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Research paper

Review of wireless body sensor networks

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Abstract

Wireless body area networks (WBANs) are emerging as important networks that are applicable in various fields. WBAN gives its users access to body sensor data and resources anywhere in the world with the help of the internet. These sensors offer promising applications in areas such as real-time health monitoring, interactive gaming, and consumer electronics. WBAN does not force the patient to stay in the hospital which saves a lot of physical movement. This paper reviews a review of WBANs. We study the following: prior researches, applications and architectures of WBAN, and compression sensing techniques.

Keywords: *Compression Sensing; Healthcare; Sensors; Wireless Body Area Network; WBAN Survey*.

1. Introduction

A Wireless Body Sensor Network is an emerging technology that can be the application in E-Health care systems [1-2]. A WBSN typically consists of a collection of low-power, miniaturized, and lightweight devices with wireless communication capabilities that operate in the proximity of a human body. Generally speaking, these devices can be distinguished into three types: sensors, actuators, and personal digital assistants (PDA) [3]. The PDA acts as a sink to collect all the information attained by the sensors and transmit it to the users (patient, nurse, physician, etc.) via an external gateway [4].

Gartner states that the worldwide wearable devices have generated a revenue of $28.7 billion in 2016, and is expected to grow from 275 million units in 2016 to 477 million units in 2020, generating a revenue of $61.7 billion [5]. The Global mobile data traffic forecast by Cisco predicts that, by 2020, the number of wearable devices will increase to 601 million globally [6]. According to a survey conducted by Ericsson Consumer Lab (Stockholm, Sweden), 60% of the participants believe that, in the next five years, biomedical sensors like smart patches, indigestible pills, and other implantable chips would be commonly used [7]. WBSNs consists of various sensors which are placed in, around, or on the human body to monitor the various parameter like temperature, blood pressure, ECG, EEG, etc. The involvement of WBSN started with defense when this technology was used in their activity [8]. Since then, it has evolved in human life and presently it is used in every field of life. The WBSNs can be applied in numerous medical and non- medical applications. [9]

Sensors are placed on both the inside and outside of the body and various bodily information is transmitted and received. Signals can even be sent to the nearest hospital in emergencies. However, because WBSNs must operate in and on the human body, unlike traditional wireless sensor networks (WSNs), sensor size in WBSNs is extremely small and energy resources are limited. Therefore, it is crucial to reduce the energy consumption of sensors in WBSN environments [10].

The underlying aims of WBAN are to acquire physiological data from the patient(s) for steady monitoring that conclusively needs an efficient routing approach [11]. The reliable, secure, and efficient implementation of routing protocol is a challenging task in WBAN due to its unique characteristics and limitations, such as energy reduction or overheating of implanted sensors nodes. The heat-rise and energy depletion influences the constancy of a network; hence the data is transmitted through various paths in WBAN. During the last decade, several studies have been carried out, and many systems have been developed on WBAN. The various characteristics of WBAN have raised the number of issues in different layers of WBAN. At the physical layer problems of interoperability, temperature control, changing topology, interference, fault acceptance, security, etc. The issues related to the MAC layer are dynamic channel assignment, control packets overhead, protocol overhead, throughput, synchronization, delay control, etc. The problems related to the network layer are mobility, localization, traffic control, temperature and heat control, optimum routing, etc. [12].

2. Related works

In this section, the state of the WBSN. Details about these models are provided next. Table 1 summarizes several studies on WSBN using various modeling techniques.

