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The state-of-the-art wireless body area sensor networks: A survey

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Abstract

Wireless body area sensor network is a sub-field of wireless sensor network. Wireless body area sensor network has come into existence after the development of wireless sensor network reached some level of maturity. This has become possible due to the tremendous technological advancement leading to *easy-to-use* wireless wearable technologies and electronic components that are small in size. Indeed, this field has gained significant attention in recent time due to its applications which mostly are toward healthcare sector. Today, tiny-sized sensors could be placed on the human body to record various physiological parameters and these sensors are capable of sending data to other devices so that further necessary actions could be taken. Hence, this can be used for diagnosis of disease and for developing serious health-complication alert systems. Considering this recent hot topic, the intent of this work is to present the state-of-the-art of various aspects of wireless body area sensor network, its communication architectures, wireless body area sensor network applications, programming frameworks, security issues, and energy-efficient routing protocols. We have tried to cover the latest advancements with some discussion on the available radio technologies for this type of network. Future visions and challenges in this area are also discussed.

Keywords

Body, healthcare, network, sensor, wireless

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Introduction

Recent scientific and technological developments are so rapidly paced that what was not even predicted before has become a reality and part of our life today. One of the notable inventions of the recent time is the small-sized electronic device called *sensor* which has the capability to observe various parameters like object movement, light intensity, temperature, magnetism, seismic activities, and so on.[1] These sensors, often with own capability of communicating within themselves or with other devices, are developed to gather data and store the recorded data to process further if needed. Such communications could take place via wired as well as wireless mode giving scope to their (i.e. the sensors) increase in number for a particular system or network.[2]

What we are witnessing today is basically the remarkable developments done in the key underlying technology, micro-electro-mechanical systems (MEMS) technology that has led to the construction of low-powered and small-sized sensor nodes which could be used to form a wireless sensor network (WSN). In general, a WSN requires no infrastructure or very little infrastructure which consists of sensor nodes that can range from few tens to thousands and those sensors in the network could work collectively for monitoring

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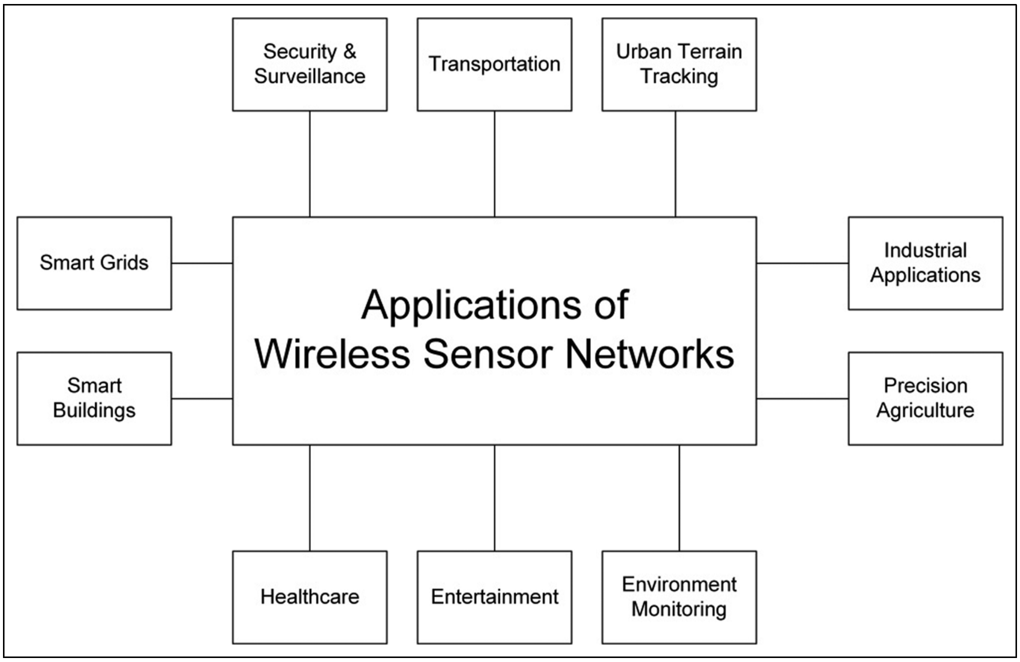

Figure 1. Applications of wireless sensor networks.

purpose. The WSNs could be categorized as either unstructured or structured. In unstructured WSN, the sensors are deployed randomly over the area of interest (AoI) while in structured WSN, the sensors are deployed at fixed locations. There is a wide range of application scenarios for both structured and unstructured WSNs.[3,4] As the sensors used in these networks are pretty small in size, they are often equipped with lightweight energy source.[2–5] In practice, sensor networks are planned to perform tasks like measurement, tracking, detection, and data classification. Various applications of WSNs include the fields of transportation,[5,6] smart grid,[7–9] healthcare,[10,11] smart bridges,[12,13] precision agriculture,[14,15] industrial applications,[16–19] security,[20–22] environment monitoring,[23–26] and urban terrain tracking,[27] as shown in Figure 1.

Arguably, the field of wireless body area sensor network (WBASN) was first introduced by Van Dam et al.[28] in 2001. Even before that time, with the increasing popularity of portable devices in 1996, Zimmerman[29] focused on how these portable devices would operate surrounding human body. Initially, personal area network (PAN) was the term used for these types of networks. PAN later was given a new name as body area network (BAN).[28] With a more recent term, *WBASN* joins different types of networks and devices to enable monitoring operation that could be performed remotely. One of the most notable application areas of WBASN is the healthcare monitoring system.[30–33] Figure 2 illustrates an example scenario of such a system.

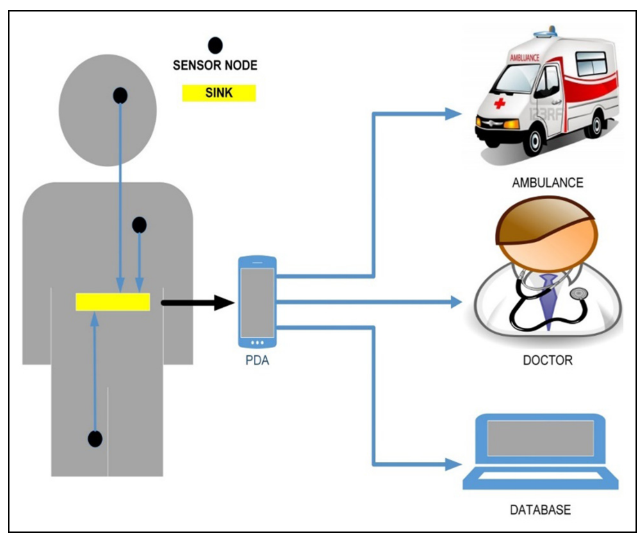

Figure 2. Wireless body area sensor network in healthcare.

Before proceeding further, it should be noted here that the term used in this article is mainly WBASN, which is sometimes termed in slightly different ways in various previous and recent works like wireless body area network (WBAN) or wireless body sensor network (WBSN). All these terms mean the same type of network that consists of sensors and it is for monitoring and measuring human physiological parameters. Sometimes, based on the context, the terms are used interchangeably in this article.

Table 1. Invasive and non-invasive sensors.

Non-invasive/wearable sensors	Invasive/implantable sensors
Electrocardiogram (ECG)	Pacemaker
Glucose sensor	Cochlear implants
Electromyography (EMG)	Implantable defibrillators
Electroencephalogram (EEG)	Wireless capsule endoscope (electronic pill)
Temperature	Electronic pill for drug delivery
Pulse oximeter	Deep brain stimulator
Blood pressure	Retina implants
Oxygen, pH value	

The tiny-sized sensors in a WBASN could be either invasive (i.e. which can be inserted into human body) or non-invasive when those are implanted or attached to the human skin. These devices do not disturb the person's activity but could record the physiological parameters during any particular activity. For instance, a patient could be monitored for his blood pressure or heartbeat or temperature or so during his or her daily routine works.[34] A player can be observed during a game or a soldier's health may be observed during training session or in the battlefield. As WBASNs are developed in order to be implemented around the human body, this allows continuous monitoring of the physiological parameters.[35] In fact, these sensors in particular could be smaller than the usual ones.

