Optimizing network lifetime in wireless body area network through cognitive radio

By

Ayisha Anisa Edishu

A Thesis Submitted to

The department of computer science and engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in computer science and engineering

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Declaration

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Ayisha Anisa

Signature: __________

This MSc Thesis has been submitted for examination with my approval as thesis advisor.

Name: Dr. B.M. Thippeswamy

Signature: ___________

Date of submission: October, 2019

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LIST OF ACRONYMS

AWGN	Additive white Gaussian noise
BAN	Body Area Network
CR	Cognitive Radio
dB	Decibel
DSA	Dynamic Spectrum Allocation
FCC	Federal Communications Commission
FSA	Fixed Spectrum Allocation
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
MAC	Medium Access Control
MATLAB	Matrix Laboratory
OSA	Opportunistic Spectrum Access
PDA	Personal Digital Assistant
PU	Primary User
SNR	Signal to Noise Ratio
SU	Secondary User
WBAN	Wireless Body Area Network
WLAN	Wireless Local Area Network
WSN	Wireless sensor network

ABSTRACT

Wireless body area network give numerous biological knowledge of patient's and monitors patient's health condition accordingly. In WBAN the most challenge is short network lifetime of nodes, caused by high energy consumption during transmission time and abnormal energy wastage. During transmission time distance has a great influence in consuming energy. Thus, in this study distance based algorithm is used to minimize power consumption during transmission time. Along with using the algorithm path loss and energy dissipation are considered as a performance metrics. At the end of the study the simulation result shows that path loss and energy dissipation are highly affected by distance.

The second condition is energy consumption during abnormal energy wastage. Abnormal energy wastage is occurred by interference. This can be occurred because during the selection of channel for transmission important issues cannot be considered. For instance, issues like the availability of free channel, the probability of collision occurrence and so on. In this study, abnormal energy wastage will be minimized greatly by considering the availability of unused channel for transmission and by using appropriate spectrum sensing technique. All the simulation method will be carried out in MATLAB environment and Energy detection technique is employed to detect whether or not the spectrum is being used. Finally the effect of SNR parameter on the detection technique is discussed and the simulation result shows that minimum SNR value is needed to decode the received signal.

Keywords: Wireless body area network (WBAN), Signal to noise ratio (SNR), Cognitive radio (CR), and Matrix Laboratory (MATLAB)

CHAPTER ONE

1. INTROODUCTION

1.1. Background of the study

1.1.1. Wireless body area network

A wireless body area network is special purpose design network under wireless sensor network (WSN). WBAN connects independent nodes (sensors) that are situated within the garments, on the body or under the skin of a person [8]. The network usually expands over the whole human body and also the nodes are connected through a wireless communication channel.

In keeping with the implementation, these nodes are placed in a star or multihop topology [8]. The concept of wireless body area network is originated from wireless personal area network and opens the means for the new era of medical diagnosis. WBANs have ability to provide highly reliable communications for medical devices that are deep-seated within the human body [8]. Wireless body area network (WBAN) is a technology that shows a rapid growth from time to time [8].

According to the role in the network, the nodes in WBAN can be classified as sensor, relay and coordinator node [24]. Sensor nodes or end nodes are miniature, limited energy, low storage capacity, and non expensive nodes that sense a patient’s biological information placed on a patient's body, on the clothes or under the skin. These sensors monitor varied very important signs and supply period of time feedback to the patient, doctors, and alternative connected persons. The relay node can act as an intermediate between the sensor node and the coordinator. If the distance between the sensor and the coordinator is high the relay node becomes an intermediate to relay the information [18]. The coordinator is a node that received the sensed data from the sensor node and also works in communicating the sensors to the outside world. Information transmission among nodes can be direct or cooperative transmission [18]. Direct transmission is when the information is transmitted directly from sensor nodes to coordinator. When the distance between sensor nodes and coordinator is high information pass through relay node, which is called as cooperative transmission [18].

WBAN Architecture

Intra-BAN communications: - is a communication among body sensor nodes and the coordinator node of the WBAN.

Inter-BAN communications: - involve communications between the coordinator node and personal devices such as notebooks, home service robots, and so on.

The beyond-BAN communication: - connects the personal device to the Internet.

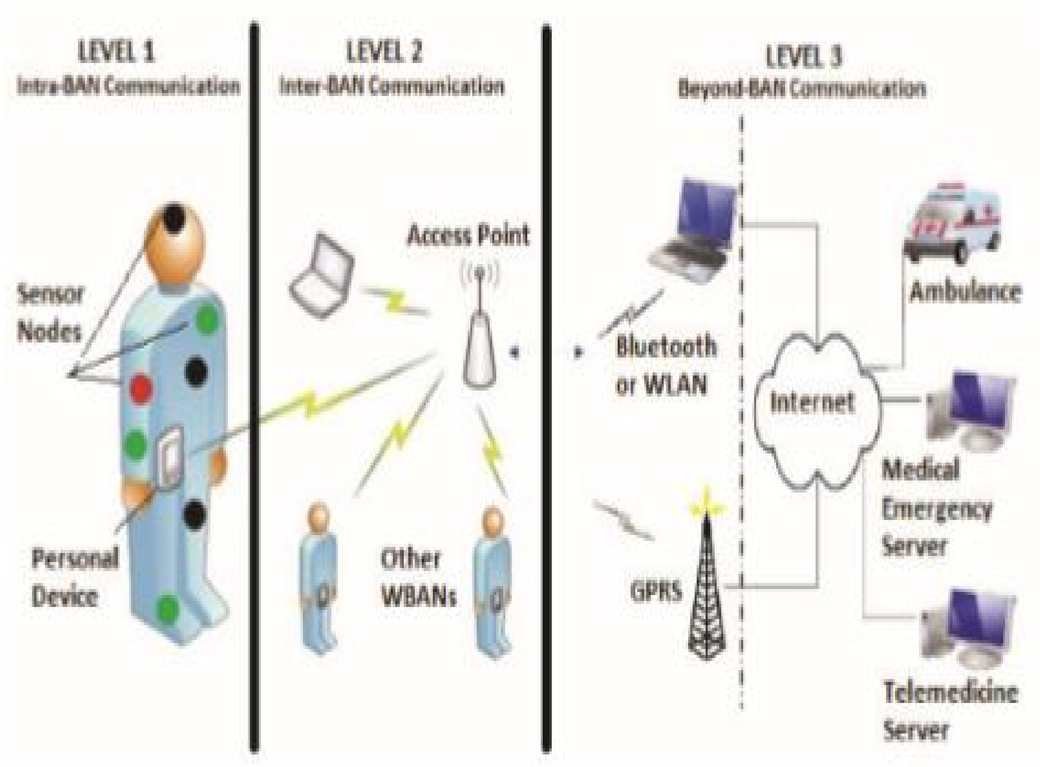

Figure 1-1-1: General architecture for Wireless Body Area Networks [24]

