Wireless Body Area Networks: Architecture, Standards, Challenges, and Applications

Muhammad Aamir Panhwar [1], Samiullah Jatoi [2]Kamran Ali Memon [3], Salahuddin Saddar [4], Muhammad Owais Raza [5] Deng ZhongLiang [6], Noor-ul-Ain [7], Saleemullah Memon [8]

[1, 3, 6, 8] School of Electronic Engineering, Beijing University of Posts and Telecommunications, China
[2] Liaquat University of Medical and Health Sciences, Jamshoro, Pakistan
[4, 5] Department of Software Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan
[7] School of Information & Communication Engineering, Beijing University of Posts and Telecommunications, China

Abstract
The increase in the use of wireless networks and pervasive computing have given rise to research on Wireless Body Area Network (WBAN). WBAN is a collection of sensors in, on, or around the human body, which is connected through a wireless network. This WBAN has many applications ranging from healthcare to human-computer interaction. Here in this article, we present a review of the past fifteen years to discuss various aspects of WBANs such as WBAN enabling technologies, architecture, and topology, design challenges, energy harvesting techniques, security and finally the applications.

Key words:
WBAN, healthcare, human-computer interaction, human body, wireless network

1. Introduction:

As the need for communication with the ubiquity and the advancement in the low-power sensor technologies has increased, it has shifted the paradigm of the wireless network towards the wireless network around the human body. But breakthrough like this was not possible without the advancement of technologies like sensor devices, radio technologies, low power Bluetooth technology, and network management schemes [1, 2]. The WBAN is a wireless technology working with the help of radiofrequency to connect various sensors on, in, or around a human body. WBAN's have a very huge range of target applications including athletic training, healthcare, workplace safety, secure authentication and consumer electronics [1]. Some of the most important processes in these networks are the collection, monitoring, and transportation of sensed data. The communication in WBANs is usually three-tiered namely beyond-BAN communications, inter-BAN communications and Intra-BAN communication [4], so here security is a very important aspect of wireless body area network. The usage of WBANs in e-Health increases its emphasis on security even more, so it is also required to ensure the integrity and confidentiality of sensed data [3]. As smartphones today can provide more complex functionalities than ever so connecting this WBAN with mobile phone can work as gateway to the main network but to enable this type of short-range communication battery time is crucial for these sensors [5], normally these sensors are powered with the integrated batteries so energy consumption is also one of the biggest challenges so for sensors like these energy harvesting mechanisms are being recommended [5] here is the general structure of WBAN as shown in the figure 1.

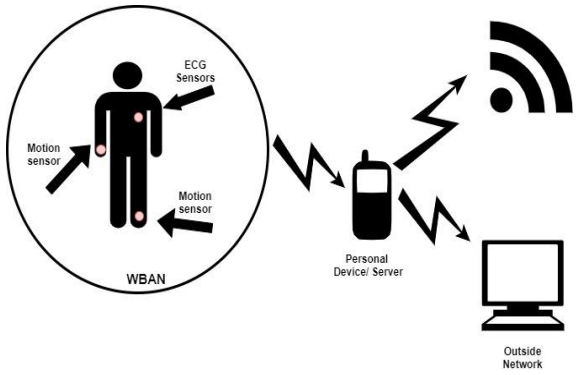

Fig. 1 General Structure of WBAN

The architecture of the paper is the following parts. In the first part is introduction and in the second part we have discussed the architecture of WBAN and third part is technologies enabling WBAN and fourth part is security in WBAN and fifth part is challenging in WBAN and sixth part is energy harvesting methods in WBAN and seventh part is WBAN Standards and in the last part is applications of WBANs.

2. The Architecture of WBAN:

Each sensor in WBAN architecture is considered as a node and each node is either placed on the human body in

Manuscript received December 5, 2019
Manuscript revised December 20, 2019

the form of the wearable device or implanted inside the human body. Each of the nodes is a sensor that stores and sample human's physiological vitals [27] in this network send some data and communicate with other nodes and mobile devices which work as gateway, There is a three tiers communication architecture for wireless body area network similar to defined in [4,5,6], figure 2 shows three tiers communication architecture. This network architecture can hold up to more than a dozen of nodes [28].

