Comparison of low-power wireless communication technologies for wearable health-monitoring applications

Conference or Workshop Item

Accepted Version

Full-text of article

Title:	Comparison of Low-Power Wireless Communication Technologies for Wearable Health-Monitoring Applications
Publication:	2015 IEEE International Conference on Computer, Communications, and Control Technology (I4CT)
Pages:	1-6
Article URL:	http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7219525
Article DOI:	10.1109/I4CT.2015.7219525
Conference Location:	Imperial Kuching Hotel, Kuching, Sarawak, Malaysia
Conference Date:	21-23 April 2015
IEEE Catalog Number:	CFP1552X-ART
Digest ISBN:	978-1-4799-7952-3

Authors:

Mohammad Ghamari,
Harneet Arora,
R. Simon Sherratt,
William Harwin.

SPHERE, School of Systems Engineering, University of Reading, Reading, UK

This work was performed under the SPHERE IRC funded by the UK Engineering and Physical Sciences Research Council (EPSRC), Grant EP/K031910/1.

Abstract

Health monitoring technologies such as Body Area Network (BAN) systems has gathered a lot of attention during the past few years. Largely encouraged by the rapid increase in the cost of healthcare services and driven by the latest technological advances in Micro-Electro-Mechanical Systems (MEMS) and wireless communications. BAN technology comprises of a network of body worn or implanted sensors that continuously capture and measure the vital parameters such as heart rate, blood pressure, glucose levels and movement. The collected data must be transferred to a local base station in order to be further processed. Thus, wireless connectivity plays a vital role in such systems. However, wireless connectivity comes at a cost of increased power usage, mainly due to the high energy consumption during data transmission. Unfortunately, battery-operated devices are unable to operate for ultra-long duration of time and are expected to be recharged or replaced once they run out of energy. This is not a simple task especially in the case of implanted devices such as pacemakers. Therefore, prolonging the network lifetime in BAN systems is one of the greatest challenges. In order to achieve this goal, BAN systems take advantage of low-power in-body and on-body/off-body wireless communication technologies. This paper compares some of the existing and emerging low-power communication protocols that can potentially be employed to support the rapid development and deployment of BAN systems.

Keywords

Health Monitoring; Body Area Networks; Wireless Communications.

I. Introduction

Due to a rapidly aging population around the world and constrained financial resources, current public-funded healthcare systems are facing new challenges. According to the United States Census Bureau [1], the number of people around the world aged over 65 years old is estimated to be 1.3 billion by 2040. In the United Kingdom, as stated by Office for National Statistics [2], the number of people over the age of 80 years is predicted to more than double by 2037. Simultaneously, public-funded healthcare systems in many developed countries are currently facing an increase in the number of patients diagnosed with chronic conditions such as diabetes and obesity. These diseases are not merely because of an aging population, but are related to improper diets and inadequate physical activities. As an example, according to World Health Organization (WHO), diabetes is predicted to be the seventh leading causes of death in 2030 [3]. These statistics imply that the cost of healthcare services is increasing rapidly, thus, healthcare systems becoming unsustainable in their current form. Early disease detection and diagnosis is extremely important; on the one hand, it assists in discovering the most beneficial pharmacological treatment and lifestyle changes for the patients, on the other hand, it helps to significantly reduce the cost of healthcare systems. Therefore, it is possible to utilize the latest technological advances in Wireless Body Area Network (WBAN) systems for the early detection and prevention of potential diseases that may occur later in life. Achieving this goal can be done by integrating ultra-low power embedded or removable sensor nodes into WBAN systems for continuous monitoring of health conditions. Sensor nodes within this system are able to capture movement and physiological information such as body temperature, blood pressure and heart rate and transmit the gathered information, either as raw samples or low-level post-processed information, to an on-site base station wirelessly in order to be further analyzed. Wireless connectivity is an important feature in BAN systems as it guarantees movability and flexibility of users. However, wireless connectivity comes at a cost of increased power usage; mainly due to the high energy consumption during data transmission. It is apparent that, new solutions are required to address the problem of the high energy cost caused by wireless connectivity.