WBAN Applications

WBANs have a number of applications, which can be classified as medical and non-medical application. Medical application includes several areas such as smart health care, assisted elderly living, emergency response and remote health monitoring. Whereas non medical applications include interactive gaming, detecting soldiers' condition during the war, interactive gaming and detecting athletes' performance at the time of competitions are some of interesting applications of WBAN.

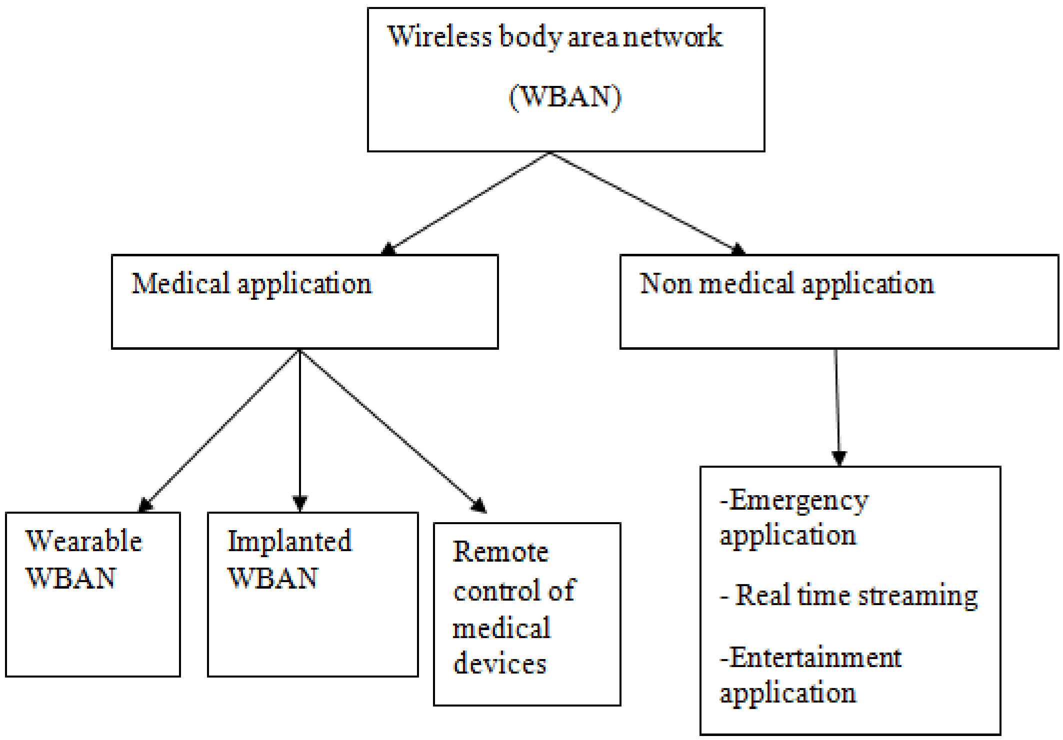

Figure 1-1-2: WBAN application

1.1.2. Cognitive Radio

Currently wireless communication and information traffic have been growing exponentially, which results excessive demand for radio spectrum resource. The radio spectrum is a limited resource which is controlled and regulated by recognized authorities like federal communications commission (FCC) in united state [26]. The current policy regarding to spectrum allocation consists allocating the channel for licensed users wireless communication system. Licensed users have the right to access that spectrum for transmission of their data. Unlicensed users don't have the right to use spectrum even when the spectrum is free. Recent studies reported that the spectrum utilization ranges from 15% to 85% in the US under the fixed spectrum allocation (FSA) policy [26].

In cognitive radio there are two users called primary users and secondary users. Primary users are those users which have got license from FCC to use the radio spectrum. Secondary users are unlicensed user to use the radio spectrum. Allocated spectrum portions are not used all the time by their owners, called primary users (PUs), which creates spectrum holes [26]. A spectrum hole, also called white space, is a frequency band assigned to a PU, but it is not being used at a particular time and at a particular location [26]. Therefore, the radio spectrum is inefficiently exploited [26]. Thus, spectrum scarcity problem need an urgent solution to achieve high spectrum access performance. A better solution to solve the spectrum scarcity issue is dynamically managing the spectrum by using free channels with secondary users without interfering the PUs signals. The opportunistic spectrum access (OSA), also called dynamic spectrum access (DSA) has been proposed to address the spectrum allocation problems [26].

In order to advance the use of the OSA, several solutions have been proposed, including cognitive radio [26]. Cognitive radio has the ability to detect the available channels from its environment and adjust its transmission parameter to improve wireless communication.

Cognitive radio becomes a new and future technology aims to solve spectrum scarcity problem caused by exponential growth in wireless communication. With this 5th generation of the wireless communication systems, the wide wireless will be interconnected offering high quality of service and data rates.

