Chapter 1
Wireless Body Area Network and Ultra-Wideband Communication

Abstract Current healthcare systems face new challenges due to the ageing population in the world. Aged population (over 65 years) has become a significant proportion of the total population in most of the countries. According to the World Health Organization (WHO), one in every four people will be over 65 years by 2056 [1]. With increasing demand for healthcare facilities, researchers have paid their attention towards improving existing healthcare infrastructure. Mobile healthcare has become a lucrative area in the eyes of researchers as well as entrepreneurs. Non-invasive and ambulatory health monitoring has become increasingly popular in modern healthcare as a solution for the increasing demand for hospital facilities. It has gained popularity not only for patient monitoring, but also in the field of sports where vital signs of sportsmen are monitored while they are on the field [2]. Ability to remotely monitor patients has many benefits. It is a solution for the increasing demand for physical infrastructure at hospitals. With the use of mobile health facilities, the requirement of patients being physically present in a hospital is eliminated. Vital body information can be transferred to a remote database via internet. Since the patients are monitored in real time while they are involved in their day to day activities, obtained parameters give more realistic overview of patient's health status. Consider a patient with high blood pressure; if it is possible to remotely monitor his/her blood pressure throughout the day, physicians can get a more realistic idea how the blood pressure builds up prior to reaching a certain threshold. Also it can eliminate inaccurate results caused by changed physical conditions that occur due to travelling to a hospital. It also makes it easy to keep track of the patient's or sportsman's health history. An early health warning system can also be implemented using this technology. An efficient Wireless Body Area Network (WBAN) is able to provide all the aforementioned benefits to both patients and physicians.

Keywords IR-UWB · WBAN · Transceivers · Patient monitoring · WPAN · WLAN · Zigbee · Bluetooth · UWB advantages

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1.1 Overview of Wireless Body Area Networks

With the recent advancement in wireless sensor networks and miniaturized hardware technologies, it has been possible to implement wireless networks that operate in and around human body. A WBAN is a networking concept that has evolved with the idea of monitoring vital physiological signals from low power and miniaturized in-body or on-body sensors. Data collected from these sensors are transferred to a remote node via a wireless medium, where the data is forwarded to a higher layer application to be interpreted.

WBAN communication can be divided into three major categories; communication between a node on body surface to an outside base station, communication between two nodes that are placed on body surface, and communication from a node that is implanted in the body to an outside node. These three communication scenarios are named off-body communication, on-body communication and in-body communication respectively [3]. The IEEE wireless body area network standard (IEEE 802.15.6 TG6) [4] had been formed in order to develop and standardize the Physical Layer (PHY) and Medium Access Control (MAC) protocols for short range, low power and highly reliable wireless communication schemes to operate in, on and around the human body. The recent activities of this standard can be found in [5]. The standard has identified eight operating scenarios for WBAN.

- Implant to Implant.
- Implant to Body Surface.
- Implant to External.
- Body Surface to Body Surface (Line-of-Sight (LOS)).
- Body Surface to Body Surface (Non Line-of-Sight (NLOS)).
- Body Surface to External (LOS).
- Body Surface to External (NLOS).

A WBAN can be used for many applications, such as physiological signal monitoring in health care environments, personnel entertainment applications and industrial communication applications for monitoring worker health conditions in safety critical environments. Hence a WBAN should be able to support a variety of data rates from a few bps to several Mbps. With recent advancements in data sensing technologies, the amount of data gathered by sensors has increased dramatically. This increases the demand for high data rate systems to transfer data. For example a 128-channel neural recording system requires a real-time wireless data transmission up to 10 Mbps [6]. Hence, a WBAN should be able to support high data rate communication. Sensor nodes used in either implantable or wearable WBAN applications are battery powered devices. Hence, power efficient operation is a critical aspect of the devices involved in WBAN communication. Furthermore, these implantable and wearable sensor nodes should have a small form factor. Since WBAN sensor nodes operate at a close proximity to the human body, it should operate within various regulations applied for Specific Absorption Rate

(SAR). Hence, transmit power control is important in wireless technologies used for WBAN applications. Basic requirements of a WBAN are listed below [7, 8];

- Support of scalable data rates
- Low power consumption.
- Small form factor.
- Controllable transmit power.
- Ability to prioritise data transmission of crucial signals.
- Secure data transmission.
- Coexistence with other wireless technologies.
- Ability to operate in multi user environments.

