarding security, safety, reliability, and fast transmission rate of a wireless area body network. Taleb *et al.* [22] presented a detailed survey on the use of low power wide area network (LPWAN) technologies, and the future 5G, B5G and 6G. Similarly, Olatinwo *et al.* [23] did also investigate LPWANs based on their power transmission, the data transmission rate and data reliability in hindsight of efficient data delivery, communication coverage and latency. Khan and Pathan [24] discussed several aspects WBAN, its communication architectures, applications, as well as programming frameworks, security issues, and energy-efficient routing protocols. Research by Narwal and Mohapatra [25] did a comprehensive review on security related challenges, such as malicious threats and malicious attack strategies and presented available solutions with detailed classification of security mechanisms, as well as recommendations for coming authentication strategies Pandey *et al.* [26] presented a detailed survey regarding the functionalities of body area networks with focus on architecture, communication, standards and protocol, applications as well as security. Research by Hariharan *et al.* [27] showed a methodical review of e-healthcare application concerning its challenges and possible solutions, including security related issues. This review is focusing on most aspects and characteristics and challenges of a WBAN, while the above-mentioned reviews are mainly focusing on only some of them. A detailed comparison between this review and the state-of-the-art surverys and reviews mentioned in related work are shown in Table 1.

Table 1. A detailed comparison between this review and related work

Authors	WBAN aspects and characteristics					Challenges			
	Architecture	Layers	Routing protocols	Comm. technologies	Applications	Energy efficiency	Performance	QoS	Security
Punj and Kumar [9]	✓		✓	✓	✓			✓	✓
Aishwarya [10]	✓			✓	✓				
Hajar *et al.* [11]	✓	✓							✓
Hasan *et al.* [12]	✓			✓	✓	✓		✓	✓
Shokeen and Parkash [13]					✓				
Yaghoubi *et al.* [1]	✓			✓		✓	✓		✓
Tavera *et al.* [14]	✓				✓				
Kaur and Kang [15]	✓		✓		✓			✓	
Saleh *et al.* [16]	✓				✓				
Adarsh and Kumar [17]	✓	✓	✓	✓	✓	✓			
Qu *et al.* [7]	✓		✓		✓				
Abidi *et al.* [18]	✓		✓		✓	✓			
Rady *et al.* [19]	✓		✓			✓		✓	✓
Zhong *et al.* [20]	✓	✓			✓	✓			✓
Ananthi and Jose [21]	✓				✓				✓
Taleb *et al.* [22]	✓			✓	✓	✓	✓	✓	✓
Olatinwo *et al.* [23]	✓			✓		✓		✓	✓
Khan and Pathan [24]	✓			✓	✓				✓
Narwal and Mohapatra [25]	✓								✓
Pandey *et al.* [26]	✓		✓	✓	✓				✓
Hariharan *et al.* [27]	✓				✓				✓
This review	✓	✓	✓	✓	✓	✓	✓	✓	✓

3. WIRELESS BODY AREA NETWORK

The rise of technological advancements and innovations in the fields of wireless communication, integrated electronic devices as well as digital electronics have resulted in the creation of a wireless network-based architecture. These networks are useful in several fields of science, engineering, entertaining and even military. However, medicine is the one field which is greatly benefiting from its possibilities since it allows for an enhanced provision regarding a variety of options to measure, analyze, detect, and diagnose various hazardous conditions of a human body [27], [28].

Several conducted surveys, the Ericsson Consumer Lab is one of the most prominent, showed that within the coming years, implantable chips and various biomedical sensors will be used very commonly within the population [3]. This is mostly due to the fact that WBANs enable relatively cheap, reliable, and highly adaptable software for e-health since it does not have any restrictions in mobility and locality [9]. Existing of many small devices as well as with a very low energy consumption rate, these nodes can be implanted within the body of the person, as well as placed on the body or even worn as a wearable on clothing, depending on its functionality [8], [29]. These nodes are categorized in three different types: sensors, actuators, and the main node. Collectively, these nodes form a WBAN [12], [18]. This WBAN consists of several programmable sensors which are equipped with wireless radio communication functionality and are primarily used to measure and monitor the patient’s physiological condition, such as heart rate, blood pressure (BP), brain activity, and body temperature. The actuators execute certain tasks based on the data given by the sensors, e.g., releasing medication within the body to regulate insulin levels for patients with diabetes [30], [31]. The collected data by the sensors is then sent to the main node, also known as body central unit (BCU) or body area network coordinator (BANC). This coordinator then sends the gathered physiological information via reachable networks, such as 4G-6G, Wi-Fi, and satellite. From there, it will be relayed to servers that are accessible to medical staff, ready to be evaluated [20], [32].