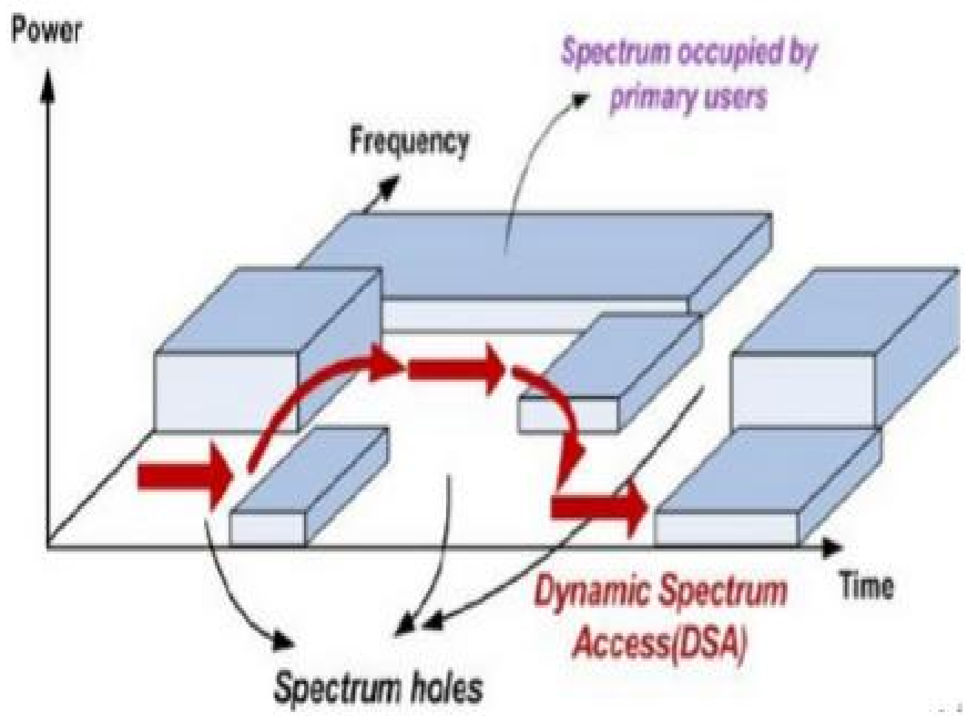

Figure 1-1-3: Dynamic spectrum access [26]

Cognitive Radio Cycle

As shown in Figure 1-4, a cognitive radio system performs a 3-process cycle: sensing, deciding, and acting [24].

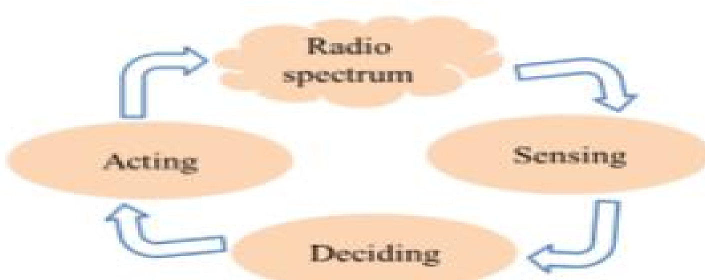

Figure 1-1-4: cognitive radio cycle [26]

1.2. Motivation

Our world is facing a globally aging population which results from both lifetime extension and Baby Boomers demographic peak [36]. As the number of population increase the need for health monitoring services also increase. So the number of population and the existing healthcare monitoring was not met. The current healthcare system suffers from severe challenges that have never met before. The healthcare expenditure has been growing enormously or hospital cost increasing highly. Because the number of hospitals is inadequate with the patients who need medical treatment, many number of patients can be treated in one room. In addition to this the patient is ordered to stay on bed for long time and the patient does not have freedom of movement. This reduces the quality of life of the patient and become difficult to conduct the health condition of the patients.

With vast growing tiny size, low cost and low power consumption nodes WBAN can give healthcare monitoring, diagnostic and medicine remotely to patients by medical specialists [36]. These miniaturized sensors located on the human body or implanted under human skin, monitoring a health condition and sending sensed data wirelessly to the coordinator. Here the coordinator node is responsible to communicate with the sensors [36]. With the help of the sensed data medical specialist have got clear health condition of the patients. This remote health monitoring system allows fast health problem treatment for wide range of people.

Since these nodes are produced in a large amount and they are low cost compared to equipments produced for hospitals, the WBAN can cover huge amount of patients compared to traditional medication. Besides these nodes are tiny in size and small, they are simple and give freedom to patients whether they are implanted or placed on human body. The advantage of WBAN is that the patient does not have to stay on bed or the patient has freedom of movement [36]. This improves the life quality of the patient and reduces hospital cost. In healthcare monitoring application sensors can be implanted under patient skin or wearable on patient body. The sensors sense patient's biological information like temperature, Electrocardiogram, blood pressure, motion, heart rate, respiration etc [36]. Then the sensed information is transmitted to coordinator node through relay node. After patient's information reached to sink or coordinator the information is accessed by the medical specialist for medication through WLAN, Zigbee or Bluetooth [36].

However, the wide application of WBAN in remote health monitoring hindered by short network lifetime of nodes. This system depends on the condition of life and death so unless the data is transmitted in real time and the life span of nodes prolong the system will be in danger.

1.3. Statement of the problem

This thesis mainly focuses on optimizing network lifetime of nodes and achieving reliable wireless communication among the body sensor and coordinator. In WBAN a major problem arises in power limitation or having limited network lifetime of nodes. This is because WBAN consists of miniaturized sensor node in which each sensor node consists of sensing unit, power unit, communicating unit and storage unit. Each sensor node consumes energy for the purpose of sensing, transmission of data and abnormal energy wastage. Sometimes abnormal energy wastage is occurred by interference which result collision, over hearing and idle listening [19]. Energy consumption of sensing is very small which can be neglected compared to energy consumption during transmission of data. Therefore, during transmission time and abnormal energy wastage there will be high energy consumption. Here the study focuses on reducing energy consumption during transmission time and abnormal energy wastage in order to enhance the life span of nodes.

During transmission time, sensor nodes face many problems in transmitting data to the coordinator. Sensor nodes should look for best or optimal channel for their transmission in order to minimize power consumption. Besides, in WBAN abnormal energy wastage can be occurred. This can be occurred because during the selection of channel for transmission important issues cannot be considered. For instance, issues like the availability of free channel, the probability of collision occurrence and so on. In this study, abnormal energy wastage will be minimized greatly by considering the availability of unused channel for transmission and by using appropriate spectrum sensing technique.

1.4. Research questions

Previously, there are different algorithms and techniques are used to optimize the network lifetime of wireless body area network. This thesis aims to use cognitive radio networks to enhance the network lifetime of WBAN. The following research questions are answered throughout the study.

