8 Wireless Body Area Networks and Sensors Networking

by
D. Goustouridis and E.D. Kyriakis-Bitzaros

Department of Electronics Engineering, Technological Education Institute of Piraeus, Greece

8.1 Introduction

The rapid development of the microelectronics and micromechanics, both in design and manufacturing, within the last decades allowed for huge advancements in the areas of sensing devices and systems. These advancements make possible:

- The development of new generation of sensors based on Micro & Nano ElectroMechanical Systems (NEMS & MEMS), or even Micro OptoElectroMechanical Systems (MOEMS).
- The miniaturization of electronics devices, with minimal requirements in power consumption
- The realization of various types of autonomous wireless networks.

These developments are critical for the design and implementation of the so call Body Area Networks (BANs) or Wireless Body Area Networks (WBANs) (Yang, 2006). In these networks a wide variety of sensors could be attached on clothing, on body or even under the human skin and transmit the environmental and/or body signals, through the network to specified control and decision points. Furthermore, in addition to the sensors a series of actuators could be also included in the WBAN, thus the network in addition to the collection of data from the environment and/or body it is capable of reacting with the environment and change the current conditions.

The wireless nature of the networks, the increased capabilities of the contemporary mobile devices (smart phones, PDAs etc.) and the wide variety of the sensors that could be used, offer numerous innovative applications not only for special application domains such as military, aerospace etc., but even for everyday life and for everyone's use. The most important of these applications is health care improvement, in a more efficient and cheaper way, in order to ameliorate the quality of life and extend life expectancy.

8.2 Sensor Networks. Why?

Electronic devices and computers are able of processing a wide range of diverse signals and act accordingly. These signals coming from the environment or the human body are analogue in nature and cover a wide range of parameters including temperature, pressure, humidity, odors, chemical or biological properties, sound, light (or images) etc. As they are recorded and processed by the electronic modules not only give information about the conditions of a certain area of the outside world or even about the conditions inside the body but could be further used for interaction with the monitored environment or the body and solve tune or recalibrate unwanted situations and events.

The events that a WBAN should handle are very similar to the events that the human brain should care of. For example if a person smells smoke from one direction decides to take an alternative path, or if he/she feels sick decides which medication he/she will use. This is exactly the situation that a WBAN try to emulate: A WBAN that is fitted on a patient body, collects important data such as heart rate, blood pressure, biochemical parameters etc. and alerts the patient itself, and/or the doctor at his office several kilometers away.

Three are the most critical parameters in a WBAN:

- The sensors and the electronic devices should be as small as possible, to be wearable without disturbing the everyday activities.
- The required power to operate the WBAN should be as small as possible in order to allow the use of small weight batteries that last very long time or even better the WBAN should collect energy from the environment (energy harvesting), so to be battery-less.
- The communication protocols should be implemented in a very efficient way to guarantee security and high throughput of information with low energy consumption.

8.3 WBAN Applications

Health Applications, Point of Care

The main use of WBANs is for health applications monitoring the physiological status of a patient either in the hospital environment or at home. For example patient monitoring is of high importance in the waiting areas of emergency departments or at the recovery phase after a surgery, to prevent lack of attention of a patient's health deteriorating rapidly. Applications of WBANs at home include monitoring of a patient with chronic diseases (e.g. pneumonological, cardiovascular diseases etc.), or during the recovery phase at home. Moreover, WBANs could also be used as diagnostic tools for monitoring physiological parameters (e.g. blood pressure, glucose) at home or outdoor environment during everyday activity.

The most common areas of use are:

- ***Cardiovascular diseases***, to prevent myocardial infarction, monitor episodic events etc.
- ***Cancer detection***, by monitoring the nitric oxide emitted from cancer cells.
- ***Asthma***, by monitoring of allergic agents in the environment.
- ***Diabetes***, glucose level monitoring, by monitoring in real time the glucose level and inject insulin automatically.
- ***Alzheimer, depression and elderly people***, by detecting any abnormal situation (i.e. via accelerometers and positioning system to monitoring the activity of the person).
- ***Epileptic Seizures Strike early warning***, by monitoring the EEG activity.
- ***Telemedicine systems***, to support unobtrusive ambulatory health monitoring for long period of time.

Sport training

WBANs can be used to identify specific postures and provide biometric and technical feedback in many sports, to improve the performance of both elite and amateur athletes and prevent from injuries due to incorrect postures.

Military

WBANs can be used in the battlefield to connect the soldiers, report their activities to the commander and monitor their physical status (stress etc.).

Vehicle drivers

WBANs can be used to monitor driver behavior, i.e. blink-rate, yawning, eyebrow raise, chin-drop, head movement, or physiological signals such as EEG, to determine the alertness level of the driver and to prevent sleeping episode by alerting the driver.

