ENERGY EFFICIENT IR-UWB WBAN BASED ON THE IEEE 802.15.6 STANDARD

A THESIS

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I remember my parents who have always been an inspiration to achieve a higher level of education. They have shaped my positive attitude in both work and life.

It requires faith to believe that there exist simple and elegant solutions to difficult problems, as well as to believe that we are gifted with the capacity to discover them. I take faith a simple step further by believing that both the structured world we live in and the ability for us to understand it are gifts from God.Therefore, I thank God for providing me with all that I need, and for sustaining me throughout my studies. I am glad to have known his love and to have experienced his faithfulness even in times when my own faith is weak.

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

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CERTIFICATE

*This is to certify that the Thesis entitled, " **ENERGY EFFICIENT IR-UWB WBAN BASED ON THE IEEE 802.15.6 STANDARD** " submitted by Mr. **ARAVIND M T** to the National Institute of Technology Calicut towards partial fulfillment of the requirements for the award of the Degree of Master of Technology in **Electronics and Communication Engineering** (**Telecommunication**) is a bonafide record of the work carried out by him under my supervision and guidance.*

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ABSTRACT

This work presents an exhaustive study on the use of one-relay and two-relay cooperative communication schemes and 2-hop communication scheme for improving the energy efficiency and reliability of ultra-wideband based wireless body area networks (UWB WBANs). Various investigations have been performed to study the impact of the parameters like packet size, hop distance and channel error rate on the energy efficiency and reliability. An optimal packet size is obtained for the maximization of energy efficiency for both on-body communication and in-body communication. The analytical and simulation results show enhanced reliability with cooperative communication than direct communication and 2-hop communication, for all values of source to destination distances. The results also depict a threshold behaviour for energy efficiency which separates the hoplength for direct transmission from the hoplength where cooperation and 2-hop communication will be useful. It is also noticed that an extension of hop distance in which energy efficienct communication can be obtained gets better in the case of 2-hop communication than with direct and cooperative communication for all propagation scenarios. The simulation results reveal that if the channel conditions are poor, when the source to destination distance is larger than the threshold value, 2-hop communication gives higher energy efficiency when compared with direct and cooperative communications.

KEYWORDS: Ultra wide band, Wireless body area networks ,Energy efficiency,IEEE 802.15.6, Cooperative communication, Optimum packet size, Reliability.

LIST OF ABBREVIATIONS

AC	Auto Correlation
ACK	Acknowledgment
ARQ	Automatic Repeat Request
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CRC	Cyclic Redundancy Check
ED	Energy Detection
FCS	Frame Check Sequence
FEC	Forward Error Correction
HBC	Human Body Communication
LOS	Line Of Sight
MAC	Medium Access Protocol
MPDU	MAC Protocol Data Unit
NACK	Non Acknowledgment
NB	Narrow Band
NLOS	Non Line Of Sight
OOK	On Off Keying
PDU	Physical Data Unit
PHR	Physical Layer Header
PSD	Power spectral density
PSDU	Physical Service Data Unit
GFSK	Gaussian frequency shift keying
QoS	Quality of Service
SFD	Start of Frame Delimiter
SHR	Synchronization Header
SNR	Signal to Noise Ratio
UWB	Ultra Wide Band
WBAN	Wireless Body Area Network
PER	Packet error rate

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CHAPTER 1

INTRODUCTION

There is a huge necessity that future health care systems aid a proactive health care management and support to focus upon disease detection and prevention mechanisms. The WBAN concept thus evolved reaps the advantages of new wireless techniques in the area of telemedicine and mobile health care application scenarios. The WBAN comprises small intelligent sensors implanted within human tissue to attain critical physiological data which are further to be monitored by doctors or health practitioners. .

IEEE802.15 WPAN working group formed task group 6 (TG6)in Nov2007 inorder to develop a standard for communication of low power devices that are functioning inside or on the body of human beings so as to perform wide domain of application ranges like consumer electronics ,medical and personal entertainment. Approval of IEEE 802.15 TG6 physical (PHY) and the medium access control (MAC) specifications for WBAN was made in 2012[1]. The MAC layer of the standard supports three PHY layers:narrow band Layer ,ultra-wide-band(UWB) layer and human body communication layer. The different narrow bands are 400 MHz, 600 MHz, 900 MHz and 2.4 GHz and the ultra wide-band (UWB) is 3.1 to 10.6 GHz.

The domain of applications of UWB (large data rate-short distance or low data rate-long distance) to a great extend is restricted by the restrictions on the transmit power(i.e; the power limit is below 0.5mW) .The physical layer signal structure balances the trade-off of UWB. The reduced transmit power implies that multiple low energy UWB pulses need to be combined to transport 1 bit of informaton [2]. Higher number of pulses per bit implies lower data rate and hence larger transmission distance can be achieved. The interference created by UWB signals on already prevailing narrow-band radio systems is very low because of its low power spectral density(PSD). The UWB transmitter skips the additional radio frequency mixing stage by producing a very short pulse, which can propagate by itself, and hence the large modules used in the current narrow band systems such as modulator, demodulator and intermediate frequency(IF) stages which are highly expensive are not a required for the UWB transceivers. This ultimately results in the size, cost and weight reduction and reduced power consumption of UWB systems compared to narrowband systems for communication.The RF mixing stage involves the injection of a carrier frequency into a base band signal and thereby transforming the base band into a pass band that has desired propagation charecteristics. The ultra high bandwidth of the UWB signal enables it to span over a range of generally used carrier frequencies. The UWB signals can propagate without the need for amplification and additional up-convertion. So, the down convertion is also absent in UWB receiver.This points out the elimination of the local oscillator in the receiver, and thus the removal of associated complicated phase and delay tracking loops. It is clear that the UWB technology enables to achieve huge data rates and also is a feasible solution for a short range-high data rate communications, apart from it being a topic of significant debate. Also, UWB is a field that needs further investigation. UWB technology is mainly subdivided into two : Impulse radio based UWB (IR-UWB) and a multiband orthogonal frequency division multiplexing (MB-OFDM) based UWB. To support multiple access, either time hopped (TH) or direct sequence (DS) technique can be used. The different acceptable modulation schemes are: pulse position modulation, pulse amplitude modulation, on-off Keying and a binary phase shift keying.

For providing spatial diversity to combat multipath fading, and for improving the link reliability and throughput of wireless sensor networks, various techniques are presently considered for research, of which, cooperative communication proposals are focussed more [3,4]. Cooperative communication uses a relay mechanism to improve the communication link efficiency. The underlying concept is that the systems having relay nodes placed between the transmitter and the receiver are used to amplify or decode and retransmit the signal to the receiver. Cooperative schemes are mainly of two types , amplify and forward (AF) and decode and forward (DF) which could be either adaptive or fixed. The relay amplifies the signal received and retransmits it to the primary receiver in the case of AF relaying scheme. In this mechanism the noise amplification also takes place. The relay mechanism in DF relaying, decodes the received signal and retransmits it to the receiver. In this mechanism the noise which is additive in nature, will not propagate from source to receiver. Cooperation can tremendously reduce the BER and thereby enhance the network lifetime, when the same is compared with direct transmission. The traditional cooperative relaying mechanism causes a wastage of the various channel resources since the relay always forward the signal without taking in to consideration the various channel conditions. Usage of the orthogonal channels for communication, by the relay and the source, causes cost of extra resources even if relaying is not needed due to successful direct communication between the source and destination pair. The conservation of the various channel resources form the main objective of incremental relaying schemes. If the source-to-destination link SNR is sufficiently high, an ack from the destination could be used to indicate that there exists a successful direct transmission link and that the technique of relaying is not needed. If the source-to-destination link SNR is not large enough for the transmission successful, a negative acknowledgement (nack) is sent by the receiver to indicate that the relay is needed for data forwarding. Thus an efficient usage of the channel resources can be done, with respect to conventional cooperation scenarios. The incremental relay scheme proposes that the relay forwards only when in times of necessity [3,4]. The conventional schemes necessitate the usage of a very sophisticated combining technique and synchronization for acquiring the spatial diversity benefits among geographycally separated relays. In the case of an incremental relaying technique, the destination process only a single signal at a time. Therefore, co-phasing and combining can be excluded, resulting in simplified receiver units.

1.1 Motivation

WBAN sensor nodes have extreme power constraints because they use batteries of really small size with comparatively lower processing and lower storage capabilities. As the battery capacity is very limited there exists a restriction in the lifetime of the node too. But the battery replacement is always not a desirable option since it may affect the patient's health. This problem is more critical where in the case the sensor nodes are implanted inside the human body, and the battery replacements would demand some surgical procedures. Also, when a WBAN is required to operate continuously and autonomously for an enormous period of time. Hence, the energy management is one of the key concerns in WBAN protocols, so that the The recharging and replacement of batteries are not very frequent and the network remains responsive in operation for a longer duration (extended network lifetime).

Parameter optimization plays a key role in the energy-efficient WBAN design. So it is extremely important that the WBAN parameters have to be chosen in an intelligible manner so that the system performance is optimized. The key objective functions chosen for the optimization are: (i) network energy efficiency; (ii) network lifetime; (iii) reliability, and (iv) delay that is experienced by the frames subject to an emergency data transmission. The key objectives may either conflict with each other, help each other or may be independent. These optimization problems can be constrained by many factors like the transmit power, transmit energy, transmit time, interference, throughput, QoS, coverage etc. In certain resource allocation problems, the decision variables are set by the network operators or by the regulatory authorities. The transmit power at the WBAN sensor nodes are set by regulatory bodies. By increasing or decreasing the transmit power the energy consumption and reliability of the network are affected. The constrained optimization problems will give rise to various output parameters such as optimal transmit power, optimal frame size, constellation size, optimal contention window (at the MAC layer), optimal hop distance, optimal throughput, optimal delay, optimal code rate etc. which can improve the performance of the network in a considerable manner.

In case of WBANs, the sensed information is always critical, and therefore, an information loss is not at all acceptable. A chance of link failure or reception of erroneous data due to any type of channel impairments always exists. Hence the protocols which account for or assure a reliable delivery of information need to be designed carefully. The conventional cooperative communication is realized to be an efficient technique to achieve higher energy savings, and a reliable delivery of information is necessary in order to overcome the effects of channel impairments like fading and noise in the communication system.

There exists different strategies which are very much concerned about the enhancement of the throughput and reliability of sensor networks and also it is a major aspect in the research by which cooperative communication schemes have gained considerable attention. The main focus is to provide spatial diversity and improve the throughput and reliability of wireless sensor networks. A typical cooperative communication scenario utilizes two distinct paths to propagate information from source to destination. One is via, direct link and the other, through relays. Incremental relay based cooperative transmission schemes can improve the communication reliability and energy efficiency in a significant manner. Cooperative communication scheme leads to hop distance extension with cooperation mechanism. The hop distance extension mechanism with cooperation focuses upon the hop distance over which energy efficient communication can be achieved. For poor channel conditions (the S-D distance exceeds threshold), the energy consumption of 1-hop communication is very likely to be wasteful due to the low probability of direct successful transmission and also cooperative communication consumes higher energy for both direct and relay transmissions. In the same scenario 2-hop communication obtains the maximum energy efficiency than 1-hop and cooperative communication when channel is poor.

1.2 Thesis objectives

Based on the literature review, the following project objectives were decided:

1. Analyze different communication schemes such as one-hop with and without relays, and two-hop in UWB based WBAN to compare the relative performance interms of reliability, energy efficiency and hop-length extension.
2. Use cooperative communication effectively to increase the reliability of the communication in WBAN.
3. Use cooperative communication and 2-hop communication to increase energy efficiency and to extend the hop length. Also find optimal packet size for optimization of energy efficiency in UWB based WBAN scenario.
4. Analyse how effectively cooperative communication reduce the transmit power compared to direct communcation for energy efficient communication

1.3 Thesis contribution

The thesis work makes the following contributionsin the field of IEEE 802.15.6 IR-UWB based WBANs:

1. Investigated energy efficiency of direct, relayed and 2-hop communication scenarios with in-body and on-body channel models.
2. Expressions for energy efficiency and packet success rate with various strategies were derived.
3. Investigated the effect of source to destination distance, packet size, transmitted power and bit error probability on energy efficiency of WBANs
4. The simulation results will be useful for the selection of most suitable packet size, hop length and transmit power. Additionally, the simulation results show that a threshold distance exists that separates the region where direct communication is more effective compared to cooperative and 2-hop communication, in terms of energy efficiency.

1.4 Thesis Organization

Chapter 1 presents an introduction to the thesis work. Chapter 2 gives an overview of characteristics of WBAN and its applications and provides an outline of the standard IEEE 802.15.6 specifications. Chapter 3 gives the reliability analysis of IEEE 802.15.6 based WBAN with UWB PHY layer specified in the standard. Chapter 4 depicts the energy consumption models of different communication schemes in WBAN such as direct, cooperation and 2-hop communication. Chapter 5 concludes the thesis by summarizing the significance of the contributions and giving future extents of the present work.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

This chapter gives a brief description on WBANs and their varied applications. It introduces the various methods of relaying and their characteristics. It also explains the need for a separate standard for the design of WBANs. It further discusses the history and various features of IEEE 802.15.6. The different PHY layer specifications are also dealt with in detail.

2.1 WBAN

Wireless sensor networks (WSNs) comprise very low power, intelligent, sensor nodes.These sensors detect the various parameters from the physical environment and transmit the collected data to a sink (or possibly multiple sinks) either via single or multiple hops. Also, WSNs comprise nodes having actuators. These actuators perform different actions in the physical environment [6]. WBANs constitute a short range wireless network which are formed by low power, lightweight sensor nodes that are eitherattached to the body surface or implanted into the tissue. The data collected by the sensors are transferred to the central hub/coordinator and it performs the data aggregation and analysis. WBAN is a quite promising technology in many different domains which include consumer electronics and sports [7]. A WBAN based human body monitoring system is able to provide many benefits for different categories of people by providing a feedback about the health condition of the patient to the doctors and many healthcare professionals. The WBAN concept was first proposed by Van Dam et.al in 2001, to take full advantage of the wireless technology and its applications in telemedicine and m-health [8]. Even if there exists many similarities between WSNs and WBANs, fundamental and important differences prevail among the network functionalities; and the different solutions and research results that are applicable for WSNs seem insufficient for WBANs. This chapter describes the key features and applications of WBANs. The chapter also provides a brief description of of physical layer specifications and IEEE 802.15.6 WBAN specifications.