- ❖ How to develop the criteria needed to select the transmission mode?
- ❖ How to minimize the distance required for communication of nodes?
- ❖ How SNR affect energy detection spectrum sensing technique?
- ❖ How to check the presence and absence of PU in the channel before it is assigned for SU?

1.5. Objectives

General objectives

The general objectives of this thesis is optimizing network lifetime of WBAN through cognitive radio.

Specific objectives

The specific objectives of this thesis are:

The use of distance based algorithm to minimize power consumption during the communication of nodes. To achieve the result MATLAB is used and after the result, the influence of distance on path loss and energy dissipations is investigated.

Energy detection sensing technique is used to determine the presence and absence of primary users. MATLAB is used to simulate the signals from the cognitive radio networks and an after getting the result; the next process is to find the relationship between SNR and detections. Finally investigate how SNR influence the detections and determine whether the simulation is working successfully.

To study and analyze the effect of SNR, probability of false alarm, probability of miss detection and probability of detection for AWGN channel model and compare the results with matched filter spectrum sensing algorithm.

1.6. Significance of the study

In this study, cognitive radio based WBAN is proposed for enhancing lifespan of nodes. The life span of nodes can be increased by reducing power consumption during transmission time and abnormal energy wastage. As mentioned previously, cognitive radio is a new wireless communication technology which is capable of sensing its environment and adapts it by changing its transmission parameter. During spectrum sensing it uses energy detection spectrum sensing technique for detecting the availability of free spectrum. The prominent performance metrics like distance, SNR and path loss was considered. Then by considering these possible traits it selects the available channel.

In addition to the above significance, CR based WBAN is used to optimize the network lifetime of nodes. By using CR based WBAN interference will be minimized, so abnormal energy wastage will be reduced.

The significance of using CR networks in WBAN is:

- New and future technology
- Resolving spectrum scarcity problem caused by exponential growth in wireless communication
- Avoids the occurrence of abnormal energy wastage
- Proper spectrum sensing will be takes place which highly reduce energy consumption during transmission time and abnormal energy wastage

The significance of using energy detection technique during spectrum sensing is:

- Energy detection has low computational expense
- Energy detection is the simplest sensing technique, which does not require any information about the PU signal to operate.
- It performs by comparing the received signal energy with a threshold.

1.7. Scope and limitation of the study

1.7.1. Scope

The scope of this study is prolonging network lifetime of WBAN using cognitive radio based WBAN. The work focuses on reducing energy consumption during transmission time and abnormal energy wastage. During transmission time distance has a great influence in consuming energy. This means if the transmission is takes place using long distance between sensor and coordinator high energy consumption will be occurred. To solve this problem some distance algorithm which introduces transmitting information using short distance will be discussed.

In WBAN abnormal energy wastage is occurred through interference on the communication signal. When communication was takes place between nodes, unoccupied and error free channels should be selected. Otherwise, interference will be happened which results abnormal energy wastage. To resolve this CR based WBAN is used for minimizing abnormal energy wastage via proper spectrum sensing. CR users access the spectrum which is allocated to a primary user, so avoiding interference to potential primary users is a basic requirement. In cognitive radio spectrum sensing is an important process because it checks whether the spectrum is used or not. In this study energy detection technique will be used whether the spectrum is occupied or not.

1.7.2. Limitation

The limitation of this study is, the study does not focus on radiation emitted by the nodes. Besides, the energy consumption in WBAN can exist during three main times: these are sensing time, transmission time and abnormal energy wastage. But comparing energy consumption of sensing and transmission, the consumption of energy during sensing is very small which can be neglected. So the study does not focus on energy consumption during sensing time.

Besides, generally cognitive radio can be classified in to two which is full cognitive radio and spectrum sensing cognitive radio. This study only focuses on spectrum sensing cognitive radio. The study does not include any description about full cognitive radio concept.

1.8. Organization of the thesis document

Chapter 2 provides a comprehensive review on research paper and studies related to this research. In this review related papers are divided in to four sections based on the technique they used to maximize network lifetime. In addition to this the chapter discusses key points on spectrum sensing and calculation for energy detection.

Chapter 3 provides the methodology and the procedure of the study used to achieve the stated objectives of the research. In general this chapter discusses the overall proposed solution for the stated statement of the problem.

Chapter 4 presents a result and discussion part of the study. The result and discussion chapter presents in two sections. The first section presents discussion of findings on energy reduction during transmission time and the second section presents discussion of findings on energy reduction during abnormal energy wastage using CR.

Chapter 5 summarizes the overall study and the main outcomes of the thesis. Finally recommendations and some future works on the study area are highlighted.

CHAPTER TWO

2. RELATED WORKS

2.1. Introduction

This part aims to provide a comprehensive review on research paper and studies related to this research. In this review related papers are divided in to four sections based on the technique they used to maximize network lifetime. This review mainly focuses on the paper related to energy efficient WBAN design. In section 2.2 Medium Access Control (MAC) techniques going to be reviewed and discussed. In section 2.3 opportunistic scheduling is introduced, which is greatly helpful for maximizing network performance. Network cross layer optimization methods and on body channel set with their advantage and disadvantage will be discussed in section 2.4. Finally in section 2.5 spectrum sensing and calculation for energy detection will be discussed.

2.2. Medium Access Control (MAC) design in wireless body area network

In WSNs many energy efficient Medium Access Control (MAC) protocols have been developed to make their lives longer. Actually, most of these protocols help WBAN to develop proper MAC design for them, such as the concept of periodic sleep mechanism. So WSNs MAC design serves as foundation for WBAN MAC design. However, there is a fundamental difference between WSN and WBAN, so the existing MAC design for WSNs is improper for WBANs. The first problem is channel attenuation in WBAN, which means the channels in WBAN may fluctuate significantly because of human's constantly physical change compared to WSNs. So allocating fixed scheduling will result in bad performance.

The second problem is that the size of sensors, which is miniaturized and tiny especially for the implanted one. So the battery size also becomes very small according to its actual size of the sensor. These sensors are more power constrained and have lower transmission power than that of the others. But at the same time reliable data transmission is the basic issue. So avoiding bad channel status and using the good ones is very advantageous.