8.4 WBAN Architecture

A WBAN is a particular case of a WSN (Wireless Sensor Network) that has certain special requirements and constrains (Latre et.al. 2011, p. 2):

- A conventional WSN is composed of a large number of sensors that, usually are distributed in large areas and sometimes at not easily accessible places (Akyildiz et.al. 2002, p. 394). For that reasons in most cases the WSN employs redundant nodes to cope with diverse types of failures. In contrary, a WBAN consists of a limited number of sensor/actuator nodes placed strategically on the human body, or hidden under clothing.
- In WBANs the transmission of sensor's data is critical and it is accomplished, usually in regular intervals, without the employment of redundant nodes, directly to a central personal server (PS), while the data exchange in a general purpose WSN is event driven, which means that data transmission takes place in an irregular time base, when an event occurs and multihop paths do exist. Furthermore, due to the personal and confidential character of the data within a WBAN, data encryption offering high-level of security and confidentiality is required.

- While energy conservation is definitely beneficial, the power consumption of the WBAN nodes it isn't as critical as for the WSN, since the replacement of the batteries is much easier. However, due to the proximity of the WBAN with the user's body, low-power transmission is mandatory to avoid hazardous influences.
- As a WBAN user moves around, the WBAN shares the same mobility pattern, while in many case the network may interfere with the WBANs of other users. In contrary a WSN is usually considered stationary.

Figure 8.1 illustrates a simplified WBAN configuration with its connection to the outside world. The WBAN consists of a number of Sensor Nodes (SN) and Actuator Nodes (AN). The sensor/actuator nodes communicate with a Personal Server (PS) that is a special node responsible for building and controlling the overall body network. The PS node could be a specifically designed node, or a general purpose device such as a smart phone or a PDA with a special application built-in. The PS transmits the measurement data to the Wireless Personal Area Network (WPAN) that consists of the user's house internet modem/ router or other wireless connected home devices. Through the WPAN the WBAN is connected to the internet to enable remote access of user data, e.g. a physician, an emergency station or a hospital could monitor or alarmed for a user/patient physiological conditions.

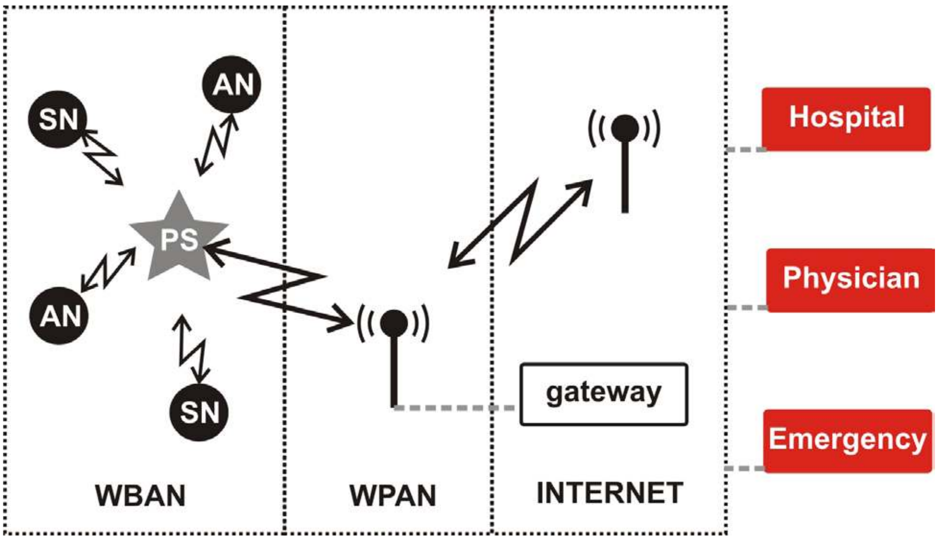

Figure 8.1 WBAN configuration and wireless connection with the internet.

8.4.1 Sensor and Actuator Node

The heart of an SN or an AN is a low-power microprocessor, which is responsible for the control of the RF, the memory and the sensor or actuator modules, respectively, as well as for the implementation of the power management scenario, which is required to maximize node autonomy. Figure 8.2, illustrates the typical structure of an SN or an AN of a WBAN, however, in many cases complex nodes acting as both sensors and actuators do exist in a WBAN. A description of the components comprising an SN or an AN is given bellow.