A typical WBAN uses a three- tier network structure as shown in Fig. 1.1. Sensor nodes and gateway nodes communicate using short range wireless communication mechanisms. Gateway nodes can choose to communicate with a coordinator node either via a short range wireless communication link or a long range wireless communication link. A Coordinator node forwards data to the internet where data can be transferred to a remote data base. Sensor nodes are connected to a gateway node in a star topology, while several gateway nodes can be connected to a coordinator node using the same topology. Sensor nodes are always attached to the body as either implant devices or wearable devices. Gateway nodes may not be attached to the body; hence, they are not power restricted like sensor nodes. Gateway nodes can communicate with coordinator nodes either using short range Wireless Personnel Area Networks (WPAN) or long range Wireless Local Area Networks (WLAN). WPAN has a range of 10 m while WLAN expands for more than 100 m.

WBANs are used in both medical and non-medical applications. Wireless Electrocardiogram (ECG) monitoring systems and wireless neural recording systems are examples of medical applications that can be implemented using WBAN techniques. WBANs can also be used for non-medical applications such as gaming and smart home control [9]. Several key components can be identified in a WBAN system for healthcare monitoring applications. *Sensor nodes* are either implantable or on-body devices that transmit vital physiological information, such as ECG, Electroencephalogram (EEG) and body temperature to an outside node. A *coordinator node* or a *router node* is used to collect and route the information sent by a sensor node and forward this information to a computer based application for interpretation. Figure 1.2 illustrates the key components of a WBAN.

A WBAN used for healthcare monitoring inherits several key requirements. An implanted or on-body sensor node is battery powered. Especially in the implantable case, human intervention in replacing the batteries should be kept at a minimum level, since it might involve surgical procedures. Hence a WBAN sensor node should consume low power. Low power transmission of signals limits the communication range (usually 0.1–2 m). As a result, an optimized low complexity MAC protocol should be used in WBANs so that it would enhance the low power operation of the sensor node.