The sensors perform mainly three tasks: sensing, processing, and communication.[36–38] In sensing task, the sensors monitor or sense the parameter for which they are capable of. In processing task, a sensor processes the collected data for comparison and storage purpose before sending that to the sink and in communication task, the processed data, that is, information is transmitted to the sink for further communication or processing.[39] In Table 1, we show a list of invasive and non-invasive sensors[40–53] all of which could do the three main tasks mentioned above.

There are various places on the human body where physiological parameters can be measured (as shown in Figure 3). Actuators can also be placed near these sensors for delivering drugs into the body. For instance, a diabetic patient is being monitored for glucose level in blood. If the sensor senses drop of glucose level, then it activates the actuator to pump a certain amount of insulin into the body.[54]

WBASNs could also provide assistance to the disabled people. For instance, an artificial retina translates electrical signals into neurological form. It consists of a matrix of micro sensors and can be implanted into the eye beneath.[55] Again, sensors can be attached for a person whose legs (are) or lower body is paralyzed, for determining the positions of the legs.[56] As understood,

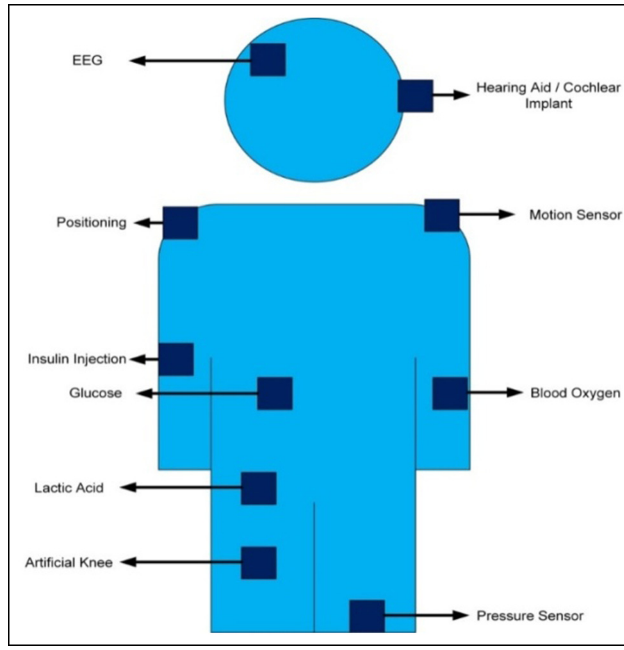

Figure 3. Human physiological parameters.

WBASN could have significant impact on the medical field in the coming days.[57–59]

In fact, while doing this survey, we have found quite a large number of research works being carried out in the field of e-healthcare. Set of sensors or sensing devices and especially, WBASN is a key component of many of these most advanced approaches. Hence, the size and thus, the ease of use of the sensor nodes in this environment are of paramount importance. Over the course of time, we are witnessing the incredible reduction of circuitry and electronics while the resources of the devices are becoming greater than that were in the past. All this has been possible due to the significant advancements in the fields of electronics like MEMS and nano-electro-mechanical systems (NEMS). The reduction in size for the sensor is indeed beneficial for making them better wearable and portable. With the size, it is also seen that the weight of the device gets reduced as well, adding more benefits and ease for transportation from one place to another (by a human being). State-of-the-art technologies also have made these small-sized devices more intelligent and often, context-aware, which has enabled these devices to perform more efficiently. Moreover, today these sensors are operated with the aid of innovative and emerging wireless technologies, making them capable of sending and receiving data with consumption of relatively less amount of energy on micro and nano levels.

The rest of the paper is structured as follows: section "WSNs versus WBASNs" explains the basic differences between WSN and WBASN, section "WBASN communication architecture" discusses the communication

Table 2. Differences between wireless body area sensor networks and wireless sensor networks.

Challenges/issues	Wireless body area sensor network	Wireless sensor network
Monitoring	Human body physiological parameters	Environment monitoring
Scale	Up to centimeters to a few meters	Meters to kilometers
Channel	Medical channel, ISM (industrial, scientific, and medical), body surface	ISM
Number of nodes	Fewer, limited in space	Many nodes are needed so that wide area is covered
Accuracy of result	Through node accuracy and robustness	Through node redundancy
Task of node	Multiple	Dedicated task
Size of node	Small is preferred	Small is preferred, but not important
Network topology	More variable due to body movement	Very likely to be fixed or static
Data rates	Non-homogeneous	Homogeneous
Replacement of nodes	Replacement of implanted nodes difficult	Performed easily, nodes even disposable
Node lifetime	Days/months	Months/years
Power supply	Inaccessible and difficult to replace in an implantable setting	Accessible and likely to be replaced more easily and frequently
Power demand	Lower	Large
Energy scavenging source	Motion (vibration), thermal heat	Wind energy and solar energy
Biocompatibility	Very important	Not important
Security level	Higher, to protect patient information	Lower
Impact of data loss	More significant	Compensated by redundant nodes
Wireless technology	Low-power technology required	Bluetooth, ZigBee, general packet radio service (GPRS), wireless local area network (WLAN)

architecture of WBASN, energy-efficient routing protocols in this area are discussed in section "Energy-efficient routing protocols for WBASN," section "Applications of WBASNs" presents the details of various types of WBASN applications, and section "Security threats" discusses the security issues. Then, radio technologies are discussed in section "Radio technologies and notable protocols," programming frameworks are discussed in section "Programming frameworks for WBASNs," and ongoing notable projects are mentioned in section "Some ongoing projects," Future scope and open research issues are discussed in section "Future scope and challenges," and finally, section "Conclusion and future studies" concludes the paper with possible future directions of study in this area.

WSNs versus WBASNs

The challenges that WBASNs face are often different than those of the traditional WSNs. We know that human body offers relatively small environment and it reacts in accordance with the internal environment as well as to the external surroundings. It is a fact that human body monitoring needs high reliability and accuracy as false readings could lead to wrong medical diagnosis or decisions on critical issues related to physiology. The sensors may also be able to move in accordance with human postures and movements which may not be a case for the sensors in a traditional WSN. In Table 2, major differences[35] and challenges of both WBASN and WSN are presented.

In order to address the specific concerns of WBASN, several survey works came out within the last decade. For the convenience of the readers, we note some of the notable works here.[30,32,34–36,39,60–65]. As the time passes by, many of these survey works become old as is the case for any continuously advancing technology. Moreover, these past works often have addressed some specific issues or have been done with a particular inclination or topic within this field. Hence, our survey is an effort to collate the most up-to-date information and present the latest advancements filling the gaps like addressing the programming frameworks and the issue of multi-sensor fusion.

WBASN communication architecture

Figure 4 illustrates the communication architecture of a WBASN monitoring system. As the figure shows, some sensors are placed on the human body. These sensors can be electroencephalogram (EEG), electrocardiogram (ECG), electromyography (EMG), or blood pressure measuring sensors. The data recorded by the sensors are sent to the nearby personal server (PS), which is known as the sink or the base station (BS). All data collected in this way in the sink are then transmitted to the outside world which may include a medical doctor, or a medical center or any medical database for further processing of data and disease diagnosis.