2.2 Important Characteristics of Wireless Body Area Networks

Important Characteristics of Wireless Body Area Networks The section describes unique WBAN features while used for health care applications [9-10]. Features are:

1. Size of the sensor devices: The WBAN devices require to be physically small so that it can be wearable or implantable. This actually limits the battery size used.
2. Transmit power: As the WBANs are incorporated into the body of the person closest to or inside, a human body, very less transmit power must be used inorder to minimize the impact of the radiation and thereby leads to the heating of human tissues.
3. Computational power and memory: Since there exists constraint in the different energy resources, the computational power and memory are limited.As a consequence, simpler and efficient algorithms are required in all layers of the protocol.
4. Lifetime and energy efficiency: The lifetime of sensor nodes in WBAN is highly dependent on the battery capacity and the power utilization on each layer of the protocolstack. Battery replacement is not possible as it affects the patient's health due to the surgical procedures involved and thus energy efficiency is a key concern.
5. Reliability: This is especially an important factor in ensuring that medical data is properly sent to the hub without interfering the patients day to day activities .
6. Latency: The different medical applications need an end-to-end latency to be less than 125 msand non-medical applications require the end-to-end latency to be less than 250 ms and the emergency applications have very strict latency requirements.
7. High attenuation: Human body comprising the bones, fat, and tissues; increasingly attenuates the electromagnetic radiations.
8. Interference and co-existence: WBANs must be able to minimize interference caused by wireless networks operating in the same band and in the vicinity.

2.3 WBAN Applications

WBANs are widely used in the healthcare, military, sports, entertainment, and many other areas and are described below [9-10] ,

1)Healthcare: WBANs find their use to be widely used for the diagnosis, monitoring and treatment of patients with many chronic problems that include diabetes, hypertension,CVDs and also events which prompt assistance like heart attack and epileptic seizure can be avoided by constant monitoring of the heart and brain activity. Medical applications of WBANs are classified into in-body communication for implanted devices (e.g. glucose monitoring)and on-body communication for wearable devices (e.g. ECG monitoring). Emotion monitoring by physiological signals allows to realize the emotional condition of a patient. A WBAN has an actuator, which, based on measurements and control, can automatically release medicine or other agents.

2)Military and Defence: The WBAN could be formed around a soldiers body, which unites various sensors, and other communication devices such as cameras and GPS enabled systems which in turn improves the quality of medical care in case of injuries to soldiers and increase their survivability in the battlefield .

3)Sports: An athletic performance can be analysed by a WBAN for training activities. In the case of a cricket or tennis player, arm movement and body posture are very important to improve performance.

4)Entertainment: WBAN plays an important role in entertainment applications such as gaming, social networking, authentication and personal information access.

2.4 IEEE802.15.6 WBAN standard

In November 2007, IEEE 802 built up a task group for the standardization of WBAN called IEEE 802.15.6. The essential goal of the IEEE 802.15.6 standard was to develop a standard for communication inorder to support low-power devices that are deployed on or implanted inside a human body to serve a variety of medical, consumer electronics (CE), and entertainment applications. An initial draft of the standard agreed in July 2011. The final version of the standard was published in February 2012. The IEEE 802.15.6 standard describes a Medium Access Control (MAC) layer that supports several PHYsical (PHY) layers, such as Narrow Band (NB), Ultra-Wide Band (UWB), and Human Body Communications (HBC) layers, as outlined in Figure 2.1. The critical issue faced was to choose the frequency bands in the advancement of WBANs.

The standard applies various frequency bands information transmission which incorporates: The Narrow Band (NB) : It includes the 400, 800, 900 MHz and the 2.3 and 2.4 GHz bands; The Ultra Wide Band (UWB):It uses the 3.1 to 11.2 GHz; and the HumanBody Communication (HBC) which utilizes the frequencies inside range of 10 to 50 MHz.Figure 2.2 depicts the IEEE 802.15.6 frequency bands. The standard IEEE 802.15.6 is the first international Wireless Body Area Network (WBAN) standard which supports communications nearby or of or within a human body to support a wide methods for medical and non medical applications.

The Medical Implant Communications Service (MICS) band is a licensed band utilized for implant communications and has the same frequency range of 402 to 405 MHz in most countries. Wireless Medical Telemetry Services (WMTSs) is a licensed band utilized for medical telemetry systems. The Industrial, Scientific, and Medical (ISM) and Ultra Wide Band (UWB) bands support high-data-rate applications and are accessible around the world. An efficient allocation of resources on the channel requires that, the standard allows the nodes and hubs (which are otherwise called coordinators) set up a a reference time base, where the time axis is divided into multiple super frames of same length.

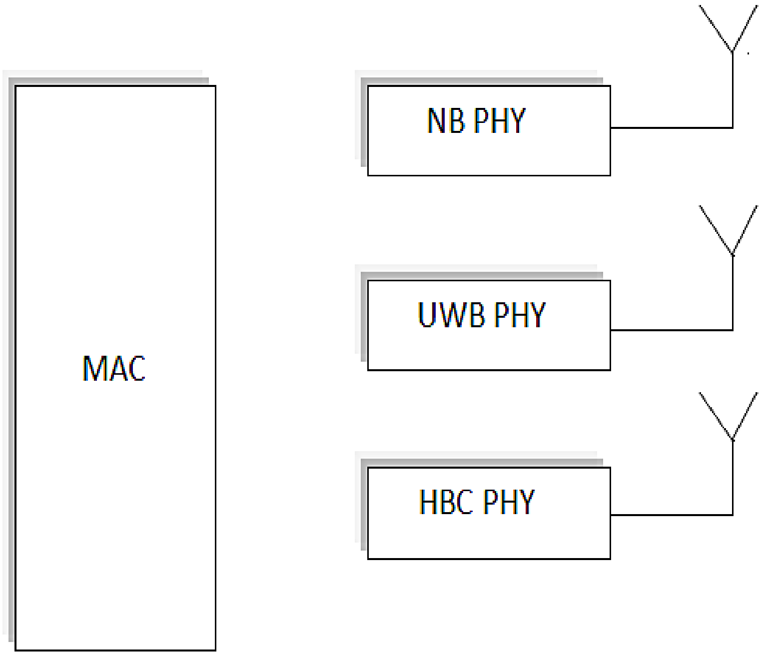


Figure 2.1: IEEE 802.15.6 MAC and PHY layers

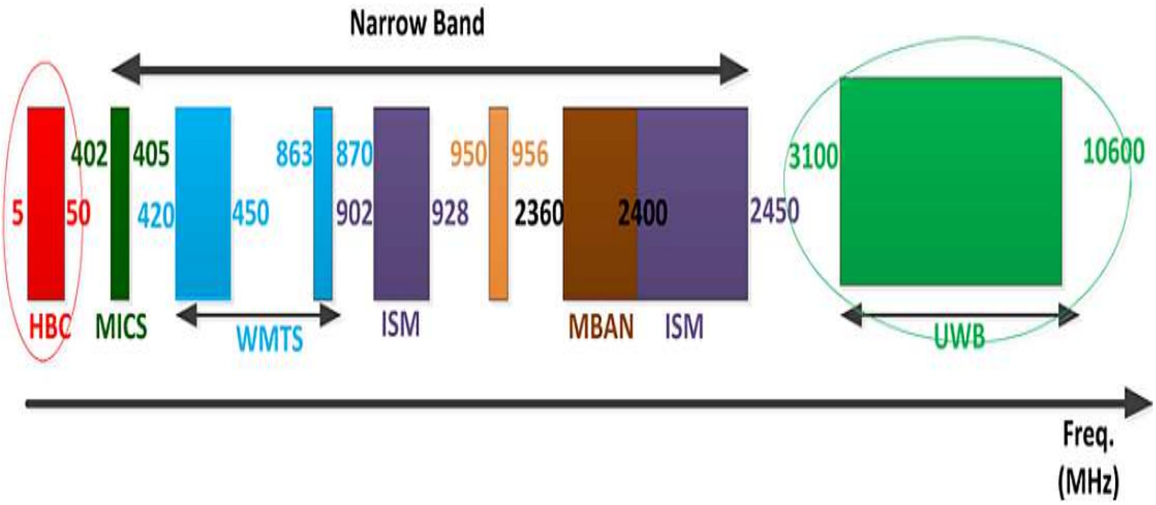


Figure 2.2: IEEE 802.15.6 frequency bands [2]

2.5 PHY Layer Specification

The IEEE 802.15.6 supports three different PHYs, i.e; NB, UWB, and HBC.

1) Narrowband PHY (NB)

The NB PHY is utilized for activation/deactivation of the radio transceiver Clear Channel Assessment (CCA) inside the present channel and information transmission/gathering. The Physical Protocol Data Unit (PPDU) frame of NB PHY contains a Physical Layer Convergence Procedure (PLCP) preamble, a PLCP header, and a PHY Service Data Unit (PSDU) as given in Fig 2.3. The PLCP preamble supports the receiver in the timing synchronization and carrier-offset recovery and is the main part being transmitted. The PLCP header which is required for a necessary successful decoding of a packet to the receiver and is transmitted after PLCP preamble using the given header data rate in the operating frequency band. The last component of PPDU is PSDU which consists of a MAC header, MAC frame body, Frame Check Sequence (FCS) and is transmitted after PLCP header utilizing any of the available data rates in the operating frequencyband. A WBAN device should be able to support transmission and reception in one of the frequency bands . In NB PHY, the standard uses Differential Binary Phase-shift Keying (DBPSK), Differential Quadrature Phase-shift Keying (DQPSK), and Differential 8- Phase-shift Keying (D8PSK) modulation techniques with the exception of 420 to 450 MHz which utilizes a Gaussian minimum shift keying (GMSK) technique.

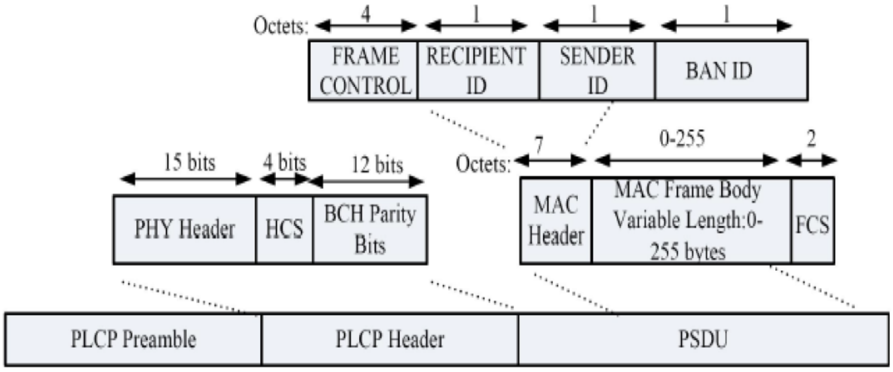


Figure 2.3: IEEE802.15.6 NB PPDU structure

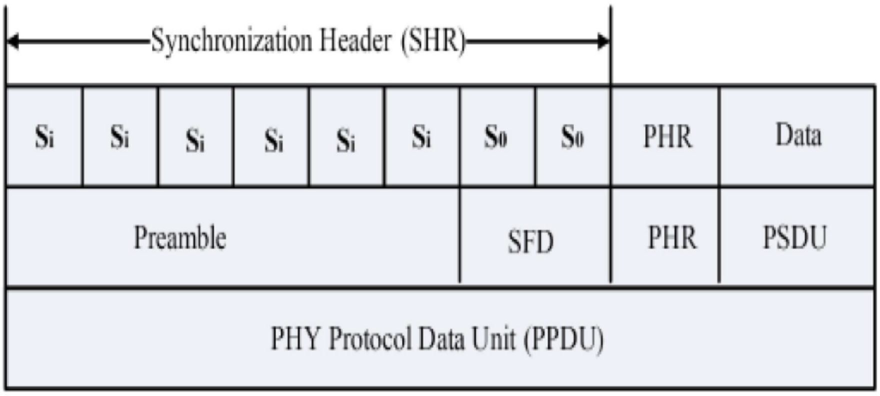


Figure 2.4: IEEE802.15.6 UWB PPDU structure

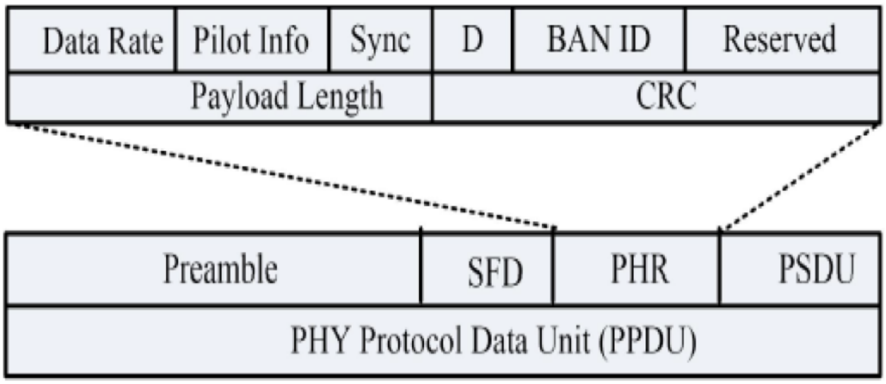
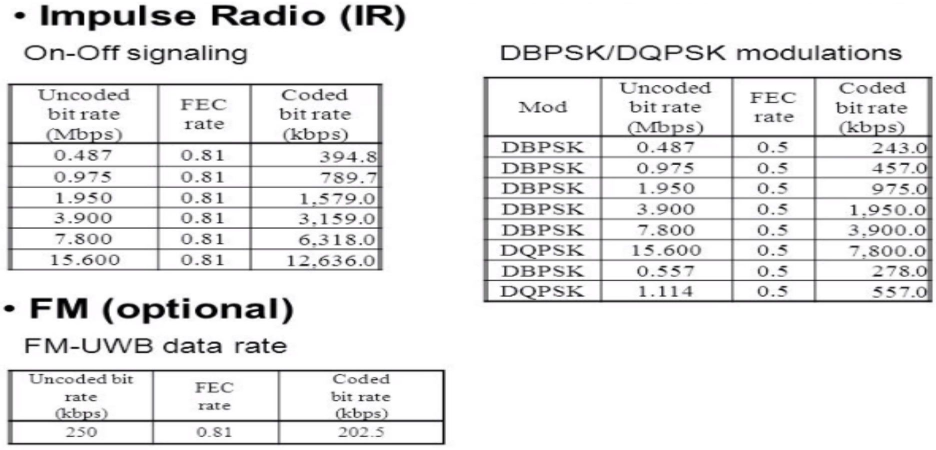


Figure 2.5: IEEE802.15.6 EFC PPDU structure

2) Ultra Wideband PHY (UWB)

UWB PHY of the WBAN occupies two frequency bands: low band and high band. And which is divided into channels which are characterized by a bandwidth of 499.2 MHz. The low band comprises 3 channels (1-3) only. The channel 2 has a central frequency of 3993.6 MHz and is considered as a mandatory channel. The high band comprises of eight channels (4-11) where channel 7 has a central frequency 7987.2 MHz and is treated as a mandatory channel, however all other channels are optional. The UWB PHY transceivers allows low implementation complexity and generate signal power levels in the order of those used in the MICS band. Fig. 2.4 shows the UWB PPDU that actually has a Synchronization Header (SHR), a PHY Header (PHR), and PSDU. The SHR is constituted by a preamble and a Start Frame Delimiter (SFD). The PHR conveys information about the data rate of the PSDU, length of the payload and scrambler seed. The information in the PHR is used by the receiver in order to decode the PSDU. The SHR is formed of repetitions of Kasami sequences of length 63. Typical data rates range from 0.5 Mbps up to 10 Mbps with 0.4882 Mbps is the mandatory one.