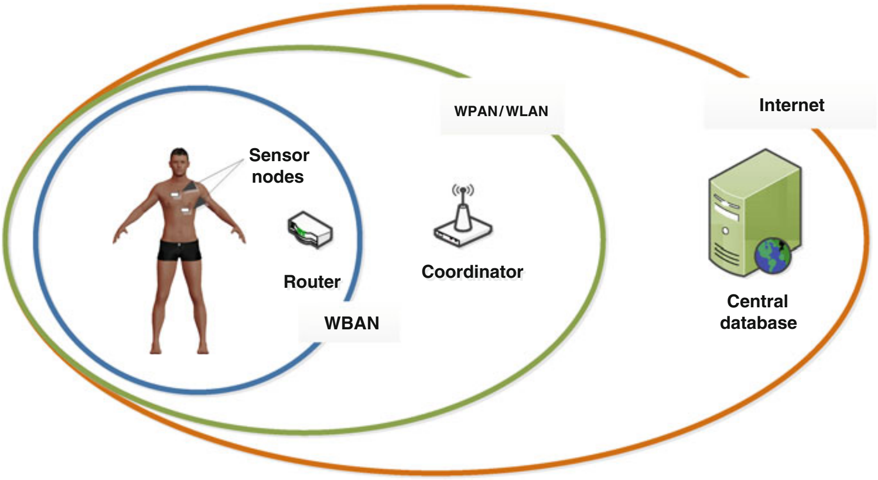

Fig. 1.1 Three-tier communication topology of a WBAN

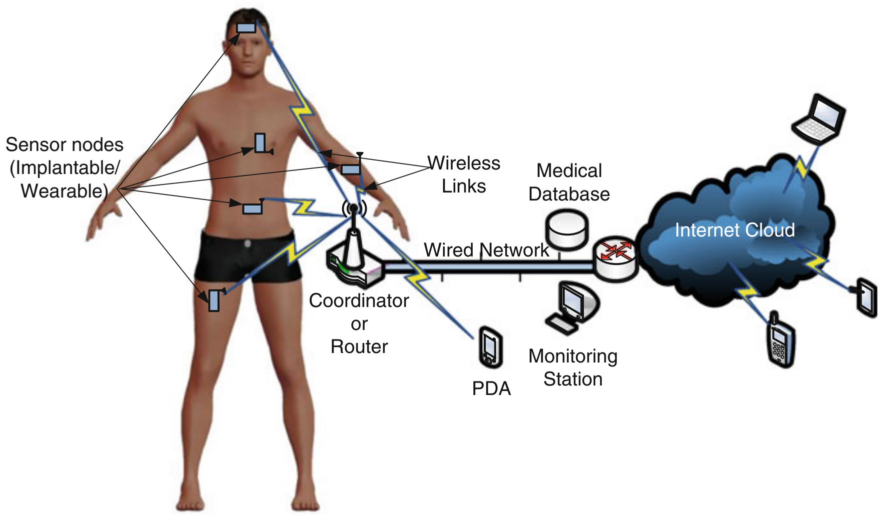

Fig. 1.2 Key components of a WBAN

A WBAN network structure consists of several tiers of interconnecting networks. The work presented in this book pays attention to the communication between sensor nodes and an immediate parent node of the sensor nodes, which can either be a central coordinator or a gateway router. This communication is named as sensor tier communication hereafter. Typically, short-range wireless communication of less than 2 m is employed in the sensor tier. Sensor tier communication is characterized by following features:

- Sensor nodes are connected to the gateway in a star topology.
- Sensor nodes have limited processing capabilities and very stringent requirements on power consumption.
- Unlike sensor nodes, gateway nodes are allowed to have higher processing power and higher battery power.
- Communication is mostly one directional from sensor nodes to a gateway node.
- Communication from the gateway node to sensor nodes consists mainly of network information and feedback.

A WBAN differs from a general Wireless Sensor Network (WSN) application because of its specific requirements. Differences between a WBAN and a more generic WSN are listed in Table 1.1. WBAN applications, such as microelectronic arrays and neural recording systems, use multi-channel monitoring, which drastically increases the amount of data that needs to be transmitted simultaneously. Wireless Capsule Endoscopy (WCE) is another type of WBAN devices that requires high data rates for high resolution video transmission. Thus, there is a demand for high data rate transmission of medical data. For example, a 128-channel neural recording system with eight bit sampling requires a data rate in excess of 10 Mbps [6]. Use of wired connections for data transmission is not feasible at all times. It restricts the movement of the patient and involves painful surgical procedures (for example in WCE). Basic requirements of a WBAN are listed below.

1. Limited transmission range (<0.01–2 m).
2. Extremely low power consumption in sleep mode (0.1–0.5 mW) for each device for longer battery life.
3. Support of scalable data rate ranging from 1 kbps to several Mbps.
4. Quality of Service (QoS) support for better handling of critical physiological signals.
5. Low latency over a multi-hop network.
6. Small form factor and light weight devices.

1.2 Physical Layer Wireless Technologies Used in WBAN Applications

There are several wireless technologies currently considered for data communication in WBAN applications. This section gives a brief introduction to some of these important wireless technologies.

Table 1.1 Differences between a WBAN and a WSN

Property	WBAN	WSN
Sensor position	Located in or on a human body or at a close proximity to a human body	Deployed over a large area
Topology	Typically comprises of multiple sensor nodes and one central receiving node (gateway node). All the sensor nodes will communicate directly with the gateway node forming a star topology	Sensors are connected based on mesh-topology, where multiple hops are supported. Each sensor in a WSN can act as a router node
Nature of data	Data from physiological signals is periodic and signals are transmitted at a fixed interval. For example, the transmission frequency of a temperature sensor can be once every minute [10]	The nature of data depends on the application. The transmission interval for WSN is irregular
Redundancy	Because of the limited space and limited sensor locations for measuring the physiological signals on the human body, only one sensor exists for measuring each physiological signal. There is no redundancy that allows for node failure in WBAN	More than one sensor can be deployed in WSN to allow for redundancy, Especially in areas where data is critical or where sensors are inaccessible
Mobility	Human body movement is unpredictable. Body movements such as bending down or swinging arms will affect the channel condition of the nodes. The interference level for WBAN systems is also unpredictable due to mobility. The level of interference will increase, when two or more users move towards each other	Nodes for WSN are typically stationary, making channel conditions more predictable
Data collection	Multiple receivers (e.g. PDAs carried by doctors and nurses) are used in WBAN systems to collect data from sensor nodes	Focuses on best-effort data collection at the central database

1.2.1 Zigbee

The Zigbee standard defines the network, security and application layer on top of the IEEE 802.15.4 standard [11], which incorporates the physical and MAC layers [12]. The physical layer of the IEEE 802.15.4 standard supports several frequency bands for data communication. It supports one channel of 20 kbps in 868 MHz band, 10 channels of 40 kbps each in 915 MHz and 16 channels of 250 kbps each in 2.4 GHz band. The MAC layer of the IEEE 802.15.4 standard is based on

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) for media access.