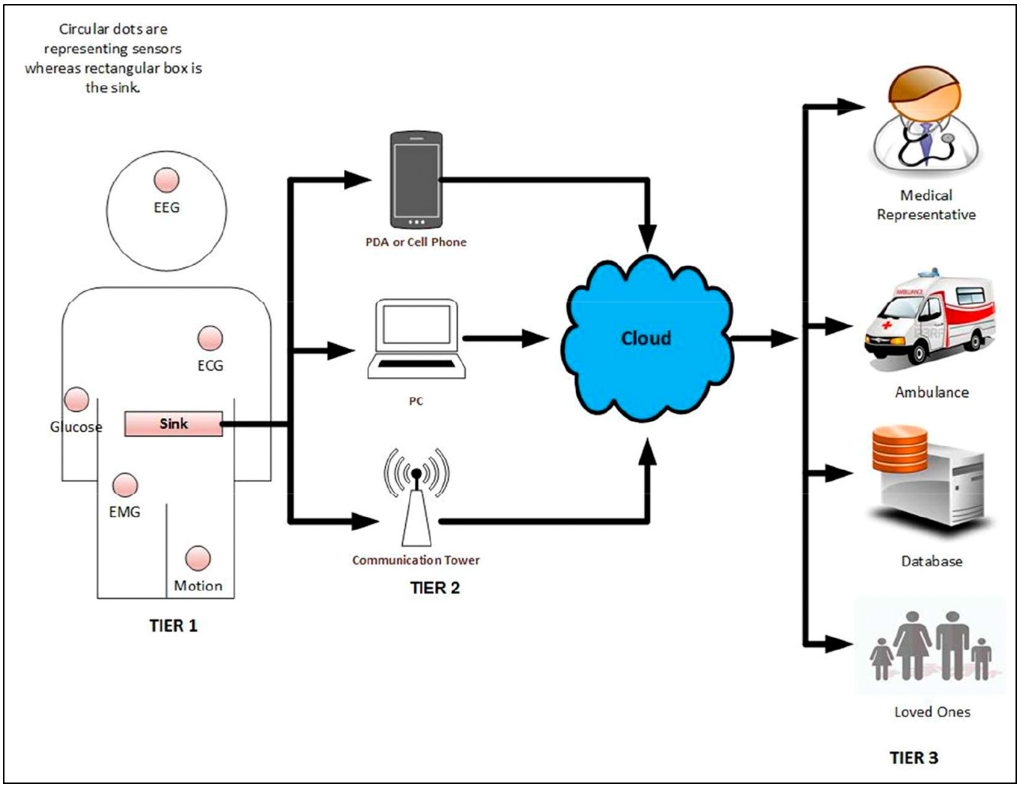

Figure 4. WBASN communication architecture.

The communications performed in WBASN architecture as depicted in Figure 4 are divided into three tiers: (1) Tier 1—intra-BASN communications, (2) Tier 2—inter-BASN communications, and (3) Tier 3—beyond-BASN communications.[66] It should be noted here that when a person in this scenario is moving, the body may be in motion during that time. Hence, the positions of the sensors involved may change in this case, that is, the WBASNs are not generally regarded to be static.

Tier-1: intra-BASN communications

In this tier, the communication can be wired or wireless. This type of communication was suggested by Zimmerman.[29] In intra-BAN communication, it is only between the sensors and the sink.[67] The range of communication in this tier is approximately 2 m in and around the human body. This tier has critical significance because the sensors are basically located within this communication range. This is the reason why the mode of communication is short-ranged. ZigBee[68] and Bluetooth[69] are used as communications technologies in this tier. The sensors observe the physiological conditions and then forward the readings to the PS/sink, which is also located within this tier. The task of the sink here is to process the collected data and transmit that to Tier-2.[34,39,66]

Tier-2: inter-BASN communications

In this tier, the communication takes place between the sink and one or multiple access points (APs). There can be infrastructure which deploys APs or in another scenario, the APs could be placed strategically in dynamic environment so that they may be able to successfully handle the emergency situations. The function of this tier is, interconnectivity between different types of networks which are easily accessible; for instance, cell phone network (or, may be Internet) to BASNs. The wireless technologies like 3G/4G, Cellular, ZigBee, wireless local area network (WLAN), and Bluetooth can be used for this tier.[34,39,66]

Tier-3: beyond-BASN communications

This tier has been designed to be used in metropolitan area networks (MANs). The medical sensor is connected to the Internet or any other network that is used to deliver the data to the recipient entities, enabling healthcare personnel to access the medical/health-related data. The recipient person could either be a doctor or a nurse.[66] The data could be also stored in the database of the patient. This makes the database an important part of Tier-3. In the database, the profile of the patient/user is stored with his or her medical history. In this tier, the doctor can also be notified by message that the patient's condition is getting worse (when a situation arises like this) and with the database record, necessary action could be taken before the patient reaches the hospital.[34,39]

Medical environment and database are the most important components of Tier-3 as these include the medical history and profile of the user. Thus, doctors or patients can be notified of an emergency status through either the Internet or a short message service (SMS). Additionally, Tier-3 allows restoring all necessary information of a patient which can be used for treatment.[66] However, depending on the application, the sink in Tier-1 can use general packet radio service (GPRS)/3G/4G instead of communicating to an AP.

As we see from Figure 4, when the environment beyond the actual WBASN is considered, the same facility could be extended to envision an environment that would connect thousands of devices to increase the e-healthcare facilities and enable long distance and remote healthcare for *hard-to-reach* patients. This grand vision is termed Internet of Medical Things (IoMT).[70] WBASN can play as the backbone for IoMT; however, when we consider the perimeter of WBASN (within Tier-2 and core part restricted to Tier-1), which is the main scope of this work, anything beyond WBASN (i.e. whatever is beyond Tier-2) would be beyond the scope of WBASN's own operation. Hence, efficient methods and techniques could be employed for the beyond-WBASN environment and appropriate mechanisms may be selected for various issues like coverage, data rate, security, privacy, and energy efficiency. It can be generally said that components like sensors, mobile phones, actuators, watches, radio-frequency identification (RFID) tags, or other devices should be able to interact and communicate with each other for achieving the goals common among them.

Energy-efficient routing protocols for WBASN

In section "WSNs versus WBASNs," we mentioned the basic differences between WSN and WBASN. One of the notable issues that we know is that the sensors in a WBASN are supposed to be relatively smaller than those of the traditional WSNs. Hence, the energy sources of these types of sensors (that may be mainly used for healthcare and medical purpose) are relatively low powered as well. Because of this reason, some energy-efficient routing protocols have been already proposed especially considering WBASN scenario. This section provides an overview of notable energy-efficient routing protocols proposed specifically or mainly for WBASN.

A protocol is presented in the work by Quwaider and Biswas[71] which uses single-hop communication for sending data from nodes to sink. This method is delay-effective (i.e. the delay is relatively less) but the nodes which are located relatively far consume more energy as compared to nodes nearby. Cost function (CF) is proposed by Nadeem et al.[72] for the accurate selection of the route toward the sink which is based on energy contained by sensors and their distance from sink. This scheme utilizes CF for the purpose of selecting the route that data may take toward the sink. The value of CF is computed on the basis of energy contained by sensor nodes and also on their distance from the sink. Among all the nodes in a particular setting, the node which will have the lowest CF value will act as parent node and remaining ones will become child nodes. In this protocol, the sensor nodes having critical data send their data to the sink directly as they would be located near the sink.

Multi-hop communication is proposed between the sink and the nodes in Seo et al.[73] However, the scheme has some drawbacks like the nodes which are near to the sink would consume relatively more energy. Also, the delay would be relatively higher. Research in Javaid et al.[74] proposes a protocol in which source node will send its critical data directly toward sink. If the data are normal, then the nodes will opt for multi-hop scheme. It is a thermal-aware protocol, that is, if the hotspot is detected in the route, then the route is changed from one to another. Another protocol is proposed in Tauqir et al.[75] where few sensors monitor the same bodily parameter. The authors consider the fact that when the sensors gather information about body organs and transmit the data, much of the energy gets utilized due to which excess heat is dissipated. This excess heat may severely damage the body tissues. Hence, keeping this in mind, the authors devise the protocol so that the transmission and data processing are done only when a threshold is reached and the rest of the sensors keep on monitoring the parameters continuously. The sensor nodes send their data to the sink with the help of relay node so that the energy consumption is reduced. The relay node is placed on the chest and would have more energy as compared to the other sensor nodes. This is because it performs data aggregation and also relays the data to the sink.