- **Impulse Radio (IR)**

On-Off signaling

Uncoded bit rate (Mbps)	FEC rate	Coded bit rate (kbps)
0.487	0.81	394.8
0.975	0.81	789.7
1.950	0.81	1,579.0
3.900	0.81	3,159.0
7.800	0.81	6,318.0
15.600	0.81	12,636.0

DBPSK/DQPSK modulations

Mod	Uncoded bit rate (Mbps)	FEC rate	Coded bit rate (kbps)
DBPSK	0.487	0.5	243.0
DBPSK	0.975	0.5	457.0
DBPSK	1.950	0.5	975.0
DBPSK	3.900	0.5	1,950.0
DBPSK	7.800	0.5	3,900.0
DQPSK	15.600	0.5	7,800.0
DBPSK	0.557	0.5	278.0
DQPSK	1.114	0.5	557.0

- **FM (optional)**

FM-UWB data rate

Uncoded bit rate (kbps)	FEC rate	Coded bit rate (kbps)
250	0.81	202.5

Figure 2.6: 802.15.6 UWB data rates [2]

3) Human Body Communications PHY (HBC)

HBC PHY operates in two frequency bands centered at 16 MHz and 27 MHz.HBC PHY operates in a bandwidth of approximately 4MHz. Both the bands are legitimate for the United States, Japan, and Korea. The operating band at 27MHz is treated as valid in Europe. HBC is the Electrostatic Field Communication (EFC) specification of PHY, and it includes the complete protocol for the structure of WBAN-type packets,, modulation, preamble/SFD, etc . Fig. 2.5depicts the PPDU structure of EFC .This is actually comprised of a preamble, SFD, PHY header and PSDU. The preamble and SFD represent the fixed data patterns. They represent the pre-generated ones and are sent before the packet header and payload. The preamble sequence is transmitted four times in order to ensure the packet synchronization. The same is detected by the preamble sequence. It also finds the start of the frame by the SFD detection.

2.6 Literature Review

2.6.1 Reliable data transfer in WBANs

Various techniques are currently being considered to enhance the link reliability, with emphasis on cooperative diversity techniques. In [3] authors investigate the use of cooperative diversity to enhance the transmission reliability against channel fading. Authors of [11] and [12] state that, cooperation can essentially lessen the BER and enhance the system lifetime of WBANs, when contrasted with direct transmission. Authors propose cooperative network coding in [13], for enhancing the reliability in WBANs. Authors of [14] find out the performance of receiver diversity in cooperative communications, with accurate relay positioning, for WBAN. Average bit error probability is also evaluated by taking into account the GFSK modulation with BCH coding.

Forward error correction (FEC) took the key to ensure reliable data transmission, and gradually became one of the most important key technologies for wireless sensor networks. In [15], authors compare the different FEC algorithms in accordance with their energy efficiency and the optimal number of measurement records is determined to be aggregated into one packet considering the wireless channel quality.

2.6.2 Energy efficiency of WBANs

Energy efficient communication being very important for WBANs to maximize the network life time, there have been many proposals to enhance the energy efficiency of WBANs. In [3] authors compare the performance of incremental relay based cooperative transmission and direct communication in terms of the energy efficiency. They take into account quality of service(QOS), power amplifier loss, the location of the relay, and optimum number of relays.

Researches have been done on the proposal of finding the optimum packet size to attain various targets in WBANs for instance [5], [16]. In [5] the authors deal with packet size optimization for maximizing energy efficiency with for the incremental relay based cooperative communication in WBANs based on narrow band physical layer. Here the data is forwarded by the relay only when it is needed, and it does not use any combining technique at the destination. The author in [16] addresses the packet size optimization to enhance the eneygy efficiency of WBAN. In [24] the authors discuss the idea of optimizing the frame length for maximizing the energy efficiency in IEEE 802.15.6 UWB WBAN. The packet success rates corresponding to both PHY modes defined in the standard are derived, and that is a fundamental concept in the cross layer design. In [25] the authors discuss about the frame length optimization for UWB based cooperative communication in WBANs.

In [22] authors investigate the analysis of energy efficiency of single-hop and single relay based co-operative communications in the context of multipath fading for different channel models . They also propose a model for energy efficiency in 2-hop communication in multipath fading. Adding to that, an optimal packet length to attain the maximum energy efficiency is also investigated. In [23] authors propose a relay selection procedure for energy efficient cooperative communication.

CHAPTER 3

ANALYSIS OF RELIABILITY OF IEEE 802.15.6 WBANs BASED ON UWB PHY LAYER

3.1 Introduction

Medical applications which are related to real-time gathering of patient's important information requires the reliability for data transportation to be high. But reliable delivery of medical data is a challenge, since the sensor to hub wireless link encounters extreme attenuation and shadowing which can bring about a high outage probability The instantaneous quality of wireless connection from the sensor node to the hub is dominated by body pauses. Inorder, to decrease warming of human body tissues and interference with other biosensors working in the same frequency band, there is a point of confinement on most extreme transmit power that can be utilized as a part of gadgets. For example the medical implant communication service (MICS) protocol determines that the effective isotropic radiated power (EIRP) to be 25 micro watts (-16dBm) in the frequency band of 402-405 MHz. Thus effective mechanisms must be designed to enhance reliability along with lower energy costs.

In this chapter, work done related to the reliability analysis of WBAN based on the UWB PHY layer is presented. Here packet success rate of direct, 1-relay and 2-relay cooperative communication and 2 - hop communication schemes are evaluated and compared. Packet success rate for all the communication scenarios are derived, here and analytical and simulation works are executed results are presented for in-body, on-body LOS and on-body NLOS cases.

3.2 System Model

Uplink comprises a communication from sensor nodes to the hub and downlink constitutes communication from hub to the various sensor nodes. According to the standard IEEE 802.15.6, a hub can handle up to 64 nodes.There are 11 channels defined for the UWB PHY in the 3.1- 10.6 GHz spectrum band, each with a channel bandwidth of 499.2 MHz.The nodes transmit in the orthogonal time slots. The standard emphasizes upon two modes for IR-UWB PHY: the Default mode and the High QOS (Quality of Service) mode. The default mode is used for nonspecific WBAN demands; and it features uses an on-off keying signaling (OOK) and BCH (63, 51) code for forward error correction. The high QoS mode is adopted for high-preference medical demands. A non-coherent receiver that is suboptimal in nature and is based on either energy detection (ED) or autocorrelation (AC) is considered because of the demand for the low complexity receivers. Depend on the position of the sensor nodes, the WBAN communication scenarios is classified into,

⟶ In-body communication (between an implant sensor node and the hub)
⟶ On-body communication with LOS channel. (between body surface node and hub)
⟶ On-body communication with NLOS channel

The path loss model for in-body communication is expressed by [19-21]:

$$Pl(d) = 10nlog(a_1.\frac{d}{d_o}) + L_{in} + X_{\sigma_0} \tag{1}$$

The on-body path loss model is expressed by [19-21]:

$$Pl(d) = Pl(d_o) + 10nlog\frac{d}{d_0} + X_{\sigma_i} \tag{2}$$

Where $Pl(d_o)$ is the propagation path loss at a reference distance d_o, n is the path-loss exponent; X_{σ_0} and X_{σ_i} follow zero mean Gaussian distributions with standard deviation σ_0 and σ_i in dB. In-body and on-body channel parameters values are given in Table 3.1 and Table 3.2, respectively.

Table 3.1: In-Body path loss model channel parameters based on UWB WBAN

channel parameters	value
d_o(in mm)	1
L_{in}[in dB]	10
a_1	0.98
n	4.22
σ_0	7.8
P_t (in dBm)	-10

Table 3.2: On-Body path loss model channel parameters based on UWB WBAN

channel parameters	NLOS	LOS
$d_o(mm)$	1	1
$Pl(d_o)$[in dB]	48.4	44.6
n	5.9	3.1
σ_i	5	6.1
P_t (in dBm)	-12	-12

The semantics of IEEE 802.15.6 UWB PPDU is illustrated in Fig:1. It includes the synchronization header (SHR), the physical layer header (PHR), and the physical layer service data unit (PSDU). The SHR contains a 63-bit Kasami sequence which is used in the start-of-frame delimiter (SFD); and a pool of 4 Kasami symbols in the preamble.This is being used inorder to assign 4 logical channels. The PHR is composed of PHY header (24 bits), check sequence (4 bits), plus 12 and 63 parity bits taken from a shortened BCH(40, 28) code in the default mode. The MPDU (MAC PDU) consist of 7 octets of header, 2 octets of frame checksum and a variable MAC frame body length of L_{fb} bits. The correct reception of PSDU unit implies the physical layer success probability. The MPDU utilize the BCH (63, 51) code. The MPDU is converted into blocks of length k = 51 bits, and it will be mapped to N_{cw} codewords of length n= 63 inorder to constitute a PHY frame. Therefore,

$$N_{cw} = \lceil \frac{72 + L_{fb}}{k} \rceil \tag{3}$$

If mod (72+L_{fb},k)$\neq$0, then $Nbs = kN_{cw} -$ (72+L_{fb}) pad bits are added to the endmost codeword where L_{fb} is the variable MAC frame length .

The SNR at the energy detection receiver can be written as [17],

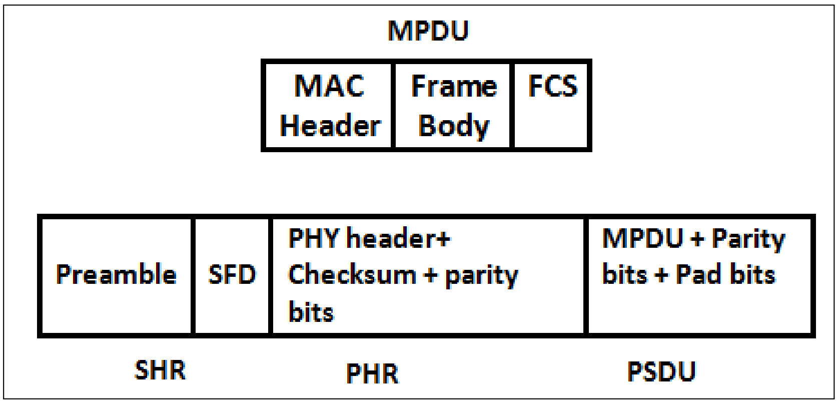


Figure 3.1: IEEE 802.15.6 UWB PPDU format.

$$SNR = \frac{2\frac{E_b}{N_o}}{4 + N_p 2TW\frac{N_o}{E_b}} \tag{4}$$

where E_b, W, N_p, N_o, T represent the integrated energy per bit, bandwidth of the signal, number of pulses per bit, noise power spectral density and integration interval per pulse, respectively. N_p is one of the optimized parameters. For the single pulse option, N_p=1 and for burst pulse case, $N_p \; \epsilon \; \{2, 4, 8, 16, 32\}$, this variable is employed to provide a balance between symbol rate and processing gain. We select the integration interval T=N_pT_p where T_p is the single pulse duration.

Performance of the direct, single relay cooperative, two relay cooperative and 2-hop schemes is compared in terms of the packet error rate and energy efficiency. Relay node is to be placed at a distance that measures exactly half of the total distance between the source and destination nodes to provide a maximum energy efficiency [5]. Equal amount of data on both s -d link and the r - d link is considered. Sice the sensor nodes transmit in orthogonal time slots, the multi-access interference effect could be neglected. A half-duplex communication is another assumption and also it is supposed that all the nodes are inside the transmission range of each other [5]. The type of the channel between the source and destination nodes in the sensor network can be on-body LOS, on-body NLOS, or in-body. The channel fades are supposed to be mutually independent for different links. In direct communication scheme, only a direct transmission between the source and the destination nodes is being permitted. If the channel between the source and the destination suffers from deep-fading and shadowing, the communication between S-D fails in the case of direct communication. The WBAN nodes experience slow fading channel because of limited mobility, and hence the channel remains in deep-fade for prolonged intervals. Therefore an automatic repeat request (ARQ)protocol would be inadequate.