Zigbee network topology defines three types of nodes: end-devices, router nodes and coordinator nodes. A Zigbee coordinator node initiates the network and manages network resources. Zigbee router nodes enable multi-hop communication between the devices in a network. Zigbee's end-devices communicate with parent nodes (router nodes or coordinator nodes) and operate with minimal functionality in order to reduce the power consumption.

The Zigbee Alliance acts as the main body that provides application profiles for Zigbee based applications. Zigbee based healthcare applications are intended to be used in non-invasive healthcare platforms. MICAZ by Crossbow [13] is an example of a commercial hardware platform that supports Zigbee communication.

Zigbee technology has several drawbacks for healthcare applications. It operates in the 2.4 GHz unlicensed industrial, scientific and medical (ISM) band alongside with WLANs and Bluetooth making the 2.4 GHz band more crowded. The power consumption of a Zigbee based sensor node is considerably high. For example, the Chipcon IC (CC2420), which is a commercially available transceiver has a current consumption of 17.4 mA in transmit mode and 19.7 mA in receive mode [14].

1.2.2 Wireless Local Area Networks

Wireless Local Area Networks (WLAN) operate based on the physical and MAC layer protocols developed in the IEEE 802.11 standard. Different versions of the IEEE 802.11 standards use different physical layer communication mechanisms. For example, the IEEE 802.11 g standard uses Orthogonal Frequency Division Multiplexing (OFDM) while the IEEE 802.11b standard uses Direct Sequence Spread Spectrum (DSSS) for physical layer communication. Even though WLAN standards are able to cater for the high data rate requirement of WBAN applications, it is rarely used in WBAN applications because of its large power consumption. For example, the most recent implementations of WLAN transmitters consume around 82 mW of power [15].

1.2.3 Medical Implant Communication Services

Medical Implant Communication Services (MICS) band uses the 401–406 MHz frequency band allocated by the Federal Communications Commission (FCC) in order to transmit data from an implanted device to an outside controller [16]. Ten channels with 300 kHz bandwidth are allocated for communication within this band. The transmit power of the communication devices that uses the MICS band is limited to −16 dBm by the FCC regulations. The use of low transmission frequency in MICS band results in low propagation loss within an implant communication environment. The regulations require MICS transceivers to use interference mitigation techniques in order to prevent interference with other radio services operating within the same frequency band. MICS devices use Listen-Before-Talk (LBT) technique in order to listen to the wireless channel before starting communication. If the channel is busy, an MICS transceiver uses Adaptive Frequency Agile (AFA) technique in order to switch into another channel. However, use of MICS band is limited to low data rate applications and it cannot be used for WBAN applications that require high data rates due to its bandwidth limitations.

1.2.4 Bluetooth

Bluetooth operates in the 2.4 GHz ISM band and uses Frequency Hopping Spread Spectrum (FHSS) in order to access the physical medium [17]. Bluetooth bandwidth spans from 2402 to 2480 MHz over 79 channels with 1 MHz channel bandwidth. It communicates based on piconet network topology, where each device in a piconet has the ability to communicate with seven other devices in the same piconet. Low energy Bluetooth technology [18] was introduced in 2009 with the intention of reducing the power consumption in Bluetooth devices. Like the Zigbee technology, Bluetooth also suffers from the interference in the 2.4 GHz band. It also lacks the scalability in terms of data rate and number of supported devices.

1.2.5 Ultra-Wideband

History of UWB communication goes back to the Hertizian spark gap experiments conducted in 1880. Shannon's experiments in 1948 highlighted the advantages of spread spectrum communication systems. In 1960s UWB attracted attention within the scientific community for radar applications. Early UWB devices consumed large amount of power; hence UWB technology was not considered for data communication applications. Emergence of semiconductor devices in the latter half of the twentieth century created the possibility of low power UWB signal generation techniques. In 2002, Federal Communications Commission (FCC) created the first report that approved UWB communication for commercial use [19]. Under this report UWB is defined as signals having a fractional bandwidth (−10 dB bandwidth) of more than 20 %, or a bandwidth of at least 500 MHz. FCC has applied stringent power requirements on UWB transmission. It allows peak power limit of 0 dBm and average power limit of −41.3 dBm/MHz. UWB is allowed to operate in both 0–960 MHz and 3.1–10.6 GHz bands. In 2005 FCC updated its