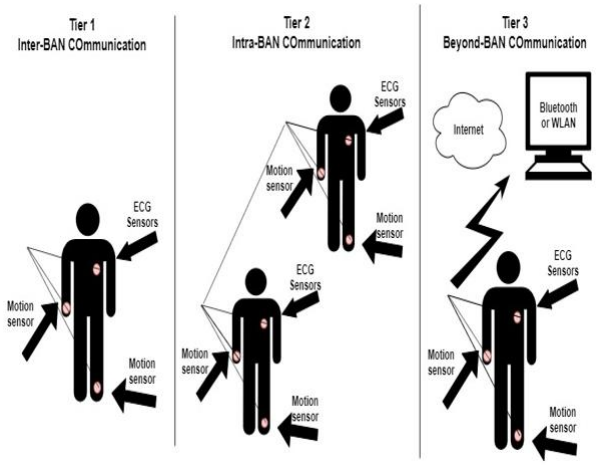

Fig. 2 Architecture of WBAN

According to [4] the three layers of communication architecture are as follow:

2.1 Intra-BAN communication:

In a single WBAN, we have more than one node when we want to communicate between these nodes and not with any other BAN or outside the BAN we will be using Intra-BAN communication it is the first tier in WBAN architecture.

2.2 Inter-BAN communication:

We know that a single WBAN has multiple nodes but when we want to communicate between multiple WBAN, we will be using the second tier of this architecture namely Inter-BAN communication.

2.3 Beyond-BAN communication:

There are plenty of network types such as local area network (LAN) and wide area network (WAN) when single WBAN is communicating outside its network with some other type of network is called Beyond-BAN communication, this is the third and last tier of this architecture.

3. Technologies Enabling WBAN

This breakthrough technology i.e. WBAN is a result of advancement in various technologies such as BLE, Sensors and network protocol, the following are technologies that enabled WBAN.

3.1 Bluetooth Low Energy (BLE):

Bluetooth Low Energy is a technology that is extended from Bluetooth standard, it is considered more suitable for WBAN because it consumes less power [29] with the help of a low duty cycle. It was designed to operate wirelessly with small mobile devices, these devices are very small to bear power consumption of normal Bluetooth technology. It provides a data rate of 1 Mbps [4].

3.2 ZigBee:

ZigBee is among one of the wireless technologies which work under low power [30] consumption environment it is defined by ZigBee specification, its targeted application radio frequency (RF) applications with low battery consumption and low data rate and higher security. Security in ZigBee is due to its 128-bit security authentication system, using which it provides guaranteed privacy and integrity. With the help of sleep mode [31] ZigBee based devices can operate for several years without changing batteries.

3.3 IEEE 802.15.6

The First standard for WBAN is IEEE 802.15.6, it serves for both medical and non-medical use of WBAN it also assists the communication around and inside of the body. This standard uses various frequency bands for data transmission such as narrowband, ultra-wideband, and human communication band. This is one very important step towards enabling WBAN because it gives a boost to the research in designing wearable sensors with low battery consumption high-frequency range and an ample number of nodes per body and priority nodes based on application requirement [9].

4. Security in WBAN

At initial stage, almost everyone involved in designing and developing WBAN was focused on architecture very few people were working on protocols and security but with its application especially in medical [32] it is very important to have a clear look at security aspects of WBAN with limited power consumption and low processing power it is very difficult to implement security in WBAN. The following are some of the techniques used for security in WBAN.

4.1 Bilinear Pairing:

It is one of the techniques used in WBAN security to ensure data integrity, it uses public and private key cryptography public key for session management and private key for normal data encryption [11].

4.2. Biometric-Based security approach for authentication:

In this technique, an individual is identified and its identity is verified by its behavioral and physiological patterns. This approach uses an intrinsic property of the human body for identification and authentication [6].

4.2.1 Heart Rate Variability (HRV):

In this method variability in heart rate is used for authentication of an individual as these signals are chaotic and have unique properties so are considered one of the best ways to secure communication [6,12].

4.3 Hidden Markov Model-Based Authentication and Selective Encryption Approaches:

It uses HMM to do authentication with help of body's intrinsic properties [12], for example in [12] blood circulation is taken as an example for the body's intrinsic property used for secure communication specifically available for WBAN.

4.3.1 Authentication using HMM-based Classification Approach:

Here in authentication using the HMM-based classification approach we train HMM of each class C and derive parameter p to perform classification of various classes of signals, here wavelet-domain HMM is used which is the statistical method used for classification of signals [14].

5. Challenges of WBAN

WBAN is an emerging technology there is a lot of issues to be resolved [7] both technically and ethically such as privacy [15]. Some of the most important challenges or problems that are needed to be resolved immediately are shown in table 1.