A protocol is proposed in Braem et al.[76] where the information regarding the child nodes is sent to the parent nodes to achieve higher reliability of the network with less delay but the balance of power is not really addressed. An energy-efficient protocol is proposed by Ahmed et al.[77] in which the characteristics of single- and multi-hop schemes are used for the purpose of reducing the path loss so that the network lifetime is increased. In this work, a CF is defined for the selection of forwarder node. CF value is computed on the basis of the distance of sensor nodes from sink. The node having higher residual energy and minimum distance from the sink would be the forwarder node. Energy is balanced by residual energy.

In Uddin et al.,[78] the path loss of a moving node is examined where an energy model is proposed for WBASN which is based on the path loss as well as on the received path power from the propagation model. A propagation prototype is also proposed based on fixed and energetic sensor nodes. Path loss is computed when a sensor node is moving with the body movements in normal distribution. Research in Coronato et al.[79] presents a situation-based architecture for the purpose of reducing stereotyped disorders of motion in kids who have sickness of autism spectrum disorder. In this model, abnormal activities are identified. The impacts of different values for εr (relative permittivity) and σ (conductivity) of tissues in a human body at a frequency of 2.45 GHz have been calculated based on three-dimensional model proposed in Kurup et al.[80] The proposed model is valid up to 8 cm for dipole antennas. The comparison of path losses of heterogeneous and homogeneous human tissues is also performed. This work gives some observation on high-frequency transmission, especially on the energy dissipation for that and its effect on human body.

In Sandhu et al.,[81] the sensor nodes are directed to transmit data toward forwarder node. This forwarder is responsible to transmit data to sink. Among all of the sensor nodes, the forwarder node selection criterion is having higher energy compared to other sensor nodes. This forwarder is merged because it minimizes the distance of the transmission, that is, between sensor node and the sink in order to conserve energy. In Chen et al.,[82] an interference-aware network is proposed for monitoring multiple patients. In fact, interference in wireless communication could force relatively higher energy consumption. The work in Braem et al.[83] tries to improve the energy efficiency through appropriate propagation models. Dedicated relay devices are introduced to avoid hotspots which would increase the network lifetime. In Elias and Mehaoua,[84] an optimal design has been proposed with relay positioning and data routing for the purpose of increasing the network lifetime. For energy efficiency, Seo et al.[73] suggest heuristic adaptive routing algorithm. This algorithm reduces energy consumption and for emergency data, guarantees Quality of Service (QoS). In Wang et al.,[85] a distributed network is proposed for medical management. Some of the features of this system are *low-powered*, easy to configure, and real-time consistent data. The protocol in Javaid et al.[86] supports mobility of nodes. In this protocol, data are forwarded from one sensor to another, known as a forwarder node, which is selected on the basis of CF defined for this protocol. The proposed CF selects the forwarder which has comparatively the least value of CF. Again, path loss reduction scheme has been introduced by the authors in Khan et al.,[87] in which accurate positioning of sensors is proposed.

The use of eight physiological sensors has been proposed in an efficient manner in Khan et al.[59] Two of the sensors are dedicated to record critical data and send their signals directly to the sink using single-hop communication. The others use multi-hop scheme for communication. The sensors which are near the sink are computed for their residual threshold energy and checked to find out which of these sensors can become a forwarder. The responsibility of this forwarder node is to gather data from sensors and after performing necessary aggregation, sending that to the sink. Simulation is carried out which shows promising results.

A new routing algorithm has been proposed in Majumder and Gupta.[88] This protocol uses three parameters: *request queue length, number of hops*, and *energy level*. These parameters are utilized by this protocol for communication and the algorithm avoids congestion. A novel and energy-efficient medium access routing protocol has been proposed in Yang et al.[89] This protocol uses hybrid scheme using time division multiple access (TDMA) scheme with carrier-sense multiple access with the collision avoidance (CSMA/CA). The authors have proposed assigning the transmission overhead and designed awaiting order state for sensor nodes for improving energy efficiency.

To overcome the problems of increased data dissemination delay and network management cost, a *network management cost* minimization framework has been proposed in Samantaand and Misra.[90] This work has tried to optimize QoS and throughput of the network. The proposed framework minimizes three things: (1) *costs for data dissemination*, (2) *interference management*, and (3) *dynamic connectivity*. A routing protocol has been proposed in Leeand and Kim[91] which is called *aSymMAC*. It proposes an asymmetrical energy balanced model between the coordinator and the nodes (in this work, the authors have used the term *coordinator* to mean *BS* or the *sink* node). This has been done for ensuring energy efficiency. The work also addresses two major issues: (1) *delivery of critical data to the coordinator* and (2) *the energy status of sensor nodes compared to the coordinator* (i.e. *BS*). The scheme was evaluated with Institute of Electrical and Electronic Engineers (IEEE) 802.15.6.

Energy efficiency is indeed an important issue for any network that contains sensors for its core operation. However, when we consider the increased data rate required for the emerging e-healthcare systems and applications, and thus, the increase of overall energy consumption, this particular issue would be relatively less relevant for WBASN because of the following reasons:

- In general sense, emerging e-healthcare systems and techniques often use the innovative architectures like cloud, IoT (Internet of Things), CPS (cyber-physical system) with WBASN for which more number of communications (like for data uploading, downloading, load balancing) would increase the required amount of processing tasks and eventually, that would increase power consumption. However, when the perimeter of WBASN is only considered, irrespective of the external (beyond WBASN) or associated networks and technologies, a patient's data or user's data would be of the same amount that is required for the healthcare service. There is a particular technical method of reading bodily parameters for instance, pulse rate or heartbeat or so. That data would still be within the acceptable limit when collected within and from the WBASN. Hence, in general, WBASN would not be that much affected by the external affairs given its actual internal function (see Tier-1 in Figure 4).

- Over the course of time, while various technologies need better data rate and thus, consume relatively more energy, it is also a fact that we are witnessing the trend of better battery technologies, energy harvesting technologies,[92] and devices with relatively greater resources while the size of the device may be kept the same or even smaller.

The issue is mainly that while data rate is important and could increase power/energy consumption, in WBASN's case, it is more about the efficient routing protocols that regulate the number of transmissions and receptions that would determine the level of energy consumption. The processing tasks for such network would be relatively less as human activity–related data should be collected periodically and always, the amount of data would be under control even if at a particular state, some bursty data could be produced due to random changes of human activities.

After discussing all these protocols and issues mentioned above, which more or less address the issue of energy in WBASN setting, in the next section, we will discuss various applications of WBASNs, some of which are for non-medical purposes.

Applications of WBASNs

The applications of WBASNs enhance the quality of life. WBASNs could be used for both medical and non-medical applications. Early detection of a disease, monitoring, post-surgery feedback, and assistance are some of the common applications of WBASNs in healthcare. On the other hand, motion or gesture detection for games and providing assistance in driving, cognitive recognition and the like are in the category of non-medical applications. In fact, WBASN applications have a wide span such as ubiquitous healthcare, military, sports, entertainment, and many other areas where human beings are involved. In Figure 5, various applications of WBASNs are illustrated.

