ENHANCING COMMUNICATION CHANNEL MODEL
FOR
WIRELESS BODY AREA NETWORKs

Dissertation submitted to Jawaharlal Nehru University
in partial fulfillment of the requirements
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MASTER OF TECHNOLOGY
In
COMPUTER SCIENCE AND TECHNOLOGY
By

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CERTIFICATE

This is to certify that the dissertation entitled **"ENHANCING COMMUNICATION CHANNEL MODEL FOR WIRELESS BODY AREA NETWORKs"** being submitted by **Mr. Vijay Prakash Bijlwan** to the **School of Computer & Systems Sciences, Jawaharlal Nehru University, New Delhi,** in partial fulfillment of the requirements for the award of the degree of **Master of Technology in Computer Science and Technology,** is a record of bonafide work carried out by him under the supervision of **Dr. Sushil Kumar, Assistant Professor**.

This work has not been submitted in part or full to any university or institution for the award of any degree or diploma.

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This is to certify that the dissertation entitled **"ENHANCING COMMUNICATION CHANNEL FOR WIRELESS BODY AREA NETWORKs"** is being submitted to the **School of Computer & Systems Sciences, Jawaharlal Nehru University, New Delhi,** in partial fulfillment of the requirements for the award of degree of **Master of Technology** in **Computer Science and Technology,** is a record of bonafide work carried out by me.

The matter embodied in the dissertation has not been submitted in part or full to any university or institution for the award of any degree or diploma.

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Dedicated to

My Family and Friends

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ABSTRACT

Wireless Body Area Networks (WBANs) is an eminent radio technology. It consists of wireless network having miniature, ultra-low-powered intelligent sensors that can be placed in, on and around the human body to measure human's physiological activities. These intelligent sensors measure, process and transmit human's physiological data to a control unit without wearer's activities constraints. Doctors access patient related data for real-time diagnosis and initiate patient's treatment procedures. Thus providing a greater mobility and comfort to patient by allowing them freedom from hospital equipment's that are used to monitor their conditions. WBANs promise economical, modest and autonomous ambulatory monitoring for a long time period. UWB is considered as a promising candidate for WBANs because of its low power consumptions, low duty cycle, high data rate and low system implementation cost.

In this dissertation, UWB based channel access model for WBANs is enhanced using Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) system. In particular, a channel access model is derived considering the parameters for path-loss and bit error ratio (BER) performance of modulation schemes, e.g. Binary phase shift keying (BPSK), Differential phase shift keying (DPSK), Binary pulse position modulation (BPPM), On-off keying (OOK) and Quadrature phase shift keying (QPSK) is evaluated. MB-OFDM is a form of UWB in which data is transmitted over multiple carriers that are separated at specific frequencies. It uses Fast Forward Transform (FFT) algorithm that captures energies in a multipath environment with 100 percent efficiency, thus providing high spectral flexibility and resiliency to the radio frequency (RF) interference and multi-path effects. Simulations of the proposed model are carried out in MATLAB R2009a. Analysis of the simulation results shows that the performance of MB-OFDM which uses QPSK modulation technique is better as compared to the other considered modulation techniques. MB-OFDM also provides maximum transmission distance for RF communication.

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CHAPTER 1

WIRELESS BODY AREA NETWORK

1.1 Introduction

A swift advancement in physiological sensors, integrated circuits having low power capability and wireless communication has set up a new genesis of wireless sensor networks for proper monitoring of health, traffic, crops and infrastructure [1]. WBAN is a RF based wireless networking technology that interconnects miniature nodes having sensor like capabilities. These nodes having small transmission range of 1∼5m, can be placed in, on, or around a human body to monitor human's physiological activities [2]. In wearable WBANs a number of intelligent sensors can be integrated for computer based rehabilitation or detection of medical conditions as earlier as possible. Thus WBANs reduces the healthcare cost and medical professions workload, resulting in higher efficiency.

The WBANs is a subset of Wireless Sensor Networks (WSNs), which represent real-time systems that sense and process parameters i.e. location, temperature, humidity and noise. A sensor node consists of four basic components

- Power unit
- Sensing unit
- Processing unit
- Transceiver unit

WSNs help realize several applications related to health, environment, traffic control, industrial and security monitoring.

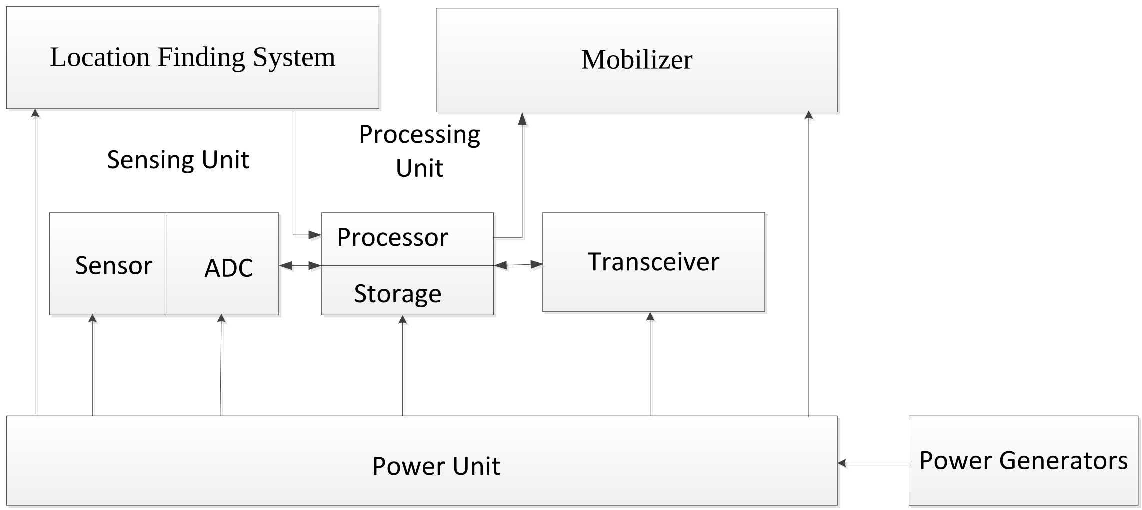

Figure 1.1 Components of a sensor node

A WSN node consists of a power generator, a mobilizer and a location finding system. Sensing units are divided into sensors and analog to digital converters (ADCs) units. Analog signals produced by the sensors are converted into a digital signal by ADC and then fed into the processing unit. The processing unit, associated with a small storage unit, manages the procedures and assists collaboration of sensor node with the other nodes to execute the assigned sensing tasks. The sensor node is connected to the network by a transceiver unit. The power unit is another most important component of a sensor node. A power unit is supported by a power scavenging unit .i.e. solar cells[3].

The coverage of WBAN is limited. The range of these nodes are about 1~5 m. So to extend its coverage area it interworks with other wireless networks, assisting connectivity of sensor devices to the outside world. IP is used for interconnection of data networks. When some abnormal conditions happen to a patient, data gathered by a sensor node is transmitted to a gateway in the form of packets. These packets are then translated into IP datagram at the edge of WBAN by the gateway.i.e. a smart phone having multiple network interfaces that enables interaction of WBANs with the owner. With the help of wired and wireless communication, data is transmitted to the physician, medical emergency team and medical information database and further actions will be initiated. For faster data transfer, communication technologies.i.e.short message services (SMS), general packet radio services (GPRS) and email services are used.