Intra-body Communication (IBC) is considered as one of the low-power communication technologies that can potentially be used in WBAN systems. IBC is a non-RF wireless communication technology which uses the human body as a transmission medium. IBC technology has recently been introduced in the IEEE 802.15.6 standard and has proven itself to have significant advantages in energy efficiency over RF communication [4]. This is due to two main reasons: firstly, due to the lower path loss without the destructive effect of body shadowing of RF communication; secondly, due to the use of electrodes as a communication interface rather than using a low-impedance antenna [5]. In addition, IBC technology is considered to be more secure and less susceptible to interference than RF communication which makes it a potential solution for the BAN applications. However, IBC technology cannot be used as the only communication solution in BAN systems. The data collected by IBC-based sensor nodes must be transferred to a local base station in order to be further processed. This cannot be done through IBC technology since this technology is only defined for in-body communications. Therefore, IBC technology is required to be combined with one of the existing low-power communication standards such as Bluetooth Low Energy (BLE) or ZigBee in order to be able to transfer the collected data to a local base station for further processing. A typical architecture of a low-power health monitoring system is shown in Figure 1. In this architecture, IBC technology is used for in-body communication. IBC-based sensor nodes transmit the sensor information to a central node which acts a coordinator. This coordinator is responsible for establishing an off-body communication link between the human body and the local base station. The aim of this paper is to provide an insight into some of the existing low-power communication protocols that can potentially be applied in WBAN systems.

The rest of this article is categorized into four sections. Section II presents the IBC technology and compares different coupling methods which are used in this approach. Section III provides an in-depth consideration of some of the latest existing low-power on-body/off-body communication protocols. Section IV discusses about some of important features of low-power protocols that needs to be considered in order to choose an appropriate wireless solution for a typical health-monitoring system. Finally, Section V provides a conclusion to this paper.

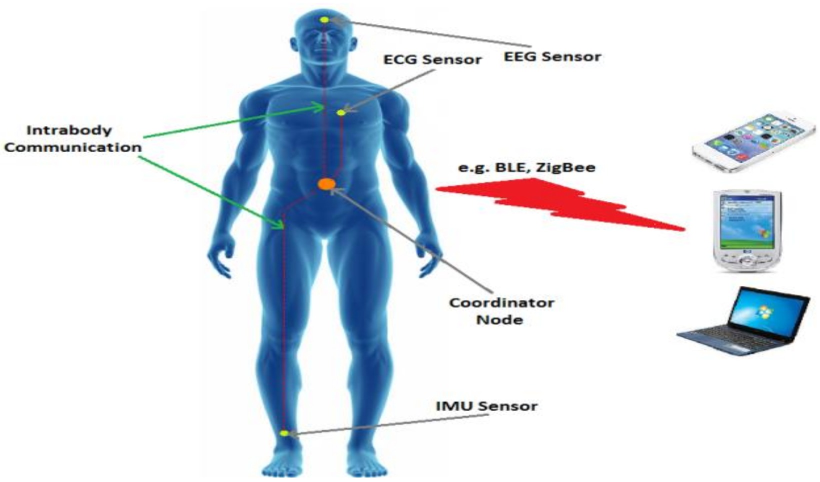
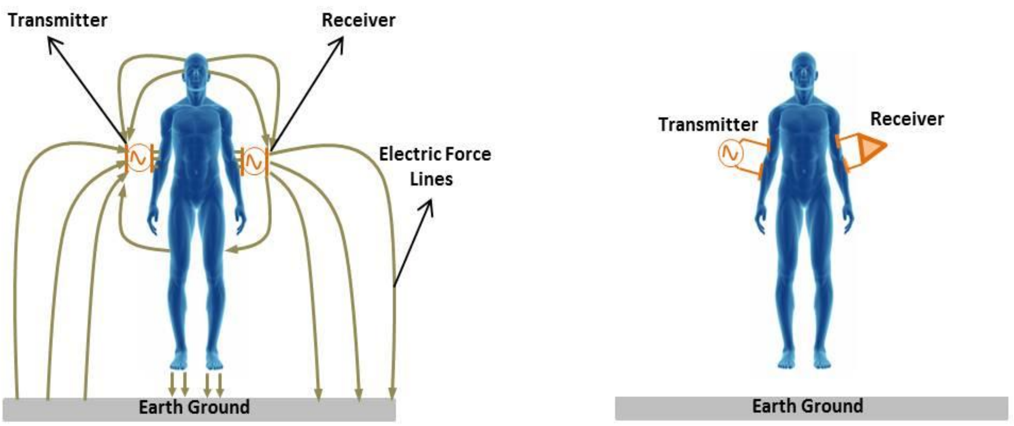