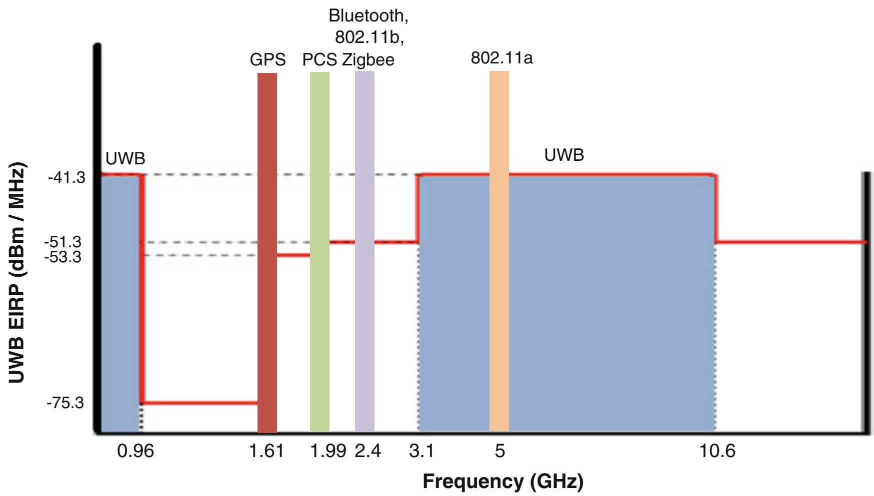

Fig. 1.3 Transmit spectrums for UWB and other wireless technologies

regulations on UWB transmit power allowing gated UWB transmission systems to transmit at higher peak powers [20]. In March 2007, an international standard for UWB communication was approved by the International Organization for Standardization (ISO) based on the Wi-Media UWB common radio platform [21, 22]. Figure 1.3 depicts the frequency spectrum of UWB transmission together with spectrums of other existing wireless technologies.

UWB communication systems can be divided into two major categories; Impulse Radio-Ultra-Wideband (IR-UWB) and Multi Carrier-Ultra-Wideband (MC-UWB). MC-UWB uses multiple sub carriers to transmit data using Orthogonal Frequency Division Multiplexing (OFDM). This technique is used by the Wi-Media alliance for wireless multimedia transmission. MC-UWB technique consumes large amount of power due to complex signal processing involved in OFDM based transceivers. For example, the Wi-Media chipset by Aleron consumes around 300 mW of power [23]; hence, it is not suitable for power stringent WBAN applications.

IR-UWB systems transmit short pulses to transmit data. Pulsed nature of UWB transmitters enables the use of simpler modulation schemes such as Pulse Position Modulation (PPM) and On-Off-Keying (OOK). Simpler modulation schemes enable less complex hardware systems implementing IR-UWB communication systems and reduce the power consumption significantly. These are among many advantages provided by the IR-UWB communication systems, making it a suitable candidate for battery powered WBAN applications. Some of the major advantages provided by the IR-UWB communication for WBAN applications are discussed in the following section.

1.3 IR-UWB WBAN System and Advantages

(1) Low power consumption of IR-UWB transmitters

WBAN devices are considered as battery powered devices. Hence, the power consumption of data transmission devices involved in a WBAN should be kept at a minimum in order to extend the battery life. This is especially very critical for implantable applications of WBAN, since replacing a device or a battery will involve an invasive surgery.

IR-UWB transmitters use discrete pulses in order to transmit data [24], whereas traditional narrow band transmitters use data modulated continuous wave signals for wireless transmission. Because of the discrete pulse transmission, a significant portion of the data transmission time in IR-UWB transmitters consists of a silent period. As a result, the electronic components involved in pulse generation can be operated at a low power mode. In contrast, traditional narrow band transmitters operate continuously throughout the data transmission period for most of modulation schemes. This difference of data mapping principal results in a significant reduction in the power consumption UWB based wireless technologies for long operation periods.

Implementation of an IR-UWB transmitter involves very few Radio Frequency (RF) components compared to continuous wave transmitters. In fact, all digital realizations of IR-UWB transmitters are achievable with the aid of state-of-the-art Complementary Metal Oxide Semiconductor (CMOS) technology [25]. In contrast, traditional narrow band transmitters utilize high power consuming RF and analog components, such as RF Power Amplifiers (PA) and analog Phase Locked Loops (PLL), extensively due to the nature of the signal generation [26].