1.2 Network Architecture of WBAN

The Network architecture of a WBAN is classified into three classes:

- Class 1:-Intra-WBAN communication
- Class 2:-Inter-WBAN communication
- Class 3:-Beyond-WBAN communication

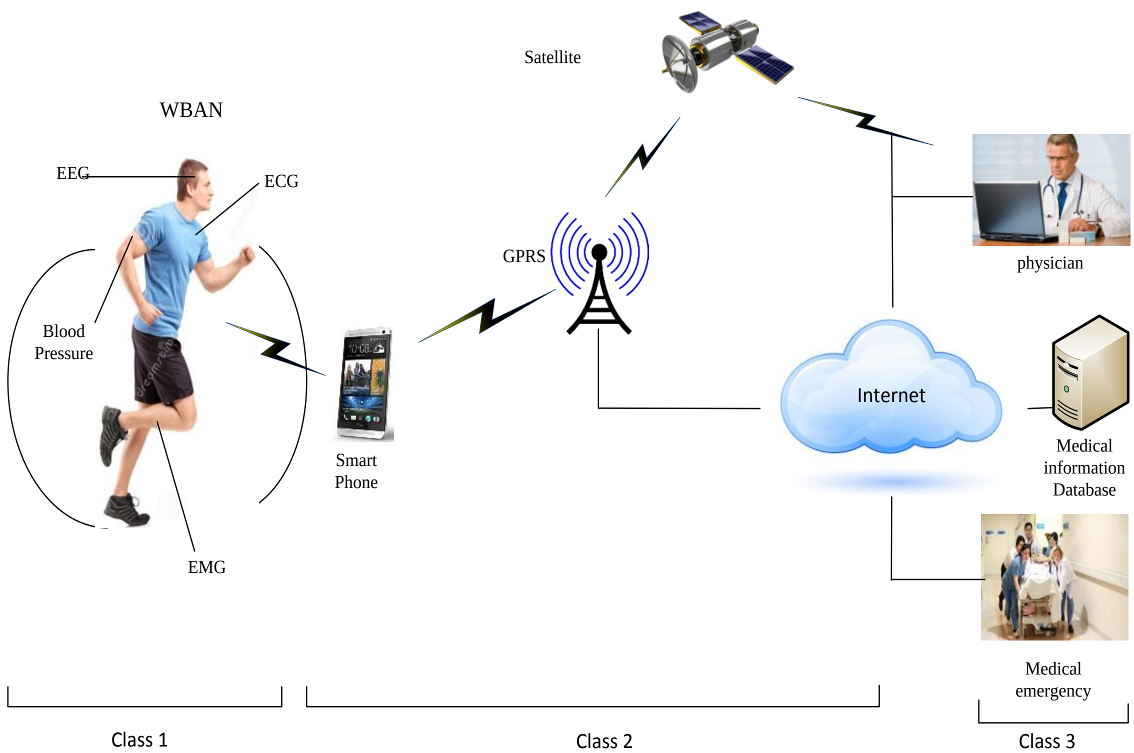

Figure 1.2 Architecture of WBAN

Figure 1.2 represents these communication classes of WBANs. In centralized network architecture of WBANs, the devices are placed at specific locations, covering whole body and the exact location of a device depends on applications. The ideal body location of sensor nodes changes due to mobility (.i.e. running, jumping); therefore, WBANs are dynamic in nature.

1.2.1 Intra-WBAN Communication

This class characterizes the communication of sensor nodes with their corresponding transmission ranges 1~5 m, in, on and around the human body. Figure 1.2 illustrates WBANs communication within a WBAN and between the WBAN and its classes. In Class-1, sensors forward physiological data to a Personal Server that is located in class-2. Then these processed physiological data is transmitted to an access point in Class-2.

1.2.2 Inter-WBAN Communication

In this class, communication takes place between the Personal Server and one or more access points. These access points can be recognized as a component of the infrastructure, or to handle emergency conditions, they can be strategically placed in a dynamic environment. Class 2 communication aims to interconnect WBANs with different types of networks that are easily accessed in our day to day life as well as Internet and the cellular networks. WBANs can be made easier to be integrated within applications, if it can support more technologies. Inter-WBAN communication can be classified into two types:

- **Infrastructure based architecture –**

  Infrastructure based architecture is used in the maximum WBAN applications as it facilitates dynamic deployment in a limited area .i.e. hospital.

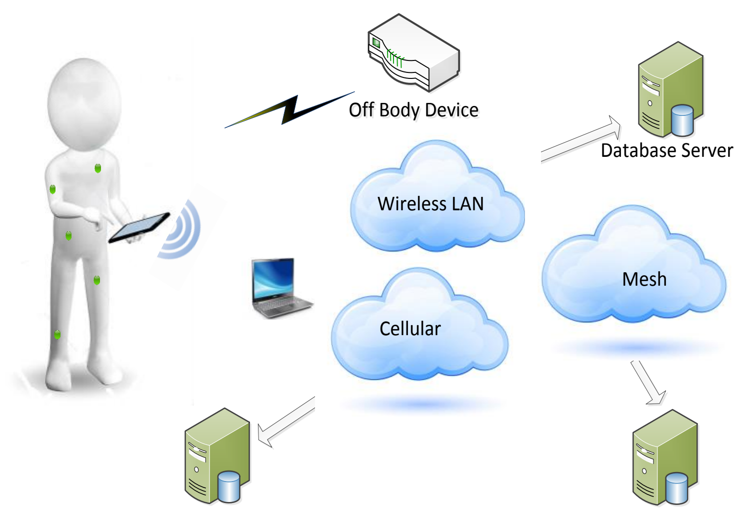

Figure 1.3 Inter-WBAN Communication: Infrastructure-based

This architecture provides centralized management and security control. The Access Points can play a database server role to its applications.

- **Ad-hoc based architecture –** In ad-hoc based architecture, multiple Access Points transmit data inside medical centers as illustrated in figure 1.4.

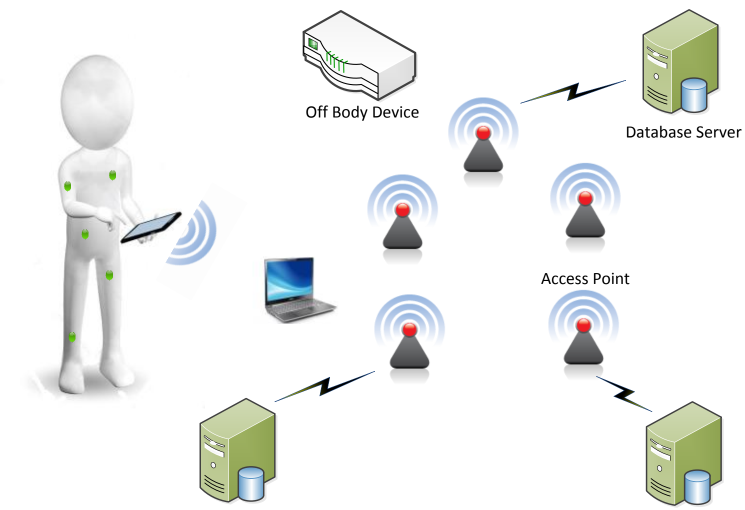

Figure 1.4 Inter-WBAN Communication: Ad-Hoc based

The Access Points form a mesh construction, enabling a resilient and swift deployment. This allows the network to be easily expanded, providing larger radio coverage because of multi-hop dissemination and supports mobility of patient. Compared to the infrastructure based architecture, the coverage range of this infrastructure is much larger and facilitates mobility in a large area. This interconnection extends the WBANs coverage area from $2 \sim 100$ m , that is convenient for short and long term setups.

1.2.3 Beyond-WBAN Communication

This communication class is designed for use in metropolitan areas. The Gateway node bridges the connection between these two classes (class 2 and class 3). The design of this class for communication is application-specific. Database is considered as one of the most important components of this communication class in medical environment that includes user profile and medical history. So whenever some abnormal conditions are detected, an emergency status is notified to the patient through Short Message Service

(SMS) or Internet. This class also facilitates the restoration of patient's information required for treatment. However the personal server in class 1 can use 3G or GPRS services instead of communicating to an access point[4].

1.3 Characteristics of WBAN

WBANs have the following characteristics:

- **Architecture**

  WBANs architecture contains two types of nodes:

  Sensor node*:* Sensor nodes are the nodes that can be placed in, on or around the human body

  Router nodes: Router nodes are the nodes around the WBAN wearer.

- **Density**

  In WBANs, the number of sensor nodes that are placed on the human body depends on application. The nodes are not placed with high redundancy to tolerate node failure as in wireless sensor networks.

- **Data rate**

  WBANs are used to monitor human's physiological activities that vary in more periodic manner. Thus application data rates exhibit at stable rate. For entertainment applications high data rate is required.

- **Latency**

  In medical environment, availability of information at right time is a key requirement. If an information is not available at right time due to latency, then this information is useless, thus for both consumer applications and healthcare, latency resulting from WBANs should be minimized. Latency occurs due to multipath components of a signal. These components are delayed replicas of the original transmitted signal that travels through a different path and each with a different magnitude and time-of-arrival at the receiver end [5].