Table 1: Challenges in WBAN

Challenges	Challenges in WBAN
Range	WBAN has very small rage i.e. few meters from body so dynamic communication management is done in [33]
Power Consumption	Need for constant power to function properly and difficult to change power source especially if it's transplanted inside human body [29]
Security	Due to low power and less processing, it's difficult to add sophisticated security mechanism to WBAN [32]
Quality of Service	One of the major challenges in WBAN is to improve the quality of service [34]
Placement	It's difficult to place many nodes in limited place [15]

6. Energy Harvesting Methods in WBAN:

WBAN is designed to work at a human level so energy efficiency is very important changing power source (batteries) may not be possible especially when these are implanted inside the human body, so various energy harvesting methods can be used such as sun, body warmth, movement or heartbeat, etc. [17, 18].

6.1 Light Energy:

Light of sun is one of the cleanest forms of energy that can be converted in electrical signals and power can be provided to the sensors. In the outdoor environment, 15milli watt per square centimeter is produced by sunlight although under indoor condition power produced is 10 milliwatt [16].

6.2 Vibration Energy:

This is the energy that is produced by the movement of the body or some physiological processes like breathing [18].

6.3 Thermal Energy:

The warmth of the body can also be a source of energy [19]. Thermal energy is converted into electrical energy using a thermoelectric transducer and can get 60 micro Watt per centimeter square [20].

7. WBAN Standards:

There is wide research in the field of sensor networks which is deployed in the proximity of the human body as these network form a unique structure. Task group 6 of IEEE 802.15 is formed to address the problem of the need for a standard for Body Area Network (BAN) or WBAN. This standard focuses on creating a communication standard for devices that can work under low power and can function in, on or around the human body, the main motive is to work for a variety of applications such as medical and consumer electronics applications [21].

7.1 IEEE 802.15.2:

The work of task group 6 of 802.15 resulted in WBAN standard IEEE 802.15.6 which was ratified in 2012 and contains one medium access-controller (MAC). This standard supports a star topology and two-hop star topology. This standard provides i.e. medical implant communication services (MICS), microscopic and macroscopic management of power, security and multiple access methods including random, scheduled and improvised [22].

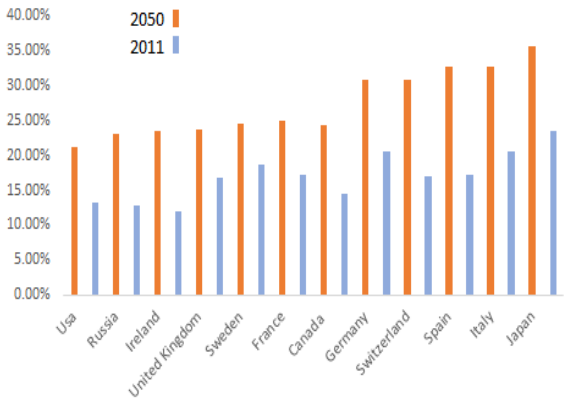

Fig. 3 Aging Population Statistics [23]

8. Applications of WBAN:

There are several interesting and innovative applications supported by WBAN such as health emergency response, assisted ambient living, and healthcare and human-computer interaction. Here in this portion, we are going to discuss both medical and non-medical applications of WBAN. Due to the increase in elderly population as shown in figure 3 and discussed in [23], the need for 24-hour monitoring systems for elderly people has risen that system must be able to record varies vitals such as temperature, blood pressure, and heartbeat and that system should also be able to do drug delivery all these requirements are fulfilled with WBAN and some support devices such as actuators for remote drug delivery [4]. Table 2 shows some major applications of WBAN.

8.1 Medical Applications:

With the help of WBAN, we can monitor physiological factors such as blood pressure, body temperature and heartbeat [24]. Now the parameters that we collected can be sent to a remote server for processing so the relevant action can be taken, WBAN can be key to detect and treat patients at early stages of the disease it could be very beneficial for some serious illnesses such as hypertension and diabetes [8, 25].

8.2 Sports:

For sport we can keep records of important physiological parameters such as blood pressure and heartbeat then this data can be used to circumvent injuries and accidents we can also be able to create improved training plans using this data [15]. Applications in this domain are mostly based on wearables used for enhancing the training of athletes by providing enough information to create better training plans.

8.3 Entertainment:

The entertainment industry can take advantage of WBAN in a variety of ways, for example, WBAN can be used for motion capturing with the help of multiple wearable accelerometer and gyroscope to track body position. In this field, WBAN is used mainly for the following three domain

- Real-Time Streaming.
- Gaming, virtual reality [26]
- Consumer Electronics

8.4 Military and Defense:

Due to the capability of WBAN to improve the performance of an individual or a team by providing necessary data. We can eliminate the threat at the individual level by simple getting data and performing certain necessary action. Inter-BAN communication can be used in the military to improve the overall performance of the pack and eliminate the risk of an accident. But in this case, the data is very sensitive so security is a major concern.