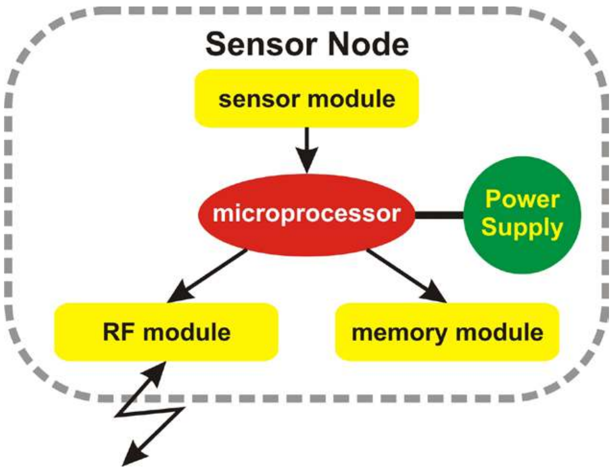

Figure 8.2a. Typical configuration of Sensor Node

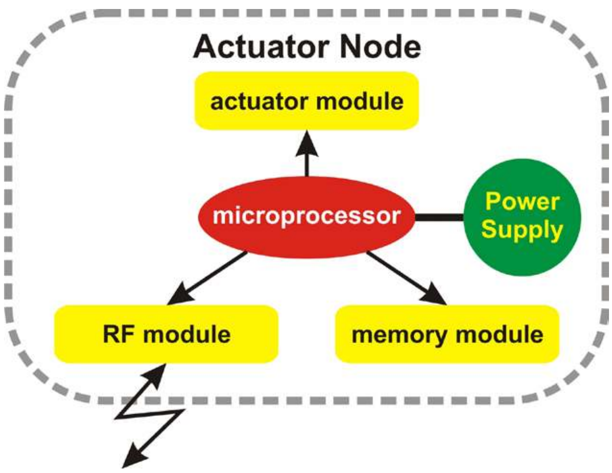

Figure 8.2b.Typical configuration of Actuator Node

Sensor/Actuator Module

Sensor and Actuator module is the key component of a WBAN node. These modules connect the physical world (analogue-physiological signals) to the electronic systems (monitoring, analysis and decision taking through the appropriate software). The SNs and ANs are usually exposed directly to or even implanted inside the human body in order to be able to measure the physiological signals and parameters. For example, to monitor the blood pressure or the blood glucose the sensing area of the sensor module must be directly exposed to blood stream. For that reason: a) the size of the modules must be small enough to preserve the normal operation of the body and b) the module area exposed to the body must have physical compatibility to human tissues, especially in the case of the implantable ones. For that in most cases the development of new manufacturing techniques and the synthesis of novel biocompatible materials are of crucial importance in the design and implementation of bio-sensors. In some other cases e.g. temperature measurement, electrical activity etc. the biocompatibility issue is not so crucial.

Actually, the sensor module comprises of two subsystems: a) the sensing element that converts the physicochemical signal to an electrically measurable signal and b) the conditioning circuit that amplifies and converts the weak and susceptible to noise sensing element's signal to a more stable one such as voltage, current or frequency. Depending on the electrical property used to sense the parameter under measurement two major categories of sensors exist, namely, capacitive and resistive ones (Tsoukalas et.al. 2006, p. 1). In capacitive sensors the physicochemical signal under measurement is converted to capacitance changes, while the condition circuit converts that capacitance changes to frequency or voltage changes. In resistive type of sensors the measurement signal is converted to resistivity changes, while the condition circuit converts that resistivity changes to current or voltage changes.

According to how sophisticated the condition circuit is different tasks can be implemented such as temperature compensation, calibration etc. In some cases mixed analogue/digital circuits are used, so that the sensors' output could be an insensitive to noise digital signal. In the case of the sensors that measure the body electrical signals (ECG, EEG, EMG) (Nemati et.al. 2012), the sensing element is an electrode while the condition circuit amplifies and stabilizes the weak electrode signals. A very important parameter of the sensor/actuator modules is the measurement accuracy of the physiological signal, while this accuracy determines the measurement accuracy and reliability of the whole system.

Microcontroller

In the Sensor Node the main task of the microprocessor is to read the sensors' data and then transmit them, after processing if necessary to the PS. In the case of an Actuator Node the microprocessor when receives an order from the PS, triggers the actuator to perform an operation, e.g. to inject some drug.

Moreover, the microprocessor of the SN or AN is responsible for the implementation of the power management scenario aiming to extend the autonomous and service-less operation time of the node. Finally, it runs the necessary diagnostics ensuring the correct operation (health) of each node and enable through their results the PS to check the health of the entire WBAN. Usually, the on-board processing requirements are low, so simple, low-cost and low-power microcontrollers such as Texas Instruments' MSP430™ Ultra-Low Power series (TI 2012), ATMEL's tinyAVR picoPower series (Atmel 2012) or equivalent are used.

Memory module

The memory module usually on-chip flash memory or RAM) is used for storing the firmware of the node as well as for temporally storage of the network and personal data and the measurements. The memory requirements are very much application dependent and range from a few Kbytes to several hundreds of Kbytes.