BodyMAC, which is introduced in [5], is a MAC design suitable for WBANs. This work focuses on MAC frame structure, bandwidth management and sleep mode mechanisms by taking the above considerations into account. The MAC frame of BodyMAC can be divided into three parts: Beacon, Contention Access Period (CAP) and Contention Free Period (CFP). CAP is used for both bandwidth request and small size data transmission. In order to save energy, the node will not conduct synchronization unless the node meets a transmission failure in Guaranteed Time Slots (GTS). Since TDMA is applied in BodyMAC, the data transmission in CFP is collision free, which ensures energy efficiency. However, one potential drawback that is not fully discussed is the energy waste due to the failed transmissions caused by clock drift.

In [1], a multi-hop network has been proposed and achieves good throughput and delay performance. The traffic of the network is controlled by setting up a spanning tree. The scheme messages will be broadcasted and used by the parent and children of each node in the tree. The performance of this multi-hop network is better than single-hop network; however the improvement of performance is based on much higher complexity and resources consumption.

2.3. Opportunistic Scheduling in wireless body area network

Most of opportunistic scheduling designs exist for cellular networks, which differ significantly from the WBANs. Thus this study concludes that using opportunistic scheduling can enhance the performance of WBANs. The major difference between cellular networks and WBANs is based on power constrained. Cellular networks are less power constrained than WBANs. The main objective in cellular network is focusing on fairness and throughput, whereas WBANs focus on reliability and energy consumption. Thus special opportunistic scheduling algorithm should be developed for WBANs so that they are able to detect the channel status and make best scheduling accordingly.

In [36], the author proposed a threshold-based scheduling scheme, which is also based on Gilbert model and monotonicity property. Each node is assigned a threshold on the delivery probability and the delivery probabilities of the time slots in a round will be calculated according to the Markov process. The timeslots are assigned according to the thresholds and the delivery probabilities of the nodes. However, the transition matrix is actually unknown to the scheduler.

The design is unable to figure out the real stochastic parameters online and the schedule made accordingly cannot be reliable.

In [19], a cognitive radio based coordinator node is designed for Wireless Body Area Networks. A simulation model has been developed for implementing cognitive radio enabled body area network for analyzing remote health monitoring system for humans. The prominent parameters such as user speed, access point delay, and connection cost are taken into account when selecting the wireless access point. The main limitation in this paper is unstable channel condition.

2.4. Cross-layer Design in Wireless Body Area Networks

There are many optimization literatures for Wireless Sensor Networks (WSNs). However WBANs have certain unique properties so that the conclusions for general WSNs may not be applied in WBANs. The energy constraint for WBANs is even harsher than that of WSNs because the volume of on-body or in-body sensor nodes needs to be tiny and the sensors are hard to be recharged generally. Since excessive radiation absorption will cause damages to the vulnerable body tissues, the transmission power of the sensor nodes and relay nodes need to be constrained. Furthermore, the body channels are highly unstable because of the irregularity of people's movements and the signal absorption incurred by body tissues. All of these constraints in WBANs make data transmissions hardly reliable.

In [20], the authors propose a relay based routing protocol for Wireless In-Body Sensor Network. Network lifetime maximization and end-to-end-delay minimization problems are formulated and solved with linear programming. However, no systematical scheme is proposed to address the optimal relay location consideration. Furthermore, since the model proposed only considers routing layer, it fails to formulate a cross-layer optimization problem.

In [38], WBAN optimization model that jointly considers relay positioning, transmission power control and routing strategy, which are the key considerations for an energy efficient network design, is still missing. One potential problem that is hard to solve is that the formulated optimization problem is non-convex and mixed-integer when multiple considerations are included simultaneously. Effective solutions need to be proposed before the model can be applied.

On body channel set

On-body channel dataset is a public dataset provided by National Information Communications Technology Australia (NICTA) and collected using a NICTA developed wearable channel sounder / radio device [38]. The dataset contains WBAN channel gain data (majority on-body, but some off-body, none in-body) in various environment, carrier frequencies and measurement scenarios. There are however, certain dataset for indoor activities, such as sleeping, sitting, walking and running, and outdoor activities, such as running and driving. The detailed channel information is described in the name of the channel data variable and destination locations of the channel link.

On-body channel dataset [38] is used to conduct simulations of on-body WBAN. For each adult subject, channel gain data of 5 channels, which are the channels from left hip to head, chest pocket, left wrist, right wrist and right ankle, are used to conduct the simulations. The coordinator locates at the left hip of the experiment object. The location of the sensors and coordinator is plotted in Figure 2-1. Compared with Monte Carlo simulation, the simulation based on real-life data is more compelling since no satisfactory channel model for on-body channels has been proposed so far.

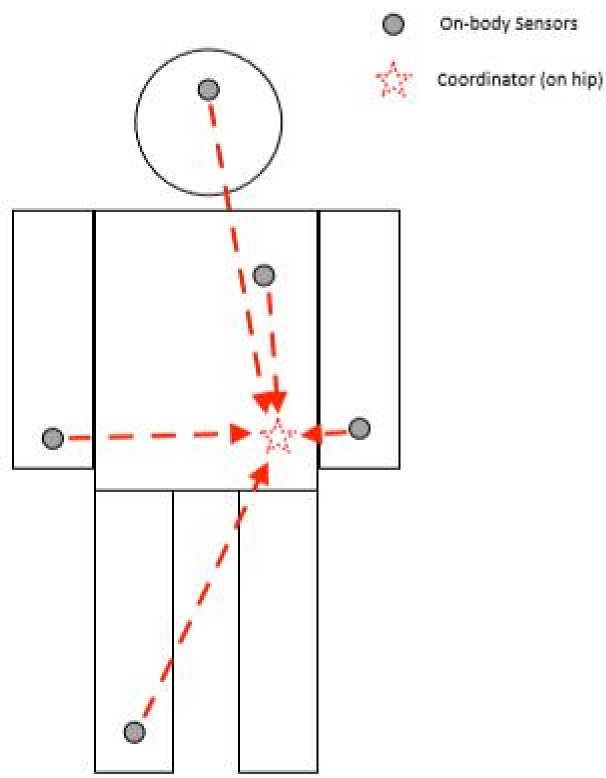

Figure 2-1: On body channel set [38]

2.5. Spectrum sensing and calculation for energy detection

Spectrum sensing promises unlicensed or secondary users, to make an adjustment to the environment by detecting some parts of spectrum which are not in used on the premise of it will not cause any interference to the licensed network, which is referred to as primary network [36]. To provide more chances for CR users to access the spectrum without causing interference to the primary networks is the main idea of spectrum sensing.