Table 2: Applications of WBAN

WBAN Field of Application	Type of Application	Wearable	Non-Wearable	Implant	Application
Health Care Application	Medical	Yes	No	No	ECG
Health Care Application	Medical	Yes	No	No	Electromyography (EMG)
Health Care Application	Medical	No	No	Yes	Diabetes control
Health Care Application	Non-Medical	Yes	No	No	Motion Detection
Military and Defense Application	Medical	Yes	No	No	Detection of life-threatening scenarios by assessing the soldier's fatigue
Sports Application	Medical	Yes	No	No	Blood Pressure, Heart Beat ad Temperature.

9. Conclusion:

In this paper, we have analyzed the work of different authors in the field of WBAN and discussed the most important parameters and research challenges in the WBAN field. It is concluded that the advancement in sensor and low power Bluetooth technologies has promoted WBAN field immensely for its use in medical and military applications. It is also seen that there is a lack of standards for WBAN so to IEEE 802.15 task group 6 was formed. It can also be noted that it has a vast variety of application but there are still some challenges that need to be addressed such as power consumption, design challenges, energy harvesting techniques and security.

Acknowledgments

The research work is financial supported by national high technology 863 program of china (No.2015AA124103) and national key R&D program no 2016YFB05502001 and carried out in state key laboratory intelligent communication, Navigation and micro-Nano system, Beijing University of posts and communications. Beijing.

References:

[1] Cao, Huasong, et al. "Enabling technologies for wireless body area networks: A survey and outlook." IEEE Communications Magazine 47.12 (2009): 84-93.

[2] Panhwar, M.A., Z. Deng, S.A. Khuhro, and D N Hakro “Distance-Based Energy Optimization through Improved Fitness Function of Genetic Algorithm in Wireless Sensor Network” Studies in Informatics and Control 27(4) 461-468, December 2018.

[3] Barua, Mrinmoy, et al. "Secure and quality of service assurance scheduling scheme for wban with application to ehealth." 2011 IEEE Wireless Communications and Networking Conference. IEEE, 2011.

[4] Negra, Rim, Imen Jemili, and Abdelfettah Belghith. "Wireless body area networks: Applications and technologies." Procedia Computer Science 83 (2016): 1274-1281.

[5] Rhee, Woogeun, et al. "Low power, non-invasive UWB systems for WBAN and biomedical applications." 2010 International Conference on Information and Communication Technology Convergence (ICTC). IEEE, 2010.

[6] Ramli, Sofia Najwa, et al. "A biometric-based security for data authentication in wireless body area network (wban)." 2013 15th International Conference on Advanced Communications Technology (ICACT). IEEE, 2013.

[7] Chen, M., Gonzalez, S., Vasilakos, A., Cao, H., & Leung, V. C. (2011). Body area networks: A survey. Mobile Networks and Applications, 16(2), 171–193.

[8] Chen, M., Mau, D., Wang, X., & Wang, H. (2013). The virtue of sharing: Efficient content delivery in wireless body area networks for ubiquitous healthcare. In Proceedings of IEEE Healthcom 2013 Lisbon, Portugal

[9] Acampora, G., Cook, D. J., Rashidi, P., & Vasilakos, A. V. (2013). A survey on ambient intelligence in healthcare. Proceedings of the IEEE, 101(12), 2470-2494.

[10] Kurunathan, John Harrison. "Study and overview on WBAN under IEEE 802.15. 6." U. Porto Journal of Engineering 1.1 (2015): 11-21.

[11] Barua, M., Alam, M. S., Liang, X., & Shen, X. (2011, March). Secure and quality of service assurance scheduling scheme for wban with application to ehealth. In 2011 IEEE Wireless Communications and Networking Conference (pp. 1102-1106). IEEE.

[12] L. Yao, B. Liu, K. Yao, G. Wu, and J. Wang, "An ECG-Based Signal Key Establishment Protocol in Body Area Networks," 2010 7th International Conference on Ubiquitous Intelligence & Computing and 7th International

Conference on Autonomic & Trusted Computing, pp. 233-238, Oct. 2010

[13] S. Bao, Y. Zhang, L. Shen, "Physiological signal based entity authentication for body area sensor networks and mobile healthcare systems," in Proc. IEEE Engineering in Medicine and Biology, pp.2455-2458, 2005.

[14] Wang, H., Fang, H., Xing, L., & Chen, M. (2011, June). An integrated biometric-based security framework using wavelet-domain HMM in wireless body area networks (WBAN). In 2011 IEEE international conference on communications (ICC) (pp. 1-5). IEEE.