3.1. Architecture of wireless body area network

The concept of a WBAN was introduced in 1996 by T.G Zimmerman. The idea is, that these nodes are distributed and deployed on the body, typically in a star formation, with the BCU as the central point. Thus, the topology, which is used primarily, is a star topology. The BCU (for example a PDS or a smartphone) acts as an interface between the sensors and external networks or even other body area networks. The signals the BCU receives from the deployed sensors within and on the body are physiological signals, such as the electrocardiogram (ECG), the electromyography (EMG) and electro-encephalograph (EEG), as well as glucose levels, BP, and body temperature. All these signals are then uploaded by the BCU, which it then uploads to the medical server within the hospital or healthcare institute for further analysis and evaluation. The medical staff is also able to send a direct order to the BCU, if a more thorough analysis for a specific body part is required [28], [30], [32], [33]. The architecture itself comprises of 3 tiers, which is the intra-WBAN communication tier, the inter-WBAN communication tier and the beyond-WBAN communication tier as shown in Figure 1 [7], [34].

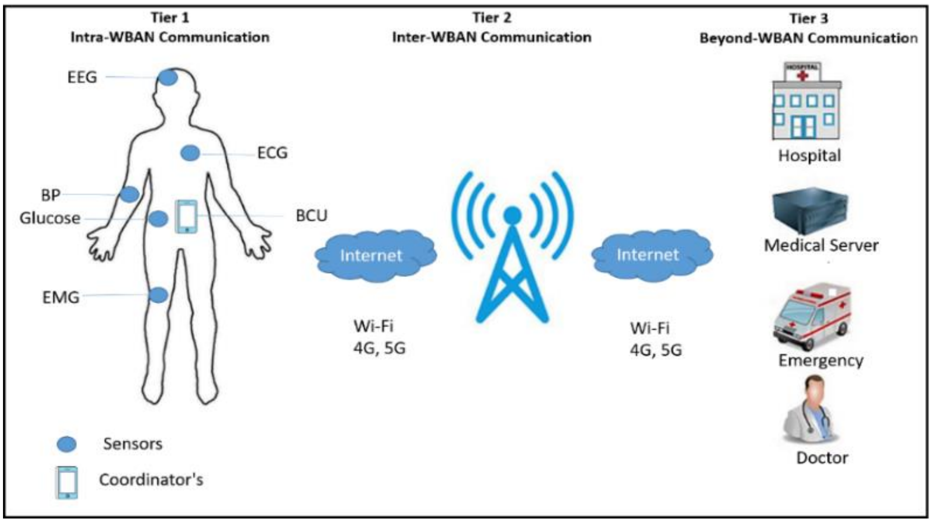

Figure 1. WBAN architecture

3.1.1. Sensors

The sensors consist of four different components. The microprocessor, the transceiver, the battery and two different types of sensor components, one type is implanted and the other is worn. These types of nodes are responsible for measuring, collecting and relaying data. They can be either kinetic sensor for determining movements, ambient sensors for communication and relay data to a near outside system and physiological sensors for the wearer's condition [1], [18], [20], [29].

3.1.2. Actuators

Like the sensor node, the actuator comprises a memory, transceiver, battery, and a specific hardware responsible for containing and managing the drug. In case of an irregularity, the sensors will notice it within the body and then notify the actuator to administer the drug directly into the patient. This is vital since this can respond fast in a case of emergency, e.g., regulating BP, blood sugar level, acute illness or even reduce high fever, can save lives [1], [18], [20].