Since CR networks are able to detect the transmission of licensed networks and avoid causing interference to them, CR networks should sense the primary spectrum band to avoid the lack of the transmission of the primary users intelligently [36]. According to that, sensing accuracy has been considered as one of the most important factors in the spectrum sensing for CR network.

Recently, many researches are around how to improve the sensing accuracy to avoid the interference as far as possible.

There are three different techniques which are commonly used in signal processing techniques for spectrum sensing [36]:

- Matched filter
- Energy detector
- Cyclostationary feature detector

The matched filter can maximize the received SNR. It requires demodulation of a primary user signal and it can perform coherent detection. The advantage of matched filter is that according to consistent, to get high processing gain less time is needed. However, a significant disadvantage of a matched filter is that a special receiver is necessary for every primary user. So the utilization of the matched filter is restricted by the drawback mentioned above.

The energy detector simplifies the matched filter to perform non-coherent detection. It detects the received signals" energy to compare with the threshold and then deduce the status of the primary signals. The disadvantage is that a threshold we used will be easily influenced by unknown or changing nose levels, so the energy detector will be confused by the presence of any in-band interference [36].

It is investigated that within a special modulation type, the cyclostationary feature detector is able to exploit the inherent periodicity in the received signal to detect primary signals since most signals vary with time periodically [36]. There is also a disadvantage that longer processing time and higher computational complexity is needed with the cyclostationary feather detector [33].

In [33], it indicated that all these methods above are depending on the transmitter detection. Through the spectrum sensing of CR users, they can deduce that whether there is a signal from primary transmitter which is present in a spectrum or not. Among the three techniques, the energy detector has been mostly widely used in radiometry [36].

Since the energy detector has been mostly widely used in radiometry. So we only introduce the energy detector in details. The energy detector is able to be implemented as a spectrum analyzer; it takes the average frequency bins of a Fast Fourier Transform (FFT) [36].

The input signal goes into the A/D converter selected by the bandpass filter first and we will get the threshold there. After we get the output from the integrator, which is compared with threshold, we will determine the presence of the primary users.

All the methods mentioned above promise CR users to improve the sensing accuracy. However, in CR networks, there will be hardware limitations to limit spectrum sensing [36]. In the ideal conditions, CR users need to sense the spectrum bands continuously through the radio frequency to avoid the interference to the primary users, while, in reality, the radio frequency cannot distinguish the primary user signals with CR user signals [36]. As we know, the energy detection is most widely used in spectrum sensing, with that CR users cannot carry out the sensing and transmission at the same time. So, according to the hardware limitation, a new sensing structure where observation period and transmission period will be separated is necessary for CR users. In this structure, transmissions should be paused during the sensing time to avoid false alarms caused by unintended CR signals [36].

Calculation for energy detection

In this thesis, the Gaussian distribution, Additive white Gaussian noise, Q-function, signal to noise ratio, and Maximum A Posteriori energy detection for spectrum sensing are mainly used through the whole process [36]. This part indicates the details of the theories.

Gaussian distribution

In probability theory, the Gaussian distribution is a continuous probability distribution that is often used as a first approximation to describe real-valued random variables with two parameters, mean value μ and the variance σ^2, the former makes the location of the peak and the latter makes the width of the distribution. The Gaussian distribution is a very important probability distribution in radio area [36].

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{(x-\mu)^2}{2\sigma^2}} \quad \text{.......... Eq. (1)}$$

Additive White Gaussian Noise

Additive white Gaussian noise (AWGN) is a type of noise which exists in the communication channels generally. In an AWGN channel model, we always assume that there's no any other distortion or effects from other sources. Additive white Gaussian noise is a model for the thermal noise generated by random electron movement in the receiver [36]. Here is an example signal with AWGN.

The above figure shows the example signal with AWGN, the blue signal is the example and the green signal is the signal with AWGN. There will be always AWGN during the transmission of signals in CR network. In chapter 3, when the received signal will be simulated, the AWGN should be added to the received signal.

Q-function

The Q-function is a convenient way to express right-tail probabilities for Gaussian random variables. For x∈R, Q (x) is defined as the probability that a standard normal random variable (zero mean, unit variance) exceeds x [36]:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}}\, dt \quad \text{...... Eq. (2)}$$

The characters of the Q-function are as follows:

- $Q(0) = \frac{1}{2}$
- $Q(-a) = 1 - Q(a)$
- $Q(a) = \frac{1}{a\sqrt{2\pi}} e^{\frac{a^2}{2}}$

The graph of the Q-function is shown in the above figure. In chapter three, where we will derive the false alarm probability and the threshold, since they obey the Gaussian distribution, the former will be expressed in terms of the Q function and the latter will be expressed in terms of the inverse of the Q function.

Signal to Noise Ratio

In analog and digital communications, signal to noise ratio (SNR) is defined as the ratio of signal power to the noise power. It indicates signal intensity relative to background noise. When the ratio is higher than 1:1, it indicates there's more signals than noise. SNR is showed as follows:

$$SNR = \frac{P_{signal}}{P_{noise}} \quad \text{.......... Eq. (3)}$$

The ratio is usually measured in decibels (dB), P is the average power. If the signal and the noise are measured within the same resistance, the SNR can be derived by squaring of the amplitude ratio:

$$SNR = \frac{P_{signal}}{P_{noise}} = (\frac{A_{signal}}{A_{noise}})2 \quad \text{.......... Eq. (4)}$$

A is root mean square amplitude. Since many signals have a very wide dynamic range, SNRs are often expressed in logarithmic decibel scale.

$$SNR_{dB} = 10\log_{10}(\frac{P_{signal}}{P_{noise}}) = P_{signal,dB} - P_{signal,dB} \quad \text{.......... Eq. (5)}$$

Eq. (6) can be written using amplitude as:

$$SNR_{dB} = 10\log_{10}(\frac{A_{signal}}{A_{noise}})\,2 = 20\log_{10}(\frac{A_{signal}}{A_{noise}}) \quad \text{.......... Eq. (6)}$$

In CR networks, to determine the spectrum availability, CR user need statistical information on the received primary signals, so the minimum SNR is the least signal level needed to decode the received signals [36]. We will determine how the SNR influences the final detection in chapter four.