Medical applications

WBASN has the true potential to transform the healthcare system as it offers sophisticated but easy-to-use diagnosis of diseases and monitoring in real life.[93] According to a study in World Health Organization (WHO),[94] by the year 2050, the global population would be around 2.1 billion who would be beyond 60 (or, above) years of age. The increase of elderly people will raise more medical health issues. According to a report from WHO, the number of deaths caused by cardiovascular disease (CVD) was about 17.7 million in 2015. This number represents 31% of the global deaths.[95] Also, more than 422 million people are suffering from diabetes. It will be the seventh leading cause of death in 2030.[96]

There are also other diseases like cancer, Parkinson's, asthma, and so on, which are chronic and could be often fatal.[39] These diseases can be prevented if they are detected in time. The application of WBASN is to enhance healthcare systems so that it becomes more effective in the early detection of any disease. Accordingly, the necessary medical measures could be taken. The medical applications of WBASNs can be generally subcategorized as wearable, implant, or remotely controlled WBASNs. Each of these would be discussed in the subsequent paragraphs.

Wearable WBASNs. The noticeable growth in quantity and development of monitoring devices highlight the need for small-sized sensing devices which have capability to operate on different frequency ranges with facility of being lightweight so that they can be wearable.[60] Let us see a few real-life applications of wearable WBASN.

Assessing soldier fatigue. Fatigue can be physical or mental. It is a feeling of exhaustion. Physical fatigue is the failure of muscles to maintain best physical performance.[97] The WBASN could be used to observe the physical performance of the soldiers during training or in the battlefields. This may also be implemented during training sessions of police forces, fire fighters, and disaster management teams. With the help of motion and lactic acid sensors, any person's performance and physical fitness could be tested. This observation could help achieve better performance by giving rest to the one who has got tired and sending another person in his place.[97]

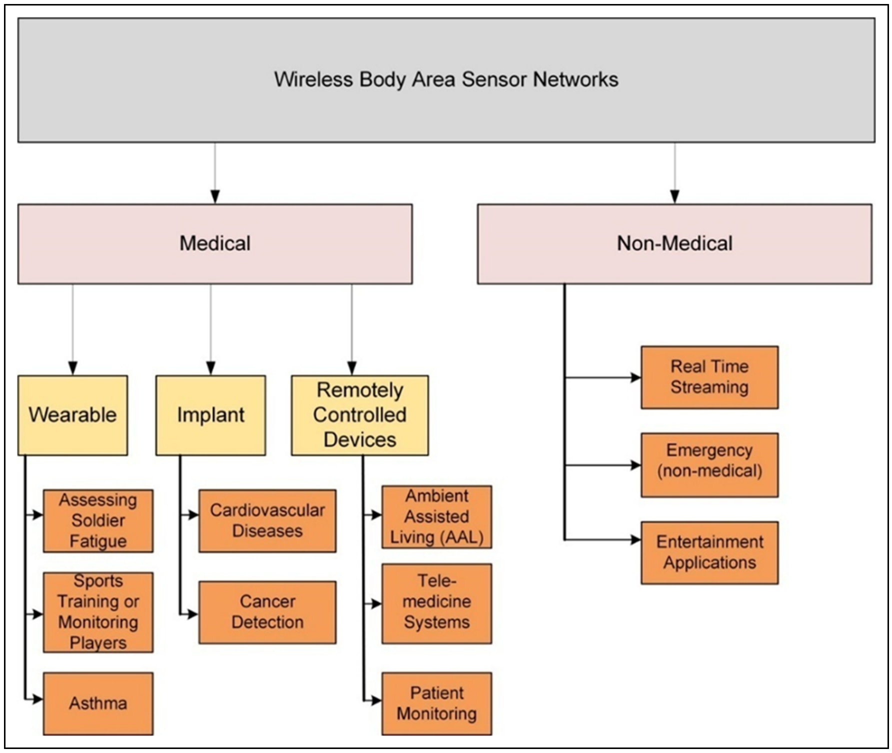

Figure 5. Various applications of WBASNs.

Sports training. During training, the players or the athletes may be observed for their performance so that they may be tested and based on their performance, they could be selected. The observed values would be stored as a feedback for future in order to make the player competent enough to give good response.

Sleep monitoring. Sleep is a basic and important human need. Healthy sleep is essential to maintain mental as well as physical health.[98] If any human lacks healthy sleep, then several disorders and fatalities[99] can occur. The consequences may be narcolepsy, which is a neurological disorder that affects the control of sleep and wakefulness, sleeping while driving or at workplace and also, it can lead to CVDs. In fact, a significant part of the world population is affected by sleep disorders.[100]

Polysomnography (PSG) is a diagnostic technique which is used to monitor sleep disorders. PSG records the sleep data which can further be saved for observation by the doctors. WBASN architectures have been proposed for observing sleep disorders and removing the complexity of using wired system of PSG through sensor nodes. For instance, a low-power architecture has been proposed in Rajagopal and Rodriguez-Villegas,[99] which evaluates sleep stages by applying automatic sleep staging algorithm (ASSA) on a central node and analog signal processing (ASP) architecture on sensor node. A prototype bio-potential sensor is designed in De Vicq et al.[100] to monitor sleep staging wirelessly.

Asthma monitoring. Asthma is a disease which has become very common and can be fatal if not treated.[101] Air pollution and weather change are believed to be linked to asthma.[102] The asthma patients need to take terbutaline as soon as possible to overcome the allergy.[103,104] The agents or the factors that cause allergy can also be monitored with the help of WBASN sensors which is helpful for people who have allergy or asthma. Asthma monitoring system assists the asthma patients in early detection of hazardous situations for asthma exacerbations.[105]

Fall detection. Fortino and Gravina[106] present *Fall-MobileGuard*, which is a novel real-time non-invasive/wearable fall detection and alarm notification system. The system uses a wearable inertial sensor node, equipped with a tri-axial accelerometer, worn at the waist, and a personal mobile device to detect and recognize different types of falls. This could be a handy system for advanced aged people who could still move but are feeble and could collapse anywhere due to their old age or other illnesses (for instance, in the case of fainting). As proposed by the authors, the detection method consists of two main processing blocks: (1)

threshold-based trigger which is executed on the wearable sensor and (2) posture classification which operates on the mobile device.

CVDs. One of the leading causes of death globally is CVD. Myocardial infarction (MI) is the most fatal one which is generally known as *heart attack* by most of the people.[107] If the abnormal conditions are monitored on regular basis, the effect of MI can be reduced using WBASN technology. One of the main applications of WBASNs is early detection of medical irregularities and symptoms.[108] Heart patients are also diagnosed with a portable ECG monitor called Holter monitor for a time period of 24–48 h.[109]

Hadjem et al.[107] propose a WBASN approach which detects MI early and in a real-time manner. To monitor cardiac activity in real-time, another wearable WBASN solution is provided in Khan et al.[110] A wearable ECG monitor was developed as noted in Delano and Sodini[111] to provide long-term data collection and analysis. Again, in Gravina and Fortino,[112] the authors present automatic methods for the detection of accelerative cardiac defense response (CDR). CDR basically refers to the idea that organisms react physiologically to the presence of danger or threat and this reactivity has a protective function because it provides the basis for adaptive behavior. In this work, the authors present a wearable application for body sensor network (BSN), to be specific, a novel method for fully automatic detection of CDR pattern. In fact, any such kind of use of sensors could ensure emergency medical treatment at the right time as the sensors would transmit data when a situation occurs.[113–116]

Implant WBASNs. Millions of people in the globe suffer from CVDs and other chronic diseases like severe joint pain, diabetes, high-blood pressure, and so on. Implantable devices having capabilities to communicate wirelessly can be used to analyze and deliver warnings to support human life. Devices for instance pacemakers, neuro stimulators, implanted cardiac defibrillators (ICD), drug pumps, and baclofen pumps have been used in the human body.