Furthermore, because of the easier data mapping in IR-UWB transmitter, complex modulation schemes are not required for IR-UWB communication systems. This feature enhances the power savings significantly. Hence, IR-UWB communication may provide a significant advantage over traditional narrow band transmitters for power intensive WBAN applications.

(2) High data rate capability

IR-UWB radios map the data bits into very short (nano second duration) pulses. This method implies a carrier-less data transmission scheme, where short pulses represent a signal with a signal power that is spread in a large bandwidth in the frequency domain. According to Shannon's capacity theorem, the data rate capacity of a channel is linearly proportional to its channel bandwidth and logarithmically proportional to increase in the Signal to Noise Ratio (SNR) of the channel. This means that the IR-UWB signals are capable of delivering higher data rates, using the high bandwidth property. A continuous wave based narrow band signal has to operate at much higher frequencies in order to transmit at the same data rates [27]. The use of higher frequencies in narrow band signals leads to higher attenuation, which has to be compensated by increasing the transmit power.

Hence, an IR-UWB transmission system is capable of achieving higher data rates while operating at low power, which makes it an ideal candidate for power intensive WBAN applications that demand high data rates, such as wireless capsule endoscopy systems [28, 29] and neural recording systems [6].

(3) Small form factor

Small size is an essential property for implantable and wearable WBAN sensor nodes. IR-UWB transmitters can be manufactured with only a few electronic components: hence the design space required is minimal. This is an advantageous property that makes IR-UWB a suitable candidate for WBAN sensor nodes.

(4) Susceptibility to multipath interference

IR-UWB uses finite resolution pulses in order to represent data bits. Unlike in the case of continuous wave signals where multipath components always overlap with time domain signals at the receiver end, the multipath arrivals of the IR-UWB signals can be easily resolved and avoided at the receiver end because of the low probability of a multipath component overlapping with the received narrow pulse in the time domain [30, 31]. This is a very useful feature in IR-UWB when it is operating around the body where the presence of multipath components can be high.

In spite of these advantages, there are some drawbacks in IR-UWB technology that should be overcome for WBAN applications. These disadvantages are listed below:

(1) Complexity of the IR-UWB receiver architecture

IR-UWB signals use narrow pulses to transmit data and the transmitted signal power is regulated to be very low in order to prevent interference to other systems. An IR-UWB receiver has to be capable of detecting these low power narrow pulses. This requires the use of high speed Analog to Digital Converters (ADC) and extensive amplification of the received signals at IR-UWB receiver front-end. This makes the IR-UWB receiver to be complex in design and results in increased power consumption. This is a major drawback in IR-UWB systems that should be overcome in order to use IR-UWB for power intensive WBAN applications.

(2) Susceptibility to interference from other wireless transmission systems

Unlike in the case of carrier based systems, IR-UWB signal power is spread across a wide bandwidth. Hence it is susceptible to interference from all the systems operating within the IR-UWB signal bandwidth. The signal processing involved in the reception of carrier based signals has to consider only the interference rejection in that particular carrier frequency, whereas for IR-UWB systems, the signal processing at the receiver end should consider interference mitigation for the whole signal bandwidth. This problem can be overcome by choosing a suitable operational bandwidth with minimum interference for IR-UWB communication. Figure 1.4

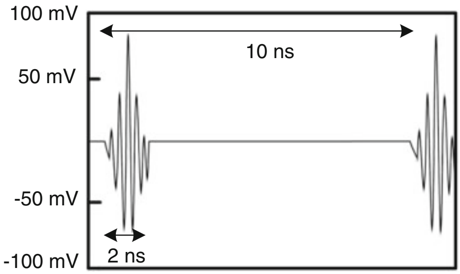

Fig. 1.4 An IR-UWB pulse stream

depicts an IR-UWB pulse stream generated by an IR-UWB transmitter. This pulse stream consists of IR-UWB pulses with a pulse width of 2 ns and a Pulse Repetitive Frequency (PRF) of 100 MHz.

1.4 Comparison of Wireless Technologies Used for WBAN

This section compares the candidate wireless technologies that can be used in WBAN applications in terms of data rate capability, susceptibility to interference, power consumption and form factor. Table 1.2 depicts some of the wireless technologies used in WBAN applications. Out of the existing wireless physical layer technologies, UWB and WLAN standards are able to cater for the high data rate requirement of WBAN applications such as neural recording and WCE. However, WLAN is rarely used in WBAN applications because of its large power consumption. MICS band can only be used for low data rate WBAN applications due to its limited bandwidth capabilities.

