A Taxonomy for Learning, Teaching, and Assessing Wireless Body Area Networks

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***Abstract*—Wireless body area networks have recently gained attention, mainly after the IEEE 802.15.6 standard had been proposed. Reviewing the literature, we easily recognize that several authors use different terminologies for a single concept or a single terminology for different concepts. This generates confusion and blocks fair comparisons between systems. In this paper, we present an overview of Wireless Body Area Networks (WBAN) with focus on the applications. Moreover, we propose a detailed taxonomy that could help to disambiguate the confusion regarding current WBAN terminology.**

Keywords*—*Wireless Body Area Networks, Medical Body Area Networks, Wireless Body Sensor Networks, WBAN, MWBAN, WBSN.

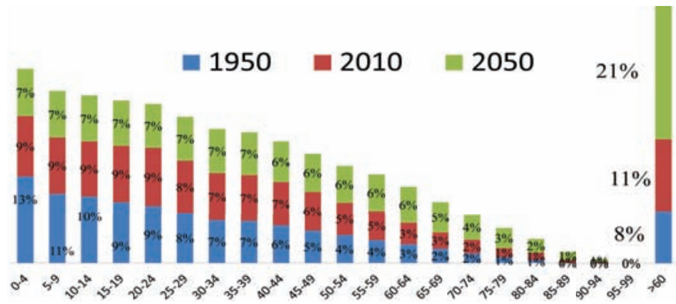


Fig. 1. World's age pyramid. Based on [1]

I. Introduction

The world population is growing fast, from 1950 to 2010 the population increased by around 4,390,405,000 individuals [1]. Further, the human life expectancy has increased too, in the same period, the elderly population (60 years old or older) augmented by about 410,647,596 individuals, representing a change from 8% to 11.1% on the composition of the population [1].The proportion of older persons is expected to double over the next four decades, as we can figure out from the Fig. 1. It is expected that this increase will overload health-care systems. In order to face this challenge, new scalable solutions centered in reducing the cost of supporting elderly people must be found. On the other hand, millions of people develop chronic or fatal diseases every year and around 80% of health-care system spending is on chronic condition management [2]. Moreover, as shown in [3], most diseases could be prevented if they were detected in their early stages. Therefore, future health-care systems must concentrate efforts on early detection and prevention of diseases. Additionally, there is increasing recognition that remote monitoring should be employed in order to diminish mortality, hospitalization, and transport costs [4].

In order to achieve health-care systems connected at person level, at least a network which can be wearable, or implanted in the human body is needed [5]. Such networks are commonly referred to as Wireless Body Area Networks [5]–[12]. Typically, The WBANs interact with other wireless technologies (i.e. WSNs, WLAN, WPAN) in order to provide a complete TI platform for connecting health care services. As an example in [13] was proposed a system concept where a WBAN node transfers energy and receives information from an implanted device, this system is shown in the Fig. 2. In order to achieve energy autonomy, the WBAN node harvests energy from the body environment (i.e. solar and thermal). This energy is transferred through an inductive link to the passive implanted device that answers with the biomedical data. These data could be used to achieve the goal of the specific application. For example, if any abnormalities are found an alarm can notify to the patient or the doctor through email or short message service (SMS), if the gateway of the WBAN node has at least 3G connectivity.

WBANs are expected to cause a dramatic shift in how people behave, in the same way the internet did. However, technical and social challenges must be faced before a natural adoption [5]. We are in the early years of the networks in, on and around the human body. There are many researchers, companies, professionals, students and consortiums developing products acknowledging for this type of networks [2], [4], [5], [14], [15], because the wide applications span (i.e. military, ubiquitous health care, sport, entertainment,etc). Since people with different skills and academic background are working on this subject, the information about the topic is sometimes difficult to understand, mainly due to the lack of standardization. It is common to find different terminologies