3.1.3. Body central unit

The BCU is also known or referred to as personal device (PD). The main function of the bcu is to act as an interface and to communicate with the components of the WBAN as well as outside units. Outside unites, such as a personal digital assistant (PDA) or smartphones are then capable to relay the signal further to the medical servers [1], [18], [20], [24].

3.2. Layers of wireless body area network

There are two layers in WBAN protocol stack as proposed by Institute of Electrical and Electronics Engineers (IEEE) 802.15.6. The physical (PHY) is responsible for data transmission and reception, while the medium access control (MAC) layer, which is on top of the PHY layer, is responsible for controlling the channel access as shown in Figure 2. Both layers exist for communication purposes in and around human body in WBANs.

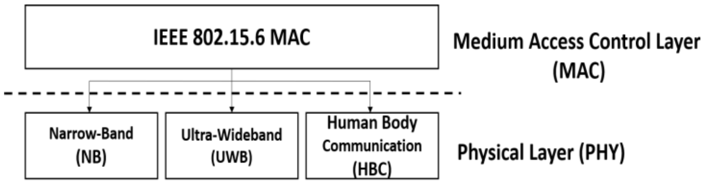

Figure 2. WBAN layers

3.2.1. Physical layer

The WBAN standard IEEE 802.15.6 has a very important task in the PHY layer. It is responsible for the activation and deactivation of the radio transceivers, the clear channel assessment (CCA), the data transmission as well as the reception. The PHY supports signal propagation with help of the ultra-wideband (UWB), the human body communication (HBC), and the narrow-band (NB) communication [9], [20], [31]. One of the great challenges regarding the PHY layer design is the channel model. Due to the human tissue, the communication of the sensors, which are deployed within the body and on the body, must be taken into consideration. Many improvements for protocols, adjusting to this challenge, have been created. However, not many of these protocols consider body movement within their parameters, even though it can have a great impact on energy efficiency, signal transmission and the overall performance of the WBAN [9], [35].

3.2.2. Medium access control layer

The importance of the MAC protocol design is seen when performance degradation of a WBAN is considered. Especially, since interference can have a great impact on the overall power consumption. Factors, such as overhearing as well as idle listening, packet collision and synchronization costs may influence a protocol negatively, if its design lacks efficiency. Another issue is that an inefficient MAC protocol can delay high prioritized communication, thus affecting the QoS negatively by neglecting to fully make use of the signal frequency bandwidth. And lastly, an efficient MAC protocol has to take the person’s movement into consideration in regard to efficiency of power as well as reliability of the entire wireless network structure [9], [20], [36].

4. WIRELESS BODY AREA NETWORK ROUTING PROTOCOLS

For a network to be established including all its devices as well as to be properly connected, routing is imperative. Aside from combining all pieces into one system, a proper path for the communication and transfer of data has to be set as well [7]. Furthermore, main factors, such as ensuring a stable and efficient system, whilst increasing efficiency of one node, are of great importance [37]. To know the different protocol strategies, is to know which one to use effectively for which issue [38]. The five most prominent protocol methods are the cluster-based routing protocol, the cross-layer routing protocol, the posture-based routing protocol, the QoS routing protocol and the temperature-based routing protocol as shown in Figure 3 [7], [9], [35], [36].