In [28] The QoS values computed through the DRT profile provide maximum reliability of data transmission within an acceptable latency and data rates. The DRT is based on the carrier sense multiple access with collision avoidance (CSMA/CA) channel access mechanism and considers IEEE

802.15.4 (low-rate WPAN) and IEEE 802.15.6 (WBASN). Then, a detailed performance analysis of different frequency bands are done which are standardized for WBASNs, that is, 420MHz, 868MHz, 2.4GHz, and so forth. Finally, a series of experiments are conducted to produce statistical results for the DRT profile concerning delay, reliability, and packet delivery ratio (PDR). The calculated results are verified through extensive simulations in the CASTALIA 3.2 framework using the OMNET++ network simulator.
In [29] Develop an Intel Galileo based WBSN platform. The physiological characteristics such as (Electrocardiogram) ECG captured from the human body can be used as an exclusive way for entity identifications (EIs) to authenticate data in WBSNs. using Matlab software. developed fuzzy vault based data authentication methods for entity identification in WBSNs.The HKD-10A sensor for ECG collection from the human and Wi- Fi module (N-2230) is used for wireless data transmission between source and destination. Three fuzzy vaults-based security algorithm for entity identification are also compared namely; MWFT, SWFT, and AC/DFT. The AC/DCT provides better FRR, FAR, and HTER values than MWFT and SWFT.
In [30] used The Castalia simulator and OMNET ++ provide power Proficiency in collecting patient data. In the data link layer, MAC (Medium Access Control) protocols WBAN helps with energy efficiency. The attributes like ECG, pulse rate, temperature are reported to the doctor and relatives/caretaker of patients for every hour to alert them.
In [31] simulate the energy consumption, throughput, and reliability for both, ZigBee IEEE 802.15.4 Mac protocol and BAN IEEE 802.15.6 exploited in medical applications using Guaranteed Time Slot (GTS) and polling mechanisms by CASTALIA software. Then, compare and analyze the simulation results. These results show that focused on giving decisive factors to choose the appropriate MAC protocol in a medical context depending on the energy consumption, some used nodes, and sensors data rates.
In [32] The identification process for establishing a decision matrix is based on a crossover of ‘time of arrival of the patient at the hospital/multi-services’ and ‘hospitals’ within mHealth. Then, the development of a decision matrix for hospital selection is based on the MAHP method. Finally, the validation of the system that is used.
In [33] Implement several scenarios using Castalia taking into account variable packet rate, network size, and temporal behavior in both single-hop and multiple hop WBAN configurations to evaluate performance in terms of QoS parameters such as packets received and power consumption. The experimental results of the simulation show, the received packets for each node degraded to a higher packet rate considering the n temporal model compared to no temporal model.
In [34] IEEE 802.15.4, Medium Access Control Protocol is designed to ensure the timely delivery of medical data, along with meeting QoS requirements for healthcare applications based on a wireless body sensor network. Guaranteed time slots (GTS) are allotted according to the variable rate of heterogeneous data traffic that is sensed by different sensor nodes ensuring energy efficiency, low latency, high throughput, etc. We simulated different scenarios representing normal and critical conditions of patients using Castalia 3.3 and OMNeT++. The results showed that there is a significant reduction in power consumption of 20% depending on the diversity of the GTS configuration. Average time-varying GTS, temporal, and varied, unrelieved time-packets are 76% at 8 nodes and 66% by varying GTS, no Temporal at 11 nodes within the 240 ms delay allowed in the healthcare application.
In [35] a Wireless Body Sensor Network (WBSN) based, portable, easily affordable, miniatured, accurate “Heartrate Monitoring System (HMS)”. HMS can be used to regularly examine the cardiac condition at home or hospital to avoid or early detection of any serious condition. The system was validated with the case study of forty healthy young subjects. The results produced by HMS were, each subjects’ 99% data was in the custom range and all subjects were healthy.
In [36] A routing algorithm based on ant optimization technology was used to efficiently distribute energy use to nodes. Thus reducing energy consumed and prolonging the life cycle of the nodes, as well as avoiding damage to the patient's body tissues. The protocol was initially compared with the conventional LEACH routing protocol to demonstrate its efficiency in extending node life, and then it was used with the experimental network to examine energy uses. The results obtained were compared with other results obtained through conventional and advanced routing protocols, and there was a significant reduction in power consumption which proved the efficiency of the algorithm.
In [37] a general analytical model for performance evaluation of the IEEE 802.15.6 based WBANs with heterogeneous traffic in terms of priority. The model is composed of two complementary submodels. The first is a renewal reward-based analytical sub- model that efficiently describes the IEEE 802.15.6 CSMA/CA Back-off process. The second sub-model is an M/G/1 queuing model with a non-preemptive priority. Using Matlab and Maple, we analyzed the analytical model under ideal channel conditions and saturated network traffic regimes. Then, we performed simulations of the IEEE 802.15.6 standard using the Castalia Simulator based on OMNeT++. Results showed the accuracy of the model for managing WBANs with heterogeneous traffic.
In [38] An application classification algorithm and a packet flow mechanism are developed by incorporating SDN principles with WBAN to effectively manage complex and critical traffic in the network. Furthermore, a Sector-Based Distance (SBD) protocol is designed and utilized to facilitate the SDWBAN communication framework. Finally, the proposed SDWBAN framework is evaluated through the CASTALIA simulator in terms of Packet Delivery Ratio (PDR) and latency. The experimental outcomes show that the system achieves high throughput and low latency for emergency traffic in SDWBANs.