[15] Barakah, D. M., & Ammad-uddin, M. (2012, February). A survey of challenges and applications of wireless body area network (WBAN) and role of a virtual doctor server in existing architecture. In 2012 Third International Conference on Intelligent Systems Modelling and Simulation (pp. 214-219). IEEE.

[16] Jain PC. Wireless Body Area Network for Medical Healthcare. IETE Technical Review (Institution of Electronics and Telecommunication Engineers, India) 2011; 28(4).

[17] BOUMAIZ, Marwa, et al. "Energy harvesting based WBANs: EH optimization methods." Procedia Computer Science 151 (2019): 1040-1045.

[18] K. Ali Memon, et al, "Optimal Transmit Power for Channel Access Based WSN MAC Protocols," Vol. 18 No. 7 pp. 51-60 2018.

[19] Demir SM, Al-Turjman F, Muhtaroglu A. Energy Scavenging Methods for WBAN Applications: A Review. IEEE Sens J. 2018; 18(16):6477-6488. DOI:10.1109/JSEN.2018.2851187

[20] Hoang DC, Tan YK, Chng HB, Panda SK. Thermal energy harvesting from human warmth for wireless body area network in medical healthcare system. Proc Int Conf Power Electron Drive Syst. 2009 ;(December):1277-128

[21] Hudak NS, Amatucci GG, Hudak NS, Amatucci GG. Small-scale energy harvesting through thermoelectric, vibration, and radiofrequency power conversion, 2008; 101301. DOI:10.1063/1.2918987

[22] Kwak, K. S., Ameen, M. A., Kwak, D., Lee, C., & Lee, H. (2009, September). A study on proposed IEEE 802.15 WBAN MAC protocols. In 2009 9th International Symposium on Communications and Information Technology (pp. 834-840). IEEE.

[23] Wong, A. C. W., Dawkins, M., Devita, G., Kasparidis, N., Katsiamis, A., King, O., & Burdett, A. J. (2013). A 1 V 5 mA multimode IEEE 802.15. 6/Bluetooth low-energy WBAN transceiver for biotelemetry applications. IEEE Journal of Solid-State Circuits, 48(1), 186-198.

[24] Rutherford, Tom, and A. Socio. "Population ageing: statistics." House of Commons library (Standard not. Retrieved Jan 2, 2013, from: www. Parliament. Uk/topics/Population Archive (2012).

[25] Movassaghi, Samaneh, et al. "Wireless body area networks: A survey." IEEE Communications surveys & tutorials 16.3 (2014): 1658-1686.

[26] Salayma, M., Al-Dubai, A., Romdhani, I., & Nasser, Y. (2017). Wireless body area network (WBAN): A survey on reliability, fault tolerance, and technologies coexistence. ACM Computing Surveys (CSUR), 50(1), 3.

[27] Malik, Bhavneesh, and V. R. Singh. "A survey of research in WBAN for biomedical and scientific applications." Health and Technology 3.3 (2013): 227-235.

[28] Otto, Chris A., Emil Jovanov, and Aleksandar Milenkovic. "A WBAN-based system for health monitoring at home." 2006 3rd IEEE/EMBS International Summer School on Medical Devices and Biosensors. IEEE, 2006.

[29] A. Milenkovic, C. Otto, and E. Jovanov, "Wireless Sensor Networks for Personal Health Monitoring: Issues and an Implementation," Computer Communications vol. in press, 2006.

[30] Wong, A. C. W., Dawkins, M., Devita, G., Kasparidis, N., Katsiamis, A., King, O., & Burdett, A. J. (2012). A 1 V 5 mA multimode IEEE 802.15. 6/Bluetooth low-energy WBAN transceiver for biotelemetry applications. IEEE Journal of Solid-State Circuits, 48(1), 186-198.

[31] *Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)*, 2007.

[32] Huynh, D. T., & Chen, M. (2016, November). An energy efficiency solution for WBAN in healthcare monitoring system. In 2016 3rd International Conference on Systems and Informatics (ICSAI) (pp. 685-690). IEEE.

[33] Al Ameen, M., Liu, J., & Kwak, K. (2012). Security and privacy issues in wireless sensor networks for healthcare applications. Journal of medical systems, 36(1), 93-101.

[34] Moungla, H., Touati, N., & Mehaoua, A. (2013, July). Efficient heterogeneous communication range management for dynamic WBAN topology routing. In 2013 First International Symposium on Future Information and Communication Technologies for Ubiquitous HealthCare (Ubi-HealthTech) (pp. 1-5). IEEE.