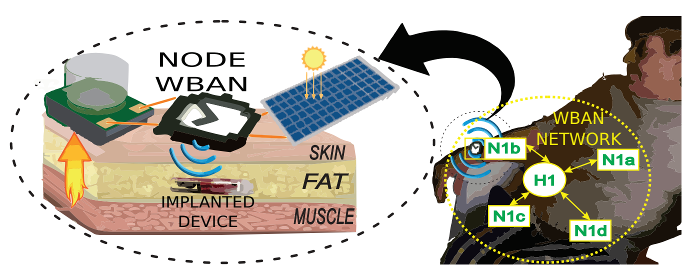


Fig. 2. Self-sustaining implanted device using Energy Harvesting and WTP.

associated to a single subject. As an example, terms as: Body sensor Network, Human Body Network, Micro Personal Area Network, Wearable Body Area Network, and Medical Body Sensor Network, are all used as synonymous for Wireless Body Area Network.

The fundamental purpose of this paper is to analyze the recent literature about WBAN focusing on applications and network properties, and achieve a coherent taxonomy for WBAN networks. Further, we present an intuitive and comprehensive comparison with other wireless networks.

II. WBAN Fundamentals

In the context of WBANs, the technical requirements such as data rate, duty cycle per device per time, power consumption, latency, and privacy are all specific for each application [5], [16]. Further, in some applications, the WBAN is only a single piece in the Information Technology (IT) infrastructure and all the system specifications determine the WBAN requirements [4]. In this section we summarize the applications of WBAN based IT systems as reported in [2], [4], [5], [7], [8], [12], [17]–[20], then we present an intuitive and comprehensive comparison with other wireless networks used in complex IT systems and finally we show a typical communication architecture for IT systems based in WBANs.

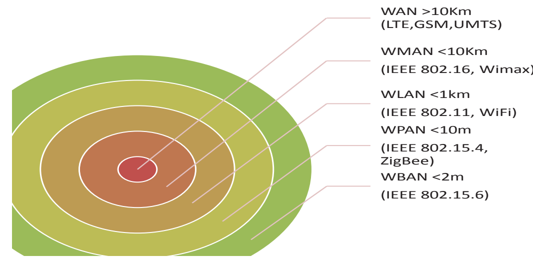
A. Applications of WBAN

The WBAN applications span is wide but the IEEE 802.15.6 standard categorizes them into medical and non-medical. Medical applications of WBAN can be employed for a) medical treatment, monitoring and diagnosis; b) prevention of medical accidents; c) remote health/fitness monitoring; d) disability assistance; e) safeguarding of uninformed (e.g. a WBAN can monitor the level of toxics in the air and warns the firefighters or soldiers when a life-threatening level is detected); f) remote control of medical devices; g) tele-medicine systems. Non-Medical WBAN applications include a) training schedule of professional athletes, b) consumer electronics ; c) advanced human-computer interfaces such as a neural interfaces, gaming consoles and virtual reality; d) personal information sharing (i.e.private or business information can be stored in body sensors for many daily life applications such as shopping and information exchange); e) secure authentication; f) non-medical emergency alert (i.e. emergency detection such as fire at home).

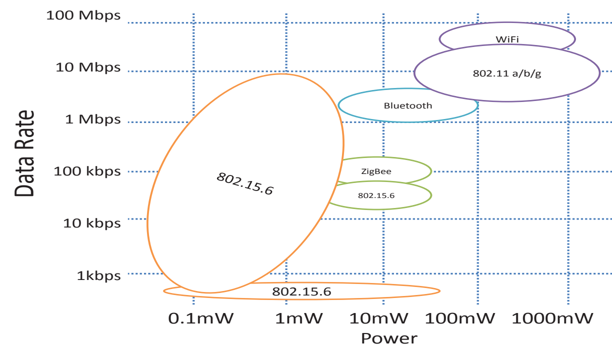
B. WBAN comparison with other wireless networks

Typically, the wireless networks can be categorized based on their geographical coverage, date rate, and power consumption. In the Fig. 3 the WBAN (IEEE 812.15.6) are compared with others wireless networks such as Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN), Wireless Metropolitan Area Networks (WMAN) , Wireless Wide Area Networks (WWAN), Zigbee, IEEE 802.15.4, and Bluetooth.