Power source

The SN and AN consume power for sensing or actuating, communicating and data processing. Most of the energy is consumed for data communication. The power is stored either on batteries (rechargeable or not) or capacitors. In some systems special energy harvesting subsystems are used for renew their energy. In such systems (Huang et al 2009) an amount of energy can be harvested from the environment (vibrations, heat, light radiation, electromagnetic fields etc.) and then stored to a capacitor or rechargeable the battery, so the sensor/actuator node could be fully or partially autonomous in energy. While a fully energy autonomous approach (with no battery) is very attractive, it is very difficult to implement in applications where a high data rate transmission is required. In any case the microcontroller is responsible for the power saving policies (power management) by shutting down the subsystems that are in an idle state.

RF module

The RF module is responsible for the wireless communication within the WBAN and consist of the transceiver and the antenna. The antenna is the one of the most critical components of the node, since its design influences considerably the efficient operation of the WBAN. The transceiver RF of the RF module is responsible for the transmission/reception of data between the SN/AN and the PS. Several issues must be taken into account in the design of the RF module, mainly the frequency and the emitter RF power that are used. First of all body sensors/actuators are placed on or even in the human body, so the propagated electromagnetic wave could be diffracted around the body or absorbed from it. The transmission signal must be of low power, but with enough bandwidth for the required data rate, to insure low Specific Absorption Rate (SAR) from the tissues according to international SAR regulations. Further issues that should be taken into consideration are the location of the WBAN, which could be indoors or outdoors and how severe is the interference from other users in proximity. The design of the antenna and the material to be used is very crucial for the communication of the node and depends on the node placement and the allowable volume that usually is very limited. The RF module is the most power consuming one, so must be in idle or shutdown mode when it is not in use.

Finally, according to the sensor type and the WBAN application continuous or burst mode data transmission at different rates is required, so the communication protocol implemented must have different specifications (please refer also to section 8.5). The most widely used sensors in WBANs, their applications and the associated data rate requirements (Latre et.al. 2011, p. 4, Chen et.al. 2011, p. 177, Ullah et. Al. 2009, p. 801) are summarized in Table 8.1.

8.4.2 Personal Server

The Personal Server is a device that gathers the information acquired by the sensors, activates the actuators, processes the data and informs the users (patient, doctor, hospital etc.) via an external gateway (i.e through the internet, cellular phone infrastructure, etc.) or a display. It consists of the power unit, an efficient general purpose processing unit, memory and a transceiver. The software of the PS may be complicated enough to take decisions for certain situations and send commands to the ANs to resolve them or could receive external orders by the person monitoring the WBAN user. In many implementations a PDA or a smart phone, offering access to the cellular infrastructure, with a specially developed application could be used as a PS for a WBAN.

Sensor Type	Application	Data rate
Accelerometer & gyroscope	To recognize and monitor body posture, for applications such as virtual reality, health care, sports, and electronic games.	High
Blood glucose	To monitor the amount of glucose circulating in the blood.	High
Blood pressure	To measure the systolic and diastolic human blood pressure.	Low
CO_2 gas sensor	To monitor changes of gaseous carbon dioxide levels and/or oxygen concentration during human respiration.	Very low
ECG sensor	To record the heart's electrical activity, to diagnose a heart disease or to monitor the effectiveness of heart medications.	High
EEG sensor	To record electrical activity within the brain.	High
EMG sensor	To record electrical signals produced by muscles contraction or at rest, for healthcare in nerve and muscles disorders.	Very high
Pulse oximetry	To measure the oxygen saturation in the blood, usually in patients with pneumonological diseases.	Low
Humidity & Temperature	To measure the temperature of the body and the ambient humidity.	Very low

Table 8.1. Typical applications and data rate requirements of sensors in WBANs.

8.5 Communication Protocols / Platforms

For the reliable and secure operation of a WBAN the communication protocols and the platform that is used is a very critical issue. The WBAN is a network that is part of a wireless (or wired) personal area network (PAN/WPAN) at the home (or the area) where the user of the WBAN lives. That network may include the personal computer, a PDA, a smart phone, home cinema, peripherals like printers etc. The PAN is connected via the router to the local area network (LAN/WLAN) that could be the network of the building, the office or the hospital where lives, works or stays the person of interest. The LAN is connected to a metropolitan area network (MAN/WMAN) and then to the wide area network (WAN). This situation is illustrated in figure 8.3.

As it is obvious, the transmission of the WBAN data over the internet as described above should be strictly private and confidential so data encryption is mandatory to protect the user's privacy. Moreover, in health care applications, the WBAN must be accessible in cases when the user is not capable to give authorization, i.e. to guarantee accessibility in trauma situations and at the same time should also guarantee the confidentiality of unauthorized persons. The data encryption becomes more difficult due to limitations in energy consumption since security and privacy protection mechanisms require a significant amount of energy.