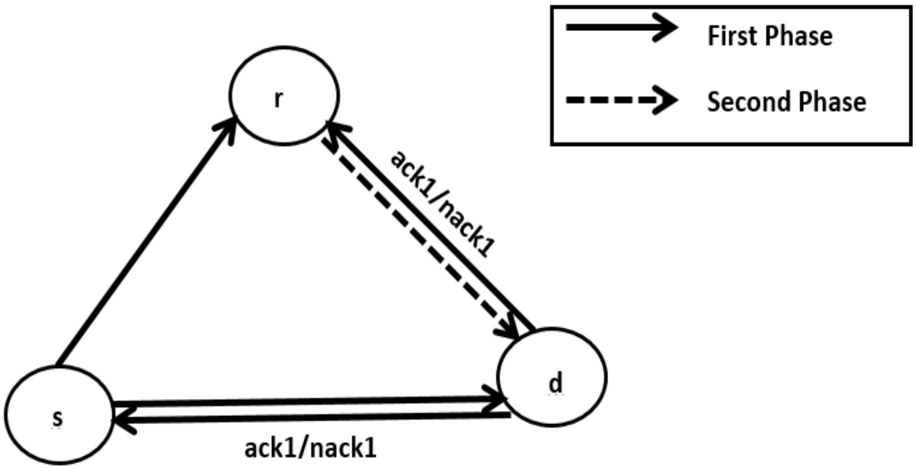


Figure 3.2: One-relay incremental cooperative communication model (ack- acknowledgement; nack- negative acknowledgement)

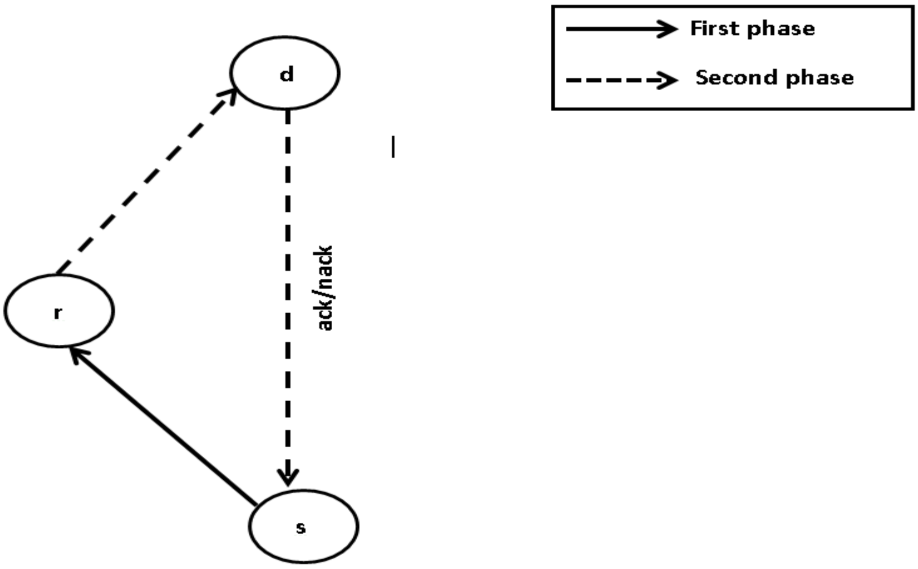


Figure 3.3: 2-hop communication model

In the second case a two-stage cooperative communication scheme is considered (see Fig 3.1)and is described as follows [5]. In the first stage of the communication, the source transmits a packet to the destination. As the the broadcast medium is wireless, relay

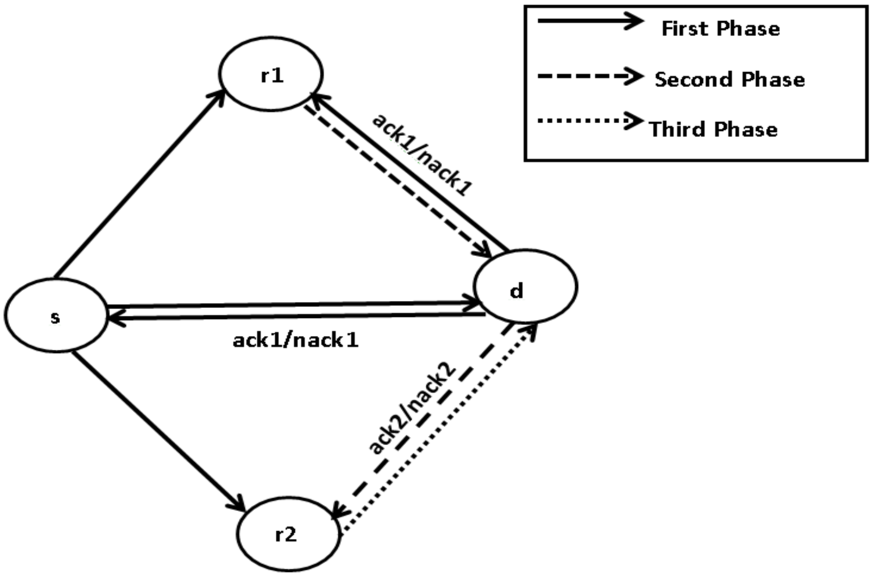


Figure 3.4: Two-stage incremental cooperative communication model

overhears the packet. In case the destination decodes the packet properly, it sends ack and relay must remain idle; and if destination does not decode packet properly, it sends nack to source. The relay, on hearing the nack, if it obtains the packet containing the data correctly in the first phase, it forwards the packet to the destination during the second phase. If the destination is able to decode the packet correctly then destination sends acknowledgment and there exists successful relaying. If destination does not decode the data properly in the second phase, the single - stage relaying fails, thus there is failure in s - d and r - d links. Whereas i f relay does not decode the packet properly in the first phase the packet is dropped. Hence single - stage relaying fails because of the failure of both s - d and s - r links. A higher layer protocol, by means of time out mechanisms and sequence numbers can effectively manage the dropped packets which are the extensions and are not described in the present analysis. In a 2-hop communication (see Fig 3.2), in the first time slot source sends packets to relay node and relay node forwards the packet to destination in second time slot.

In the fourth case, as listed above, a three-stage cooperative communication model is used, which is illustrated in Fig 3.3 [5]: Assume a given source with two potential relays r1 and r2 for help. The first phase of cooperation begins when the source transmits the data packet to destination and it is being overheard by the relays and they also attempt to decode this packet. If the destination is successful in decoding the packet, it will send back ack(ack-1) and therefore the relays remain inactive. But, if the decoding at the destination is not done properly, it will send back nack(nack-1) which the relays also receive. The second phase is initiated when the relay r1 forwards the data packet to the destination. As usual, if the destination is successful in decoding the packet, it will send back ack(ack-2). If once again the decoding is not done successfully, the destination will send back nack(nack 2), indicating the demand for another phase of communication. Upon over hearing nack 2, relay r2 forwards the data packet, initiating the third phase. It may be noted that, even if r1 does not successfully transmit in the second phase, r2 could forward the packet in the third phase, if it received the data packet properly in the first phase.

3.3 PACKET SUCCESS RATE

The expressions for calculating the packet error rate(PER) for direct, cooperative communication and 2-hop communication schemes are presented in this section. The PER analysis is depend on the channel models for WBAN.

If we know the error correction capability (t),we can calculate the code word error probability as [24],

$$p_{\text{cw}} = \sum_{j=t+1}^{n} \begin{pmatrix} n \\ j \end{pmatrix} (p_{bu})^{i} (1 - p_{bu})^{n-j}, \tag{5}$$

where p_{bu} represents the uncoded bit error probability and is given by [18]

$$p_{bu} = Q(\sqrt{SNR^{r}}) \tag{6}$$

Note that SNR^{r} can be obtained from the formula for SNR given by Equation 4.1 by replacing E_b with rE_b, where r denotes the code rate .

The coded bit error probability can be thus written as [13]

$$p_b = \frac{1}{n} p_{cw} = \frac{1}{n} \sum_{j=t+1}^{n} \binom{n}{j} [p_{bu}]^j [1 - p_{bu}]^{n-j} \tag{7}$$

If l is the total length of the PSDU, then the packet-error probability can be expressed as

$$pe = 1 - (1 - p_b)^l \tag{8}$$

Therefore, successful reception probability of PSDU is given as,

$$ps = 1 - pe \tag{9}$$

The packet success rate for the 1-relay cooperative communication scenario can be found as follows. Let $pe_{sd}, pe_{sr}, pe_{rd}$ represent the error probabilities of packet reception for the s - d, s - r and r - d links, respectively. As a single stage incremental relaying is taken into consideration, packet error happen either when both s - d and s - r links fail, or when s - d and r - d links fail, at the same time s - r link is error free. Therefore, the packet error probability for 1-relay cooperative communication can be written as,

$$pe^1_{cc} = pe_{sd} pe_{sr} + pe_{sd}(1 - pe_{sr}) pe_{rd} \tag{10}$$

Therefore the success probability for the 1-relay cooperative communication is

$$ps^1_{cc} = 1 - pe^1_{cc} \tag{11}$$

To find the packet error rate for 2-hop communication scheme, two events are considered: The transmission failure from source to relay link in the first time slot is considered as first event . The successful transmission from source to relay link in the first time slot, and transmission failure from relay to destination link in the second time slot is the second event .

Therefore, packet error rate for 2-hop communication can be written as,

$$pe_{2-hop} = pe_{sr} + (1 - pe_{sr})pe_{rd} \tag{12}$$

and the success probability for the 2-hop communication scenario is,

$$ps_{2-hop} = 1 - pe_{2-hop} \tag{13}$$

Two potential relays, r1 and r2, are assumed to be available to help the source for two-relay cooperative communication. Let packet error rates of source-to-relay r1 (s - r1), source - to - relay r2 (s - r2), relay r1 - to -destination (r1 - d) and relay r2-to-destination (r2 - d) links be represented by $p_{e,sr1}, p_{e,sr2}, p_{e,r1d}$ and $p_{e,r2d}$, respectively. The two-relay transmission fails if :

(1)All three links fail, ie; s - d, s - r1 and s - r2 fail.

(2) The direct communication and the first - stage relaying (through r1) fail; also, relay r2 cannot decode and forward the data packet because of the failure of s - r2 link.

(3) The direct communication and the first- stage relaying (through r1) fail and relay r2 successfully decodes and forward the data packet; however r2-d link fails.

(4) The s - d and s - r1 links fail but s - r2 link is error free; so r2 decodes and forwards but the transmission fails as a result of channel error in r2 - d link.

Therefore, packet error rate for two - relay cooperative communication can be written as,

$$\begin{aligned} &pe_{cc}^{2} = pe_{sd}pe_{sr1}pe_{sr2} + pe_{sd}(1 - pe_{sr1})pe_{r1d}pe_{sr2} + \\ &pe_{sd}(1 - pe_{sr1})pe_{r1d}(1 - pe_{sr2})pe_{r2d} + pe_{sd}pe_{sr1}(1 - pe_{sr2})pe_{r2d} \end{aligned} \tag{14}$$

and the probability of success for this scheme is,

$$ps_{cc}^{2} = 1 - pe_{cc}^{2} \tag{15}$$

3.4 Results and discussion

The various analytical and simulation results are obtained from the mathematical models presented in the previous section, using MATLAB.We performed Monte Carlo simulations to validate the analytical results. Tables 1,2 and 3 show the different system related parameters required for getting the results. The different system parameters related to in-body communication channel, on-body LOS and on body NLOS communication channels are got from [19], [20] and [21]. The WBAN nodes are kept at a distance separation of a maximum of 5 meters and payload size is set to a maximum of 2000 bits as per the IEEE802.15.6 standard. The path loss which is distance dependent, log normal shadowing, Rayleigh fading and additive white Gaussian noise into the simulations are also considered. The receiver is non coherent energy detection based, targeting on low complexity WBAN applications. On-off keying modulation with BCH coding is used for simulation, based upon the standard specification.

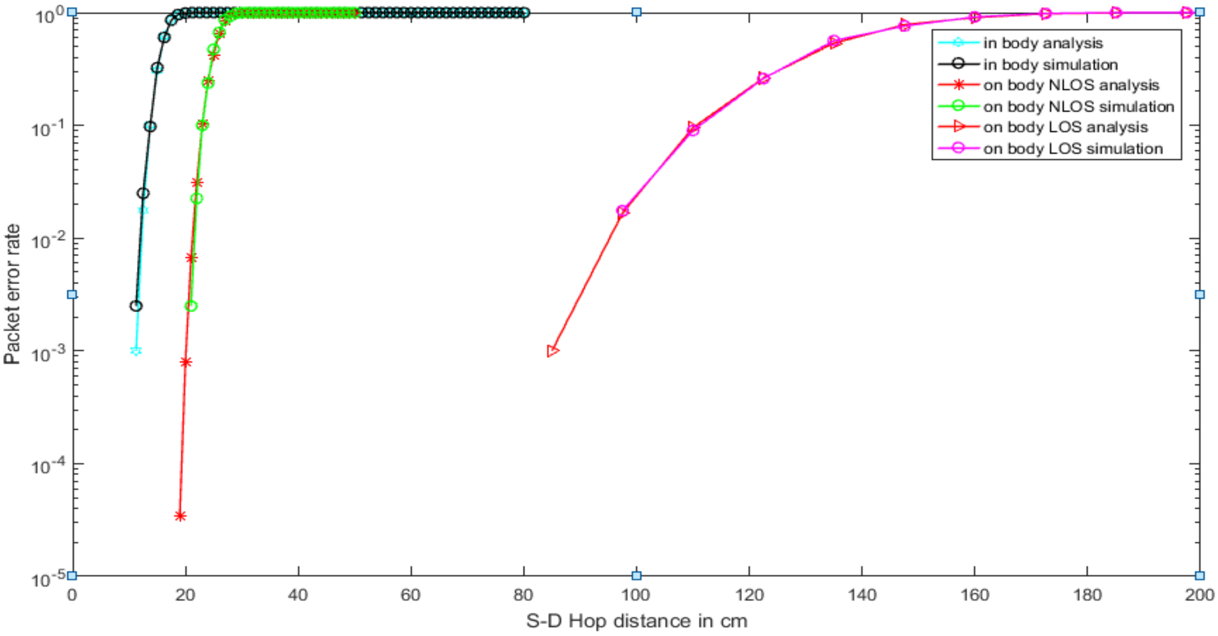


Figure 3.5: packet error rate vs source to destination hop distance for on-body LOS, on-body NLOS and in-body channels (packet size 500 bits):only direct communication

The analytical and simulation results for the PER of direct, 1-stage and 2-stage cooperative communication and 2-hop communication techniques in WBAN is explained. The packet size is set as 500 bits and the packet error rate (PER) is evaluated by changing the the source-destination distance. The cooperative relaying scheme employs hop lengths for source-to-relay and relay-to-destination links as equal to half of the distance from source to destination. The analytical and simulation results for PER in direct communication for on-body and in-body case are shown in Fig 3.5. Figures 3.6, 3.7 and 3.8 depict both the simulation and analytical results for the PER of on-body LOS, in-body and on-body NLOS communication scenarios for direct, 2-hop and cooperative communication schemes. It is noticed that the packet error rate for cooperative communication is lesser than that of direct communication and 2-hop communication, without regard of the source to destination distance. A direct link when not reliable, the cooperative communication leads to lowering of the PER because of the possibility of an alternative independent faded path through relay. Thus co-operative phenomenon can extend the hop length, for which a reliable communication can be attained. Another important comparison is the impact of the channel model on each communication scheme. For a given source-destination distance, on-body LOS has the least impact and in-body channel has the worst impact, which is quite intuitive.That is, for a given packet error rate, on-body LOS channel gives the maximum hop length and the in-body channel gives the minimum hop length. It is also observed that PER is lower when two relays are made use for cooperative communication.