In several works, Wireless Body Area Networks are considered as a special type of a Wireless Sensor Network (WSN) or a Wireless Sensor and Actuator Network (WSAN), with its own requirements. However, traditional sensor networks do not tackle the specific challenges associated with the interaction



(a) Geographical coverage comparison



(b) Date rate and power consumption comparison

Fig. 3. Wireless network comparison. Based in [5].

between the network and the human body. For example, the implanted sensors has a small form factor resulting in a higher need for energy efficiency. Further, if the data are medical information, the reliability of the network must be guarantee. Other example are the wearable sensor nodes, they can move with regard to each other, e.g. a sensor node placed on the wrist moves in relation to a sensor node attached to the hip, Therefore the system requires mobility support. Additionally, the WBAN nodes are heterogeneous, i.e, they have dissimilar: data rate, power consumption and latency [19]. In brief, although challenges faced by WBANs are in many ways similar to WSNs, there are intrinsic differences between them, requiring special attention [12]. A schematic view of conventional network challenges in WBAN, WSN and WLAN is presented in the Fig. 4. It is important to clarify that the illustrated challenges do not involve human compatibility, which is important only in WBAN technologies.The IEEE 802.15.6 overcomes the constraints of the WBAN technologies as its focus is specifically on networking within and around the body [5], [7].

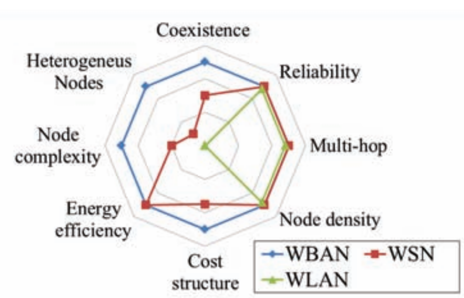


Fig. 4. Schematic view of conventional network challenges in WBAN, WSN and WLAN. Based on [21]

C. Simplified architecture of WBAN

1) Isolated WBAN: Unlike WSNs that normally operate as autonomous systems, a WBAN seldom works alone [17]. An isolated WBAN is a wireless network composed by different types of nodes. The IEEE 802.15.6 standard considers two possible topologies: one-hop or two-hop star topology with one node in the center of the star [7]. By functionality, the nodes are classified as coordinator, end nodes and relay nodes. The coordinator transmits and receives information from and to the end nodes and the relay nodes (sensors and actuators) and handles interaction with other users (i.e. a display or external gateway). A difference between the end nodes and the relay nodes is that the relay node may transfer messages to end notes or to coordinator. On the other hand, concerning the implementation, the nodes are classified as: implant node (in body), body surface node (0-2 cm away from the body) and external node (around 2-5 cm away from the body). In Fig. 5 some of the possible implementation scenario of those topologies are shown.

2) IT solution based in WBAN: The Fig. 6 illustrates a general architecture of a WBAN based health monitoring system. Typically, the generic communication process may be separated into three different tiers, as follows: Intra-WBAN communication (Tier-1), Inter-WBAN communication (Tier-2) and Beyond-WBAN communication (Tier-3) [17]. In the tier-1 the internal WBAN communication between nodes takes place (IEEE 812.15.6). The communication going on the tier-2 is used to interconnect WBANs with various networks that are easy to access in daily life, such as the Internet and cellular networks. The communication process takes place between the coordinator node of the WBAN and one or more access points (APs). Compared to intra-WBAN communications, wireless technologies for inter-WBAN communication are mature, and include: WLAN, Bluetooth, Zigbee, cellular, and 3G, etc. The Tier-3 communications are used to achieve the goal of the specific application, and should adapt to the requirements of user-specific services. For example, if any abnormalities are found based on the up-to-date body signal transmitted to the database, an alarm can notify to the patient or the doctor through email or short message service (SMS), therefore in this example we need at least 3G.