- **Mobility**

  WBANs wearer may move anywhere. The nodes attached to a wearer move together and in the direction of the wearer. Thus, mobility imposes a lot of constraints in WBANs performance.

1.4 Applications of WBAN

The main functionality of WBANs is the transmission of audio, video and image data through communication channel. Applications of WBANs are classified into three categories as depicted in figure1.5.

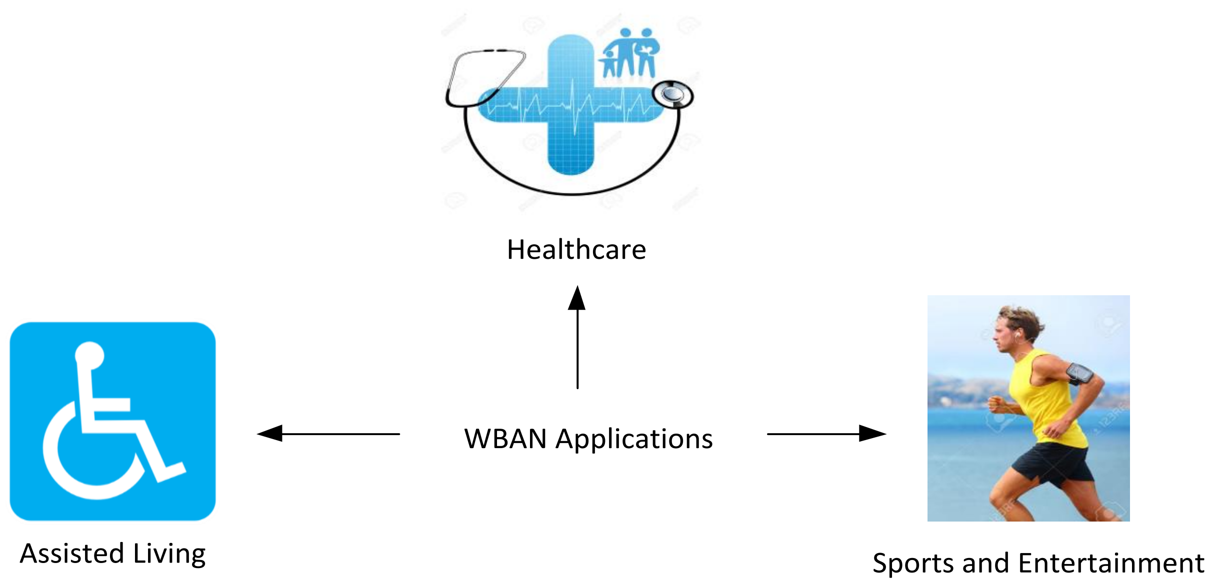

Figure 1.5 WBAN Applications

- **Health care**

  WBANs automatic provides medical services through monitoring of patient's physiological data. Physiological data received from the various sensors are transmitted to a command unit. The command unit sent this data to a doctor or a nurse. The doctor or a nurse analyze the patient data and make decision according to the patient's condition whether the patient need medicine or the prescription. This data is sent to Action unit that prescribes a medicine to the patient. After this the perception sensor that prescribes a medicine, real time monitor the patient condition as well as collect other physiological data. This process runs continuous to provide wide range of healthcare services[6].

Several WBAN research projects have been developed in various Universities. The ***codeblude*** project developed at Harvard University monitors hospital environments .In this project, many router nodes are placed on the wall. Zigbee radio technology is utilized by these nodes. Mesh network is subscribed by the patients using multicasting method .There is no centralized or distributed server and database for storage and control. Functionality of localization is provided by MoteTrack with 1 m accuracy .There is a packet loss due to mobility and multi hop transmissions and bandwidth is confined to 40 kbps per receiver[7].

Advanced Health and Disaster Aid Network project was developed at John Hopkins University to monitor mass causality incidents. In this project an electronic triage tag system can be deployed on victims .Wireless functionality is provided for communication between personal and central server .For different kinds of users a web portal is provided, e.g. emergency department personnel, incident commander and medical specialists. GPS is used to provide outdoor localization and MoteTrack is used for indoor environment. There is a mobility constraint for patients due to the less no. of nodes. Because of limited bandwidth, a few no. of nodes can be placed on patients[8].

Wearable Health Monitoring Systems developed at University of Alabama monitor ambulatory health status at large scale .In this project, each patient have a star topology network that is connected via cellular network or Wi-Fi to healthcare provider. Personal server is implemented on cell phone, which coordinate data collection using TDMA mechanism. Each user is provided an interface through which data can be transferred to a central server. Physicians can access information and alerts can be generated by agents running on server.

Drawback of this project is that it can hamper system performance by consuming a lot of power and cost associated with data uploading[9].

- **Assisted Living**

  Assisted living is a housing facility provided for disabled people who are dependent. WBAN applications can serve major role in assisting these people. Intra-body communication (IBC) applications help handicapped people in their daily activities.i.e. Information about doorway or crosswalk can be conveyed to a blind person by sending him/her voice messages; with the help of IBC enabled sensor embedded inside his/her shoes. IBC applications also help deaf people in comprehending of audio messages with the help of IBC enabled eyeglass that displays text and IBC enabled speakers.

- **Entertainment and Sports**

  WBANs have key role in entertainment and sports field. In sports, with the help of wearable WBAN devices, athlete can regularly check their body parameters .i.e. blood pressure, glucose level, ECG etc. to remain fit every day. WBANs have following applications in entertainment field:

  - Images stored in digital camera can be viewed on TV screen.
  - Music stored in MP3 player can be played in audio systems.
  - Video clips recorded by a video camera can be played on TV screen.

1.5 Wireless Body Area Network Sensors

Sensors are the main components of WBANs. They are the bridge between the physical world and electronics systems .According to previous studies; human physiological signals have low amplitude and frequency range. Therefore, a low data transmission rate and sampling frequency would be sufficient. But, how many no. of sensors and what kind of sensors are required, largely depends on application scenario and system infrastructure .A variety of sensors are used to monitor human's physiological signals.i.e. Accelerometer, Gyroscope, ECG, EEG, EMG.

1.6 Wireless Body Area Network Radio Technologies

Various technologies involved in the realization of WBAN are described below.

- **Bluetooth Low Energy**

  This radio technology is also known as Bluetooth low end extension. It wirelessly connects devices to a mobile node .This technology is an ideal choice for health monitoring applications .It supports data rate of 1Mbps.

Table 1.1 Comparison of WBAN technologies

Technology	Frequency band	Data rates(b/s)	Coverage area (m)	Network topology
Bluetooth low energy	2.4 GHz	1M	10	Star
Ultra wide band	3.1-10.6GHz	480M	<10	Star
Bluetooth 3.0+HS	2.4 GHz	3-24M	10	Star
ZigBee	ISM	250k	30-100	Star/mesh

- **Ultra wide-band**

`UWB works under radio frequency band $3.1 - 10.6$ GHz .UWB has low power spectral density emission .Therefore it is suitable in short range and indoor environment[10].

- **Bluetooth 3.0+HS**

This radio technology supports data rate from $3 - 24$ Mbps and also supports application that transfer bulk data files.

- **Zigbee**

Zigbee or IEEE 802.15.4 technology focuses on applications with a low data rates and a low power consumption capability. Compared to Bluetooth, UWB Zigbee devices can work in three ISM band supporting data rate from $20 - 250$ Kbps

1.7 Research Issues

As WBANs is a new research area, there are various research issues that are described

- **Physical characteristics of electronic circuits and sensor materials**

Sensors are placed on human's body or even may be implanted. So their size and their compatibility with human tissues are crucial .Because RF circuits are placed in a close proximity to a human body, so a low transmission power for WBANs devices are needed to protect human tissues.

- **Development of improved propagation and channel models**

Body area propagation environment has been defined at link level .So there arise a need of accurate channel model that helps researcher's to predict the impact of channel on network level performance. Factor's such as reliability, latency, energy consumption affects such a model .So we need to device more adequate network architecture and efficient routing algorithms for WBANs.