Table 1: Literature Survey

Author name	Simulation devise or method	Methodology	Future scope in research	Evaluation results of the proposed	Year of publication
Negra et al.[13]	-	Numerous techniques have proven to support WBAN applications, such as remote monitoring, biofeedback, and living assistance by responding to specific service quality requirements (QoS).	-	-	2016
Habib et al. [14]	Adaptive sampling technique	Progress on energy-efficient mechanisms based on data reduction for BSNs. It reviewed compressive sensing and adaptive sampling approaches to reduce the amount of data collected and transmitted over the network.	Reduce the number of bits needed to represent the sensed data before transmission, while taking into consideration the trade- off between the computational cost and the compression ratio. Then, combine the compressive data model with an adaptive sampling technique to further reduce the collected data	Provided a discussion about the differences and the advantages of the different techniques and formalized an open question concerning the data compression in BSNs.	2017

			before transmission.		
Hegde and Prasad [15]	OMNeT++, Castalia3.2	The lower layer parameters in WBAN by analyzing throughput using Temporal and noTemporal variations	-	Evaluates for WSNs over wired networks and results in WBAN in medical applications with greater efficiency. Requirement of QoS with limitation of power in sensor nodes of WBANs, and deploying equipment in larger numbers with low cost and high efficiency.	2017
CHEN et al [16]	FPGA and synthesized by the VLSI technique	A VLSI implementation of a micro control unit (MCU) for wireless body sensor networks (WBSNs). This design consists of interface, encryption, four register banks, compression, and detection of QRS points.	VLSI implementation using adiabatic logic	MCU design contained 7.61k gate counts and consumed 1.33 mW when operating at 200 MHz by using a 90-nm CMOS process.	April 2017
Sodagariet al. [17]	CR	Investigates how cognitive radio and dynamic spectrum access are used for BANs to save spectral resources. Specifically, the features associated with the usage of the three major cognitive radio paradigms of underlay, interweave and overlay in these networks.	Investigation of the performance of CR-enabled MWBANs with moving bodies.	A comparison between the common methods of spectrum sensing as well as spectrum access. It also focused on fixed and triggered sensing and access timing methods.	2018
Takabayashi et al. [18]	MATLAB	The performance of the quality of service (QoS) control scheme in a multi- hop WBAN based on the IEEE Std. 802.15.6 is evaluated.	Evaluate on a WBAN due to the existence of selfish nodes. it will also devise a method of removing detected selfish nodes.	The Pd became high when the ratio of the measurement value at the first collision and the second collision was 1: 2, and the Fd became low when the rate was 2: 1. It was also found that the Pd decreased with the increase in the number of nodes.	2018
Waheed. et al. [19]	Two-Way Relay Cooperation	The reliability and energy efficiency in WBAN applications play a vital role. The analytical expressions for energy efficiency (EE) and packet error rate (PER) are formulated for two-way relay cooperative communication. link length extension and diversity is achieved by joint network-channel (JNC) coding the cooperative link.	-	provided a gain of approximately 54% inefficient link length compared to the direct link for in- body communication, 51.6% for on-body LOS, and 50% for on- body NLOS. It is shown that an extended hop length of 7.5 10% in one-way relay communication and 5–7.5% in two-way relay cooperation for in-body, 8.5–14% for one-way relay communication, and 5.5–8.5% for two-way relay cooperation in on-body LOS scenario and 5–7% for one-way relay communication and 3.5–5% for two-way relay cooperation in case of on-body NLOS is achieved for cooperative communication in the simplest case	February 2018