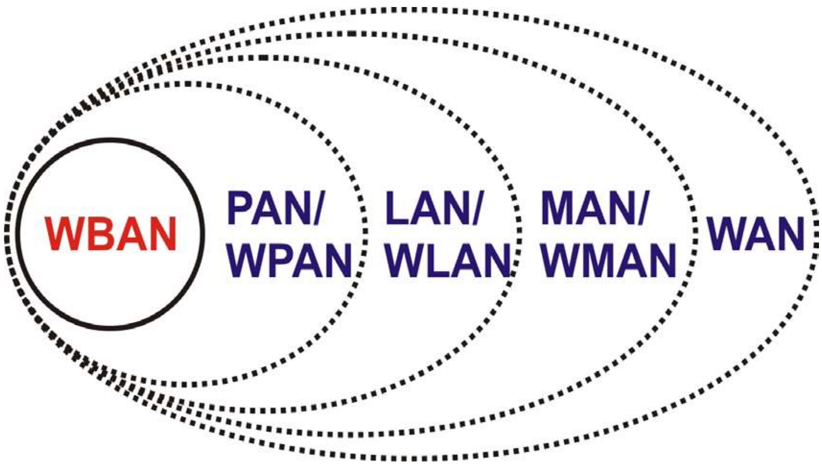

Figure 8.3. WBAN hierarchy in comparison with other networks

Another very critical parameter of the used communication platform is the supported data transmission bandwidth. In Table 8.2 data rates, power consumption and privacy of various applications are given (Ullah et. Al. 2009, p. 801). While in most sensor nodes the required data rate is relative small, in a WBAN that may consists of tenths of nodes the overall data rate that the personal server should manage can be easily rose to several or tenths of Mbps , so the communication platform must be able to handle such relatively high data volume.

Application type	Sensor Node	Data Rate	Power Consumption	Privacy
In-Body Applications	Glucose monitor	~2 Kbps	Very LOW	HIGH
	Pacemaker	~2 Kbps	LOW	HIGH
	Endoscope capsule	~2 Mbps	LOW	MEDIUM
On-Body Medical Applications	ECG	~ 100 Kbps	LOW	HIGH
	EEG	~50 Kbps	LOW	HIGH
	EMG	~300 Kbps	LOW	HIGH
	Blood Pressure	~10 bps	HIGH	HIGH
	Blood Saturation	~20 bps	LOW	HIGH
	Temperature	~100 bps	LOW	MEDIUM
	Motion Sensors	~50 Kbps	LOW	HIGH
	Cochlear implant	~100 Kbps	LOW	HIGH
	Artificial Retina	~500 Kbps	MEDIUM HIGH	HIGH
On-Body non Medical Applications	Audio	~1 Mbps	MEDIUM HIGH	LOW
	Voice	~100 Kbps	MEDIUM LOW	MEDIUM
	Social Network	~200 Kbps	LOW	HIGH

Table 8.2. Data rate, power consumption and privacy requirements for WBAN medical applications.

The available media access control (MAC) communication protocols that can be implemented in a WBAN are quite limited. As described above, they must comply simultaneously to the requirements of high data rate and low power consumption, low SAR, high encryption and reliability. In figure 8.4 the features of existing MAC protocols are illustrated. The most widely used and emerging radio technologies for WBANs and WPANs (IEEE 802.15 working group) are the Bluetooth (IEEE 802.15.1), IEEE 802.15.4 and ZigBee, UWB (ultra wide band, eg. wireless USB) and IEEE 802.15.6. An overview of MAC protocols designed for wireless sensor networks (WSNs) can be found in (Akyildiz et.al. 2002).

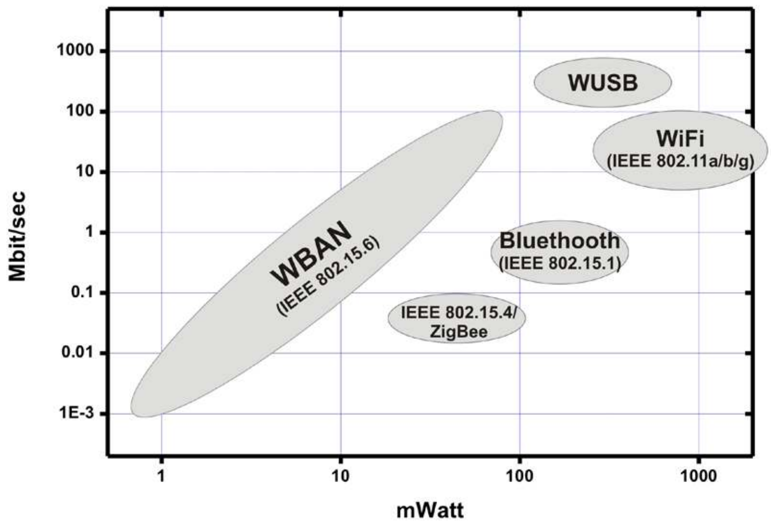

Figure 8.4. WBAN MAC requirements compared with available wireless protocols.