- **Networking and resource management schemes**

  WBANs Applications differ from the applications of a Sensor Networks. Power management, network configuration and sensor calibration problems need to be revisited. Device configuration is required because a sensor node may leave or join the network at any point of time. Dynamic resource management is also required in WBANs [12].

- **Security, authentication and privacy issues**

  In WBANs, distributed mechanism is used to store patient's physiological data. This approach makes patient's data more vulnerable to being lost. Thus, protection of patient's data is important against malicious modification. An efficient authentication technique is also required for data privacy[13]

- **Power supply issues**

  In WBANs, for data collection, processing and transmission, an energy source is required. Most of the WBAN devices required battery power to operate. Batteries associated with the wearable devices are replaceable, but, in implant devices they are not easily replaceable. Thus remote battery recharging and energy harvesting techniques can be employed [14].

1.8 Organization of Dissertation

After the comprehensive introduction presented in this first chapter of the dissertation, the rest of the chapter of the dissertation is organized as follows. In chapter 2, channel modeling in WBANs is introduced by discussing various techniques to address the number of issue in the area. In chapter 3, an extensive review of related literatures is presented by exploring recent channel modeling techniques in WBANs. In chapter 4, enhancement in channel modeling in WBANs by improving BER with the help of digital modulation techniques is presented. In chapter 5, simulation and analysis of results are discussed. Chapter 6 concludes the dissertation with some future research directions in the area.

CHAPTER 2

CHANNEL MODEL FOR WBAN

The WBAN Task Group TG6 or IEEE 802.15.6 proposed WBANs for medical and non-medical devices. These devices can be categories as wearable (those that can be placed on the human body) and implanted (those that are implanted inside the human body).

The channel model describes the path loss of WBAN devices. The shadowing by human body or obstacles in proximity of human body is also accounted. The channel model is required for performance evaluation of various physical layer proposals. A legitimate comparison of various proposals is the main goal of these channel models [15].

2.1 Channel Model

Channel refers to a medium between the transmitting and the receiving antenna.

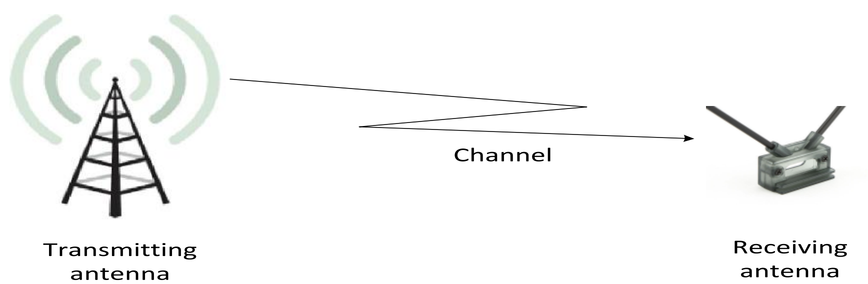

Figure 2.1 Wireless channel

Wireless signal's characteristics changes as it travels from a transmitter antenna to a receiver antenna. Various factors such as the distance between two antennas, propagation path followed by the signal and the surrounding environment around the propagation path .i.e. buildings, trees etc. The received signal's profile can be obtained from the transmitted signal if there is a model of the medium between transmitter and the receiver antenna, known as a channel model.

In WBANs the electromagnetic waves propagate form the implanted or non-implanted devices. As we know that the body shape and tissue structure of human is complex in nature, so deriving a simple path loss model is difficult. WBAN antennas are planted inside or on the body surface of human, thus WBANs channel model needs to assess the body influence on the radio propagation.

2.2 WBANs Channel Model

WBANs devices operate form frequency band 405 MHz - 10.6 GHz. Table 2.1 lists all possible WBANs scenarios in which these devices work, along with description and frequency band[16].

Table 2.1 WBAN channel model scenarios with descriptions

Scenario	Description	Frequency band	Channel model
C1	Implant to Implant	402 – 405 MHz	CM1
C2	Implant to Body surface	402 – 405 MHz	CM2
C3	Implant to External	402 – 405 MHz	CM2
C4	Body Surface to Body Surface (LOS)	13.5, 50, 400, 600, 900 MHz 2.4, 3.1-10.6 GHz	CM3
C5	Body Surface to Body Surface (NLOS)	13.5, 50, 400, 600, 900 MHz2.4, 3.1-10.6 GHz	CM3
C6	Body Surface to External(LOS)	900 MHz 2.4, 3.1-10.6 GHz	CM4
C7	Body Surface to External(NLOS)	900 MHz 2.4, 3.1-10.6 GHz	CM4

The maximum transmission range of WBAN devices is 5m. All channel models along with communication links are shown in figure 2.2.

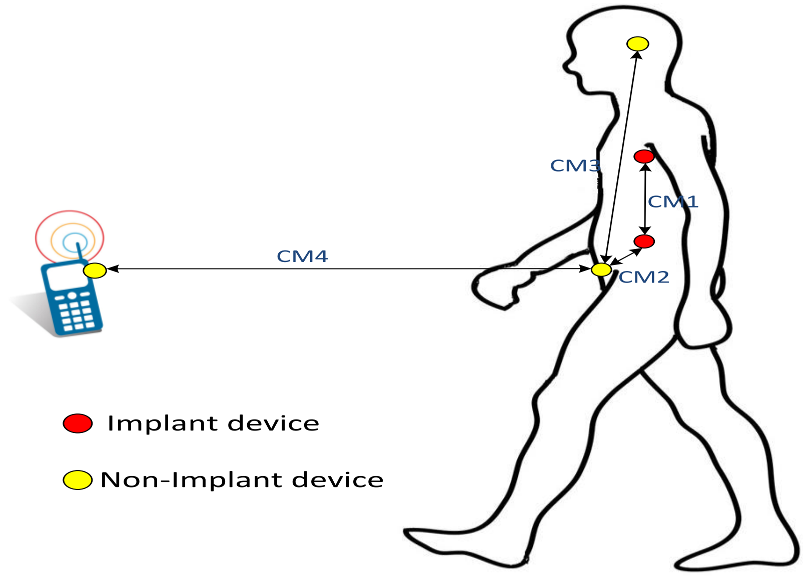

Figure 2.2 Communication links for WBAN

2.3 Channel Characterization

The channel model of wireless communication systems can be categorized in to types:

- An Analytical Model
- An empirical model

  Analytical models are based on mathematical expressions. Due to errors in approximations and simplifications, the results of analytical model of communication channels are inaccurate.

  Empirical models are based on real wireless communication experiments for various communication types and physical characteristics.

2.4 Antenna Effect

WBANs antenna are placed in, on or around a human body. These antennas are affected by environment around the human body. So we need to understand the changes in antenna pattern. Antenna form factor is also application dependent. It affects the antenna performance that is very crucial for overall system performance. So WBANs antenna are designed according to the human tissue and used in channel model measurements.

WBAN antennas can be categories into two parts:

- **Electrical antenna**

  These antennas produce large E-field normal to the tissue interface resulting in overheating of the fat tissue. E-field in fat is higher because the permittivity of fat is lower than muscle.i.e. Dipole

- **Magnetic antennas**

  These antennas produce an E-field tangential to the tissue interface. Since they are less coupled to the body than an electrical antenna, therefore they do not overheat the fat.i.e. Loop

2.5 Electrical Properties of Body Tissues

Human body is not considered as an ideal medium for RF wave transmission as it is partially conductive in nature and having materials with different dielectric constants and thickness. Therefore, human body experience high loss due to the power absorption and radiation pattern destruction.

2.6 Fading

Fading is defined as a deviation of the attenuation that affects a signal over propagation medium. In WBANs, fading is caused due to reflection, diffraction, energy absorption, shadowing by body and multipath environment around human body. Fading are of two types

- **Small Scale Fading**

  In small scale fading, the amplitude and phase of received signal changes rapidly within a small local area. This change happens for a short duration of time due to changes in on-body device locations.

- **Large Scale Fading**

  In large scale fading, fading occur due to motion over large areas (distance between on-body antenna positions and external node .i.e. hospital, office.

2.7 Path Loss

Path loss is defined as the reduction in power density of an electromagnetic wave as it propagates through space. In WBANs, path loss is both distance and frequency dependent.

$$PL(d) = PL_0 + 10n\log(\frac{d}{d0})$$

Where, PL_0 = path loss at reference distance d0 and n = path loss exponent.