Bhatia and Kumar [20]	MADM method	Investigates for best network selection from the available networks depending upon different QoS requirements for different WBAN applications. The different multiple attribute decision-making algorithms are used.	Application of game theory approach for network selection.	The scheme can select the best network for different data traffics for cognitive-enabled WBANs.	March 2018
Khan, R. A., & Pathan, A.-S. K. [21]	-	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.	An interesting direction would be investigating edge computing-based/assisted BSN systems and would also have an impact on the BSN and WBASN	-	March 2018
Omuro et al.[22]	CSMA/CA	These works detect the selfish node in WBAN utilizing CSMA/CA defined in IEEE 802.15.6	an effective error control scheme for multi-hop WBANs should be considered. Also, PHY evaluation indexes were mainly considered. Hence, evaluating the system delay and throughput in the network layer should be considered for multi-hop cases. As an extension of IEEE Std. 802.15.6, cases with greater than three hops should also be evaluated and analyzed theoretically.	The numerical results show that the scheme outperforms the standard scheme in terms of the PDFR, some transmissions, and energy efficiency. Case 3 showed better performance than the other cases at both hops. When d2hops was fixed, it was shown that performance became optimal when d1st = d2nd (except Case 2) from computer simulations and theoretical analysis. This result is expected to greatly contribute to the optimization of how nodes and hubs are arranged when designing a WBAN.	November 2018
Murtaza Cicioğlu and Ali Çalhan [23]	SDN, WBAN routing algorithm	a WBAN architecture based on the SDN approach with a new energy-aware routing algorithm for healthcare architecture is proposed. To develop a more flexible architecture, a controller that manages all HUBs is designed. The proposed architecture is modeled using the Riverbed Modeler software for performance analysis.	Develop new algorithms using fuzzy logic for multi-attribute decision making, considering different parameters such as specific absorption rate (SAR) and data rate to improve routing algorithm. The routing algorithm is designed only for inter-WBAN communication.	IEEE 802.15.6 for intra-WBAN communication and WBANFlow architecture for inter-WBAN communication are developed, and all the QoS requirements are met. At the same time, a new energy-aware routing algorithm named SDNRouting, which runs on the controller and its performance is analyzed for different cases.	April 2019