III. Proposed taxonomy for WBAN

Using the references analyzed we propose some definitions for the most common type of WBAN networks. First we understand that a wireless body area network is such a wireless network composed by sensor/actuators nodes (N) and hubs (H), that operates in, on, or around body (but not limited to human bodies) and supports a variety of medical and non-medical applications. This definition is based in [5], [7], [8], [12], [17], [22], where BAN and WBAN are used as synonymous. In our point of view, a WBAN is a BAN subcategory. Additionally, special cases of the WBAN are defined as follows: 1) when all nodes are sensors in a WBAN, the network is called Wireless Body Sensor Networks (WBSN), in agreement with [23]–[27]; 2) when all the nodes (N) and hubs (H) are on the human body, the networks are categorized as wearable (W-WBAN and W-WBSN), as found in [28], [29]. On the other hand, if some N or H are in the human body, the network is recognized as implanted (I-WBAN and I-WBSN), as found in [27], [30]–[32].

The WBAN have many applications, but the medical field is maybe the most important. There are many players working to develop products that changes the medical paradigm of

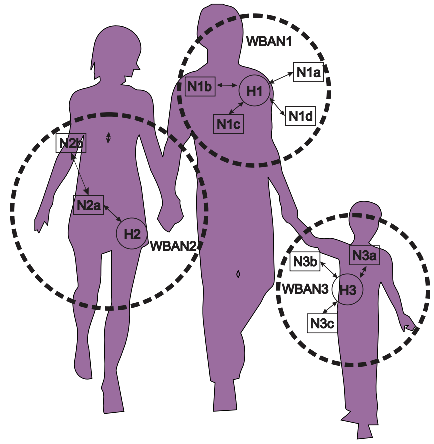


Fig. 5. Simplified architecture of a isolated WBAN

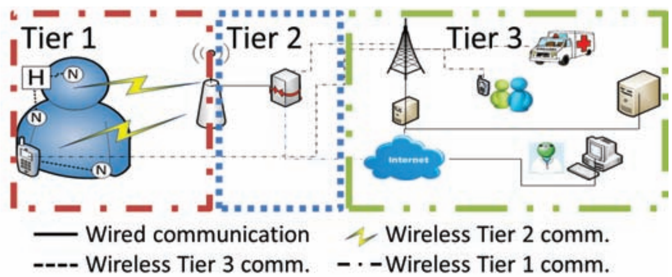
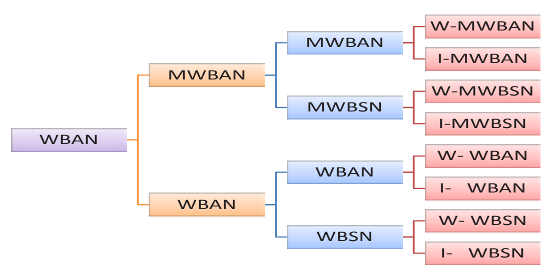
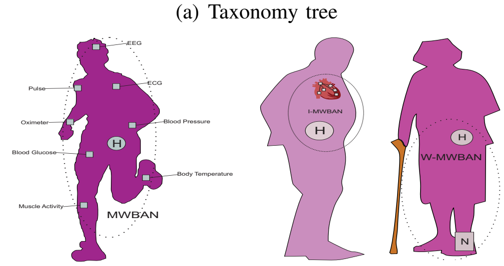


Fig. 6. Simplified architecture of Medical TI solution based in WBAN. Based in [17]



(a) Taxonomy tree



(b) MWBAN (c) I-MWBAN (d) W-MWBAN

Fig. 7. Proposed WBAN taxonomy.

prognosis and treatment. In this scenario the WBAN must be explored, developed and implemented in a specific framework (legal, safety, ethic, etc). The Medical Wireless Body Area Network (MWBAN) is a wireless communication technology designed to electro-monitoring and electro-stimulating the human body wirelessly, through tiny nodes/actuators in, on or around the body. This definition is based in [6], [18], [33], [34]. Following the definitions brought in the past paragraph, it is possible to define Medical Wireless Body Sensor Networks (MWBSN), wearable MBAN (W-MWBAN), wearable MBSN (W-MWBSN), implanted MBAN (I-MWBSN), but this terms have not been found in the studied literature. The proposed taxonomy tree and some examples are illustrated in Fig. 7.