Cancer detection. Cancer is a leading cause of deaths worldwide. Sensors having capability to monitor cancer cells can be integrated in a WBASN. For instance, these sensors are able to diagnose tumors without the need of biopsy.[61]

Diabetes control. A condition in which the body loses the ability to utilize insulin is known as diabetes. It is the eighth-leading cause of death by disease as one study mentions.[117] The number of people having diabetes is predicted to reach 438 million by the year 2030, which would make 7.8% of the total population during that time.[118]

Remotely controlled medical sensor devices. WBASNs provide an incredible prospect for health monitoring remotely.[119] The aim of ambient assisted living (AAL) is to focus on exploiting emerging information and communication technology (ICT). One of the core objectives of AAL is to support the elderly people in their daily life.[120]

AAL. The basic aim of AAL in WBASN is toward the betterment of elderly people so that they might be able to live independently with kind of self-care with the aid of modern technologies. AAL provides environment for enhanced living. Some of the AAL applications are the hospitals which are dedicated for long-term care, smart apartments, and smart homes. All these applications make AAL very suitable for providing assistance to the old aged people.[120,121]

Telemedicine systems. BASNs were proposed for connecting electronic components to provide convenience to users. It is mostly applicable in telemedicine and m-health (mobile health) applications.[122]

Patient monitoring. Monitoring of physical activities has turn out to be more and more significant because they are linked with health status. WBASN systems have the capability of allowing internetworking with other networks as well as other devices.[123]

Non-medical applications

The applications of non-medical WBASNs are noted below.

Biometrics. WBASN-based applications for non-medical purposes could be seen in banking sector, for locking or unlocking smartphones or laptops or for other secure services. Bio-related signals can be used to provide signatures. Bio signals like ECG, voice, movements of the body, temperature of facial skin, respiration rate, and so on can be used in such applications.[122]

Entertainment applications. The fields like sports and entertainment are also very attractive for WBASN applications. Sensors could get activated during exercise sessions or during lying on bed or sofa or so. For instance, some kind of music could get turned on in home based on the individual's posture or some kind of video could start playing on the TV screen during exercise, and so on.[124]

Table 3. Characteristics of in/on-body applications.

Application type	Sensor node	Data rate	Duty cycle (per device) % per time	Power consumption	QoS (sensitive to latency)	Privacy
In-body application	Glucose sensor	Few kbps	<1%	Extremely high	Yes	High
	Pacemaker	Few kbps	<1%	Low	Yes	High
	Endoscope capsule	>2 Mbps	<50%	Low	Yes	Medium
On-body medical application	ECG	3 kbps	<10%	Low	Yes	High
	SpO2	32 kbps	<1%	Low	Yes	High
	Blood pressure	<10 bps	<1%	High	Yes	Medium
On-body non-medical application	Music for headsets	1.4 Mbps	High	Relatively high	Yes	Low
	Forgotten things monitor	256 kbps	Medium	Low	No	Low
	Social networking	<200 kbps	<1%	Low	No	High

QoS: Quality of Service; ECG: electrocardiogram.

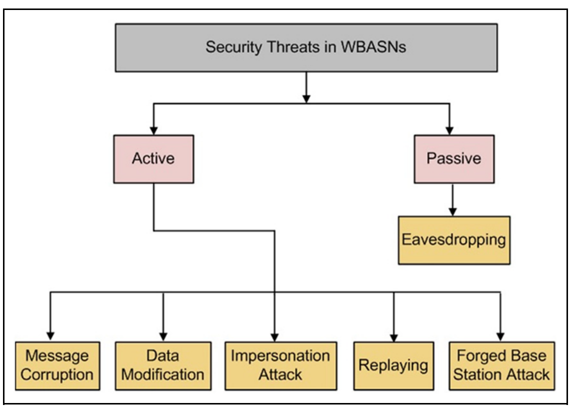

Figure 6. Security threats in WBASNs.

Emergency (non-medical). The main objective of all WBASN applications is improving the user's quality of life. However, the technological requirements of WBASNs are often application specific. Some in-body and on-body applications are shown in Table 3.[61]

Security threats

There are different types of threats and attacks by which the BAN data can be stolen and compromised. The threats are categorized as either active or passive, as shown in Figure 6.[125] The attacks are mainly eavesdropping, message corruption, modification of the data, replaying and impersonation attacks. As the information is regarding the health of a human being, if it is stolen, it could be used for activities that may be harmful. Table 4 illustrates the attacks against WBASN.[126]

Eavesdropping

Eavesdropping means secretly listening to a conversation (without the knowledge of the legitimate entities who are participating in a communication scenario). Attacker may intercept radio signals between the nodes in a WBASN easily.[126–129]

Table 4. Attacks against WBASN.

Attack assumptions	Risks	Requirements
Computational capabilities	Data modification Impersonation	Data integrity Authentication
Listening capabilities	Eavesdropping	Encryption
Broadcast capabilities	Replaying	Freshness protection

WBASN: wireless body area sensor network.

Message corruption

This is an advanced version of eavesdropping. In this attack, the adversary not only eavesdrops but also can delete partial or full data[126,130] causing message corruption. Such data would be unusable for processing.

Data modification

Although message corruption means modification of some data, we make a slight distinction between message corruption and data modification because, in case of specific data modification attack, the attacker may edit/alter, replace, or remove some portion or all of the data. If the modified data reach at the destination for further processing, that may result in false diagnosis.[126–128]

Impersonation attack

An impersonation attack is basically an attack in which case an attacker successfully assumes the identity of one of the legitimate parties in a system or in a communication protocol. If any attacker eavesdrops the data or impersonates any other legitimate entity and captures data, then he or she may make illegal use of that.[22,128]

Replaying

The attacker may resend the data signal after some instance of time. At the receiver side, this repeated message appears to be valid. Receiving is a part of communication depleting energy source of the senor so if attacker is replaying messages, then the intention may be to deplete the energy source so that sensor may stop working.[128,130,131]

Forged BS attack

In this attack, the attacker impersonates the PS. As WBASN has a relatively small-sized network, this kind of attack could happen. The impersonator can collect sensitive data by duping the legitimate sensor nodes that this is the actual PS.[132]

Indeed, security and secure transmission of data are of key importance for WBASN. Patient data should be provided appropriate level of privacy, authenticity, and integrity. Also, only the authorized entities should be allowed to access the data. Hence, the authorization aspect of security is also important. However, when it comes to this particular setting (i.e. the case of WBASN), what important is the lightweight nature of the security mechanisms so that those could be run on the wearable or implanted sensors or so. Given this issue, there are quite a good number of lightweight security mechanisms and secure communication models[133–135] for sensor networks that could be easily applied on WBASN setting irrespective of server-dependent or server-independent model.

Table 4[126–128] illustrates the WBASN's security risks and their corresponding security services. As a WBASN does not generally have many nodes like a usual WSN, that is, a limited number of nodes in a network (within pretty small area), the attacks like sinkhole attack or wormhole attack or Hello flood attack, and so on[22] are not that much relevant to such setting.

Radio technologies and notable protocols

In this section, radio technologies for WBASN are discussed such as Bluetooth, ZigBee, Bluetooth low-energy technology (Wibree), ultra-wideband (UWB), and others.

Bluetooth

It is a wireless technology which is low powered and has been integrated in many devices.[136] It is a data communication standard which is designed for wireless communication between small, mobile devices.[137]

Table 5. Bluetooth specifications.