2.8 Shadowing

Shadowing is defined as fluctuations in the received signal power when some object obstructs the propagation path between the transmitter and the receiver. Path loss when shadowing is considered is given as

$$PL = PL(d) + S$$

Where, PL(d)= path loss at distance d and S = shadowing components.

2.9 Power Delay Profile

Due to multipath reflections, the channel response of WBANs appeared as a series of pulses that depends on the time resolution of the measurement system. Power Delay Profile gives the distribution of received signal power over a multipath channel as a function of propagation delays. [17].

CHAPTER 3
RELATED WORK

On-body propagation channel models for WBANs are the models, in which WBAN devices placed on the human body, communicate to each other. As the human body is not an ideal medium for RF wave transmission so there is a high power loss due to power absorption. Other factors such as path loss and body shadowing also affect the WBANs channel performance. So based on RF technology various channel models have been studied heavily in last decade.

3.1 WBAN Carrier Frequency Performance Evaluation

In[18], performance of carrier frequency of WBANs for its different values has been evaluated using BPSK modulation. Rayleigh and Weibull distributions have been used to generate the power profile of WBAN channel and all measurements are derived from NICTA channel measurements. Simulation is performed for three values of carrier frequency ranging from $420 - 2500$MHz and WBAN channel performance is evaluated for BPSK modulation. The simulation result shows that minimum BER is resulted at carrier frequency 2400 MHz using BPSK modulation. Hence, 2400MHz is the suitable carrier frequency for WBANs using BPSK modulation.

3.2 WBAN Link Error Rate Performance Evaluation

In[19], the performance of error rate link for a low data rate WBANs has been evaluated and compared for efficient Rake receiver structures. Fading power delay profile has been generated using Rayleigh and Weibull distributions. The model is based on the large-scale measurements inside or on the surface of the human body. All measurements are derived from NICTA channel measurements. The BER has been obtained by using different modulation schemes i.e. BPSK, Pulse Amplitude Modulation (2-PAM), Bi-orthogonal Keying (2-BOK).With the help of graph obtained, Rake receivers BER performance is evaluated. Simulation result shows that 2-PAM is suitable among all three modulation schemes. It has been observed that for all modulation schemes, selective rake receiver (SRake) for optimum number of fingers performs better than partial rake receiver (PRake).

3.3 WBAN BER and PER Performance Evaluation

In [20], a UWB based channel model for WBAN is presented and with the help of derived channel models, performance of different modulation schemes is evaluated.This model is a statistical model and the parameters are obtained from the actually measured channel transfer function in a hospital room environment. The model enables performance evaluation of BER and Packet error rate (PER) for WBAN using various signaling schemes i.e. BPSK, DPSK,BPPM and OOK. The results shows that BPSK provides the best performance among all modulation schemes.

CHAPTER 4

PROPOSED WORK

A channel model for WBANs using UWB frequency band in [21] is taken as the reference and performance is evaluated using derived channel model. Channel characteristics .i.e. path loss is evaluated. For enhancing the WBANs channel, various modulation schemes are used for bit error rate (BER) performance evaluation.

Measurements are necessary part to develop UWB on-body channel model that plays a vital role in exploring behavior of a channel. A miniaturized UWB antenna having good performance capability is needed to develop the channel. A miniaturized UWB antenna developed by SkyCross (SkyCrossTM SMT-3TO10M-A) is used as a reference antenna. Electrical and mechanical specifications of reference antenna are given below[22].

4.1 Electrical Specifications (SkyCrossTM SMT-3TO10M-A)

The Electrical Specification of reference antenna is given in Table 4.1

Table 4.1 Electrical Specifications of SkyCross antenna

Parameters	Values
Frequency Range	3.1-10.6 GHz
Polarization	Linear
Gain	2.75 dBi at 5.25 GHz
Efficiency	70 % at 5.25 GHz
Pattern	Omni-directional around axis of antenna
Feed Impedance	50 Ohms unbalanced

4.2 Mechanical Specifications (SkyCrossTM SMT-3TO10M-A)

The Mechanical Specification of reference antenna is given in Table 4.2

Table 4.2 Mechanical Specifications of SkyCross antenna

Parameters	Values
Size	13.6 L x 16.0 W x 3.0 H mm 0.54 L x 0.63 W x 0.12 H in
Weight	0.3g

Return loss of SkyCross antenna is given as

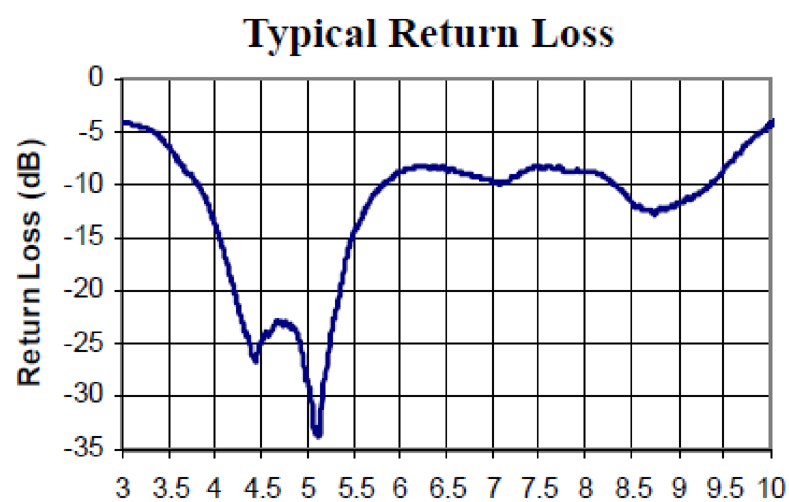

Figure 4.1 Return Loss of SkyCrossTM SMT-3TO10M-A Antenna

Measurement specifications are listed in Table 4.3:

Table 4.3 Measurement specifications

Eqipment	Parameter	Value
Vector network analyzer	VNA	Agilent EB8363B
	Frequency range	3 - 11 GHz
	Number of points	1000
	Sweep time	Auto
	Calibration	Full 2 port
	IF bandwidth	1 KHz
Human body	Gender	Male
	Height	170 cm
	Weight	65 kg
	Posture	sitting
Office room	Size	8*4*4 m^3
Antenna(SkyCrossTM SMT-3TO10M-A)	Distance to body	10mm
	Orientation	Head to Head

4.3 UWB Pathloss Model

Due to complex human body structure and the strong antenna body interaction, Electromagnetic wave propagation on body experience losses in received power due to absorption, reflection and diffraction.

Figure 4.2 shows the measurement positions where the antennas are attached. One of the antennas (master node) that are connected to the port 1 of VNA is attached to the waist and other antenna (sensor node) connected to port 2 of VNA takes one of the ten positions.

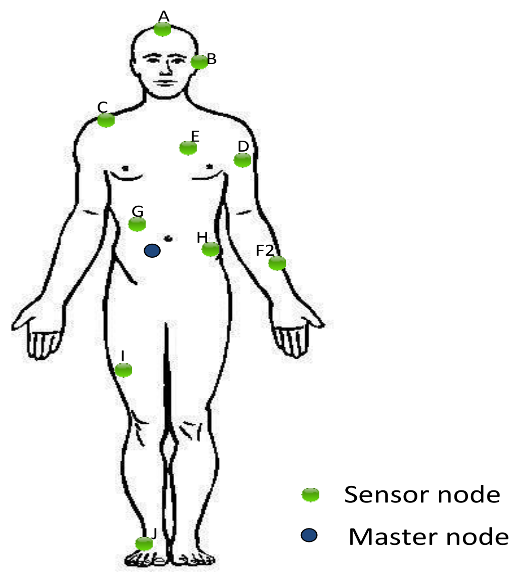

Figure 4.2 On body antenna measurement position

The table given below shows the sensor's position index, location where the sensors are placed, corresponding sensor used to measure human's physiological data and the distance measured along the body surface between the fixed and the other antennas.