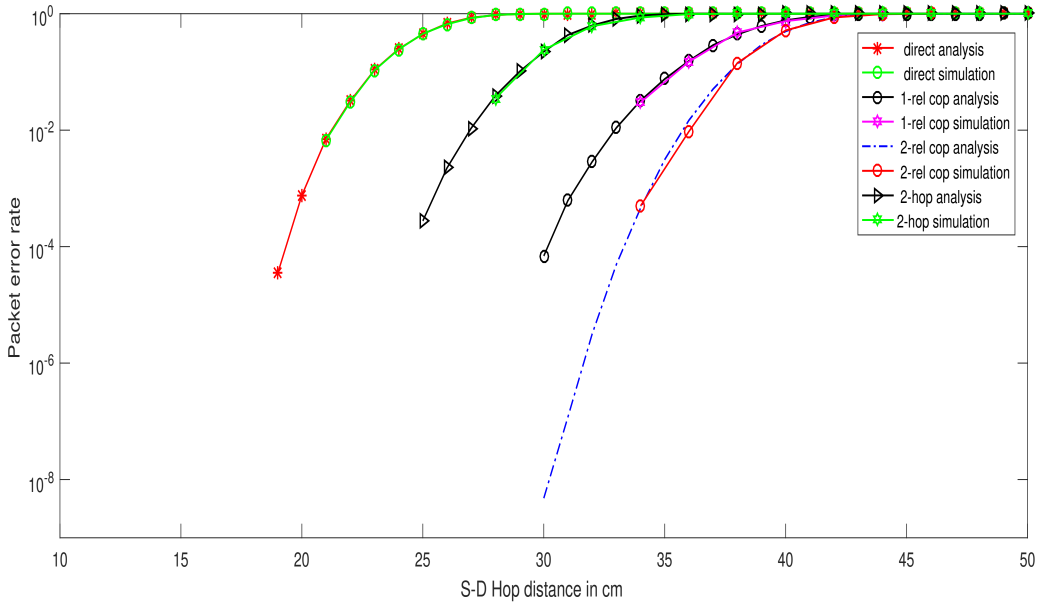


Figure 3.6: Packet error rate vs source to destination hop distance for on-body NLOS channel (packet size 500 bits):1-relay, 2-relay and 2-hop communication.

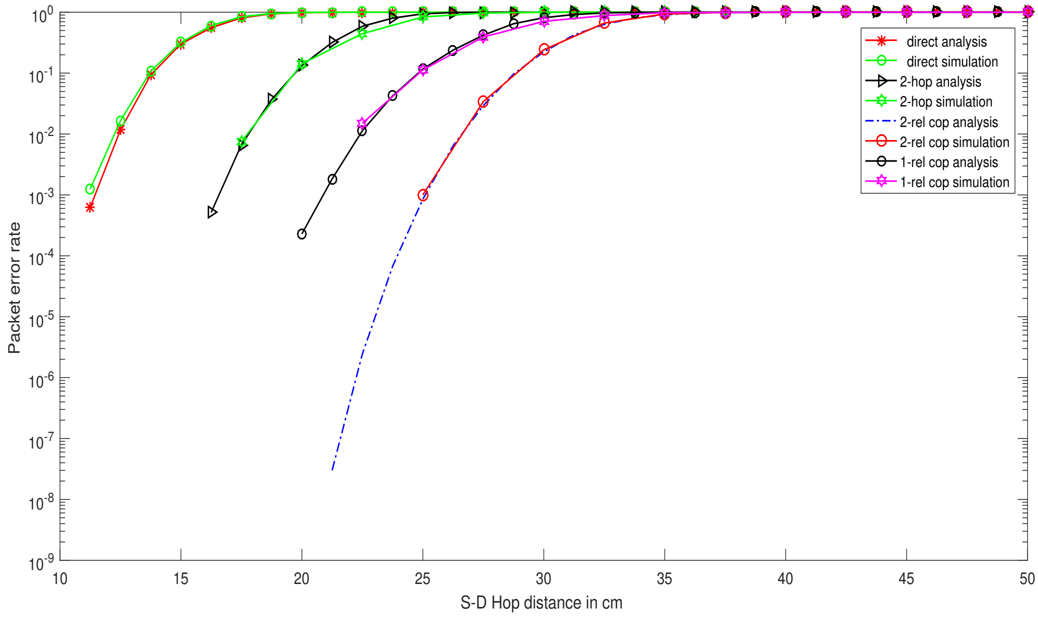


Figure 3.7: Packet error rate vs source to destination hop distance for in-body channel (packet size 500 bits):Direct, 1-relay, 2-relay, 2-hop communication.

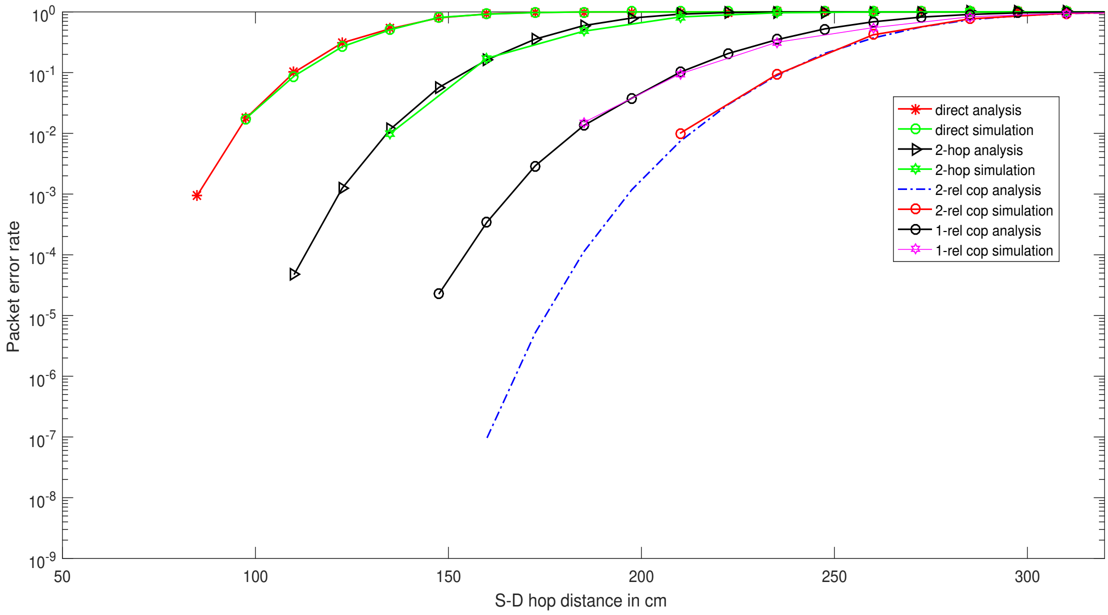


Figure 3.8: Packet error rate vs source to destination hop distance for on-body LOS channel (packet size 500 bits):Direct, 1-relay, 2-relay, 2-hop communication.

3.5 Chapter Summary

In this chapter reliability of various WBAN communication approaches, such as direct, one-relay and two-relay cooperation, and two-hop for various WBAN channel models such as in-body and on-body(both LOS and NLOS) are assessed. The results of the analysis and the simulation reveal that, cooperative communication enhances the reliability with respect to direct communication. It is observed that PER is lower when two relays are made use for cooperation compared with single- relay case. When the first stage of relaying results in a failure, the relay r2 helps to enhance the reliability of the communication. Also, as the path loss for LOS channel is lesser than when compared to a NLOS case, for a known PER, LOS channel supports a larger hop length than NLOS. It is also taken into notice that, when source to destination distance is kept fixed, PER is the worst for in-body communication when looked at on-body communication, because of the excessive path loss of the in-body communication channel.

CHAPTER 4

ANALYSIS OF ENERGY EFFICIENCY AND OPTIMIZATION OF PACKET SIZE

4.1 Introduction

Packet length is an important criteria which influences the reliability of transmission and energy consumption of a communication link. With fixed transmitting power a long packet enhances the packet error probability and thereby it increases the average number of transmissions in an automatic-repeatrequest (ARQ) system. However,for smaller packet size the rate of transmission success is supposed to be increase,but short packet will lessen the system efficiency because of the packet overhead. Hence, an optimum packet length has to be found in orderto minimize the energy consumption.

As discussed earlier, cooperative and multi-hop communications are treated as effective methods to enhance the energy efficiency of BANS [22-23]. An additional spatial diversity, as the result of cooperation by adopting an independent multipath via the relay, can enhance the reliability of transmission in opposition to various channel disorders like fading.

The energy efficiency aspect of different WBAN schemes are analyzed in this chapter and also an optimum packet size is derived for the maximization of energy efficiency based on the IR-UWB physical layer, specified in the standard IEEE 802.15.6. Inorder to compare the consumption of energy between cooperative and non cooperative transmission schemes, we take into account both transmit circuit energy and receive circuit energy. Detailed investigations are carried out to study the influence of hop distance (sensor node to hub distance) on the energy efficiency and reliability aspects of the sensor networks.The four transmission schemes include: direct transmission; single-relay cooperation; two-relay cooperation; and two hop communication. We study of the problem of an optimal packet length, with the constraint of the packet success probability, that is targeted to bring down the utilization of energy. The consequence of path loss and shadowing of the channel are accounted in the energy efficiency calculation.

4.2 ENERGY CONSUMPTION MODEL AND ANALYSIS

This portion describes the energy efficiency models of direct,1-stage and 2-stage cooperative communication, and 2-hop communciations in detail. The energy resources available for the sensors are limited and also the sensors need a long operation time. Re-charging the battery of the hub is a feasible task and thus the sensors and hub have dissimilar energy consumption costs. Therefore, the uplink energy consumption cost, i.e, from the sensors to the hub is higher compared with the case of the reception on the downlink.

Let E_{enc}/E_{dec} represents the energy needed for data encoding/decoding. Also let E_{tx-ack}/E_{rx-ack} denotes the energy needed for the transmission/reception of acknowledgment packets. We denote by C_{r-dl}, C_{t-dl}, C_{r-ul} and C_{t-ul}, the energy consumption costs for reception and transmission on the downlink and uplink scenarios respectievely. Let E_{tx-p} represents the total energy needed for the pulse transmission (includes the processing energy of the electronic circuit and radiation energy) and E_{rx-p} represents the total energy utilized by electronic circuits for the pulse reception. Let R represents the coding rate of data payload, indicated as number of bits per symbol and β be modulation index (1/2 for on-off signalling and 1 otherwise).

4.2.1 DIRECT COMMUNICATION

We considered that l encoded bits are there in the data packet for transmission from a sensor to the hub. The energy needed for transmitting a packet of l bits is given by

$$E_{tx-d} = \frac{\beta N_p E_{tx-p} C_{t-ul}}{R} l + C_{t-ul} E_{enc} \tag{16}$$

The encoding energy for BCH code can be calculated as,[26]

$$E_{enc} = (2nt + 2t^2)(E_{add} + E_{mul}) \tag{17}$$

where n is the codeword length, t is the error correcting capability,E_{add} is the addition energy consuption E_{mul} is the multiplication energy consumption.

The energy utilized to receive the data packet could be expressed as,

$$E_{rx-d} = \frac{N_p E_{rx-p} C_{r-ul}}{R} l + C_{r-ul} E_{dec} \tag{18}$$

The decoding energy(E_{dec}) for BCH code can be calculated as,[27]

$$E_{dec} = (4nt + 10t^2)E_{mul} + (4nt + 6t^2)E_{add} + 3tE_{inv} \tag{19}$$

where E_{inv} is the energy consumed for inversion operation.
Similarly, the energy utilization related with transmission and reception of acknowledgment packets of size l_{ack} bits are given by

$$E_{tx-ack} = \frac{\beta N_p E_{tx-p} C_{t-dl}}{R} l_{ack} \tag{20}$$

$$E_{rx-ack} = \frac{N_p E_{rx-p} C_{r-dl}}{R} l_{ack} \tag{21}$$

Let E_0 represents the total energy that is needed for transmission and reception of the acknowledgment packets and data encoding and decoding,

$$E_0 = E_{tx-ack} + E_{rx-ack} + C_{t-ul} E_{enc} + C_{r-ul} E_{dec} \tag{22}$$

Therefore, the total energy spent for transfering a data packet of size l bits for the direct communication (1-hop) can be expressed as,

$$E_{total}^{1-hop} = \frac{\beta N_p E_{tx-p} C_{t-ul}}{R} l + \frac{N_p E_{rx-p} C_{r-ul}}{R} l + E_o = x(N_p l/R) + E_o \tag{23}$$

where

$$x = \beta E_{tx-p} C_{t-ul} + E_{rx-p} C_{r-ul} \tag{24}$$

Energy efficiency is formalized as the fraction of favorable energy for successful communication of a packet of L_{fb} bits to the total consumed energy, it can be computed as,

$$\eta_{DC} = \frac{x(N_p L_{fb}/R)}{x(N_p l/R) + E_o} ps \tag{25}$$

where p_s is the packet success rate, obtained in the previous chapter for different communication schemes.

4.2.2 SINGLE-RELAY COOPERATIVE COMMUNICATION

To compute the average total energy consumption per bit of cooperative communication, three events are taken into consideration. The first event taken into account is the successful transmission of source to destination link(s-d) in the 1st time slot which consumes energy $E_1$with probability $(1 - pe_{sd})$. The energy spent is

$$E_1 = E_{tx-d} + 2E_{rx-d} \tag{26}$$

because both the receiver and the relay receives the packet. The second event considered is the transmission failure of source to destination link(s-d) and source to relay link(s-r) in the 1st time slot together, which spend an energy E_2; this event occurs with probability $pe_{sd}pe_{sr}$. E_2 can be expressed as,

$$E_2 = E_{tx-d} + 2E_{rx-d} \tag{27}$$

The third event considered is the transmission failure of source to destination link, and the successful transmission of source to relay link in the 1st time slot with probability $pe_{sd}(1 - pe_{sr})$. The energy spent can be expressed as,

$$E_3 = 2E_{tx-d} + 3E_{rx-d} \tag{28}$$

Therefore, total energy expenditure of cooperative communication on the average can be expressed as,

$$E_{total}^{1-cc} = E_1(1 - pe_{sd}) + E_2 pe_{sd} pe_{sr} + E_3 pe_{sd}(1 - pe_{sr}) \tag{29}$$

The total energy spent for the transmission of acknowledgment packets in 1-relay cooperative communication can be written as,

$$E_{cc,ack}^{1} = (E_{tx-ack} + 2E_{rx-ack})[1 + pe_{sd}(1 - pe_{sr})] \tag{30}$$

Here $E_{cc,ack}^{1}$ is total energy expenditure related with transmission of either ack or nack by the destination in first and second phase.Transmission of ack/nack in the second phase happens with probability $pe_{sd}(1 - pe_{sr})$.