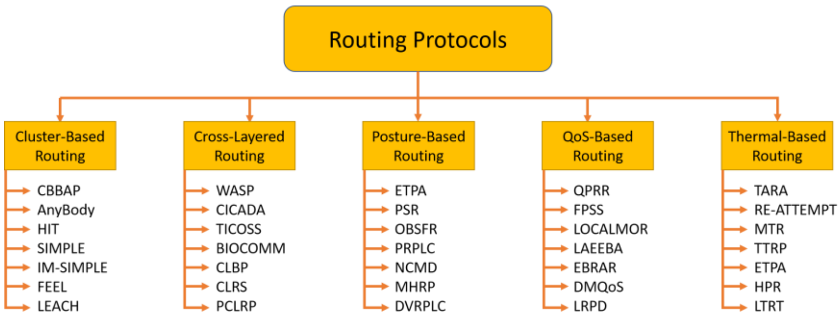

Figure 3. WBAN routing protocols

4.1. Cluster-based routing

Originally from WSN, this routing protocol has shown through several experiments, that clustering is ideal for WBAN. Low energy adaptive clustering hierarchy (LEACH) [7], [39] ensures stable network connectivity as well as equalized power consumption, as the number of sensors as well as the distance between them change. Furthermore, it is also able to adjust into a dynamic structure. The way this protocol proceeds is by dividing all nodes within a network environment into several clusters. Each of these clusters will have one cluster head, picked by the algorithm. The head's responsibilities are to integrate and forward communication into the clusters, thus lowering overhead of the direct communication. Some examples of cluster-based routing are "dual sink approach using clustering (DSCB)" and "an energy efficiency routing protocol (CRPBA)" [18], [35], [36], [38], [40].

4.2. Cross-layer routing

To ensure the WBAN's continues communication, taken various factors, such as human tissue, movement, and outside influence, into consideration, several strategies have been presented. One of the most prominent ones is the concept of the cross-layer routing. The idea is that the layers are normally set into stringent boundaries within the open systems interconnection (OSI) model, which results in data being confined in the correspondent layers. The strategy of the cross-layer optimization is to sever these restrictions and thus enable data access between layers which enhances the communication and interaction greatly. Combined with the appropriate routing protocols, despite the existing challenges, communication is improved scientifically. Some examples of cross-layer routing protocols are "a priority-based cross layer routing protocol (PCLRP)", "cross-layer design for optimizing transmission reliability, energy efficiency, and lifetime (CLDO)", "cross-layer retransmit strategy (CLRS)" and "cross-layer optimization based on prediction" [9], [35], [36].

4.3. Posture-based routing

The prime indicator of this protocol is to evaluate its network structure, whilst taken human physiology into consideration. Regardless of the body's position, as well as movement and other dynamic processes are also included into the calculation. This dynamic approach is especially important, since in real life the person wearing the sensors, as well as the ambient environment is dynamic. For example, if it is possible to predict in advance and to determine the coming action, due to the regularity of the body's movements, then a reduction in data transmission delay, as well as an enhancement in its rate can be achieved. Some examples of posture-based routing are "a novel mobility handling routing protocol (MHRP)" and "energy-efficient and distributed network management cost minimization (NCMD)" [2], [9], [35].

4.4. Quality of service-based routing

This type of routing protocol is used primarily for WBAN applications which have certain constrains within their resources by adhering to the quality of service. Examples of QoS are energy efficiency, data security, data priority, data transmission and link reliability, thermal emission as well as low transmission delay. Some examples of quality of service-based routing are "designing lightweight QoS routing protocol (LRPD)" and "hybrid data-centric routing protocol (HDPR)" [2], [9], [18], [35].

4.5. Temperature-based routing

As the name implies, for the proper calculation of its path, this protocol is considering the node's temperature as the main indicator. The reason behind this strategy is to avoid overheating the nodes by purposely avoiding nodes with higher temperature and thus keeping the overall thermal emission as low as possible. Some examples of temperature-based routing are "thermal-aware routing algorithm (TARA)", "a new energy-efficient routing protocol (ER-ATTEMPT)", "trust and thermal aware routing protocol (TTRP)" and "a mobility-based temperature-aware routing protocol (MTR)" [35], [36], [41], [42].

5. WIRELESS BODY AREA NETWORK COMMUNICATION TECHNOLOGIES

WBAN are normally designed for short ranges, for reasons of security and energy efficiency. A greater range increases the possibility for malicious attacks whilst also consume more energy to keep the range high. To reduce interference with ambient networks as well as energy consumtion, several technologies, such as Bluetooth, Bluetooth low energy (BLE), ZigBee, Wi-Fi and UWB can be used, depending on its needs and requirements as shown in Table 2 [1], [9], [22], [24], [43].