Maximum A Posteriori Energy Detection for Spectrum Sensing

The maximum a posteriori (MAP) detector is known to be optimal in CR networks. When CR users start the spectrum sensing to detect the primary users‟ status, the received signal r (t), can be expressed as [36]:

$$r(t) = \begin{cases} n(t) & H_0 \\ s(t) + n(t) & H_1 \end{cases} \quad \text{.......... Eq. (7)}$$

Where H_0 stands for no signal transmitted, and H_1 stands for signal transmitted, s (t) is the signal waveform, and the n (t) is a zero-mean AWGN. The detection probability Pd and the false alarm probability P_f can be expressed as Eq. (8) through the MAP detection:

In Eq. (8), λ is a decision threshold of MAP detection. P_f should be kept as small as possible to avoid underutilization of transmission opportunities, in another hand, P_d should be kept as large as possible for the same reason.

$$P_d(\lambda) = P_r[Y > \lambda|\mathrm{H}_1]$$

$$P_f(\lambda) = P_r[Y > \lambda|\mathrm{H}_0] \quad \text{.......... Eq. (8)}$$

For the sake of getting the energy of the signal, the output signal of A/D converter and bandpass filter with bandwidth W is squared and integrated over the sensing time [36]. So we can get the output of the integrator, Y, compared with the threshold to determine the absence or the presence of the primary user.

In the MAP detection, the output of the integrator is known as the Chi-square distribution [16]. If the number of samples is large, with the central limit theorem, we can assume that the Chi-square distribution is approximate as Gaussian distribution [36].

From Eq. (8), (9), the false alarm probability P_f can be derived in terms of the Q function, expressed as follows [14]:

$$p_f\ (w, t_s) = \ Q(\frac{\lambda - 2t_s\ w\sigma n^2}{\sqrt{4t_s\, w{\sigma_n}^4}}) \quad \text{.......... Eq. (9)}$$

From the Eq. (10) we can get that the false alarm probabilities varies with the W and the observation time . We can get the threshold λ as:

$$\lambda = \sqrt{4t_s w\sigma n^4}\, Q^{-1}\left(P_f\right) + 2t_s w\sigma n^2 \text{..........Eq. (10)}$$

The parameters, the false alarm probability and the threshold are the important parameters in CR networks; the false alarm probability should be kept as small as possible to avoid underutilization of transmission opportunities [36].

CHAPTER THREE

3. PROPOSED SOLUTION

3.1. Introduction

This chapter presents the methodology used to achieve the stated objectives of the research. This research is focused on prolonging the network lifetime of nodes in WBAN so much of the work will be conducted through simulation.

3.2. Simulation

This method involves representing the actual system using simulation program. This involves identifying suitable simulation tool and defining parameters to visualize the relationship in actual system. Simulation is widely used methods in a research because it gives visualize output to understand the actual system easily. It also allows variation of system parameter to execute what if analysis in a short period of time. Simulation doesn't produce a tangible project, it is just a simulation.

3.3. Research Methodology

In this research, simulation is used as a primary method to carry out the work. As described earlier simulation allows representation of the actual system in a cheaper way. Here MATLAB is used for this work to be able to capture how the network lifetime of the nodes in WBAN are optimized by using cognitive radio.

In this chapter, the proposed solution is presented in to two sections. In section 3.4 reducing energy consumption during transmission time is going to be discussed. In section 3.5 reducing energy consumption during abnormal energy wastage is presented.

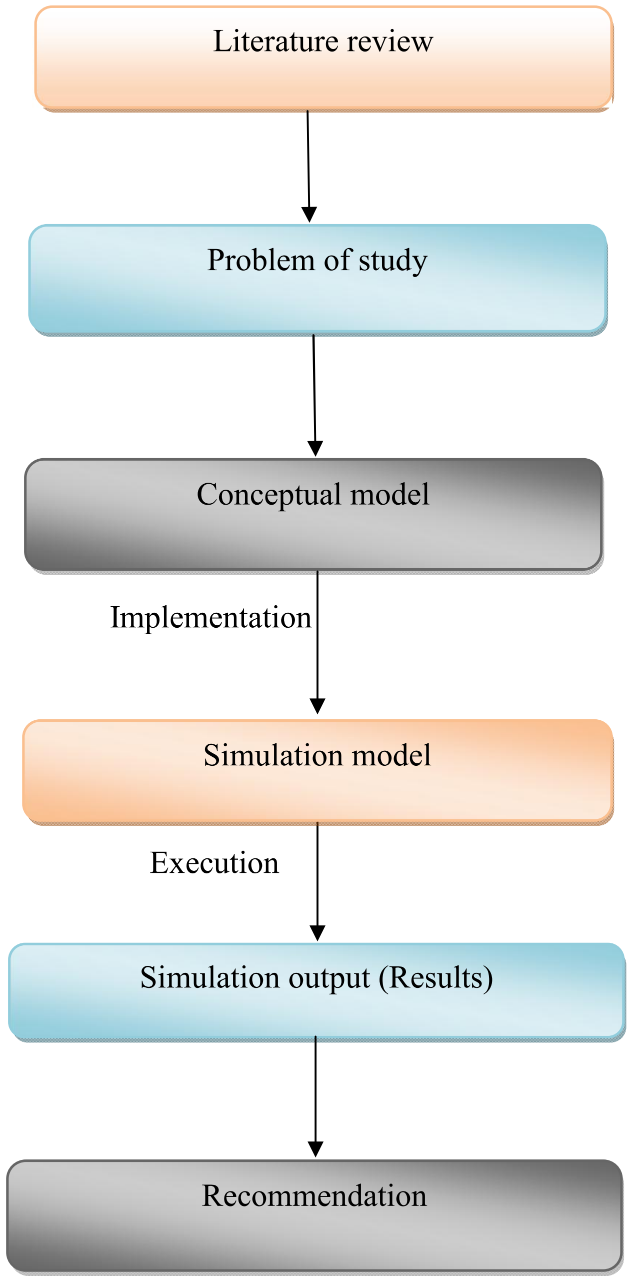

Figure 3-1: Research Methodology

3.4. Reducing energy consumption during transmission time

During transmission time, sensor nodes face many problems in transmitting data to the coordinator. Sensor nodes should look for best channel for their transmission in order to minimize power consumption. During transmission time distance has a great influence in consuming energy. This means if the transmission is takes place using long distance between sensor and coordinator high energy consumption will be occurred.