Table 4.4 WBAN sensor nodes and their distance from the master node

Position index p	Position	Sensor	Distance[mm]
A	Head	EEG	742
B	Left ear	Body temperature	570
C	Shoulder	ECG	402
D	Left upper arm	Blood pressure	424
E	Chest	ECG	258
F1	Left hand	Spo2	410
F2	Left hand	Spo2	390
G	Right rib	ECG	176
H	Left waist	ECG	180
I	Thigh	EMG	400
J	Ankle	Acceleration	984

The path loss obtained is shown by following equation

$$\mathrm{PL}\big(\mathrm{d}(\mathrm{p})\big) = -20 * \log_{10}\{\frac{1}{\mathrm{N_s}}\frac{1}{\mathrm{N_f}}\sum_{\mathrm{j}=1}^{\mathrm{N_s}}\sum_{\mathrm{n}=1}^{\mathrm{N_f}}\mathrm{H_j^p}\,(\mathrm{n})\}$$

Where, $\mathrm{PL}\big(\mathrm{d}(\mathrm{p})\big) =$ Path loss at position p, at which the distance between T_X and R_X is a function of position p, $\mathrm{N_f} =$ Number of frequency samples of VNA, $\mathrm{N_s} =$ Number of snapshots and $\mathrm{H_j^p}(n) =$ Measured $S21$ for position P, J^{th}snapshot and *n*th frequency samples.

The WBAN pathloss model for UWB is given by

$$\mathrm{PL(d)} = \mathrm{a}\log_{10}\mathrm{d} + \mathrm{b} + \mathrm{N}$$

Where, $\mathrm{PL(d)} =$ Pathloss in dB at a distance d in mm, a , b = Parameters derived by least square fitting to measure pathloss and N = Stochastic term, having a log- normal distribution with zero mean and standard deviation of σN (dB) .

Parameters of on-body pathloss model

Table 4.5 On-body pathloss model parameters

Parameters	**Values**
a	13.99
b	16.26
σN	4.61

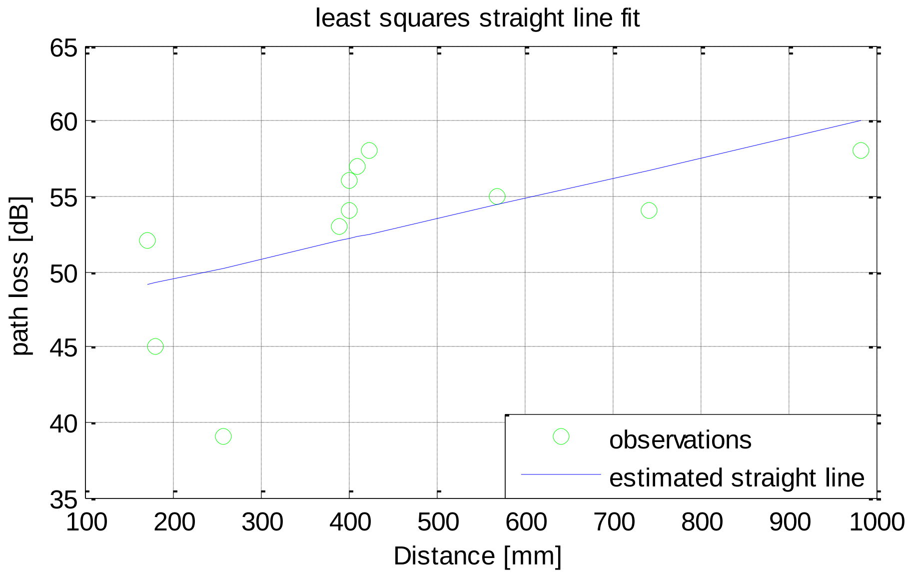

Figure 4.3 Path loss model for UWB band

4.4 Signal-to-noise ratio (SNR) calculation

Received signal power of a transmitter antenna is given as

$$P_{RX} = P_{TX} + G_T + G_R - P_L \text{dBm}$$

Where, P_{RX} = Received signal power, P_{TX} = Total transmitted power, G_T = Transmitter antenna gain, G_R = Receiver antenna gain and P_L= Path loss.

Signal to noise ratio SNR is given as

$$\text{SNR} = \frac{P_{RX}}{P_N}$$

Where, P_N = channel noise.

Normalized SNR ${Eb}/{N0}$ is given by the following equation

$$Eb/_{N0} = \frac{\text{SNR} * \text{B}}{\text{Rb}}$$

Where, B = Noise bandwidth and Rb = Bit rate in bits/second.

4.5 MB-OFDM System

MB-OFDM is one of the favorable applicants of PHY layer of short range, high data rate UWB communications. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation and play vital role in system performance of MB-OFDM. It is a low cost digital component that implements the multicarrier orthogonality using FFT algorithm. MB-OFDM enables UWB transmission to acquire all the strength of OFDM technique by combining OFDM with the multiband approach. OFDM modulation is employed within the MB-OFDM approach in each 528 MHz wide band and using frequency hopping technique, data is transmitted across different bands. Each parallel bit stream can be mapped onto one of the OFDM subcarriers[23].

According to the ECMA-368 specifications, an MB-OFDM system occupies 14 bands, each band having a bandwidth of 528 MHz. This technique captures multipath energy efficiently with a single RF chain. These 14 bands are divided into 6 band groups. The first 12 bands are grouped into 4 band groups (band group1-band group 4), and the last two bands formed band group 5. Band group 6 is defined within the spectrum of band group 3 and band group 4 that contains band 9, 10 and 11 in agreement to operate within worldwide spectrum regulations. This grouping allows transmitter and receiver in processing a signal with smaller bandwidth using frequency hopping techniques.

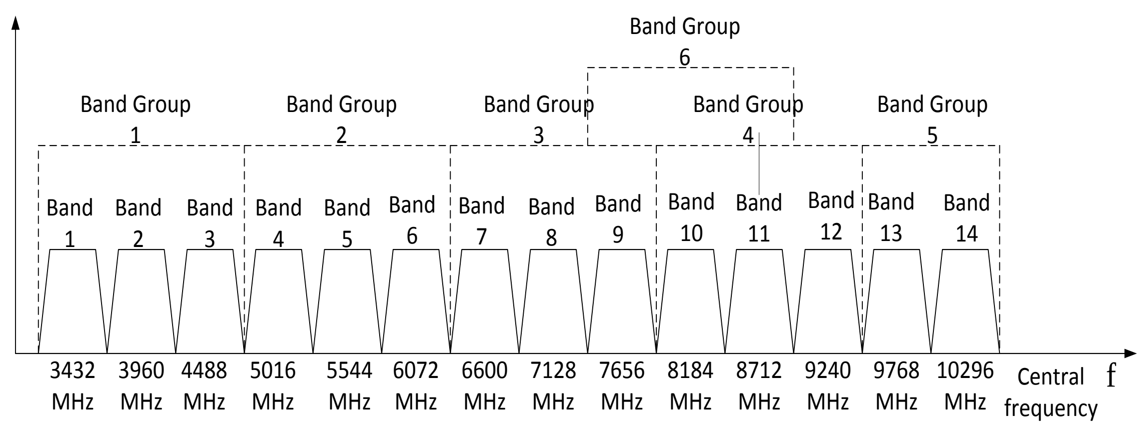

Figure 4.4 Band group allocations

MB-OFDM employs Quadrature Phase Shift Keying as modulation schemes in ECMA-368 that describe UWB radio platform. ECMA-368 used a dual QPSK soft-demapper that utilize the inherent Time-Domain Spreading (TDS) and guard symbol subcarrier diversity in enhancing the performance of a receiver and minimize hardware and power requirements by merging decoding operations together[24].

4.5.1 Architecture of MB-OFDM

The architecture of MB-OFDM transmitter and receiver is shown in figure 4.5 and figure 4.6 respectively.

- **MB-OFDM transmitter**

  The input bit streams are scrambled at the transmitter, and then a forward error code is used to provide resilience against the transmission errors. The encoded sequence is interleaved and mapped to the frequency bits of an OFDM symbol. The frequency-domain information is now transformed into a time-domain OFDM symbol by an Inverse fast Fourier transform (IFFT). The OFDM symbols are converted into continuous time-domain analog waveforms, up-converted to the desired central frequency, and then transmitted.