The Bluetooth (IEEE 802.15.1) and the Bluetooth Low Energy (BLE previously known as WiBree), operates in the 2.4GHz ISM band, covers a range of 1m–100m and at version 2.0 +EDR supports a maximum data rate of 3Mbps at relatively high power consumption. The low energy version support a maximum data rate of 1Mbps. Although some implementations of WBANs use Bluetooth (Johansson et.al. 2001), due to the relative high energy consumption and the complex protocol stack is not a suitable MAC protocol for WBANs applications.

The IEEE 802.15.4 and the based on that standard ZigBee protocol is the most widely used MAC protocol for WBAN implementations (Zigbee, Timmons & Scanlon, 2004, Li & Tan 2005). It operates on one of three possible unlicensed frequency bands: 868 MHz, 902-928 MHz and 2.4GHz, and can support a data rate up to 250Kbps (at 2.4GHz). It has very low power consumption and it covers a range up to 10m. While it has limited data rate, up to now is the best solution for low data rate WBANs.

The general conclusion is that neither the IEEE 802.15.1, nor the IEEE 802.15.4 was designed to support WBANs as described above, so a specialized MAC protocol is needed. Such effort is given from the IEEE 802.15 task group 6 (IEEE 802.15.6) that started in 2007. As describes itself, *the scope of IEEE 802.15 task group 6 is development of a communication standard optimized for low power devices and operation on, in and around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics / personal entertainment and other* (IEEE802.15.6, Kwak et.al, 2010). The IEEE 802.15.6 will likely employ UWB protocols (at frequencies 3.1–10.6 GHz), however the time frame for product commercialization incorporating this standard still remains unknown. Table 8.3 summarizes the WBANs draft requirements.

Distance	2m standard, 5m special
Piconet density	2–4 nets / m2
Devices per network	max. 100
Net network throughput	100 Mbit/s max
Power consumption	~ 1mW / Mbps (@ 1 m distance)
Startup time	< 100 µs
Latency (end to end)	10 ms
Network setup time	< 1 sec

Table 8.3. WBAN requirements as in IEEE 802.15.6 protocol.

8.6 WBANS projects

Bellow the most relevant projects in the field of WBANs are summarized:

CodeBlue (Shnayder et.al. 2005)
In this project implemented at the Division of Engineering and Applied Sciences of Harvard University, several types of body sensors (e.g., pulse oximeter, ECG sensor) are individually connected to Zigbee-enabled radio transmitters, where patients' sensor devices publish all relevant information directly to an access point. The physicians subscribe to the network by multicasting and they can specify the information they need, such as the identification of the patient(s) of interest, and the types of body signals that need to be collected. It also has a flexible security model, in addition to the ability to prioritize the critical.

AID-N (Gao et.al. 2007)

In this project, although the WBAN utilizes a similar mesh structure as done in CodeBlue, its application scenario is different. Instead of deploying access points on the wall, wireless repeaters are located along a predefined emergency route. When an emergency situation happens, medical staff can recognize the correct emergency route. Due to its application as a medical emergency response system, a GPS module is included to the PS to provide an outdoors location service. The body sensor(s) are first connected to a PS through cable(s), whose signals can be delivered to a remote database by the PS through a WiFi or cellular network.

SMART (Curtis et.al. 2008)

In this project were monitored the physiological signals from patients in the waiting areas of emergency departments. There have been various cases in which the medical team has found that the patient's health deteriorates rapidly while waiting in an emergency room. Since time is of an essence in this situation, patients' lives cannot be risked because of the lack of attention provided in emergency rooms. The SMART system can be used to collect data from various patients waiting in an emergency room, and wirelessly send it to a central computer that collects and analyzes the data. This way, patients can receive treatment before the condition worsens.

ALARM-NET (Wood et.al, 2006)

Alarm-Net is a wireless sensor network for assisted-living and residential monitoring. It integrates environmental and physiological sensors in a scalable, heterogeneous architecture. It creates a medical history log, while preserving the patient's privacy. Authorized care providers may monitor resident health and activity patterns, such as circadian rhythm changes, with a automatic 24/7 monitoring system, which may signify changes in healthcare needs. Wearable sensor devices can sense even small changes in vital signals that humans might overlook, such as heart rate and blood oxygen levels, boosting accuracy.

HipGuard System (Soini et.al. 2008)

HipGuard system is developed for patients who are recovering from hip surgery. This system monitors patient's leg and hip position and rotation with embedded wireless sensors. Alarm signals can be sent to patient's Wrist Unit if hip or leg positions or rotations are false, and hence HipGuard system can provide useful real-time information for patient rehabilitation process.