Therefore, energy efficiency for single -stage cooperative scheme can be written as,

$$\eta_{cc}^{1} = \frac{x(N_p L_{fb}/R)}{E_{total}^{1-cc} + E_{cc,ack}^{1}} ps_{cc}^{1} \tag{31}$$

4.2.3 2-HOP COMMUNICATION

Energy efficiency calculation of 2 - hop communication for narrowband WBAN communication is proposed in [9]. We do similar calculation for impulse-radio UWB PHY. In order to compute the total energy utilization of 2 - hop communication, two events are taken into account: the first event is the successful transmission from source to relay link in the 1st time slot and it consumes energy E_1; this event occurs with probability $(1 - pe_{sr})$. Event 2 is the transmission failure of source to relay link in the 1st time slot which utilize an energy E_2 with probability pe_{sr}. E_1 and E_2 can be written as,

$$E_1 = 2E_2 = 2\{E_{tx-d} + E_{rx-d}\} \tag{32}$$

The total avaerage energy consumption of 2 - hop communication is expressed as,

$$E_{total}^{2-hop} = E_1(1 - pe_{sr}) + E_2 pe_{sr} \tag{33}$$

The total energy spent for transmission of acknowledgment packets in 2-hop communication $(E_{2-hop,ack})$, can be written as,

$$E_{2-hop,ack} = (E_{tx-ack} + E_{rx-ack})[1 - pe_{sr}] \tag{34}$$

Here $E_{2-hop,ack}$ is the energy spend for the transmission of either ack or nack by the destination when the relay decodes and forwards the packet to the destination (occurs with probability $(1 - pe_{sr})$)

Therefore energy efficiency of 2-hop communication can be written as,

$$\eta_{2-hop} = \frac{x(N_p L_{fb}/R)ps_{2-hop}}{E_{total}^{2-hop} + E_{2-hop,ack}} \tag{35}$$

4.2.4 TWO-RELAY COOPERATIVE COMMUNICATION

Energy efficiency calculation of 2-relay cooperative communication for narrowband WBAN communication is done in [4], which is extended to IR-UWB PHY. Inorder to compute the energy efficiency, we take into consideration the different events for packet transmission as follows:

(1) Direct communication is sucessful, with probability (1-pe_{sd}), and because of the broadcast nature of the medium the two relays overheard the data sent from sourse. Therefore, total energy consumed in this case is $(E_{tx-d} + 3E_{rx-d})$

(2)The s - d link fails, whereas s-r1 link is error free, and the relay r1 decodes and forwards the packet with probability $p_{e,sd}(1 - p_{e,sr1})$, causing an energy expenditure in total as $(2E_{tx-d} + 4E_{rx-d})$

(3) Both s - d and s - r1 links fail, whereas s-r2 link is error free. The probability corresponding to this event is $p_{e,sd}p_{e,sr1}(1 - p_{e,sr2})$ and the energy expense is same as in case 2.

(4) The s - d link fails, whereas s-r1 link is error free, and relay r1 forwards the packet after decoding, but r1 - d link and s - r2 are in error and the packet is discarded at the relay r2. The probability corresponding to this event is, $p_{e,sd}(1 - p_{e,sr1})p_{e,r1d}p_{e,sr2}$ and the energy expense is same as in case 2.

(5) The s - d link fails, whereas s - r1 link is error free, and the relay r1 forwards the packet after decoding, but r1 - d link is in error and first-stage relaying fails. Though, the s - r2 link is error free, and the relay r2 forwards the packet after decoding. The probability of this event is $p_{e,sd}(1 - p_{e,sr1})p_{e,r1d}(1 - p_{e,sr2})$ and the energy consumed in this case is $(3E_{tx-d} + 5E_{rx-d})$

(6) The s-d link, s-r1 link and s-r2 link all fail with probability $p_{e,sd}p_{e,sr1}p_{e,sr2}$ and the energy consumed in this case is $(E_{tx-d} + 3E_{rx-d})$.

Therefore, the average energy consumption in total for the data packet transmission can be calculated as,

$$\begin{aligned} E^{2-cc}_{total} &= (E_{tx-d} + 3E_{rx-d})(1 - pe_{sd}) + (2E_{tx-d} + 4E_{rx-d})pe_{sd}(1 - pe_{sr1}) \\ &+ (2E_{tx-d} + 4E_{rx-d})pe_{sd}pe_{sr1}(1 - pe_{sr2}) + (2E_{tx-d} + 4E_{rx-d})Pe_{sd}(1 - pe_{sr1})pe_{r1d}pe_{sr2} \\ &+ (3E_{tx-d} + 5E_{rx-d})pe_{sd}(1 - pe_{sr1})Pe_{r1d}(1 - pe_{sr2}) + (E_{tx-d} + 3E_{rx-d})pe_{sd}pe_{sr1}pe_{sr2} \end{aligned} \tag{36}$$

Likewise, the energy consumption in total for transmission of an ack/nack packet can be calculated as,

$$\begin{aligned} E^{2}_{cc,ack} &= (E_{tx-ack} + 3E_{rx-ack}) + (E_{tx-ack} + 3E_{rx-ack})pe_{sd}(1 - pe_{sr1}) \\ &+ (E_{tx-ack} + 2E_{rx-ack})pe_{sd}(1 - pe_{sr1})pe_{r1d}(1 - pe_{sr2}) \\ &+ (E_{tx-ack} + 2E_{rx-ack})pe_{sd}pe_{sr1}(1 - pe_{sr2}) \end{aligned} \tag{37}$$

The first term in (37) relates to the energy spent in connection with the ack/nack transmission in the first phase by the destination (ack transmission probability is (1-pe_{sd}) nack transmission is with probability pe_{sd}). In the second phase also either ack or nack is transmitted, by the destination the probability by which r1 decodes and forwards the packet to the destination is $pe_{sd}(1 - pe_{sr1})$, the second term in (37) denotes the energy expenditure related with this case. Relay r2 forwards the packet in the third phase which is followed by another series of ack/nack transmissions. This occurs as a result of the following reasons: (i) failure of direct communication and r1-d link,while s-r2 link is error free; and (ii) failure of both s - d and s - r1 links, while s -r 2 link is error free. The third and fourth terms in (37), represent energy expenditure with respect to these two case.

Therefore, energy efficiency of two-stage cooperative communication can be calculated as :

$$\eta_{cc}^{2} = \frac{x(N_p L_{fb}/R)}{E_{total}^{2-cc} + E_{cc,ack}^{2}} ps_{cc}^{2} \tag{38}$$

4.2.5 Optimal packet size

The optical packet size is charecterized by the payload size that maximizes the energy efficiency, and can be derived by taking$\frac{d\eta}{dL_{fb}} = 0$ where η denotes the energy efficiency of the respective communication scheme. In the case of direct communication, the optimal packet size can be derived as [9],

$$L_{1-hop}^{Opt} = -\frac{v}{2} + \frac{1}{2}\sqrt{v^2 - \frac{4v}{ln(1 - pe)}} \tag{39}$$

where $v = \frac{E_o R}{xwN_p}$, w=1+$\frac{r}{k}$, $r = \frac{k}{n}$ is the code rate. The expressions of optimal packet size for cooperative communication and 2-hop communication schemes cannot be obtained in closed form. However, we can obtain them using numerical methods. UWB system parameters and values employed for numerical results are given in Table 4.1.

Table 4.1: UWB System Parameters [19], [20], [21]

N_p	32
W	499.2MHz
T	2ns
C_{t-ul}	0.9
C_{r-ul}	0.1
C_{r-dl}	0.9
C_{t-dl}	0.1
E_{tx-p}	20pJ
E_{rx-p}	2.5nJ
l_{ack}	144
$N_0(dBm)$	-100

4.3 Results and discussion

Figure 4.1 shows the comparison of the energy efficiency of a single stage cooperative communication and direct communication for the NLOS in an on-body communication channel versus transmit power for different s-d hop distances.We consider that the source and the relay transmit with same powers, as it is simple to implement because optimization space is one-dimensional. For very small distances the energy efficiency is constant, because the transmit power constitutes a smaller part of the total utilized power in the whole process for small distances. For larger distances, transmit power actually comprises a larger part in the total utilized power, and hence energy efficiency varies sighnificantly with transmit power. The results clearly indicate that in source-destination distances below threshold, direct transmission is very much energy efficient than cooperation, that is the power consumption due to cooperation (receiving and processing process) is more than its gains (i.e, saving the transmit power). For distances greater than threshold, the cooperation gain increases as the transmit power starts occupying a major part of the total power consumed. The result highlights that as the distance increases energy efficiency falls down due to high packet error rate.It is also noticed that energy efficiency of direct communication falls quickly than cooperative communication due to its high packet error compared to cooperative communication. Further, for for large distances the energy efficiency of direct communication is very low for all the values of transmit power; i.e; for large distances whatever be the transmit power the energy efficiency of direct communication is very low, see Figs 4.1 (e) and (f). Similar results are obtained when the same experiments are performed for the 2-relay case. From the results we can conclude that, for larger distances it is better to go for cooperative communication instead of direct link where energy wastage is more. Cooperation can provide certain gains with regards to the transmit power required, due to spatial diversity which it adds to system. The additional processing and receiving power consumption at the relay and destination nodes needed for cooperation is clearly a trade-off when applying cooperation.While considering the network design we should treat both the positive and negative aspects. For calculations of energy efficiency, appropriate packet size for a given link length could be estimated by simulations.

Fig 4.2 shows energy efficiency against packet size for different bot error probabilities in an on-body LOS channel for the case of direct communication. It is noticed that optimum packet size increases rapidly as the probability of bit error decreases. From Fig: 4.3 it is observed that for fixed bit error probability the energy efficiency of cooperative scenario is lower compared to direct communication because of extra processing and receiving energy at the relays. It is noticed that for very small bit error probability, the corresponding energy efficiency is high due to low enerrgy wastages and the energy wastage increases with bit error probility resulting small energy efficiency.

EE is analyzed for various hop-lengths and multiple packet sizes, with the maximum size being 2000 bits as specified by the standard [1], in order to examine the greatest achievable value of efficient energy. Figs 4.4, 4.5 and 4.6 depict energy efficiency vs packet size for in-body, on-body NLOS and on-body LOS channels respectively with two different hop lengths. Below an optimal packet size, the energy efficiency decreases due to the overhead proportion that is high when compared with the payload size. If the size of packet is larger than an optimal value, energy efficiency decreases due to the rise in PER. But for better channel conditions, an optimal behavior is not seen. In such scenario, the PER is comparatively low thus the energy efficiency is not influenced by a packet size variation. But if the size of the packet is very small, then there is an increased overhead in each packet which will limit the energy efficiency. When the source to destination distance is increased to large values, an optimal behaviour is not exist for direct communication and the energy efficiency is approximately equal to zero, because the PER of direct communication become one at this distance. Similarly, an optimal behavior is not seen in the case of small PER. Obviously, in error-prone channel, the cooperative communication will support a higher packet size and thus maximum energy efficiency is obtained.

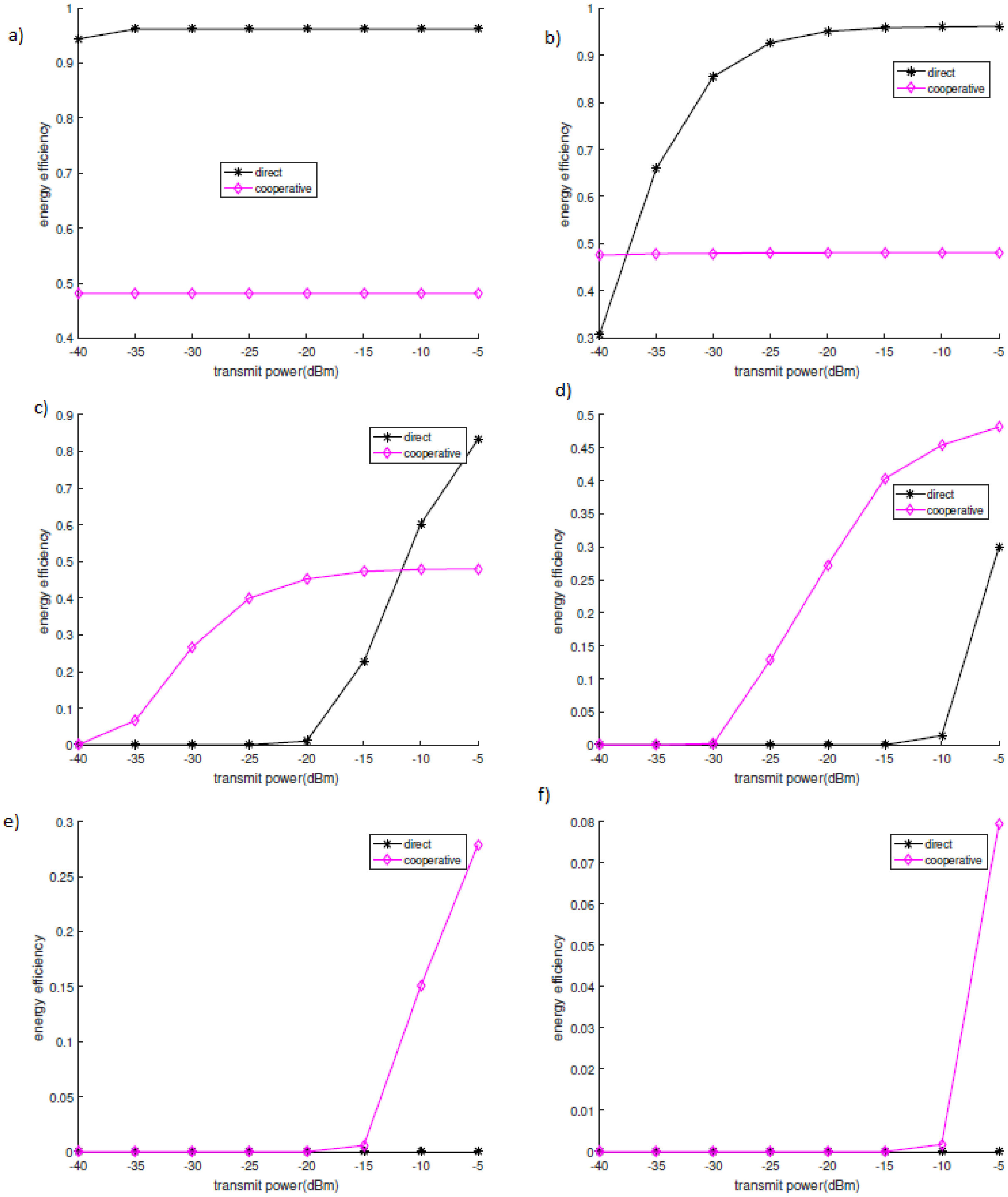


Figure 4.1: Energy efficiency vs transmit power for on-body NLOS communication. Figures (a)-(f) denote the simulation plots for s-d hop distance of about 7cm, 17cm, 47cm, 67cm, 117cm and 147cm, respectievely (packet size 500 bits, $p_b = .04$).