5.1. Bluetooth

Bluetooth, which has been created for short range communication networks. The network structure of Bluetooth is the piconet consisting of one master and several slaves which can communicate with each other simultaneously. While the maximum communication range is about 10 meters, it is possible to form a scatter net by connecting several piconets together and thus extending the range up to 100 meters with a data rate of 3 Mbps. Devices using this standard work in the industrial, scientific, medical (ISM) signal frequency band with 2.4 GHz. One strong aspect of Bluetooth is that its devices can communicate with each other in the no line of sight (NLOS) condition, which makes it very useful for applications with short range conditions. For example, the data transmission between WBAN and server or WBAN to WBAN [1], [9], [22], [43], [44].

5.2. Bluetooth low energy

BLE was designed with the goal in mind to better adapt to the needs of WBAN, since the power consumption rate of the Bluetooth standard is not efficient enough to be implemented in most WBAN applications. BLE, however, is more suitable since it uses low duty cycle operations to reduce power consumption. Its devices, which are in comparison smaller and weaker to the normal standard, are excellent for the purpose of health monitoring with a data rate of 1 Mbps. While Bluetooth can establish pair synchronization within seconds, BLE is able to do this in milliseconds, since it is using less channel for communication. This is especially important for WBAN since data latency is a high priority topic when it comes to emergency respond and other critical issues [1], [9], [22], [43], [44].

5.3. ZigBee

The ZigBee standard has a low data rate and functions on radio frequency (RF) bands 2.4 GHz, 915 MHz, and 868 MHz with 250 kbps as the highest rate, with a range between 50 and 70 meters. It uses 802.15.4 as its PHY layer as well as the MAC protocols and is a tailor-made concept for the purpose of low data rate and low power consumption as well as long life systems, which is very useful for applications which require long term operations such as the monitoring of heart rate and brain activity or BP. It also helps with cost reduction due to its reduced data rate as well as its simplified communication protocols. One can formulate its duty cycle often below the 1% mark of the time ratio, when taking the duration of a device being in an active state in contrast to the total timespan into consideration. This ensures a higher longevity for batteries [10], [11], [22], [43].

5.4. Ultra wide band

The UWB, which was developed for short-range communication, was standardized by the IEEE 82.15.6 task group 6. It has a frequency allocation between 3.1–10.6 GHz with 499.2 MHz channel bandwidth and a data rate up to 480 Mbps. Therefore, in the last couple of years, a trend towards the UWB can be observed. With its large bandwidth option, the high data rate as well as low power consumption, combined with functionalities, such as anti-multipathing, one can see the reason why it is getting used more frequently for WBAN in recent time [1], [9], [22], [43].

5.5. RuBee

RuBee, which is established by the IEEE 1902.1 standard protocol [24], uses a bi-directional active wireless protocol and operates with long wave magnetic signals for transmission and reception of 128-byte short packets of data within a local network. It is purposefully designed for high security level, extended battery life and stable transmission distance in harsh environments. RuBee also enables the networking of devices by peer-to-peer and is an on-demand packet-based protocol. Furthermore, its low operating frequency results in a very low power consumption, thus enabling prolonged battery life of up to 15 years with one single lithium button cell battery, while also providing up to 50 feet of coverage distance. Unfortunately, RuBee requires a bigger antenna size, making this technology unfortunately not so suitable for WBAN applications [9], [24], [43].

5.6. Zarlink

Zarlink uses cyclic redundancy check (CRC) error detection and reed-solomon error correction scheme to establish a reliable link of communication. It has also the option to operate as an implant or a base station. The implantable medical device (IMD) mode for the implant and base mode for the base station. In IMD mode, the radio is generally “asleep”, resulting in low power consumption of μW compared to mW in other modes. However, no communication between two nodes can be established if either node’s radio is “asleep”. Thus, a specific approach is required to awaken the receiver’s radio to ensure the senders and receivers transmit and listen operations are congruent. There are two known methods to deal with this issue, either it can be done by utilizing an ultra-low power 2.4 GHz radio or by using the IMD processor itself [9], [10], [24], [43].