Zigbee, Bluetooth and WLAN operate in the 2.4 GHz unlicensed ISM band; hence create interference issues to each other [32, 33]. UWB frequency spectrum is affected by the interference due to the operation of WLAN devices in the 5 GHz band. However, it is possible to choose the operational bandwidth of UWB from a wide spectrum that ranges from 3.1–10 GHz. Hence, the GHz interference can be avoided if a sub-band of UWB spectrum is used for UWB communication. The MICS band has a dedicated spectrumfor data communication; hence, it is subjected to minimum interference from other wireless technologies.

Low power consumption and small form factor are important aspects of a wireless technology that can be used in WBAN applications. In order to assess these capabilities of a particular wireless technology, it is important to analyze some of the wireless sensor platforms that have been developed based on different wireless technologies. Table 1.3 depicts some of the available WBAN platforms that are commonly considered for WBAN applications. These devices operate using a low supply voltage ranging from 2–3 V. From the available narrowband sensor platforms, Microsemi (formerly Zarlink) platform provides a Complementary Metal

Table 1.2 Candidate wireless technologies for WBAN communication

Properties	Wireless technology					
	Zigbee	WLAN		MICS	Bluetooth	UWB
Frequency	2.4 GHz	2.4 GHz	5 GHz	401–406 MHz	2.4 GHz	3.1–10.6 GHz
Transmit power	0 dBm	10–30 dBm	10–30 dBm	−16 dBm	0 dBm	−41.3 dBm/MHz
Number of channels	16	13	23	10	10	_
Channel bandwidth	2 MHz	22 MHz	20 or 40 MHz	300 kHz	1 MHz	≥500 MHz
Data rate	250 kbps	11 Mbps	54 Mbps	200–800 kbps	1 Mbps	850 kbps up to 20 Mbps
Range	0–10 m	0–100 m	0–100 m	0–10 m	0–10 m	2 m

Oxide Semiconductor (CMOS) based Integrated Circuit (IC) transceiver with the lowest power consumption based on the MICS and 433 MHz ISM bands for WBAN applications. This IC is used in the Given Imaging's PillCam WCE devices for low power narrow band based implant communication [34]. The MICA2DOT sensor platform provides a full hardware implementation on a small sensor platform. However, the power consumption of the transmitter is considerably high compared to that of the Microsemi's narrow band system. An implementation of a small wearable pulse wave monitoring system that uses a Bluetooth based transceiver is presented in [35]. The total current consumption of the systems is estimated to be 51 mA, inclusive of the current consumption of the Bluetooth transceiver, which is estimated to be 21 mA with an operating voltage of 3.3 V. The power consumption in a Zigbee and 2.4 GHz ISM band based sensor nodes are considerably high compared to other sensor node designs. The comparison in Table 1.3 shows that the if a sensor node is designed based on UWB utilizing mainly a transmitter and minimizing/eliminating the use of a receiver, it will perform better than the narrowband based systems in terms of power consumption, form factor and data rate.

It can be concluded that the UWB presents some unique benefits over other wireless technologies in the design of WBAN sensor nodes including the low power requirements of UWB transmitter, high data rate capability, low form factor and reasonably uncomplicated circuit design. In terms of interference rejection, UWB spectrum provides a large bandwidth; hence, a sub-band of UWB can be selected for a particular application such that the interference from other bands is minimized. Furthermore, IR-UWB is preferred over MC-UWB because of the possibility of low complexity and low power consuming hardware implementation. IR-UWB is referred to as UWB in the remainder of this book unless mentioned otherwise.