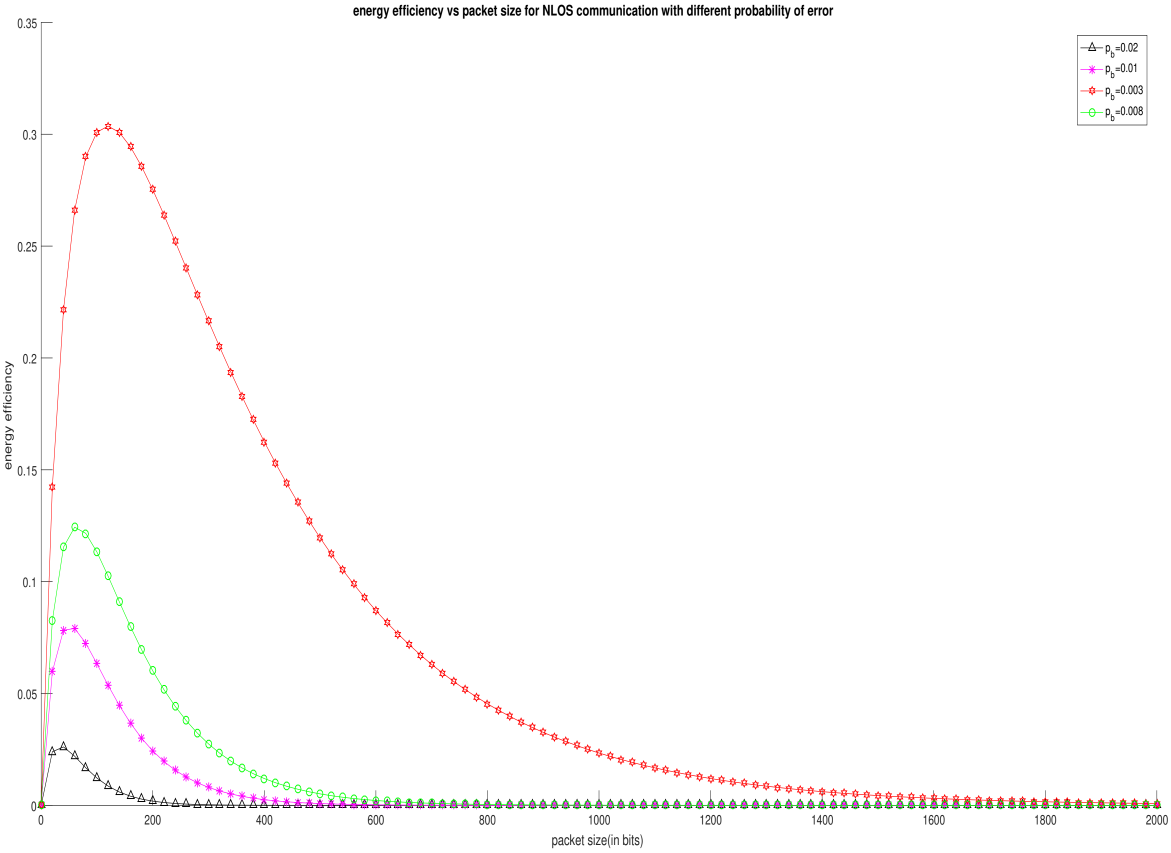


Figure 4.2: Energy efficiency vs packet size for on-body LOS direct communication for different bit error probability (s-d hop distance= 100cm)

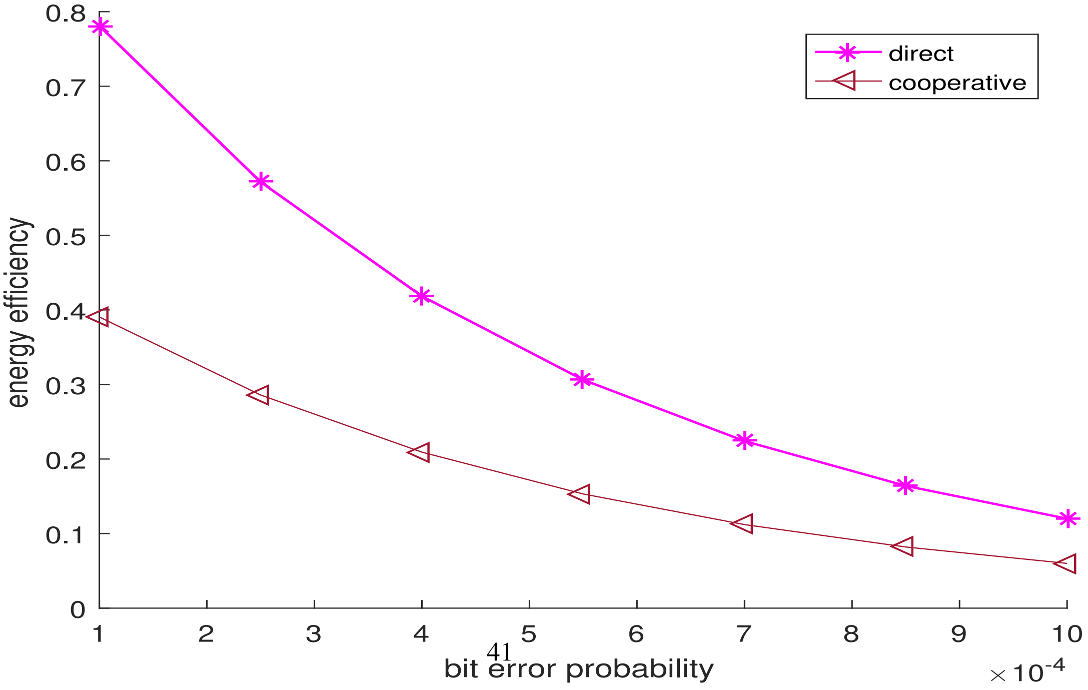


Figure 4.3: Energy efficiency v/s bit error probability for on-body LOS direct and 1-relay co-operatove communication. (s-d hop distance =27 cm)

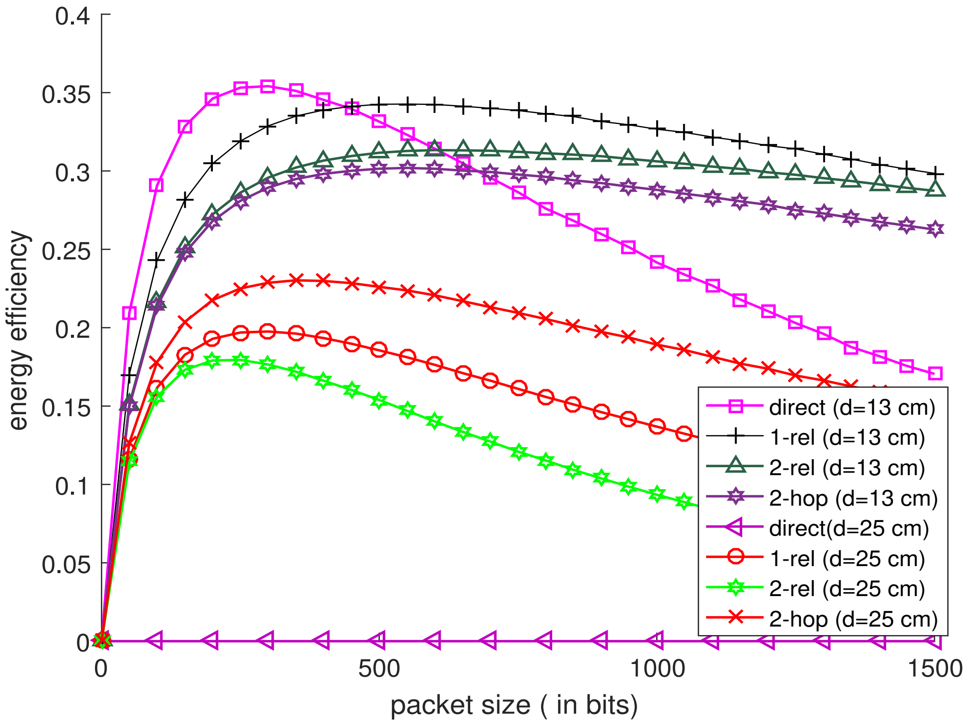


Figure 4.4: Energy efficiency vs packet size for in-body channel

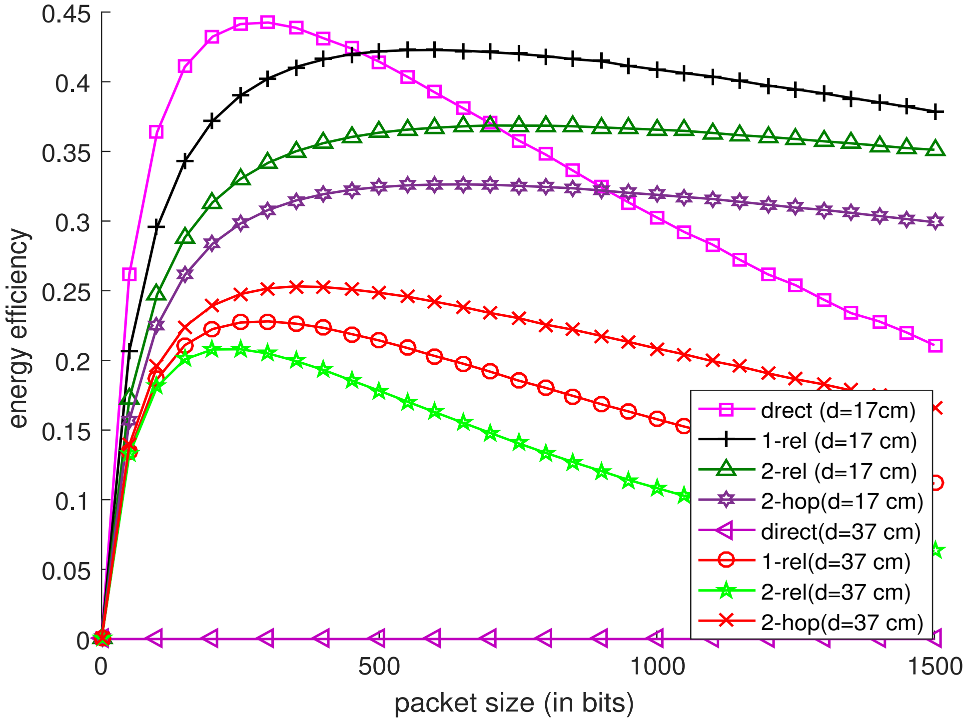


Figure 4.5: Energy efficiency vs packet size for on-body NLOS channel

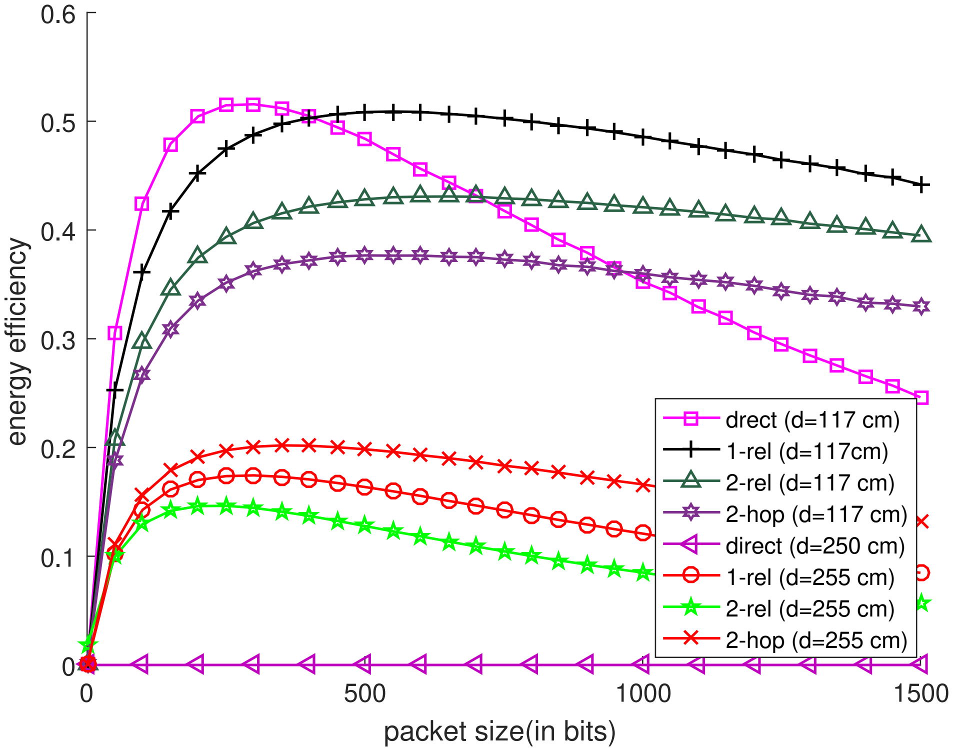


Figure 4.6: Energy efficiency vs packet size for on-body LOS channel

Figs 4.7-4.10 show simulation results of the energy efficiency against the source-to-destination hop distance for a fixed payload size. There exists a threshold distance which separates the area in which direct communication is superior from the area where co-operative communication is more beneficial. Below the threshold, eventhough the co-operative communication increases the reliability (lower PER), the energy efficiency is affected more by the extra amount of transmissions and decoding aspects by the relays. From Fig: 4.7 it is observed that energy efficiency drops quickly for large packet size due to higher packet error, and also it is observed that smaller packet length will give higher hop length than large packets,because of low packet error loss. Fig 4.8 reveals that for in-body communication the energy efficiency diminishes considerably at a hop length of 20 cm for direct communication while a one-relay and two - relay cooperation enhance the hop distance to about 35 cm and 2-hop communication extends the hop distance to about 42 cm. The values corresponding for on-body LOS communication are 210 cm, 430 cm and 600 cm.Results reveal that, a two-realy technique in co-operative