5.7. Wi-Fi

Wi-Fi, or wireless local area network (WLAN) uses the IEEE 802.11 standard. Technically, Wi-Fi is using four standards, namely 802.11a, 802.11b, 802.11g and 802.11n, which are running on the ISM frequency band with 2.4 and 5 GHz and a have a range of 100 meters. Wi-Fi enables high-speed combined with a very high data rate, which makes it a suitable candidate for video conferencing and streaming. Most devices have integrated Wi-Fi such as smart phone, tablets, computers, and laptops. However, due to its very high-power consumption, it is not very useful for most applications of WBAN and can only be used for specific tasks [1], [22], [43], [45].

Table 2. Wireless communication technologies for WBAN

Wireless communication	RF	Data rate	Network topology	Scope (m)
Bluetooth	2.4 GHz	780 Kbps	Star	10-150
BLE	2.4 GHz	1 Mbps	Star	10
ZigBee	868 MHz/915 MHz/2.4 GHz	20/40/250 Kbps	Star/mesh	10-100
UWB	3.1-10.6 GHz	110-480 Mbps	Star	5-10
RuBee	131 KHz	9.6 Kbps	P2P	30
Zarlink	402-405/433-434 MHz	200-800 Kbps	P2P	2
Wi-Fi	2.4/5 GHz	72-600 Mbps	Mesh	100

6. WIRELESS BODY AREA NETWORK APPLICATIONS

There is a huge variety of applications existing within the WBAN standard. Furthermore, some of those applications are worn on clothing, near the body, some directly on the body, and some are implanted within the body. They can be generally categorized into medical and non-medical applications, which some of them are listed in subsection below [3], [13], [14], [28], [46].

6.1. Medical applications

6.1.1. Telemedicine

With telemedicine applications, it is not just possible to monitor and gather physiological data, but also possible to provide many services such as video conferencing with doctors and medical staff, online consultation, and remote medical diagnosis [6]. This is very helpful for people who don’t have easy access to medical centers and hospital due to their own condition or locality restrictions. This way, doctors can remotely treat patients, as well as offer e-prescription for medicine medicine [9], [10], [33].

6.1.2. Rehabilitation

Many patients must undertake a rigorous rehabilitative treatment after leaving the hospital due to a critical or suboptimal condition which requires adjustments. Normally, this kind of treatment needs a longer period until undesired behaviors and/or motion have been corrected by repetitive actions. Whether this is external, like a limp injury, or internal, and like a stroke. Certain behaviors are to be adjusted to prevent this from happening again. With the option of undertaking this effort remotely, resources, such as medical staff, time, money can be saved and a better training regime can be described so that the overall rehabilitation time is shortened [9], [24], [31].

6.1.3. Assisted living

A similar idea to the remote healthcare monitoring is provided by applications for assisted living. This option is a great help for both patient and hospital. Patients can now be at home being monitored and assisted remotely and thus reducing the patient overload in hospitals. The idea how it works is that the physiological data, which is collected by the sensors, are periodically sent to medical center server/control unit. Thus, medical staff can monitor, evaluate, and act upon an emergency while the patient is able to stay at home [9], [10], [33].

6.1.4. Biofeedback

These types of applications allow the user to self-monitor, meaning that the user is now able to adjust his/her activity by having access to his/her own physiological data, such as BP, heart rate, glucose level, and body temperature. Thus, biofeedback is helping the user to learn about the own condition which leads to a better and healthier lifestyle. Biofeedback in general is not an invention. As a matter of fact, it is known and used since 1960s. Over the period of time, it was verified that it helps people control emotional states and other issues such as migraine and BP [9], [24], [31].

6.2. Non-medical applications

6.2.1. Sports

With the help of WBAN, it is now possible to use these wireless sensors to efficiently measure signals. Signals, such as blood pressure, respiration rate, heart rate, body temperature as well as posture of the wearer during the PHY activity. This technology enables better monitoring and improved training regime due to more accurate data, resulting from WBAN [9], [10], [33].

6.2.2. Military

Even in military there are many opportunities to implement WBAN. Aside from the similar applications for measuring BP, heart rate, respiration rate and movement, it is also possible to further enhance their strategic formations. Whether soldiers are moving in formation to a specific direction, or break and attack or retreat, these movements can be additionally supported by implementing and deploying cameras, RF, and GPS. The possibilities are vast thus WBAN would greatly improve an operation in terms of precision, time and of course avoiding unnecessary fatalities [9], [10], [33], [46].