Table 1.3 Sensor platforms for WBAN applications

Sensor	Company	Wireless technology	Frequency	Data rate	Physical dimension	Power/Current	
						Tx.	Rx.
UWB based	Ref. [36]	UWB	3.5–4.5 GHz	10 Mbps	27 × 25 × 1.5 mm (board)	8 mW	–
	Ref. [37]	UWB – Tx., ISM- Rx.	Tx.- 3.5–4.5 GHz, Rx.- 433 MHz	Tx. -5 Mbps Rx.- 19.2 kbps	30 × 25 × 0.5 mm (board)	3 mW	10 mW
	Ref. [28]	UWB	3.1–10.6 GHz	10Mbps	3 × 4 mm^2 (IC) 5 cm (board length)	0.35 mW	62 mW at 10 Mbps
Mica2 (MPR400)	Crossbow [13]	ISM (Proprietary)	868/916 MHz	38.4 kbps	58 × 32 × .7 mm (board)	27 mA	10 mA
MicAz	Crossbow [13]	Zigbee	2.4 GHz	250 kbps	58 × 32 × .7 mm (board)	17.4 mA	19.7 mA
Mica2DOT	Crossbow [13]	ISM (Proprietary)	433 MHz	38.4 kbps	25 × 6 mm^2 (board)	25 mA	8 mA
CC1010	TI [38]	Narrow band (Proprietary)	300–1000 MHz	76.8 kbps	12 × 12 mm^2 (IC)	26.6 mA	11.9 mA
CC2400	TI [38]	ISM (Proprietary)	2.4 GHz	1 Mbps	7.1 × 7.1 mm2 (IC)	19 mA	23 mA
MICS based	Microsemi—ZL70250 (Formerly Zarlink) [39]	MICS	402–405 MHz, 433 MHz ISM	800 kbps	7 × 7 mm^2 (IC)	5 mA under continuous TX/RX operation	
	Ref. [40]	MICS	402–405 MHz	8 kbps	–	25 mA	7.5 mA
Bluetooth based	KK-22 [35]	Bluetooth	2.4 GHz	115 kbps	18 mm^2 (board)	21 mA under continuous TX/RX operation	

1.5 Scope of the Book

This book focuses on several important areas regarding WBAN and IR-UWB communication that are described below;

(1) Hardware platform development for IR-UWB based WBAN communication

This book thoroughly discusses several hardware design techniques that can be used in the development of IR-UWB based hardware platforms that include IR-UWB transceiver design techniques and full sensor node implementations. This book also presents the development of a unique sensor node design that uses an IR-UWB transmitter for data transmission and a 433 MHz ISM band receiver for data reception. Furthermore, development of a dual band coordinator node that facilitates the data communication of multiple sensor nodes is presented. Various properties of IR-UWB pulses such as rise time, pulse width and PRF, are analyzed in detail in order to develop an IR-UWB transmitter with optimum performance.

(2) MAC protocols for IR-UWB based WBANs

MAC protocol plays a key role in facilitating reliable and power efficient communication between multiple sensor nodes. This book discusses various MAC protocols that are available in the literature paying attention to their critical aspects, such as power efficiency, throughput capability and data transmission delay. This book also presents a UWB MAC protocol that provides efficient data transmission in WBANs applications. This MAC protocol uses a beacon enabled super frame structure in order to schedule the data transmissions of sensor nodes; hence reduces the multiple access interference in the network. Furthermore, it is designed to dynamically control the Pulses Per Bit (PPB) value used for UWB data communication using control messages sent via the narrow band feedback path. This leads to dynamic BER and power control at the sensor nodes, which helps to improve the reliability of communication and power efficiency of sensor nodes under dynamic channel conditions. A simulation platform developed using the Opnet modeler [41], which is a commercially available network simulation software, is presented. Important properties of the UWB communication system, such as physical layer pulse based UWB transmission, multipath and fading properties of IR-UWB and WBAN channel models, and multiple user interference, are incorporated into this simulation platform. Main intention of these simulation-based studies is to investigate the feasibility of the UWB communication method before going into hardware implementation. It also provides a mean of analyzing the performance of the UWB MAC protocol in an environment where a large number of sensor nodes are involved in communication.

(3) Implementation and experimental evaluation of a UWB MAC protocol in hardware platforms

This book discusses the implementation considerations of UWB MAC protocol spaying attentions to features, such as synchronization of IR-UWB signals, data packet structures and dynamic configuration of sensor nodes according to the change in propagation channel conditions. Performance of the MAC protocol isalso analyzed in terms of important performance indicators, such as Bit Error Rate (BER) delay and power consumption of the sensor nodes.

(4) Analysis of the electromagnetic effects of UWB communication for implant applications

High data rate implant communication is one of the lucrative future directions for IR-UWB communication. This book presents studiesof the electromagnetic effects of IR-UWB based implant communication systems, such as the variation of Specific Absorption Rate (SAR) and tissue temperature increase, through finite element based simulations, which successfully show the feasibility of IR-UWB communication for implant devices.

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