IV. Conclusion

The proposed taxonomy allows to unify and centralize discussions about the WBAN technologies, departing from the adequate terminology. Further, it helps to simplify the process of searching and indexing the information associated to these technologies, saving time and accelerating the process of understanding the WBAN key concepts.

Acknowledgment

The first author would like to thank COLCIENCIAS and the Pontificia Universidad Javeriana for the financial support.

References

[1] UNDESA-Population-Division, "World population prospects: The 2012 revision," New York, United Nations Department for Economic and Social Affairs (UN DESA), Working Paper No. ESA/P/WP. 228, 2013.

[2] E. Jovanov and A. Milenkovic, "Body area networks for ubiquitous healthcare applications: opportunities and challenges," *Journal of medical systems*, vol. 35, no. 5, pp. 1245–1254, 2011.

[3] W. H. Organization, *Global health risks: mortality and burden of disease attributable to selected major risks*. Geneva, Switzerland: WHO Press, 2009.

[4] N. Bui and M. Zorzi, "Health care applications: a solution based on the internet of things," in *Proc. of the 4th Int. Symp. on Applied Sciences in Biomedical and Communication Technologies*. ACM, 2011, p. 131.

[5] S. Movassaghi, M. Abolhasan, J. Lipman, D. Smith, and A. Jamalipour, "Wireless body area networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 3, pp. 1658–1686, 2014.

[6] D. Wang, D. Smith, R. Krasinski, M. Ghosh, and A. Batra, "Emerging spectrum regulation for medical body area network," in *IEEE Int. Conf. on Body Sensor Networks*, 2013, pp. 1–6.

[7] *IEEE standard for local and metropolitan area networks part 15.6: Wireless body area networks*, IEEE Std. 802.15.6, 2012.

[8] D. M. Barakah and M. Ammad-uddin, "A survey of challenges and applications of wireless body area network (wban) and role of a virtual doctor server in existing architecture," in *3th Int. Conf. on Intelligent Systems, Modelling and Simulation*, 2012, pp. 214–219.

[9] J. Y. Khan, M. R. Yuce, G. Bulger, and B. Harding, "Wireless body area network (wban) design techniques and performance evaluation," *Journal of medical systems*, pp. 1–17, 2012.

[10] E. Dolatabadi and S. Primak, "Ubiquitous wban-based electrocardiogram monitoring system," in *13th IEEE Int. Conf. on e-Health Networking Applications and Services*. IEEE, 2011, pp. 110–113.

[11] H.-B. Li and K. Hamaguchi, "A prototype ban for medical and healthcare monitoring based on high band uwb," in *14th Int. Symp. on Wireless Personal Multimedia Communications*, 2011, pp. 1–5.

[12] B. Latré, B. Braem, I. Moerman, C. Blondia, and P. Demeester, "A survey on wireless body area networks," *Wireless Networks*, vol. 17, no. 1, pp. 1–18, 2011.

[13] A. Fajardo and F. Rangel de Sousa, "Design methodology for maximizing the power transfer from dc harvesters to ac loads," presented at the IEEE Int. Symp. on Circuits and Systems, Montreal, Canada, 2016.

[14] K. Becher, C. P. Figueiredo, C. Muhle, R. Ruff, P. M. Mendes, and K. Hoffmann, "Design and realization of a wireless sensor gateway for health monitoring," in *Ann. Int. Conf. of the IEEE Engineering in Medicine and Biology Society*, 2010, pp. 374–377.

[15] R. Carroll, R. Cnossen, M. Schnell, and D. Simons, "Continua: An interoperable personal healthcare ecosystem," *IEEE Pervasive Computing*, vol. 6, no. 4, pp. 90–94, 2007.