Figure 1. A typical architecture of a low-power health - monitoring system

II. Intrabody Communications Approaches

The IBC technology has two main approaches: capacitive coupling and galvanic coupling as shown in Figure 2. These two coupling techniques indicate how electrical signals are transmitted through the human body. Each coupling method requires using two pairs of electrodes. In the capacitive coupling method, two of the electrodes which are signal electrodes are attached on the human body. One of the signal electrodes is attached on transmitter side and the other signal electrode is attached on the receiver side. The other two detached electrodes (ground electrodes) are floating. In this coupling technique, a current loop through the external ground creates the signal between the body channel transceiver. The transmitter's signal electrode generates the electric field in to the body. The generated signal in the human body is managed by an electrical potential where human body is a conductor and ground is the return path. The fundamental concept behind the capacitive coupling communication is based on the fact that human body is capacitively coupled to a surrounding environment [6]. Alternatively, galvanic coupling method is done by coupling Alternating Current (AC) in to the human body. In this technique, AC current is flowed through the body and human body is considered as a waveguide. This method of communication uses differential signaling which is applied between transmitter electrodes. Main signal propagation in galvanic coupling is performed between the two transmitter electrodes and a mostly-attenuated signal is received at the receiver's electrodes. In the galvanic coupling method, the ion content of the human body is the actual carrier of signal transmission and reception and all electrodes (two pairs) are attached to the human body. Table I compares capacitive coupling with galvanic coupling [6] [7].



(a) (b)

Figure 2. a. Capacitive coupling based IBC b. Galvanic coupling based IBC

Table I.
Comparison between Capacitive Coupling and Galvanic Coupling

Properties	**Capacitive Coupling**	**Galvanic Coupling (waveguide)**
Data Rate	Up to 10 Mb/s	Few Kb/s
Transmission Quality	Strongly influenced by external environment around the body	Influenced by body physical parameters
Transmission path	Return signal path	Single signal path
Connectivity with ground	Required	Does not required
Method of transmitting electrical signals	Single-ended signaling	Differential signaling
Number of TX and RX electrodes	One pair	Two pairs
Electrodes locations	Body surface	Body surface/implanted
Vulnerability to interference and subject's movement	More vulnerable	Less vulnerable
Suitability for higher frequency (tens of MHz) applications	More suitable	Less suitable
Suitability for longer body distance applications	More suitable	Less suitable
Suitability for low frequency (tens of KHz) applications	Less suitable	More suitable
Suitability for applications with smaller body distance	Less suitable	More suitable

III. On-Body and Off-Body Communications

Apart from using the human body as the transmission medium, sensor nodes can also use environment for communication. This type of communication can be categorized as: i) on-body: when sensors present on the body communicate with each other ii) off-body: when the communication needs to be done between an on-body coordinator and a monitoring device at some distance away from the body. A number of existing wireless technologies can be used for these types of communication. Some of these low power technologies have been discussed further in this section.

A. Bluetooth Low Energy

Bluetooth low energy (BLE) is a low power, short range radio frequency standard developed by the Bluetooth SIG. The motivation behind this standard was to facilitate applications which make use of ultra-low power devices and hence have limited network lifetime. BLE increases the lifetime of such systems by providing support for i) simple device discovery, ii) power efficient peak, average and idle modes, iii) reliable transmission of data [8]. The BLE protocol stack comprises of two components i.e. a host and a controller. The host consists of higher layer functionality (LLC, SMP, ATT, GAP, GATT) whereas the controller includes the lower level layers.

The data transfer among these nodes is 1 Mbps. Similar to classic Bluetooth, BLE operates at 2400MHz frequency band but supports only 40 channels in comparison to Bluetooth's 79 channels. This decrease in number of channels leads to significantly less time for synchronization. Also, BLE supports two types of products, i.e. standalone chips and dual chips. The standalone chips have sensors that only interact with each other whereas dual chips are equipped with personal server and are capable of talking to other standards as well [9]. Although, this interoperability makes the network robust, it might also increase the chances of interference from other devices operating in the same frequency band. BLE uses adaptive frequency hopping technique to avoid such interferences. Thus, BLE is a compatible, reliable and secure means of communication. All these features make BLE a promising solution for health monitoring applications. A number of health device profiles like Health thermometer profile, heart rate profile, Glucose profile have been specified for BLE.