Technology	Data rate	Frequency	Maximum range
Bluetooth IEEE 802.15	723 kbps	2.4 GHz	10–100 m

Bluetooth operates at ISM (industrial, scientific, and medical) frequency band of 2.4 GHz.[138] Data as well as voice communication are possible through Bluetooth. The frequency, data rate, and the range of Bluetooth are shown in Table 5.[139]

ZigBee (IEEE 802.15.4)

The standard adopted by ZigBee is the IEEE 802.15 Task Group 4 (TG-4) which is a low data rate wireless personal area network (WPAN) standard.[140] ZigBee is a technology usually associated with home automation systems. It has two physical bands 2.4 GHz and 868/915 MHz having data rates of 250 kbps for 2.4 GHz, 20 kbps for 868 MHz, and 40 kbps for 915 MHz. It was later improved and enhanced for a low data duty cycle ($<0.1\%$), low power (extending battery life multi-month to years) setting.[141] ZigBee is considered for networking of two end-devices just like Bluetooth. It has some advantages due to the fact that it is relatively low cost and it consumes low amount of power. In fact, it is sometimes considered as an alternative to Bluetooth.[142]

Bluetooth low-energy technology (Wibree)

Previously, it was called low end extension for Bluetooth and then came the name, *Wibree*. It was basically designed for connecting small devices to mobile terminals wirelessly. It is expected to provide a data rate of up to 1 Mbps.[34] It is a relatively better choice for WBASN applications in which less power consumption is required, which is possible using low-duty cycle operation.[62]

UWB and IEEE 802.15.6

UWB technologies have frequency allocation of 3.1–10.6 GHz and are projected to be used in WBASNs because of their capabilities like anti-multipath capabilities, large bandwidth availability, and low power consumption.[143] It was developed for short range communications and was standardized by IEEE 802.15.6 Task Group 6 (TG-6).[144] This technology has frequency range of 3.2448–4.7424 GHz in low band and 6.24–10.2336 GHz in high-band having 499.2 MHz channel bandwidth.[145]

ANT

ANT is a protocol designed for PANs.[146] The components that run using ANT are low powered, low cost and are operated at 2.4 GHz ISM band. Interconnection of tens to hundreds of nodes is possible in ANT protocol and this ability makes it a better choice for practical networks. Bluetooth hardware's power consumption is greater at least by 10 times compared to ANT. The issue that makes ANT energy efficient is the fact that most of the time, the system is kept at ultra-low power sleep mode. If transmission occurs, that is performed within the shortest possible time and just after transmitting, the ultra-low power sleep mode is again activated.[147] Overall, it provides data rate of 1 Mb/s.[63]

RuBee (IEEE 1902.1)

RuBee uses the standard protocol IEEE 1902.1.[148] The features that make RuBee very much suitable for WBASNs are high security level, long battery life, efficient transmission distance, and stable operation. It operates at low frequencies, that is, below 450 kHz. It is based on two-way wireless protocol using long wave magnetic signals for the purpose of sending and/or receiving data. The data are short up to 128 bytes only. RuBee operates at a frequency that cannot be attenuated by metal or liquid allowing its deployment in any environment that RFID is not able to handle.[148,149]

Sensium

Sensium allows healthcare providers to continuously monitor patients at low cost. An ultra-low-power platform is provided by Sensium to *on-body* applications for low data rate. The sensors send multiple data to server that could either be a computer, laptop, PC (personal computer), PDA (personal digital assistant), or a mobile phone, which is used to forward the data to other entities. Sensors are kept either in sleep mode or in standby mode till they have their assigned time slot for data transmission. It could create wireless links to smartphones.[63,149,150]

Zarlink

Zarlink is suitable for medical implants. It combines cyclic redundancy check (CRC) error detection with Reed–Solomon coding scheme to achieve a link. This link is considered very reliable. As a fact, the world's first camera capsule suitable to be swallowed uses Zarlink's radio-frequency (RF) chip. This chip is designed for gastrointestinal tract examination and it sends two images of movie quality in a second. The main reason of using Zarlink transceiver is its low current consumption as it remains in a sleep mode for most of the time.[100,103]

Z-Wave and Insteon

Both of these technologies are the registered mesh networking technologies which are developed for home automation. Z-Wave operates on 2.4 GHz ISM band while 900 MHz ISM band as well as power lines is used by Insteon. Z-Wave belongs to next-generation wireless networking arrangement enabling internal networking or could be used for remote control. It uses low-powered and reliable radio waves which can travel through building walls.[100,151]

Programming frameworks for WBASNs

In this section, some of the programming frameworks for WBASN are discussed.

Activity-aaService (activity as a service)

In Gravina et al.,[152] a cyber-physical framework is proposed. This system is able to monitor human activities either in *online* or *offline* mode and it supports both the individuals and the communities. The researchers used automatic fall detection, physical energy estimation, and smart wheel chair support for the purpose of evaluating the proposed solution. They have also evaluated the performance by analyzing several parameters like CPU usage, processing load, memory footprint, and data transmission time.

BodyCloud

In Fortino et al.,[153] the researchers design a large-scale BAN which is based on BodyCloud architecture. BodyCloud is a multi-tier application-level architecture. It is an integration of SaaS-level (Software as a Service-level) cloud-based computing and SPINE (Signal Processing In Node Environment). SaaS framework is Google supported engine while SPINE is a flexible BAN framework. Modality, Group, View, and Workflow are the actual programming ideas used in this work.

CODEBLUE

In Shnayder et al.[154] and Malan et al.,[155] the researchers integrate wireless low-power sensors with PDAs and computers. Their proposed system is mainly for patients. With the system, during the test phase, the authors analyzed patients and transmitted data to their family/friends. The name of this proposed system was given, *CodeBlue* and at that time, the authors' experiments were successful for pulse oximetry mote. They used adaptive spanning-tree multi-hop routing algorithm which was based on the TinyOS Surge protocol. In order to minimize interference, they used dynamic transmission power scaling.

SPINE

In Fortino et al.,[156] a framework named SPINE (signal processing in node environment) has been proposed which is an open-source programming framework. This framework supports BASN applications and it provides a platform that allows using both hardware and software on the choice of selection because of its capability to support heterogeneous components.

TITAN

In Lombriser et al.,[157] TITAN framework is presented. It is used for context recognition in dynamic sensor network environment. TITAN is a dynamic reconfigurable framework which adapts context recognition algorithms to perform reconfiguration and is an efficient system due to its capabilities like high-speed processing, easy programming, and fast reconfiguration approach.

Some ongoing projects

This section summarizes some of the works that have been developed recently in the field of medical wearable devices.

OvulaRing

It is the product of VivoSensMedical GmbH.[158] This product has been developed for doctors/gynecologists, who can use it during pregnancy of women or for determining fertility. It helps women in their ovulation. Especially, it helps in determining when they are most fertile and are ovulating to conceive a child.

VitalPatch

VitalPatch®[159] is a wearable biosensor. This sensor has the capability to sense and monitor eight vital signs in real-time continuously. The parameters which it can monitor are as follows:

1. Heart rate;
2. Single-lead ECG;
3. Respiratory rate;
4. Heart rate variability;
5. Skin temperature;
6. Body posture;
7. Fall detection;
8. Activity.

The recorded data can be accessed on a mobile platform.

FreeStyle Libre

It is a glucose monitoring system which has been designed by Abbott[160] for diabetic patients. It is applied to the upper arm with an applicator. This applicator is disposable. When sensor is applied, a fiber is inserted under the skin. According to the Abbott Diabetes Care data file, the users agreed on the point that this system of glucose monitoring is easier as compared to the traditional finger prick test.

Zio XT®

This product has been developed by iRhythm.[161] The aim of this product is detecting the abnormal activities of the heart. This component can work continuous up to 24 consecutive days. The patients have the flexibility of taking shower, sleep, or even exercise wearing Zio. This component is able to record heartbeats for about 20,000 minutes.

A brief comparison of some of the existing projects is presented in Table 6.[40] The different aspects have been considered in terms of different communication scenarios.

Future scope and challenges

The future of WBASN is very bright as continuous research is being done by the researchers from both academia and industry. The involvement of tech giants in this field boosted the efforts for practical use of WBASN-based systems. What was thought to be a dream few decades back has basically started happening today. In this section, we describe the scope and future vision of works and applications in this area along with the challenges that may hinder the technology's progress and practical implementation in real-life applications.

Scope and future vision

The betterment of human life is a continuous process. WBASN has indeed a great potential to contribute to the betterment of our life. The applications, especially related to medical and healthcare issues, could be made available even in the remote places in the developing countries. We are already witnessing a boom of the use of sophisticated medical devices that use various types of sensors. As the time goes ahead, the research activities in this area would become stronger. This is a field where the imagination and reality are often very close. With the advancements in electronic chips and wireless communications technologies, it is possible today to

Table 6. Existing and ongoing WBASN projects.