MobiHealth (Mobiheatlh, Neves et.al. 2008)

Mobihealth is a mobile healthcare project funded by the European Commission, to create a generic platform for home healthcare using WBAN based sensors. In this project GPRS/UMTS wireless communication technology for transferring data, are used to provide continuous monitoring to patients outside the hospital environment. MobiHealth targets, improving the quality of life of patients by enabling new value added services in the areas of disease prevention, disease diagnosis, remote assistance, physical state monitoring and even in clinical research. The patients wear a lightweight monitoring system which is customized to their individual health needs. Therefore, a patient who requires monitoring for short or long periods of time doesn't have to stay in hospital for monitoring. With the MobiHealth BAN the patient can be free to pursue daily life activities.

IBBT IM3 (IBBTIME)
The Flemish IBBT IM3-project (Interactive Mobile Medical Monitoring) focuses on the research and implementation of a wearable system for health monitoring. The solution consists of four elements or zones: a) The patient zone, including mobile sensors for registering the physiological parameters: Electrocardiogram, heartbeat, respiration, etc. b) A medical hub: A cell phone or personal digital assistant (PDA), which collects the data registered for the patient and transmits it. c) An IM3 backend server, which securely stores and processes the data; including customised algorithms and event managers, which can give a first interpretation of the data and fulfils privacy regulations. d) The biodata viewer, which can be used by care personnel for remote monitoring of patients. Patient data is collected using a WBAN and analyzed at the medical hub worn by the patient. If an event (e.g. heart rhythm problems) is detected, a signal is sent to a health care practitioner who can view and analyze the patient data remotely.

LifeShirt (LifeShirt)
LifeShirt although it isn't a WABN system that collects and transmits wireless data, it is presented here due to the fact that it is a commercially available system. LifeShirt comprises of a comfortable and lightweight garment with embedded sensors that continuously collect information on a range of cardiopulmonary parameters, such as blood pressure, EEG, audio, temperature and blood oxygen saturation. The LifeShirt Recorder™ is a mobile device that continuously encrypts and stores the subject's physiologic data on a compact flash memory card. It enables healthcare professionals and researchers to accurately monitor more than 30 vital life-sign functions in the real-world settings where patients live and work.

Finally in (De Rossi et.al. 2003) is presented the implementation of a truly wearable, instrumented garments which are capable of recording biomechanical variables. Although it isn't a WBAN system, comfortable garment devices (a smart shirt, a leotard and a glove) which can read and record vital signs and movements with sensors fabricated together with the garment are presented. The sensing function is based on piezo-resistive fabric sensors, based on carbon-loaded rubbers (CLR) and different conductive materials.

8.7 Concluding Remarks

The use of WBANs brings together technological advances in diverse areas ranging from electronic devoces and wireless networks to new sensing materials and multifunctional fabrics giving the possibility to make the every day life of anyone safer and more comfortable. Especially, the area of health monitoring and telemedecine has attracted the interest of the research community and a lot of efforts have been devoted to it in order to increase life expectancy and quality of life at a reduced cost.

Two are the main issues that should be resolved to enable the wide adoption of WBANs in many application domains. The development and commercialization of a protocol standard, like the IEEE 802.15.6 and the evolution of industrial processes for the incorporation of sensors and actuators in fabrics and therefore to comfortable garments, which will have the capability to record vital signals and movements and interact with the humans without any disturbance to the user's routine.

8.8 References

(Akyildiz et.al. 2002) Akyildiz, I.F., Su, W., Sankarasubramaniam, Y. & Cayirci, E. 2002 'Wireless sensor networks: a survey', *Computer Networks*, vol.38, pp. 393–422.

(Arshak et.al. 2007) Arshak, K., Jafer, E., McGloughlin, T., Corbett T., Chatzandroulis S., & Goustouridis, D. 2007, 'Wireless Measurement System for Capacitive pressure Sensors Using Strain Compensated SiGeB', *IEEE Sensors 2007*, October 28–31, 2007.

(Atmel 2012) Atmel Corp., Online Doc., http://www.atmel.com/products/microcontrollers/avr/tinyAVR.aspx

(Chen et.al. 2011) Chen, M., Gonzalez, S., Vasilakos, A., Cao, H., & Leung, V. 2011 'Body Area Networks: A Survey', *Mobile Netw Appl* vol.16, pp.171–193.

(Curtis et.al. 2008) Curtis, D., Pino, E., Bailey J., Shih, E., Waterman, J., Vinterbo S., Stair, T., Guttag, J., Greenes, R., & Ohno-Machado, L. 2008 'SMART – An Integrated Wireless System for Monitoring Unattended Patients', *J. of the American Medical Informatics Association*, vol. 15, no 1, pp. 44–53.

(De Rossi et.al. 2003) De Rossi, D., Carpi, F., Lorussi, F., Mazzoldi, A., Paradiso, R., Scilingo E.P., & Tognetti, A. 2003, 'Electroactive Fabrics And Wearable Biomonitoring Devices', *AUTEX Research Journal*, Vol. 3, No. 4, pp. 180–185.