B. ZigBee

Zigbee is another wireless technology which offers a platform for communication of low power, short range, and low data rate applications. It uses the Physical and MAC layer specifications of IEEE 802.15.4 and uses its own network, security and application layers. Zigbee has some prominent features which make it a possible candidate for on body/off body communications. These features include: i) Communication range of 10-100m. ii) Support for low transmission rates. iii) Provision of low power sleep mode. The devices in this technology can switch to low power sleep mode when they are not involved in data exchange [10]. The Physical layer of a Zigbee system allows it to operate in 2400, 915 and 868 MHz frequency bands. These bands offer different data rates like 250 KB/s (2400 MHz), 40 KB/s (915 MHz) and 20 KB/s (868 MHz). It supports a total of 27 channels with a channel bandwidth of 2 MHz each. This layer employs direct spread spectrum (DSSS) as the modulation technique which is highly tolerant to interference and noise.

The MAC layer uses CSMA/CA as the channel access mechanism. The network layer of the Zigbee provides support for two types of devices i.e. reduced functional device (RFD) and full functional device (FFD). A FFD can act both as a coordinator and an end node whereas RFD does not have capability of becoming a network coordinator. Any device in a Zigbee network can connect to a maximum of 254 devices and the size of the entire network can be up to 65535 nodes. These devices can arrange in peer to peer, star, cluster tree or mesh topologies. Hence, this network supports a great flexibility in terms of connectivity. Apart from flexibility, scalability, low power consumption, short range and large network capacity, standard also has advantages of good security, shorter delays (15-30 ms) and low cost. All these features match perfectly with the considerations of a typical body area network in a health care environment. The Zigbee Alliance has developed a Zigbee Health Care Profile for monitoring and management of health services. It defines a number of devices specifically for aged patients, disease management and health and fitness.

C. IEEE 802.15.6

The IEEE 802.15.6 describes Physical layer and MAC layer standards for Wireless body area networks. It specifies three physical layers i.e. Narrowband (NB), Ultra Wideband (UWB) and Human Body Communications (HBC) layer. Each of these layers operates at different frequency bands and has different rates. The Narrowband physical layer has 7 different frequency bands which lie in MICS (402- 405 MHz), WMTS (420-450 MHz & 863-870 MHz) and ISM (902-928 MHz &

950-956 MHz & 2360-2400MHz &2400-2450MHz) bands. The Ultra wideband physical layer operates in low and high frequency bands. Both these bands are divided into a number of channels with bandwidth of 499.2 MHz each. The low band is divided into three channels and high band is divided into 8 channels [11].

The HBC layer uses electric field communication technology and operates in only two frequency bands of 16 MHz and 27 MHz with channel bandwidth of 4 MHz [12]. The selection of appropriate physical layer can be made depending on the type of the application. For example, NB physical layer is suitable for low power biomedical applications, UWB layer is appropriate for higher data rate applications and HBC layer can be used when human body is used as a channel [13]. All these layers are supported by a common MAC layer. The MAC layer organizes the nodes into one-hop or two hop star topologies. The operation of such network is controlled by a centralized hub. Every WBAN has only one hub but can have 0 to mMaxBANSize number of nodes. The nodes communicate via any of the three communication modes supported by this layer. These communication modes are beacon mode with superframe boundaries, non-beacon mode with boundaries and non-beacon mode without superframe boundaries. In beacon mode with superframe boundaries, the beacons are transmitted by the hub in active superframes only. These active superframes may be followed by a number of inactive superframes in case of unscheduled transmission. In case of non-beacon mode with superframe boundaries, the hub operates only during the Medium Access Phase only. In non-beacon mode without superframe boundaries, the hub provides either or both unscheduled Type II polled allocations. For fair medium access in each period of the superframe, a number of access mechanisms have also been specified. These include Random access mechanisms (CSMA/CA or Slotted Aloha), Improvised and unscheduled access (Unscheduled polling) and Scheduled access and variants (1-periodic or m-periodic allocations). The features of this standard compared with other aforementioned standards are shown in table II.