[16] B. H. Jung, R. U. Akbar, and D. K. Sung, "Throughput, energy consumption, and energy efficiency of ieee 802.15.6 body area network (ban) mac protocol," in *IEEE 23rd Int. Symp. on Personal Indoor and Mobile Radio Communications*, 2012, pp. 584–589.

[17] M. Chen, S. Gonzalez, A. Vasilakos, H. Cao, and V. C. Leung, "Body area networks: A survey," *Mobile Networks and Applications*, vol. 16, no. 2, pp. 171–193, 2011.

[18] G. Fang, E. Dutkiewicz, M. A. Huq, R. Vesilo, and Y. Yang, "Medical body area networks: Opportunities, challenges and practices," in *11th Int. Symp. on Communications and Information Technologies*, 2011, pp. 562–567.

[19] H. J. Yoo and C. V. Hoof, Eds., *Bio-Medical CMOS ICs*, 1st ed. New York: Springer, 2010.

[20] T. Falk and M. Maier, "Context awareness in wbans: a survey on medical and non-medical applications," *IEEE Wireless Communications*, vol. 20, no. 4, 2013.

[21] T. Zasowski, "A system concept for ultra wideband (uwb) body area networks," Dept. Elect. Eng, Ph.D. thesis, Federal Institute of Technology (ETH), Zurich,Switzerland, 2007.

[22] J. N. Bae, Y. H. Choi, J. Y. Kim, J. W. Kwon, and D. I. Kim, "Efficient interference cancellation scheme for wireless body area network," *Journal of Communications and Networks*, vol. 13, no. 2, pp. 167–174, 2011.

[23] G.-Z. Yang, Ed., *Body sensor networks*. New York: Springer Verlag, 2006.

[24] B. Lo and G.-Z. Yang, "Key technical challenges and current implementations of body sensor networks," in *Proc. 2nd Int. Workshop on Body Sensor Networks*, 2005.

[25] H. Li and J. Tan, "Heartbeat-driven medium-access control for body sensor networks," *IEEE Trans. Inf. Technol. Biomed.*, vol. 14, no. 1, pp. 44–51, 2010.

[26] C. A. Otto, E. Jovanov, and A. Milenkovic, "A wban-based system for health monitoring at home," in *3rd IEEE/EMBS Int. Summer School on Medical Devices and Biosensors*, 2006, pp. 20–23.

[27] Y. Hao and R. Foster, "Wireless body sensor networks for health-monitoring applications," *Physiological Measurement*, vol. 29, no. 11, 2008.

[28] V. Leonov, "Energy harvesting for self-powered wearable devices," in *Wearable Monitoring Systems*. New York: Springer, 2011, pp. 27–49.

[29] F. Tufail and M. Islam, "Wearable wireless body area networks," in *Int. Conf. on Information Management and Engineering*, April 2009, pp. 656–660.

[30] R. Kohno, K. Hamaguchi, H.-B. Li, and K. Takizawa, "R&d and standardization of body area network (ban) for medical healthcare," in *IEEE Int. Conf. on Ultra-Wideband*, vol. 3, 2008, pp. 5–8.

[31] W.-Y. Chung, Y.-D. Lee, and S.-J. Jung, "A wireless sensor network compatible wearable u-healthcare monitoring system using integrated ecg, accelerometer and spo2," in *30th Ann. Int. Conf. of the IEEE Engineering in Medicine and Biology Society*, 2008, pp. 1529–1532.

[32] J. Xing and Y. Zhu, "A survey on body area network," in *5th Int. Conf. on Wireless Communications, Networking and Mobile Computing*, 2009, pp. 1–4.

[33] B. Zhen, H.-B. Li, and R. Kohno, "Ieee body area networks for medical applications," in *4th Int. Symp. on Wireless Communication Systems*, Oct 2007, pp. 327–331.

[34] C. C. Wang, J. M. Huang, L. H. Lee, S. H. Wang, and C. P. Li, "A low-power 2.45 ghz zigbee transceiver for wearable personal medical devices in wpan," in *Dig. of Tech. Paper Int. Conf. on Consumer Electronics*, 2007, pp. 1–2.