6.2.3. Lifestyle and entertainment

There is a huge market for using WBAN in the commercial sector regarding lifestyle and entertainment. WBAN can be beneficial for many services in our daily life. Think of navigation, what is already used with our smartphones nowadays. Content creation for wireless gaming, music, video or just transmit from one device to another, such as from the smartphone to the TV via streaming. Even baby phones, which are equipped with microphone and camera are very useful tools which improve the overall quality of life [9], [10], [33], [46].

7. WIRELESS BODY AREA NETWORK CHALLENGES

With its sheer endless possibilities, WBAN has also many challenges. Some of these challenges are major ones, such as energy efficiency, performance, QoS and security to deal with. These can be seen as high priority or critical issues, especially, when it has a great impact on implanted sensors and thus can affect a patient health.

7.1. Energy efficiency

Energy is regarded as one of the major challenges not just for WBAN, but generally all WSN. From considering the right standard, to using the right protocol throughout all layers of the OSI network model, to the very idea of saving energy with methods such as sleep modus and EH [12], which is the ability to harvest energy from limitless ambient sources, and is then used to power the devices as well as to recharge their batteries, such as photovoltaic EH (PVEH), piezoelectric EH (PEH), thermoelectric EH (TEH) and RFEH [12], [47]. Furthermore, protocols were invented for different layers within the OSI model to tackle this issue, such as idle listening, collisions, clock drifting, overhead and overhearing for the media access control, data load balancing and energy sensible routing mechanisms for the network layer and data aggregation, compression, and fusion for the application layer. Protocols and methods on the transport layer were targeting issues such as bottlenecks and congestions since these are hotspots for energy wastage and are also influencing packet loss ratio (PLR) as well as communication latency. Another topic is the heat generation caused by electromagnetic radiation due to the power of radio frequencies. The reason behind is that the microchips within the sensors can heat if the data transmission is not low enough, which results in serious harm, such as burning and even cell degeneration for the wearer [1], [12], [20].

7.2. Performance

One of the advantages of the sensors is the fact that they are very small and therefore simple in complexity which results in low power consumption. However, this advantage can also be seen as a disadvantage, since their batteries are also very small, approximately 1 cm^3. As mentioned before, removing some of the sensors can only done be performing surgery, which complicates the entire process. Therefore, it is paramount to develop life cycles which can last many years, if not decades. To realize this, several steps are to be considered. One of them, is to ensure that there are no redundant devices within a body since all sensors are of equal significance. Another step is to ensure a very low transition power to reduce the influence of interference as much as possible. Furthermore, the movement of the body must be taken into consideration as well and thus, it must be ensured that the network is robust enough to endure changes in the topology. Since the aim of the WBAN is primarily set to be used in the medical sector, all the sensors' collected data are from a physiological origin. Thus, reliability as well as reduced data delay are also extremely important. Furthermore, a high level of security must be delivered and maintained due to the highly confidential and sensitive data. Lastly, since sensors, generally speaking, are heterogeneous, that can result in different requirements of resources in regard to reliability, power consumption and data rate [1], [22], [31].

7.3. Quality of services

Not all wireless systems are the same. This is especially valid for WBAN since its requirements do differ from other WSNs, when discussing QoS. Although it is understandable to imply QoS in any WSN to WBAN, it is not correct. Extending the life cycle of the WBAN is not the only focus. It also must be ensured to keep the data rate as low as possible, to ensure a high security level as well as to keep the whole system robust and reliable more than any other wireless system, since mistakes can harm the person wearing it and that would be a grave error. Furthermore, it is challenging to designate QoS for a healthcare system due to the fact the environments influence on a WBAN are quite irregular. Although aspects such as bandwidth reservation, transmission of power, latency as well as reliability are common for QoS, for WBAN, the following QoS aspects are valid [12], [22], [23], [48].