Table II.
Comparison Between Zigbee, Bluetooth Low Energy and IEEE 802.15.6

Characteristic	**ZigBee**	**Bluetooth Low Energy**	**802.15.6**
Frequency Band	2400 MHz 868 MHz - 915 MHz	2400 MHz	402MHz - 405 MHz 420 MHz - 450 MHz 863 MHz -870 MHz 902 MHz -928 MHz 950MHz-956MHz 2360MHz-2400 MHz 2400 MHz -2483.5 MHz
Bit Rate	868 MHz: 20 Kb/s 915 MHz: 40 Kb/s 2400 MHz: 250 Kb/s	1 Mb/s	Kbps-10 Mbps
Modulation Type	BPSK, O-QPSK	GFSK	DBPSK, DQPSK, D8PSK
Nominal TX Power	–32 dBm to 0 dBm	-20 dBm to 10 dBm	-40 dBm to -10 dBm
Receiver Sensitivity	-85 dBm	-70 dBm	-95 to -83 dBm
Number of Physical Channels	A total of 27 channels: 16 channels in the 2450 MHz 10 channels in the 915 MHz 1 channel in the 868 MHz	40 Channels are used in FDMA: 3 Channels as advertising channels 37 Channels as data channels	402- 405MHz- 10 channels 420-450 MHz- 12 channels 863-870 MHz- 14 channels 902-928 MHz- 60 channels 950-958MHZ- 16 channels 2360-2400MHz- 39 channels 2400-2483MHz- 79 channels
Channel Bandwidth	Each channel is 2 MHz wide with a wasteful 5 MHz spacing	Each channel is 2 MHz wide with no wasteful spectrum	402- 405MHz- 300 kHz 420-450 MHz- 320kHz 863-870 MHz- 400kHz 902-928 MHz- 400 kHz 950-958MHZ- 400kHz 2360-2400MHz- 1 MHz 2400-2483MHz- 1 MHz
Multiple Access Scheme	CSMA-CA, slotted CSMA-CA	FDMA, TDMA	CSMA-CA, slotted ALOHA , Polling
Network Topology	P2P, Star, Cluster Tree, Mesh	P2P, Star	Star (One hop, two- hop extendable)
Single-hop / Multi-hop	Multi-hop	Single-hop	Single hop, Multi Hop
Nodes / Active Slaves	> 65000	Unlimited	256
Range	100 Meters	10 Meters	2-5Meters

D. Radio Frequency Idenfication

Radio frequency identification technology (RFID) is considered as one of the potential contenders for on-body/off-body communication. RFID is a wireless automated data collection technology which is useful in remotely tracking and tracing of events and also capable of storing some information about them. A conventional RFID system consists of a reader and a tag. A reader sends RF- interrogatory signals to the tag which in turns transforms the energy of these signals according to the information stored on it. The reader then sends this information to the database [14]. Depending upon the type and requirements of application active, passive or semi-passive tags can be used. Active tags have their own power source whereas passive tags gain power from the reader's signal. Semi-passive tags have features of both active and passive tags. These tags behave as active tags if they are at a far distance from the reader and have to utilize their own battery; on the other hand they behave as passive tags if they are quiet near to the reader and can make use of reader's signal energy to power themselves. Table III shows the different features of active and passive tags. An RFID system can operate in low frequency, high frequency and ultra-high frequency bands. Table IV enlists the different operating frequency bands, their read range, type of tags, available standards and the features of the communication in a particular frequency band. In health care applications, RFID technology is being extensively used for patient tracking and safety [15].

Table III.

Characteristics of Different RFID tags

Characteristics	**Active Tags**	**Passive Tags**
Power	Battery operated	No internal Power
Read Range	Long (100m+)	Short (3m)
Data Storage	Large Read/Write (128kb)	Small Read/ Write (128b)
Tag Size	Larger	Smaller
Cost	Expensive	Cheaper
Signal Strength	Low	High

Table IV.