Project	Target application	Intra-BAN comm.	Inter-BAN comm.	Beyond BAN comm.	Sensors
BASUMA[151]	Health monitoring	UWB	N/A	N/A	ECG, reactive oxygen sensor (ROS), SpO2 sensor, spirometer
MobiHealth[162]	Ambulatory patient monitoring	Manually	ZigBee/ Bluetooth	GPRS/Universal Mobile Telecommunications System (UMTS)	ECG
AID-N[163]	Emergency response system	Wired	Mesh/ZigBee	Wi-Fi Internet Cellular networks	Blood, pulse, ECG
MAHS[164]	Healthcare	Bluetooth	Wireless network	Internet	Spirometer, pulse, temperature, pressure
Code Blue[154]	Medical care	Wired	ZigBee/mesh	N/A	Motion, pulse oximeter
LifeMinder[165]	Real-time daily self-care	Bluetooth	Bluetooth	Internet	Galvanic skin response (GSR) electrodes, pulse meter, thermometer, accelerometer
SMART[166]	Health monitoring in waiting room	Wired	802.11.b	N/A	SpO2 sensor, ECG
CareNet[167]	Remote healthcare	N/A	ZigBee	Internet/ multi-hop 802.11	Gyroscope, tri-axial accelerometer
ASNET[168]	Remote health monitoring	Wired or wireless interface (Wi-Fi)	Wi-Fi/Ethernet	Internet/Global System for Mobile Communications (GSM)	Temperature, blood pressure
WHMS[169]	Healthcare	Wired	Wi-Fi	N/A	Electrocardiogram (EKG or ECG)
Human++ [170]	Entertainment, medical, assisted living, lifestyle	UWB	N/A	N/A	ECG, EMG, EEG
WiMoCA[171]	Sport/gesture detection	Star topology and time table–based Medium Access Control (MAC) protocol	Bluetooth	Wi-Fi/Internet/ cellular networks/ Bluetooth	Tri-axial accelerometer
Ayushman[172]	Health monitoring	ZigBee	802.11	Internet	EKG, blood pressure, oximeter, gyroscopic sensors, accelerometer, gait monitoring sensors
MIMOSA[173]	Ambient intelligence	Radio-Frequency IDentification (RFID)/ Bluetooth/Wibree	UMTS/GPRS	Internet	RFID sensors, any sensors
Lifeguard[174]	Ambulatory physiologic monitoring for space and terrestrial applications	Wired	Bluetooth/ Internet	Bluetooth/Internet	ECG, respiration electrodes, pulse oximeter, blood temperature, built-in accelerometer
IBBT IM3[a]	Telecare and telemedicine services	N/A	N/A	Internet	Respiration, ECG, heart rate
MITHril[b]	Healthcare	Wired	Wi-Fi	N/A	EKG, ECG
UbiMon[c]	Healthcare	ZigBee	Wi-Fi/GPRS	Wi-Fi/GPRS	3Leads ECG, 2Leads ECG strip, SpO2

WBASN: wireless body area sensor network; BAN: body area network; UWB: ultra-wideband; ECG: electrocardiogram; GPRS: general packet radio service; EMG: electromyography; EEG: electroencephalogram.
[a]https://www.iminds.be/en/projects/im3
[b]https://www.media.mit.edu/wearables/mithril/
[c]http://www.doc.ic.ac.uk/vip/ubimon/home/index.html

build various types of sensing platforms which could be used in various innovative ways. There are some renowned IT companies, commonly called as *tech giants* like Siemens, Apple, Google, and so on, who are competing to gain their own market advantage in the areas related to WBASN. This competition could pave the way for low-cost practical use of WBASN technologies in different parts of the globe.

Today, our life is heavily dependent on technology. With the frequent use of mobile devices and other small gadgets in daily life, human beings now offer a perfect platform to monitor their physiological parameters automatically and electronically. As a futuristic vision, one of the most significant applications of WBASN that could be seen in the coming days could be in e-healthcare sector with the aid of virtual reality (VR). Paired with mechanicals like special haptic gloves, the low latency of 5G has the potential for touch signals to be transmitted over a mobile network. Using such a combination of most advanced technologies, at least *lower-risk real-time* virtual surgery could be performed. Such a mechanism could also be used as a training tool to teach new skills to the surgeons in remote locations and offer them a way to practice and learn the required muscle memories.[175,176] To clarify a bit, the term *muscle memory* is often used synonymously with *motor learning*, which is basically a form of procedural memory that involves consolidating a specific motor task into memory through repetition. A long-term muscle memory could be created for that task when a movement is repeated over time, eventually allowing it to be performed without conscious effort.[177] If the machines can make moves like human beings via remote interfaces, that would really be a significant step forward in the medical sector. Sensors would be the key devices in any such mechanism.[178] In future, with the advancement in the areas of IoT and CPS, with the additional number of smart devices around us, the existing platform could be better suited for the best use of various types of WBASN applications, some or many of which are yet to be known.

Challenges

The practical use and implementation of any technology is never unchallenged. There are indeed quite a few notable challenges that WBASN faces today and could face in the coming days as well. Effective solutions may reduce or tackle some but overall, some issues would be unsolvable and would be sometimes context specific.

One of the most critical challenges is the human body posture. Most of the sensors developed for this area are operated based on light of sight (LoS) communication. LoS is basically a type of propagation that can transmit and receive data only where transmitter and receiver stations are in view of each other without any sort of an obstacle between them. LoS can happen when a human body's front and back sides are used; however, during sleeping, there could be only one side for such communication or no suitable side at all due to user's various positions and use of pillows, blanket, and so on—so, signal transmissions could really be hampered. Again, when a human being is in sitting position, the sensors may not be able to communicate properly due to non-line of sight (NLoS). Another challenge is the movement of a human being. During movements, the arms, legs, and the middle body could make an angle that makes it difficult for the sensors to communicate with other sensors or other devices.

Energy consumption is an important challenge for WBASN. The sensors need energy for all types of communications and sensing activities. More research needs to be carried out to make these sensors more energy efficient while the protocols should be made more lightweight. Various energy scavenging technologies should be utilized and battery lifetime should be improved. In fact, some of these challenging issues are related to other related fields like electrical and electronic engineering or so, but advancements in those fields would also greatly contribute to the area of WBASN.

WBASNs could also be merged with cognitive radio technology so that the sensor's radio may be turned on or off by itself based on specific context and thus, some energy could be saved. Building a properly working cognitive network is a great challenge. If WBASN has some kind of cognitive computations involved, it would greatly contribute to various application scenarios.

In some very recent works,[179,180] the issue of multi-sensor fusion for BSN has been addressed. There is a recent trend of the BSN technology being transitioned to the multi-device synchronous measurement environments. As such, fusion of data from multiple, potentially heterogeneous, sensor sources would be a fundamental yet challenging task. This would eventually directly impact the performance of the application. Very few works have been done so far on this specific issue and hence, developing efficient technical solutions for effective fusion of BSN data remains as a challenge. Another interesting challenge is how the sensors in a WBASN can use gait analysis and body temperature to convert those into energy.

Conclusion and future studies

WBASN is still a relatively new technology which has the great potential to revolutionize healthcare applications in the coming future. In this work, we summarized various aspects and issues of WBASN. We have tried to cover the most recent advancements in this field while some general discussions have been presented for the general readers of the topic. When the expected outputs of various ongoing projects (and more that may come in the future) are available, WBASN would be stronger in its practical applications and it would directly impact the public health sector adding ease to our daily life. As a future work, an interesting direction would be investigating edge computing based/assisted BSN systems. As increasingly, more and more papers are being published on edge computing, these recent developments would also have impact on the BSN and WBASN.

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