7.3.1. Delay

Due to its nature, many sensors within a WBAN are directly implanted within a body to collect and relay vital physiological information of the wearer's condition. The problem is that, for example, human tissue or body motion can cause a great impact on the network. Especially in terms of delayed communication, which would be rendered obsolete and even critical for the wearer, if vital information, which is received by the medical staff, is delayed [20], [22].

7.3.2. Latency

While delay is one big issue within a WBAN, the latency is another big challenge to master. As the name implies, latency cause information, in form of packet, to arrive later due to high traffic, long queues or even taking a longer route to avoid congestion. As mentioned before, the right routing protocols are required in order to deal with these issues, since the outcome may be just as critical as delay [22], [23].

7.3.3. Reliability

The basic understanding of reliability is that it factors in the amount of an attended computation process' succession. Meaning, that measuring reliability is in direct correspondence with its success rate. However, due to several factors, such as type of application and different handling by users, the understanding of what is exactly reliable will vary from situation to situation. So, for a general understanding, what is defined as successful if a link can traverse with an excellent precision and recall. At the same time, ensuring that the authentic representation of recourses is retrieved in a timely manner [22], [23].

7.3.4. Data rates

To set the right measurement and definition of the data rate, one has to provide the bit error rate (BER) which is normally an indicator for number of lost packets. As for medical devices, the rate of reliability is depending upon the data rate. While certain devices that function with a low data rate are able to manage a higher BER, there are other ones, which function with a higher data rate but, on the other hand, require a low BER [20].

7.3.5. Data priority

Since not all data can be set on the same level of priority, it is one of the main challenges, regarding the correct routing protocols within a WBAN. For example, the priority level of physiological information regarding body temperature should not be on an equal priority level such as a fatal condition. Thus, a proper routing decision must be smart and fast since it can cost the life of a patient in a worst-case scenario [2], [49].

7.4. Security

Security as well as privacy are two very sensitive topics in a WBAN. While the term privacy relates to the possibility for the user, to have control over the own data regarding the collection and distribution, the term security is in relation to the protection against malicious intent. Both, privacy as well as security are automatically set upon whether data is created, processed, transferred, or even stored. As a matter of fact, the health insurance portability and accountability act (HIPAA) enforces policies and mandates to ensure that within a WBAN, all existing devices which carry the responsibility to gather the user's physiological data are equipped with security standards against malicious intent, such as tampering and unauthorized access. Due to this high level of security, other QoS such as data integrity, data security and throughput are very much constraint and thus need to be considered when designing a security architecture [1], [20], [22], [27], [50].

8. CONCLUSION

The WBAN's sheer possibilities as well as its supported functionalities do not disappoint in regards what it has promised. Among the available WSN, the WBAN is unique due to its tailor-made design and architecture to fulfill the required needs. Although, it is represented and is of great usage in sectors such as entertainment and military, the realm of medicine, is where WBAN really shines. It is not only a means to allow patients to be monitored, treated, and consulted but also to ensure their wellbeing by detecting possible health threats which could develop into fatal sicknesses, or monitoring BP and glucose levels, to ensure the patients status is stable. However, the greatest boon behind these fantastic inventions, which is the wireless network with its many, tiny sensors, is also its own greatest challenge. Since many of these tiny sensors are implanted within a patient's body, exchanging their batteries is extremely hard and displeasing. Furthermore, for some sensors, it is only possible to exchange batteries by performing a surgery to remove the device out of the body first. This leads to necessity to improve in methods to preserve energy as much as possible so that the life cycle of a network is as much extended as possible, for decades, if possible. To realize this challenge, many strategies have been implemented. From designing the appropriate standard, to efficient protocols within each of the layer of the OSI model, up to the point of enforcing security policies and mechanisms to prevent malicious intent, while, at the same time, ensuring that the benchmarks for the QoS are as high as possible. And, when it comes to routing protocols, there is a lot of potential, given the fact that there is a great selection of various strategies, which are tailor-made for specific applications, to reduce energy consumption and heat generation in sensor nodes. All this great endeavor shows the hardship behind WBAN, and it also shows how much it still can be improved. Thus, a detailed comparison between this review and the ones mentioned in related work section was presented, to highlight the potential areas that can be further improved.

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