Operating Frequency Bands, Read Range, Types of Tags, Standards and Features of the Communication in the Given Band [16],[17]

Frequency Band	**Range**	**Tag Type**	**Standard**	**Features**
120– 150 kHz	1-10 cm	Passive	ISO 14223/1	Inexpensive, Good penetration, Short read range, Slow read speed
13.56 MHz	1 cm - 1 m	Passive	ISO 18000-3	Short to medium range, Medium speed, Expensive systems
433 MHz	1–100 m	Active	ISO 18000-7	Long range, High speeds, Expensive, Line of sight to read
865- 868 MHz 902- 928 MHz	1cm–20 m	Passive, Semi-Passive, Active	ISO 18000-6C	Long range, High speeds, Expensive, Line of sight to read
2450- 5800 MHz	1–100 m	Active	ISO 18000-4	Long range, High speeds, Expensive, Line of sight to read
3.1– 10 GHz	1 to 200 m	Active	ISO 18000-5	Long range, High speeds, Expensive, Line of sight to read

IV. Discussion

The selection of an appropriate communication technology is highly critical for the efficient functioning of a health monitoring system. This section highlights the features of the different available technologies which should be considered while making a choice. As explained in section II, IBC allows the receiver and transmitter to communicate over a very short range inside the body. This significantly reduces the power consumption of the sensor nodes present on the body and helps in prolonging their lifetime. Intra body communications can thus be considered as a promising solution for low power wearable health monitoring systems. In a typical health monitoring environment, data collected from the sensors is not directly transmitted to the hospital rather it is initially collected by the coordinator which transfers it to the access point; from there it is sent to the hospital. In this scenario, IBC can be used effectively for interconnecting on-body sensors with the coordinator but for sending data further to the access point, IBC may require a touch device like smart phone to transfer the collected data .This device will then act as an access point and can relay the data further. Although, this type of communication is inexpensive, yet it requires a lot of effort from the patients and hence might not be suitable for people suffering from diseases like dementia. Therefore a system that requires least input from the patients is desirable. Such a system can be designed by using IBC for interaction between the body sensors and the coordinator which can be further connected to the access point with other low power wireless technologies like Zigbee, BLE, RFID etc. This type of system will have the effective low power consumption without requiring any extra effort from the users. A number of low-power wireless technologies for connecting the coordinator to the base station are available. Out of these, ZigBee and Bluetooth are most widely used. The preference of Zigbee over Bluetooth (or BLE which is the updated version) or vice versa can be made based on the following factors:

A. Communication Distance

ZigBee is a wireless Local Area Network (LAN) technology, therefore covers a greater distance than BLE which is a wireless Personal Area Network (PAN) technology and is limited to a shorter distance. There are scenarios in many wearable health monitoring systems, where collected data is required to be transmitted to an access point within a room environment. In these scenarios, BLE is considered the best option, as it covers the required distance. However, there are scenarios, where wearable devices are required to transfer the collected data to a local station located in other side of the house. If no other home networking infrastructures such as Power Line Communication (PLC) or Ethernet is used, ZigBee is considered the best option, since BLE is not able to cover the entire area.

B. User Flexibility

According to Bluetooth SIG, most of the Bluetooth-based smartphones will support Bluetooth LE by 2018. This will provide flexibility to users, since a BLE-enabled smartphone could be used as an access point. Whereas, ZigBee requires a ZigBee-enabled device as an access point.

C. Protocol Efficiency

It is one of the most important factors in selecting an appropriate low-power wireless technology. This is due to the fact that an inefficient protocol expends most of its time transmitting overhead information rather than transferring the actual payload. Therefore, only little data may be transmitted over a fixed duration of time and devices transmitting the packets may soon run out of batteries. The protocol efficiency can be computed as the ratio of actual payload information to the total length of packet. It is thus simple to determine the protocol efficiency of the ZigBee and BLE Protocols by examining their packet formats; BLE protocol is 66 percent efficient and ZigBee protocol is 76 percent efficient. Based on this analysis, ZigBee technology is shown to be more protocol efficient than BLE protocol. However, it must be noted that, in many low-power low data-rate monitoring systems, wearable devices are only required to use partial of the total available payload space to transmit a few number of bytes, thus lower protocol efficiency does not mean a protocol is unsuitable.

V. Conclusion

This paper provided a comparison of some of the existing low-power wireless protocols that could possibly be used in wearable health-monitoring applications. In this article, the communication technologies have been broadly classified into intra-body communications and on/off body communications. The intra-body communication uses body as the medium of propagation whereas on/off body communication uses environment as the medium. IBC provides an ultra-low power means of communication which if combined with the existing low-power on-body/off-body communication technologies can significantly reduce the overall energy consumption of the system which is the one of the critical requirements of wearable health-monitoring applications.