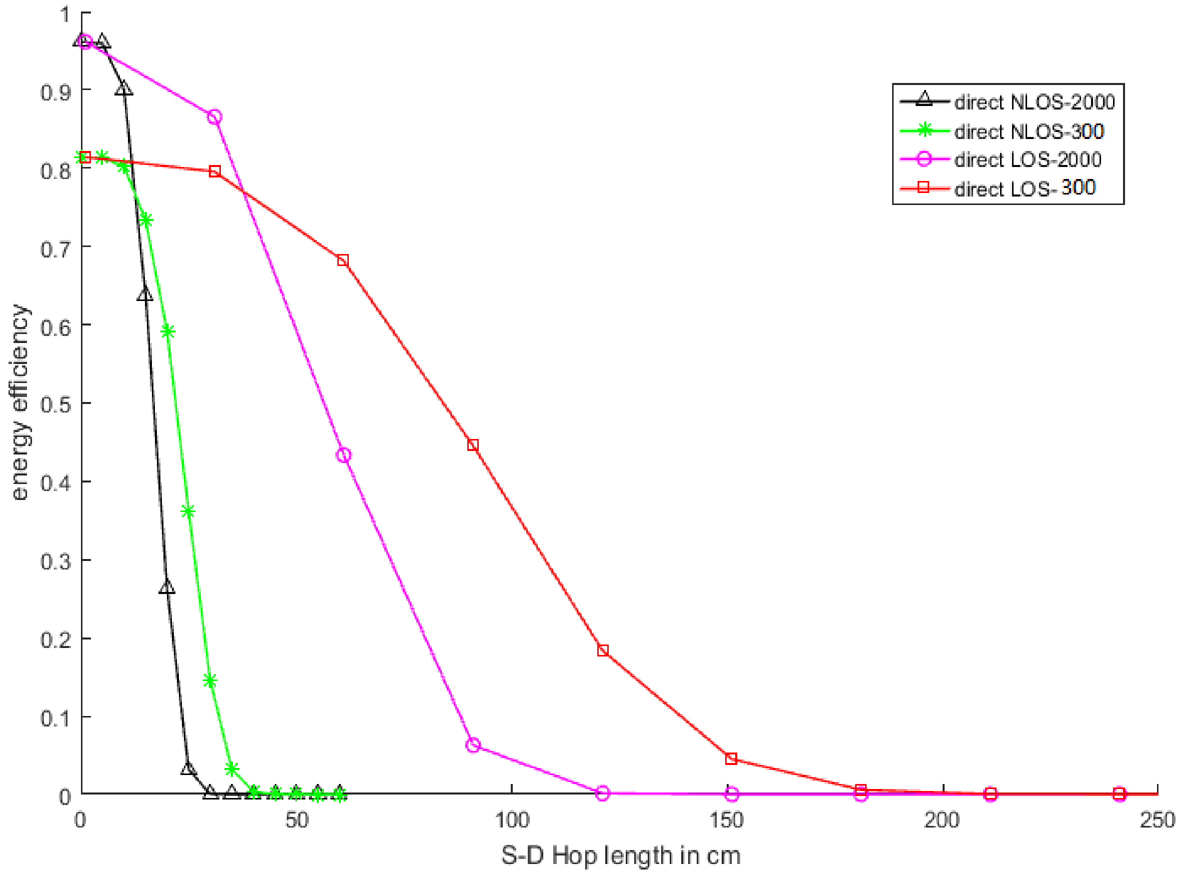


Figure 4.7: Energy efficiency v/s source to destination hop distance for on-body LOS channel for packet size of 2000 bits and 300 bits for direct communication .

scheme does not increase energy efficiency if when compared with one-relay cooperation because of the extra processing and receiving enegy at the two relays.The two-relay does not extend the hop length when compared with one-relay,although it improves the communication reliability as the total energy utilized when two relays involved is greater than the energy efficiency enhancement induce by low PER. Tables 4.2-4.4 consolidate the maximum achievable hop distance, threshold hop lengths and optimal packet size for the various cases.

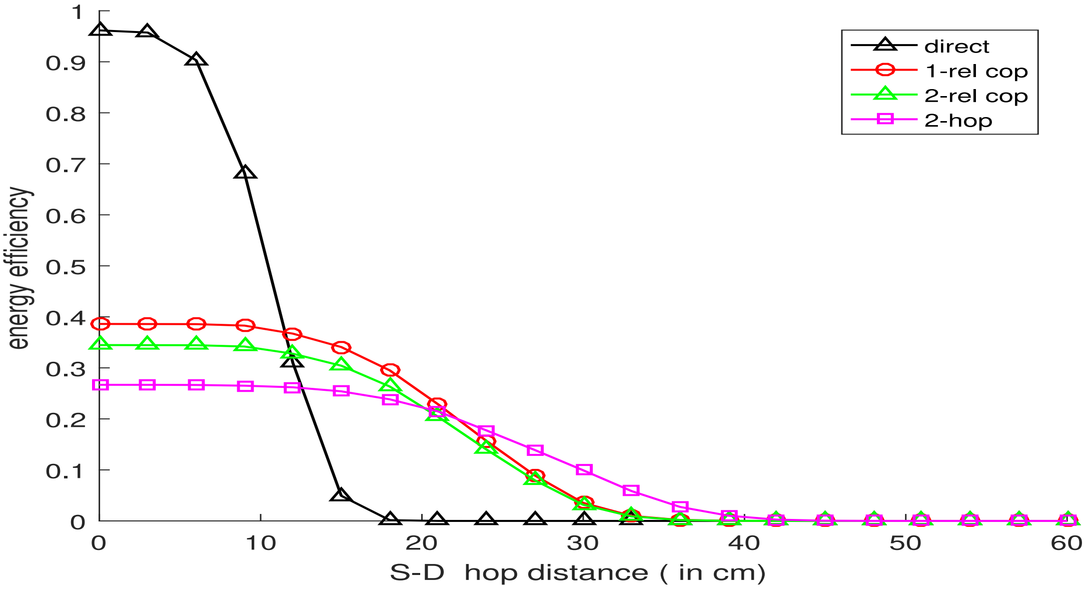


Figure 4.8: Energy efficiency v/s source to destination hop distance for in-body channel (packet size 350 bits).

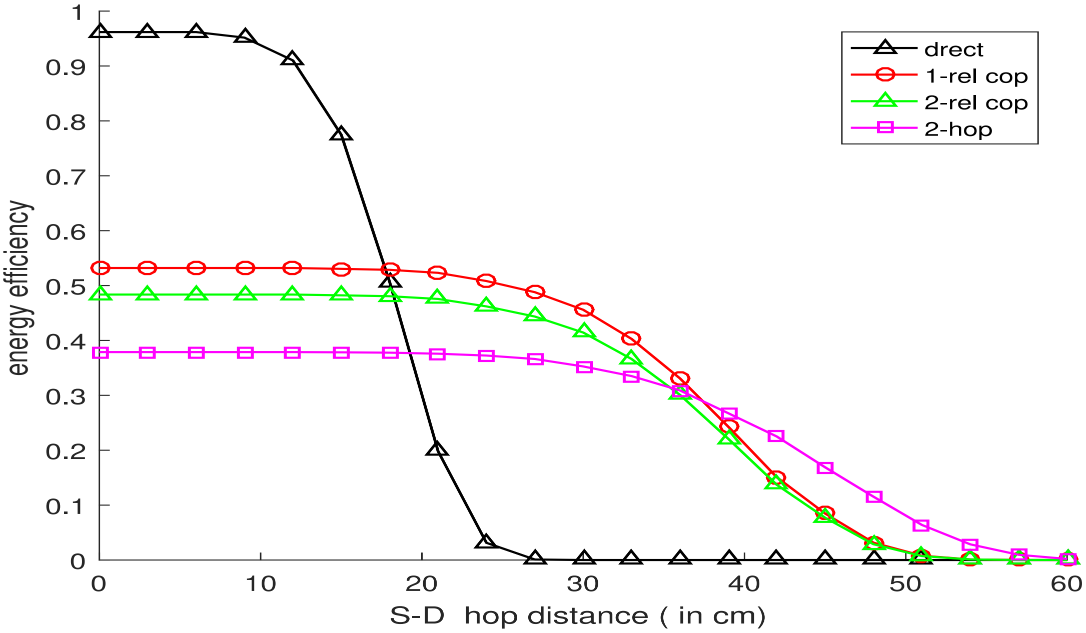


Figure 4.9: Energy efficiency v/s source to destination hop distance for on-body NLOS channel (packet size 350 bits).

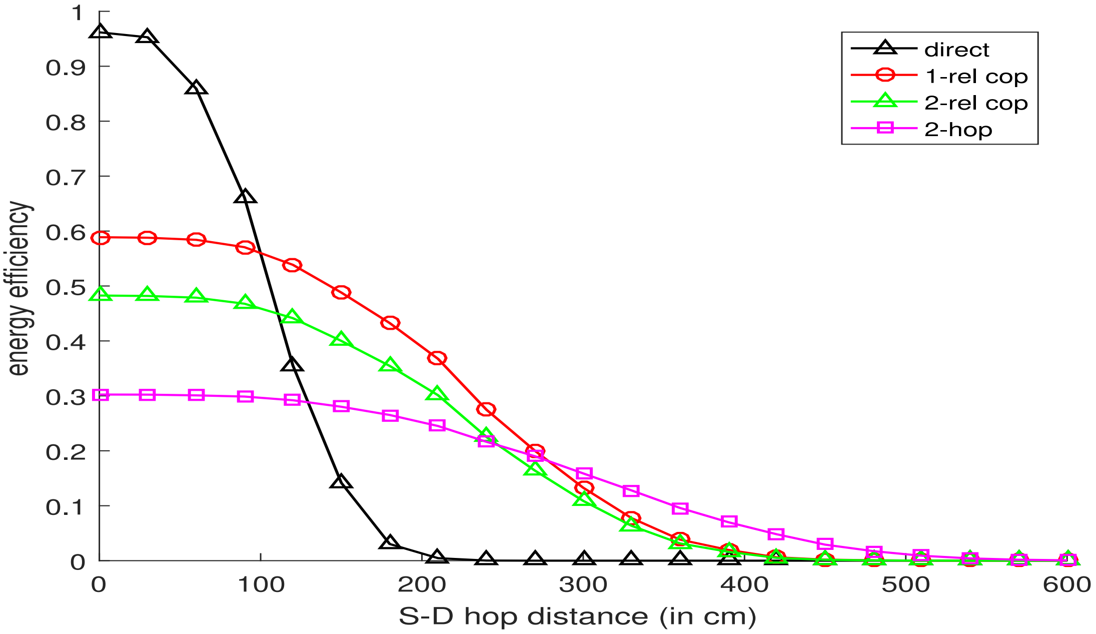


Figure 4.10: Energy efficiency v/s source to destination hop distance for on-body LOS channel (packet size 350 bits).

Table 4.2: Threshold value of source to destination hop length for packet size=350 bits .

WBAN Scenarios	Threshold distance(in cm)
in-body	14
on-body (NLOS)	19
on-body (LOS)	130

Table 4.3: Comparison of maximum achievable hop distance (cm) providing energy efficient communication for different communication scenarios

WBAN Scenarios	in-body	on-body (NLOS)	on-body (LOS)
Direct	18	28	220
1-relay Cooperative	37	52	440
2-relay Cooperative	37	52	440
2-hop	42	60	600

Table 4.4: Comparison of optimal packet size (bits)

WBAN Scenarios	in-body	on-body (NLOS)	on-body (LOS)
Direct	300	300	300
1-relay Cooperative	600	650	500
2-relay Cooperative	700	800	680
2-hop	550	650	600

4.4 Conclusion

We evaluated the energy efficiency of WBANs based on UWB PHY layer defined in the standard IEEE 802.15.6.Both in-body and on-body(both LOS and NLOS) communication scenarios in WBAN have been assessed by counting the influence of packet success rate in the analysis.Energy efficiency maximization was assessed and investigation were conducted to find the optimum packet size.It has been observed that the optimum packet size foe enregy- efficient cooperative and 2-hop communication is greater than direct communication.Under poor channel conditions the use of cooperative and 2-hop strategies will enhance the energy- efficiency, support higher packet size and expand the hop distance.The results also prove that there is a threshold which exists and separates the regions of the direct transmission from the regions where cooperation is advantageous with respect to the energy efficiency. In the case of in-body communications, if the threshold is below about 14 cm, cooperation overhead is greater than gains acquired and it is well noted that direct communication proves to be highly energy efficient.For an on-body LOS communication, the threshold distance equals about 130 cm for a particular set of channel parameters. If the distance is greater than the threshold value, the gains in co-operative method are attained.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Thesis Summary and Conclusion

This chapter portrays the significance of the work done in this thesis.The fundamental goal of the thesis was to propose measures to enhance the communication reliabilty and energy efficiency of WBANs. So we investigated the use of cooperation and 2-hop communication schmes in enhancing the performance metrics mentioned above.The UWB PHY layer specifications defined in the standard IEEE 802.15.6 were considered for analysis. Chapter 3 considered the analysis of communication reliability of WBANs for 1) Direct communication 2) cooperative communication (both 1-relay and 2-relay case) and 3) 2-hop communication with decode and forward relays. In Chapter 4, energy consumption models for WBANs based on the UWB PHY layer were formulated. As a result of various analytical and simulation studies, we have shown that, if the direct transmission is compared with the incremental relay based cooperative transmission techniques between source and destination, the latter actually increases the reliability of the communication as well as the energy efficiency. The results also indicate that there is a threshold which separates the regions of the direct transmission from the regions where cooperation is advantageous with respect to the energy efficiency.The results obtained, gives some guidelines in finding out the optimal number of relays for a given communication scene. We also notice that an increase of a number of relays is not always advantageous.One must be a little cautious before applying the technique of the cooperative communication in sensor networks. The three steps have to be taken into account:1) Whether the cooperation technique is to be applied or not. 2) If it is decided to choose a partner or relay for cooperation, how it is to be done efficiently?. 3) The number of the relays to be determined inorder to be assigned to help the source which actually is an important factor in cooperative communication scenario. For maximising the energy efficiency in error prone channels, the optimal size of the packet was also estimated. The same is greater than for direct communication and 2-hop communication schemes. The number of relays employed is not always efficient with respect to the energy efficiency but improved communication reliability can be attained with multiple relays. Our numerical results however show that the 2-hop communication scheme gives maximum energy efficiency as well as a highest optimal payload size in poorer channel conditions

5.2 Future Scope

1. As a future work, detailed research of the different cooperative diversity techniques for WBANs can be carried out. The other areas of future scope includes the determination of an optimal relay position and an energy conscious topology design for cooperative WBANs.The current work can be extended for a cooperative relaying scheme that uses hybrid relays which includes a combination of Amplify and Forward and Decode and Forward. This relaying is superior to the different techniques of classical cooperative relaying. Since the AF and DF relaying are available with their own set of advantages and disadvantages, a hybrid relaying scheme can have the advantages of both the techniques.
2. In recent times, cooperative network coding (CNC) has been suggested as an effective approach to fight against packet loss, to reduce the latency is reduced because of retransmissions, and to enhance the success probability of data at the destination. So, one of the immediate future work is the design, analysis and implementation of the CNC for WBANs.

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