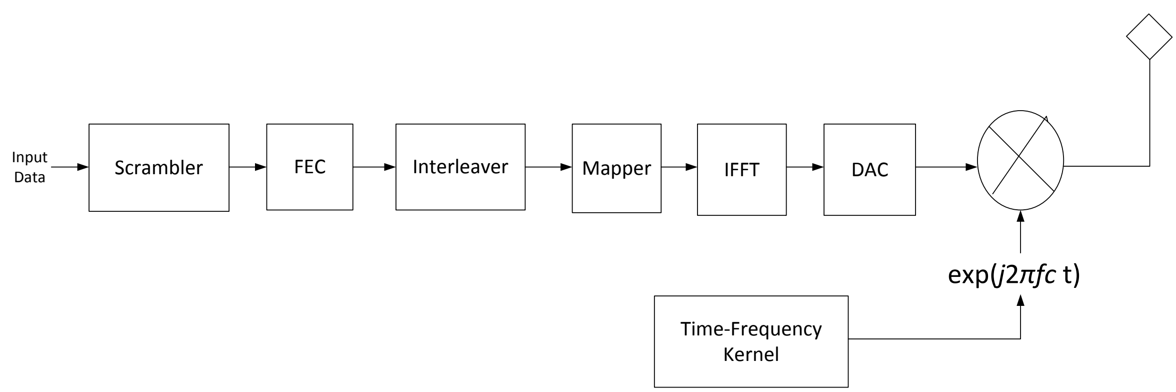

Figure 4.5 MB-OFDM transmitter

- **MB-OFDM receiver**

At the receiver, the received signal is amplified with the help of a low-noise amplifier (LNA) and using in-phase and quadrature mixers, it is down-converted to the complex baseband. Then the time frequency kernel produces the sequence of sub-band central frequencies according to the applicable time-frequency code. To remove out-of-band interferes, the complex baseband signal is low-passed filtered and then sampled and quantized with the help of 528 MHz ADC to get complex digital baseband signal.

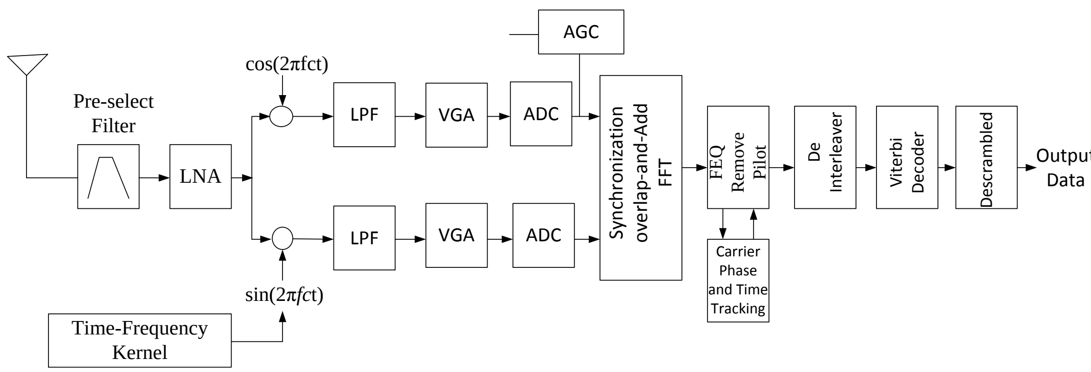

Figure 4.6 MB-OFDM receiver

Now, processing of these signals starts with the packet detection to identify on-air packet. The automatic gain control (AGC) loop controls the setting of the variable gain amplifier (VGA) at the input of the ADC to retain the best possible signal swing. The time-frequency-kernel is initiated by the receiver at packet detection. It searches for the sync frame sequence to determine the optimal FFT placement window for each of the three sub-bands. At the start of OFDM symbol, the samples corresponds to the zero-padded-suffix (ZPS) are added with the help of overlap-and-addmodule. To get the frequency-domain information, the FFT operation is then performed and the output is equalized by frequency-domain equalizer (FEQ). At the output of the FEQ, a phase correction is applied to revoke the carrier and timing mismatch effects between the transmitter and the receiver. Each OFDM symbol uses pilot tones to derive the digital phase-locked loop (PLL). The FEQ output is demapped and deinterleaved before it is passed to the Viterbi decoder. The error corrected bit sequence is then descrambled and passed on the MAC[25].

4.5.2 MB-OFDM PHY operation

A physical layer convergence protocol (PLCP) sub layer is introduced to operate the PHY service interface to the MAC. This protocol sub layer provides a method that converts a PHY Service Data Unit (PSDU) into a PLCP Packet Data Unit (PPDU).It consists of three components

- PLCP preamble (contains Packet/Frame synchronization and channel estimation sequence)
- PLCP header
- PSDU

PLCP preamble

Packet/Frame sync	Channel estimate	PLCP Header	PSDU
12/24 OFDM	6 OFDM Symbols	12 OFDM Symbols	53.3 Mbps

Figure 4.6 PPDU structure

To provide robustness in communication channel, these components are added properly for error detection and correction schemes. When a packet is transmitted, first PLCP preamble is sent, followed by the PLCP header and then PSDU is sent. PLCP Preamble and PLCP header are processed at the receiver to help in demodulation, decoding and delivery of the PSDU.

4.5.3 Measurement of Propagation distance

According to Federal Communications commission, the average power is defined as 1mW per MHz. The total transmitted power P_{TX} can be calculated using PHY Service Data (PSD) and the operating bandwidth. Assuming that there is no power loss at the transmitter and transmit antenna gain is 0 dBi.

$$P_{TX} = -41.25 + 10\log(f_U - f_L)\ \text{dBm} \qquad (1)$$

Where, -41.25 dBm/MHz = Effective Isotropic Radiated Power/MHz of UWB,
f_L, f_U = Lower and upper frequency of the operating bandwidth.

The path loss PL is given as

$$\text{PL} = 20log_{10}\left(\frac{4\pi f_g d}{c}\right) \text{dB} \quad (2)$$

Where, f_g = Geometric mean of the lower and upper frequencies in Band group 1 that offers a fair value for the system path loss, d = Distance between the transmitter and the receiver and c = Speed of light ($3 * 10^8$m/s).

Received signal power(P_{RX}) can be obtained with the help of (1) and (2)

$$\text{P}_{RX} = P_{TX} + G_T + G_R - P_L dBm \quad (3)$$

SNR at receiver input is defined as[26]

$$\text{SNR} = \frac{\text{P}_{RX}}{\text{P}_N} \quad (4)$$

Where, P_{RX} = Received signal power and P_N = Noise Power (dBm).
Noise power is calculated as

$$\text{P}_\text{N}(\text{dBm}) = \text{T}_\text{N} + 10\log_{10}(\text{B}) + \text{N}_\text{F} + \text{I}_\text{L} \quad (5)$$

Where, T_N= Thermal noise spectral density (dBm/Hz), B = Effective bandwidth,
N_F = Noise figure (dB) and I_L = Implementation loss (dB).

Signal-to-interference (SIR) ratio is given as

$$\text{SIR} = \frac{\text{P}_{\text{RX}}*\Delta\text{P}}{\text{P}_{\text{I}}} \qquad (6)$$

Where, ΔP = Increase of the receiver sensitivity due to interference signal and
P_I = Received power of interference signal.