References

[1] United States Census Bureau (2014) Unprecedented Global Aging Examined in New Census Bureau Report Commissioned by the National Institute on Aging, Available at: https://www.census.gov/newsroom/releases/archives/aging_population/cb09-108.html(Accessed: 10 March 2014).

[2] Office for National Statistics (2014) National Population Projections, 2012-based Statistical Bulletin, Available at: http://www.ons.gov.uk/ons/rel/npp/national-population-projections/2012-based-projections/stb-2012-based-npp-principal-and-key-variants.html (Accessed: 10 March 2014).

[3] World Health Organization (2010) Global status report on non-communicable diseases, Availableat: http://www.who.int/nmh/publications/ncd_report_full_en.pdf (Accessed: 27 May 2014).

[4] Lee, H., Lee, K., Hong, S., Song, K., Roh, T., Bae, J., Yoo, H-J (2013) 'A 5.5mW IEEE-802.15.6 wireless body-area-network standard transceiver for multichannel electro-acupuncture application', Solid-State Circuits Conference Digest of Technical Papers, pp. 452 - 453.

[5] Bae, J., Cho, H., Song, K., Lee, H., Yoo, H-J., (2012) 'The Signal Transmission Mechanism on the Surface of Human Body for Body Channel Communication', IEEE Transactions on Microwave Theory and Techniques, 60(3), pp. 582 - 593.

[6] Seyedi, M., Kibret, B., T. H. Lai, D., Faulkner, M., (2013) 'A Survey on Intrabody Communications for Body Area Network Applications', IEEE Transactions on Biomedical Engineering, 60(8), pp. 2067 - 2079.

[7] Callejon, M.A., Naranjo-Hernandez, D., Reina-Tosina, J., M. Roa, L., (2012) 'Distributed Circuit Modeling of Galvanic and Capacitive Coupling for Intrabody Communication', IEEE Transactions on Biomedical Engineering, 59(11), pp. 3263 - 3269.

[8] LitePoint Corporation (2012) Bluetooth low energy, United States of America: LitePoint Corporation.

[9] Cao, H., Leung, V., Chow, C., & Chan, H. (2009) 'Enabling technologies for wireless body area networks: A survey and outlook', IEEE Communications Magazine, 47(12), pp. 84-93.

[10] He, D. 2010. ‘The ZigBee Wireless Sensor Network in Medical Care Applications’. Proceedings of International Conference on Computer, Mechatronics, Control and Electronic Engineering (Changchun, August 24-26, 2010), 497-500. DOI=http://dx.doi.org/10.1109/CMCE.2010.5610435.

[11] Ullah, S., Mohaisen, M., & Alnuem, M. A. (2013) 'A review of IEEE 802.15. 6 MAC, PHY, and Security Specifications', International Journal of Distributed Sensor Networks, 2013, DOI= http://dx.doi.org/10.1155/2013/950704.

[12] IEEE (2012) IEEE standard for local and metropolitan area networks Part 15.6: Wireless Body Area Networks.

[13] Wong, A., Dawkins, M. ; Devita, G. ; Kasparidis, N. ; Katsiamis, A. ; King, O. ; Lauria, F. ; Schiff, J. ; Burdett, A. (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), pp. 186-198.

[14] Fuhrer, P., & Guinard, D. (2006). 'Building a Smart Hospital using RFID Technologies.' Proceedings of the 1st European Conference on eHealth (Fribourg, Switzerland, October 12 - 13, 2006), 131-142.

[15] Yao, W., Chu, C. H., & Li, Z. (2010, June). 'The use of RFID in healthcare: Benefits and barriers'. Proceedings of IEEE International Conference on RFID-Technology and Applications (Guangzhou, June 17-19, 2010), 128-134.

[16] International RFID Institute (2014) RFID Technologies, Available at: http://rfidinstitute.org/rfid-technologies/ (Accessed: 21 May 2014).

[17] The UK I.T Association (2014) RFID Frequencies., Available at: http://ukrfid.innoware.co.uk/hardware/rfid_frequencies (Accessed: 21 May 2014).