			It is therefore planned to use the routing algorithm developed in future studies in intra-WBAN communication.		
Abidi et al. [24]	MATLAB	proposed an effective new protocol for the wireless body area network, using a gate body sensor, to direct data to its final destination	focus on Study cooperation between the contract to improve system performance.	satisfactory results in terms of network stability and lifetime. Because of the collaborative characteristics of wireless body area networks	April 2019
Alkhayyat et al. [25]	TCMN, IEEE 802.15.6.	A cognitive cooperative communication with two master nodes, namely, as two cognitive master nodes (TCMN), which can eliminate the collision and reduce the retransmission process.	Design and investigate a MAC protocol for inter- WBSN cooperation.	The energy-saving of the TCMN is 99% concerning DTM and ICCM under IEEE 802.15.6 CSMA.	May 2019
Latha R and Vetrivelan P [26]	Telemedicine techniques, Bayes' theory.	A collection of telemedicine techniques used by WBANs. The probability of sending emergency messages can be determined using Bayes' theory with probability evidence. The maximum linear regression linear prediction (MAP) can be applied, and the binary classification can be used as a substitute for MLE.	-	Explains the network model with 16 variables, with one describing immediate consultation, as well as another three describing emergency monitoring, delay- sensitive monitoring, and general monitoring. The remaining 12 variables are observations related to latency, cost, packet loss rate, data rate, and jitter.	April 2020
Zeinab Shahbazi and Yung-Cheol Byun[27]	Castalia and Blockchain technique	Wireless Body Area Networks (WBANs) used by Castalia a simulation tool its comparison is made with Multipath Ring Routing Protocol (MRRP), thermal-aware routing algorithm (TARA), and Shortest-Hop (SHR).	The planning to extend the proposed protocol to deal with the different body postures, i.e., the postural movement of the body will be considered along with the maintained temperature and energy of the network.	The protocol performs significantly better in balancing of temperature (to avoid damaging heat effect on the body tissues) and energy consumption (to prevent the replacement of battery and to increase the embedded sensor node life) with efficient data transmission achieving a high throughput value.	June 2020

3. WBAN application

Wireless body area network applications are proving themselves very efficiently and these applications are not just for human health care monitoring but there are also many other applications such as sports, fitness, gaming, electronics, measuring body position, location of a person, military, and many other that are using WBAN approach for different purposes, Figure1 shows some applications that are used by human and are based on WBAN systems. The astonishing use of WBAN applications is for health care, entertainment, sports, and fitness applications, all these applications are very demanding and reliable.

From the list of many advanced WBAN applications, few are fully developed and can empower their technologies in a real time environment; some of these applications are discussed below. [39]

Fig. 1: Applications of WBAN. [39].

3.1. Health care

Health care and a health delivery system based on WBSN requires multidisciplinary research and development in biology, physiology, physics, chemistry, micro/nanotechnologies, material sciences, industrial sectors like medical devices, electronics, microchips, technical textiles, and telecommunications and related engineering disciplines. Moreover, all economically developed countries are undergoing social changes such as aging populations, further integration of people with disabilities, and an increase in chronic diseases. These changes will accelerate further development and market growth of WBSNs. [40]

3.2. Entertainment

Wireless body sensor networks (WBSNs) mostly consist of low-cost sensor nodes and implanted devices which generally have extremely limited capability of computations and energy capabilities. Mobile wearable and wireless muscle computer interfaces have been integrated with the WBSN sensors for various applications such as rehabilitation, sports, entertainment, gaming, and healthcare. [41]

3.3. Lifestyle and sports

In Sports, WBSN can be used to examine the health of the athletes. Readings can be taken from the athletes without requiring them to exercise on a treadmill.
Coaches can take a closer look at the strong and weak points of an athlete by measuring various body conditions like change in a heartbeat, oxygen level, etc. during a race and other real-life scenarios. This can help in improving their shortcomings and improving their skills.

3.4. Military

Uses of WBSN in defense are many. Examining the health condition of soldiers, checking the level of hydration, tracking their location and body temperature monitoring are few of them. All the readings can be used for providing help to the soldiers when they get injured, to get an idea of when strength, precision, attention have to be enhanced and can also be used for reducing incidents of friendly fire due to misunderstanding in identity by telling them their exact location and identity time to time. [42]

4. Architecture of WBSN

In this section, Table 2. the architectures of the WBSN. Details about the previous researches:

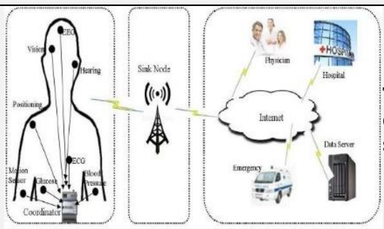
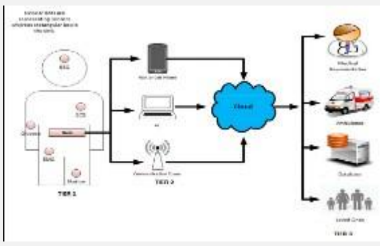
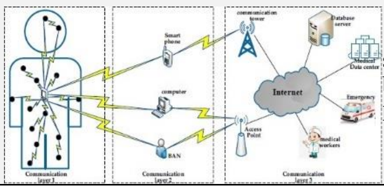
5. Compressive sensing

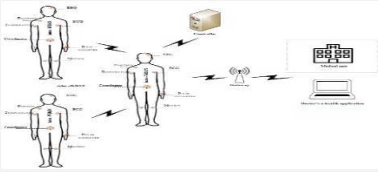
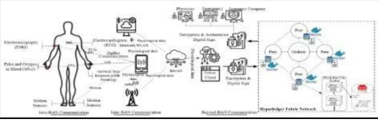
Compressed sensing (CS) is a signal processing technique that enables signal reconstruction from a small set of linear projections, called measurements, provided the signal is sparse in some domain. Compressed sensing (CS) has emerged as a promising framework to address these challenges because of its energy-efficient data reduction procedure [44]. Compressive sensing samples the signal by a much smaller number of samples than required by the Nyquist–Shannon theorem. It is based on an assumption of sparsity for the signal. Naturally, this assumption is true for most data forms of information in nature. Compressive sensing mainly is a challenge to:

a) Compressively measure a signal while its information content is kept preserved.
b) To recover the original signal after compressive sensing. The compressive method has a great application potential and can be used in a wide range of applications, like:

- Location-based services [45].
- Signal processing [46].
- Texture analysis [47].
- Power line communications [48].
- Power quality analysis [49–51].
- Power system planning [52-53].
- Human motion analysis [54].

Table 2: Comparison Between Previous Architectures

Author name	Architectures of the WBSN	Communications performed in WBSN			Year of publication
		Tier1	Tier2	Tier3	
Sonakshi Gupta and Parminder Kaur. [43]		The on-body and /or embedded wearable sensors hubs	Base stations (sink)	The remote medical server by means of the standard base, for example, web.	October 2015
Khan et al.[21]		Electroencephalogram (EEG), electrocardiogram (ECG), electromyography (EMG), or blood pressure measuring sensors.	Personal server (PS), known as the sink or the base station (BS).	A medical doctor, or a medical center, or any medical database.	March 2018
Zheng et al. [12]		sensors attached to the body surface or implanted into the body.	Smartphones, personal computers, or other intelligent electronic devices.	The terminal data center is mainly composed of remote servers providing various applications.	April 2019

Murtaza Cicioğlu and Ali Çalhan. [23]		sensor nodes and a HUB, IEEE 802.15.6	Gateway, such as a Wi-Fi	SDN approach	April 2019
Zeinab Shahbazi and Yung-Cheol Byun [25]		All sensor nodes implanted in or on the human body	Through wireless technology such as Bluetooth, WiFi, and ZigBee.	The blockchain model	June 2020

- Medical image processing [55].
- Human–robot interaction [56].
- Electrocardiogram processing [57].
- Image enhancement [58-59].
- Image adaptation [60].
- Software-intensive systems [61].
- Agriculture machinery [62-63].
- Data mining [64].

6. Conclusion

In this paper, we review previous researches on wireless body area networks. In particular, this work provides an overview of previous researches, applications, and architectures in WBAN and sensor compression technology. WBAN is a very useful emerging technology having immense utilities and benefits in daily life not only for Healthcare but also for Athletic training, Public Safety, Consumer electronics, secure authentication, and Safeguarding of uniformed personnel. We feel that this review can be considered as a source of inspiration for future research directions.

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