(Gao et.al. 2007) Gao T., Massey T., Selavo L., Crawford D., Chen B., Lorincz, K., Shnayder V., Hauenstein L., Dabiri F., Jeng J., Chanmugam, A., White D., Sarrafzadeh M., & Welsh, M. 2007 'The advanced health and disaster aid network: a light-weight wireless medical system for triage', *IEEE Trans Biomed Circuits Syst*, vol.1, no 3, pp. 203–216.

(Huang et.al 2009) Huang, L., Ashouei, Yazicioglu, F., Penders, J., Vullers, R., Dolmans, G., Merken, P., Huisken, J., de Groot, H., Van Hoof, C., & Gyselinckx, B. 2009 'Ultra-Low Power Sensor Design for Wireless Body Area Networks: Challenges, Potential Solutions, and Applications', *International Journal of Digital Content Technology and its Applications*, vol. 3, no 3, pp. 136–148.

(IBBTIM3) IBBT-IM3 project, http://www.ibbt.be/en/projects/overview-projects/p/detail/im3

(IEEE802.15.6) IEEE 802.15 WPAN TG 6 Body Area Networks. http://www.ieee802.org/15/pub/SGmban.html.

(Johansson et.al. 2001) Johansson, P., Kazantzidis, M., Kapoor, R., & Gerla, M. 2001 'Bluetooth: an enabler for personal area networking', *IEEE Network*, vol. 15, no. 5, pp. 28–37.

(Kwak et.al, 2010) Kwak, K.S., Sana Ullah, S., & Ullah, N. 2010 'An Overview of IEEE 802.15.6 Standard', *ISABEL 2010* (*Invited*), Rome, Italy.

(Latre et.al. 2011) Latre, B., Braem, B., Moerman, B.C., & Demeester, P. 2011 'A Survey on Wireless Body Area Networks', *Wireless Networks*, vol.17, no 1, pp. 1–18.

(Li & Tan 2005). Li, H., & Tan, J. 2005 'An ultra-low-power medium access control protocol for body sensor network', *27th Annual International Conference of the Engineering in Medicine and Biology Society*, IEEE-EMBS, Shanghai, 2005, pp. 2451–2454.

(LifeShirt) LifeShirt from VivoMetrics, http://vivonoetics.com/products/sensors/lifeshirt/

(Mobiheatlh) Mobihealth project, http://www.mobihealth.org.

(Nemati et.al. 2012) Nemati, E., Deen, M.J. & Mondal, T. 2012 'A Wireless Wearable ECG Sensor for Long- Term Applications', *IEEE Communications Magazine*, pp. 36–43

(Neves et.al. 2008) Neves, P., Stachyra, M., & Rodrigues, J. 2008 'Application of Wireless Sensor Networks to Healthcare Promotion', *Journal of Communications Software and Systems,* Vol.4, No.3, pp. 1845–6421.

(Shnayder et.al. 2005) Shnayder, V., Chen B., Lorincz K., Fulford-Jones T.R.F., & Welsh M. 2005 'Sensor networks for medical care' *Harvard University Technical Report TR-08-05*.

(Soini et.al. 2008) Soini, M., Nummela, J., Oksa, P., Ukkonen, L., & Sydänheimo, L. 2008 'Wireless Body Area Network For Hip Rehabilitation System', *Ubiquitous Computing and Communication Journal*, vol. 3, no. 5, pp. 42–48.

(TI 2012) Texas Instruments, Online doc. http://www.ti.com/lsds/ti/microcontroller/16-bit_msp430/overview.page

(Timmons & Scanlon, 2004) Timmons, N.F., & Scanlon, W.G. 2004 'Analysis of the performance of IEEE 802.15.4 for medical sensor body area networking', *First Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks*, Oct. 2004, pp. 16–24.

(Tsoukalas et.al. 2006) Tsoukalas, D., Chatzandroulis, S., & Goustouridis, D. 2006 'Capacitive Microsensors for Biomedical Application', *Encyclopedia of Medical Devices and Instrumentation, 2nd Edition*, John Wiley & Sons, vol. 2, 2006 pp. 1–12.

(Ullah et. Al. 2009) Ullah S., Khan, P., Ullah, N., Saleem, S., Higgins, H. & Kwak, K.S. 2009 'A Review of Wireless Body Area Networks for Medical Applications', *International J. of Communications, Network and System Sciences (IJCNS)*, vol. 2, no. 8, pp. 797–803.

(Wood et.al, 2006) Wood A., Virone G., Doan T., Cao Q., Selavo L., Wu Y., Fang, L., He Z., Lin S., & Stankovic, J. 2006 'ALARM-NET: wireless sensor networks for assisted-living and residential monitoring', *Technical Report CS-2006-11*, Department of Computer Science, University of Virginia.

(Yang, 2006) Yang, GZ 2006, *Body Sensor Networks,* Springer-Verlag, London.

(Zigbee) ZigBee Alliance, Offcial webpage, http://www.zigbee.org.