From (4) and (6)

$$\text{SIR} = \frac{\text{SNR}*\Delta\text{P}*\text{P}N}{\text{P}I} \qquad (7)$$

Noise-to-interference ratio is given as

$$\text{NIR} = \frac{\text{P}N}{\text{P}I} \qquad (8)$$

From (7) and (8)

$$\text{SIR} = \text{SNR} * \Delta\text{P} * \text{NIR} \qquad (9)$$

Received interference power level P_I is given by

$$P_I = \frac{P_{TX}*G_T*G_R}{\text{PL}} \qquad (10)$$

From (2) and (10) transmission distance can be calculated as

$$\text{d} = \frac{c}{4\pi f_g}\sqrt{\frac{P_{TX} * G_T * G_R * \text{NIR}}{\text{P}_\text{N}}}$$

CHAPTER 5
SIMULATION AND RESULTS

5.1 Performance Evaluation

The UWB based WBAN performance is evaluated using the derived channel model. Modulation schemes are used for BER performance evaluation of derived channel model. BER error probability of OOK, BPPM, DPSK, BPSK and MB-OFDM-UWB that employ QPSK as modulation schemes, are evaluated with respect to the normalized signal to noise ratio (EbN0). The BER error probability of each modulation schemes is summarized as following

5.1.1 BER error probability of modulation schemes

- **OOK**

  OOK is an amplitude-shift key (ASK) modulation in which digital data is represented as presence or absence of carrier wave. Binary 1 is used for presence of a carrier for a specific duration and binary 0 is used for absence of carrier[27]. The bit error probability of OOK modulation is given by

$$P_b = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}} * \sqrt{\frac{E_b}{N_0}}\right) \quad (11)$$

- **BPPM**

  BPPM is a form of Pulse position modulation (PPM) that encoded m message bits by transmitting a single pulse in one of 2^m possible required time shifts. This procedure repeats for every t time, thus resulting transmitted bit rate as m/t bps. PPM is widely used in infrared (IR) wireless communications. In BPPM two bits are transmitted in a symbol for transmission[28]. The bit error probability of BPPM is given by

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b/N_0}{2\sqrt{2}}}\right) \tag{12}$$

- **DPSK**

DPSK is a form of phase modulation (PM) in which data is conveyed by changing the phase of a carrier wave. Phase is unchanged for the transmission of symbol 1, and phase of the signal is advanced by 180 degree for the transmission of symbol 0. Change of the phase is very slow and almost constant over two bit intervals[29]. The bit error probability of DPSK modulation is given by

$$P_b = \frac{1}{2} * exp^{-E_b/N_0} \tag{13}$$

- **BPSK**

BPSK is a form of phase shift keying (PSK) and also called as phase reversal keying. It is termed as 2PSK as it uses two phases that are separated by 180 degree. It modulates 1 bit per symbol, so this modulation technique is not suitable for the high data-rate applications[30]. The bit error probability of BPSK is given by

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{14}$$

- **MB-OFDM-UWB with QPSK**

MB-OFDM-UWB employs QPSK modulation. This modulation scheme is also known as quadriphase or 4-PSK. QPSK divide the phase of the carrier signal by allocating four equally spaced values for the phase angle as π/4, 3π/4, 5π/4 and 7π/4, thus providing a major advantage over BPSK by having the information capacity double to it [31]. The bit error probability of QPSK is given by

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{15}$$

The simulation parameters for UWB system are given in the table 5.1.

Table 5.1 Simulation parameters for UWB system

Modulation parameters	Values	MB-OFDM parameters	Values
Symbol duration	1024 ns	Frequency	3168-4752 MHz
Bandwidth	503 MHz	Symbol duration	312.5 ns
Pulse duration	1.9 ns	Data rate	53.3 Mbps
Burst pulse duration	32.0 ns	Data length	1024
Data rate	1 Mbps	Subcarriers	128
Noise figure	7 dB	Transmitter antenna power	-9.9 dBm
Transmitter antenna power	-16.8 dBm	Guard interval	70.08 ns
Packet size	128 Bytes	Forward error code	YES
Forward error code	None	Modulation method	QPSK

5.1.2 BER error probability performance evaluation

As shown in the figure 5.1, the BER error probability of BPSK and MB-OFDM-UWB (using QPSK) are comparably better than other modulation schemes.

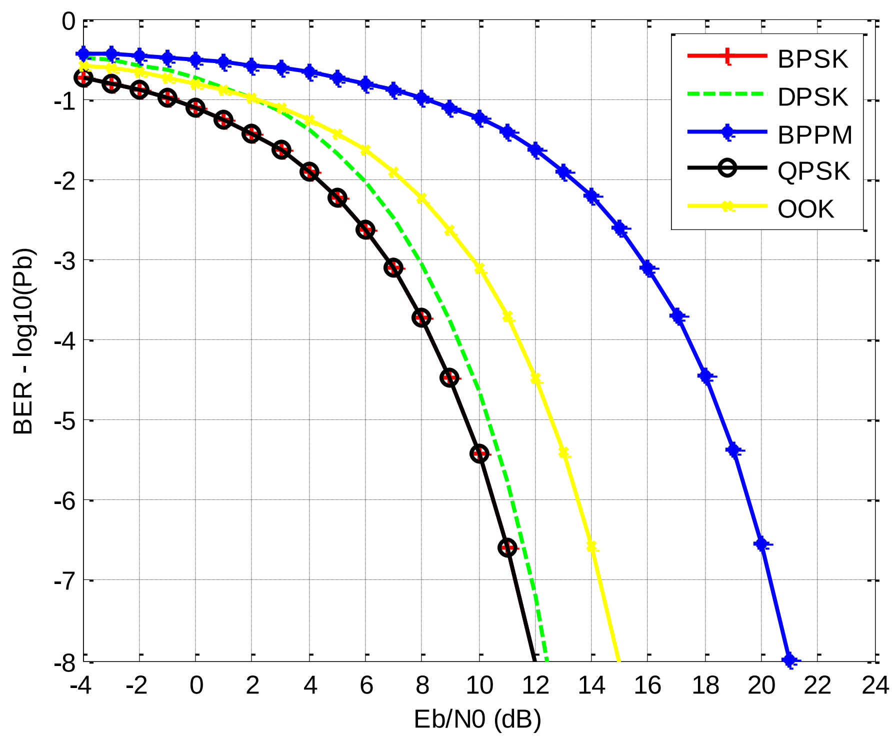

Figure 5.1 BER performance evaluations of modulation schemes

BPSK and QPSK have same BER error probability but QPSK has major advantage over BPSK by having the information capacity double to it as it divides the phase of the carrier signal by allocating four equally spaced values for the phase angle as π/4, 3π/4, 5π/4 and 7π/4. Therefore QPSK is a highly bandwidth efficient digital modulation technique than BPSK.

5.1.3 Transmission distance performance evaluation

Figure 5.2 shows the transmission distance performance evaluation of RF communication among 53.3 Mbps MB-OFDM and modulation schemes .i.e. OOK, BPPM, DPSK and BPSK.

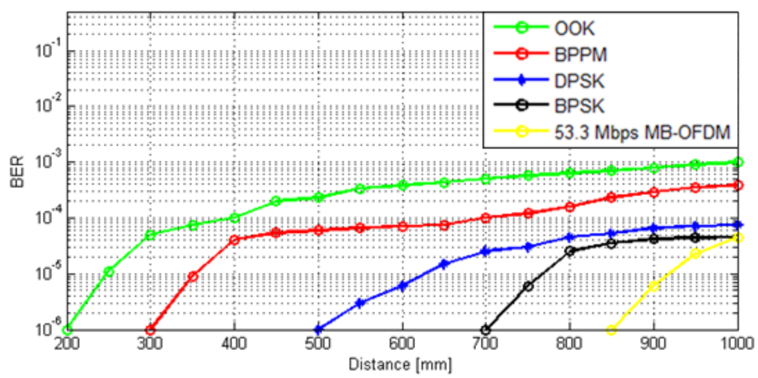

Figure 5.2 Transmission distance performance evaluation

It is observed that transmission distance capability of 53.3 Mbps MB-OFDM is comparably better than other modulation schemes. Therefore MB-OFDM is a favorable applicant of PHY layer of UWB communications.

CHAPTER-6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

In this dissertation, an enhancement in channel modeling in WBANs by improving BER with the help of digital modulation techniques is presented. In particular, UWB-based WBAN path loss model is derived using considered parameters. To improve BER and transmission distance, MB-OFDM technique is utilized. Different modulation techniques such as OOK, BPPM, DPSK and BPSK are compared considering their BER and transmission distance. From the analysis of simulation results, it can be clearly observed that the performance of MB-OFDM which uses QPSK modulation technique is comparable better as compared to the other considered modulation techniques. The outcomes of the analysis will be significantly useful in the design of physical layer for applications that use UWB in WBAN-UWB communication.

6.2 Future Work

In future research, authors will explore the area by considering other performance parameters such as packet error rate, reliability, latency etc. The consideration of theses will enhance the accurate channel modelling. Considering the fact that WBANs is a new research area, the other issues of the area such as characteristics of electronic circuits and sensor materials, network and resource management, security and power supply, need to be investigated in future.

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