3.4.1. Conceptual model

The conceptual model is based on typical WBAN application, based on factors affecting energy consumption during communication of nodes. The model provides the relationship between various components and attributes.

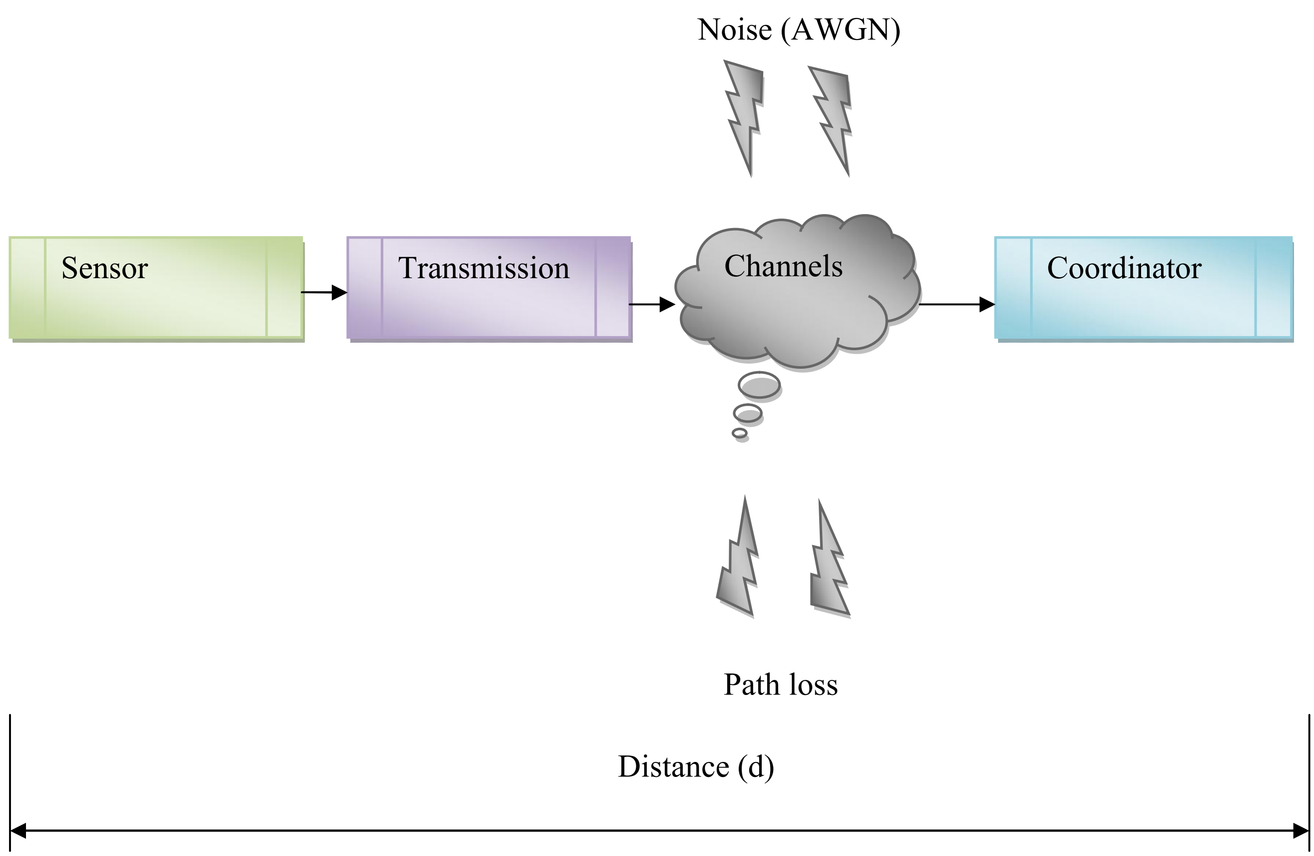

Figure 3-2: Conceptual model

3.4.2. Model components

Sensor: - this unit contains sensors that are placed on patients' body or implanted under the skin of a patient. The sensor node gathers biological information from patients' body like temperature, pressure heart rate and so on.

Transmission unit: - the transmission unit mainly acts as a bridge between the sensor and the coordinator. This unit relays or transmits the sensed data from the sensor to the receiver or the coordinator. Here distance is the prominent parameter in relaying of the signal.

Channel: - this represents various parameters between the sensor and the coordinator. In this model path loss and noise (AWGN) are considered as a channel parameter because they are mainly affected by a distance.

Coordinator: - is a node that receives the collected biological data from the sensor.

3.4.3. Procedure of the study

In this section the basic issue is minimizing energy consumption during data transmission time by using short distance for communication of nodes. This can be achieved by considering the distance between the sender and the receiver. Distance has a big influence in power consumption of nodes in WBAN. For instance, when sensor node sends data to the coordinator node which is found far from it, the energy dissipation also increased accordingly. Thus, to reduce such a problem having a communication using short distance is a great solution. Therefore, if the distance is high from the sender to the receiver, then the transmission will takes place using an intermediate node called relay node. Otherwise the transmission will be held directly from the sender to the coordinator.

Generally, this procedure contains four basic steps in order to reduce energy consumption during transmission time.

- Random node deployment
- Calculating distance between node pairs and coordinator
- Selecting direct or cooperative transmission
- Calculating path loss and energy dissipation

❖ Random node deployment

The first step is randomly generating nodes on XY plane. Here five sensor nodes and one coordinator node are selected. Node 1 up to node 5 was considered as sensor nodes. From the sensor nodes some nodes are acts like both relay and sensor node. In another word relay node is selected from the five sensor nodes. So relay nodes can perform both the sensing and the data relaying activities. Some nodes are selected as relay only for the purpose of relaying the data from the sensor to the coordinator.

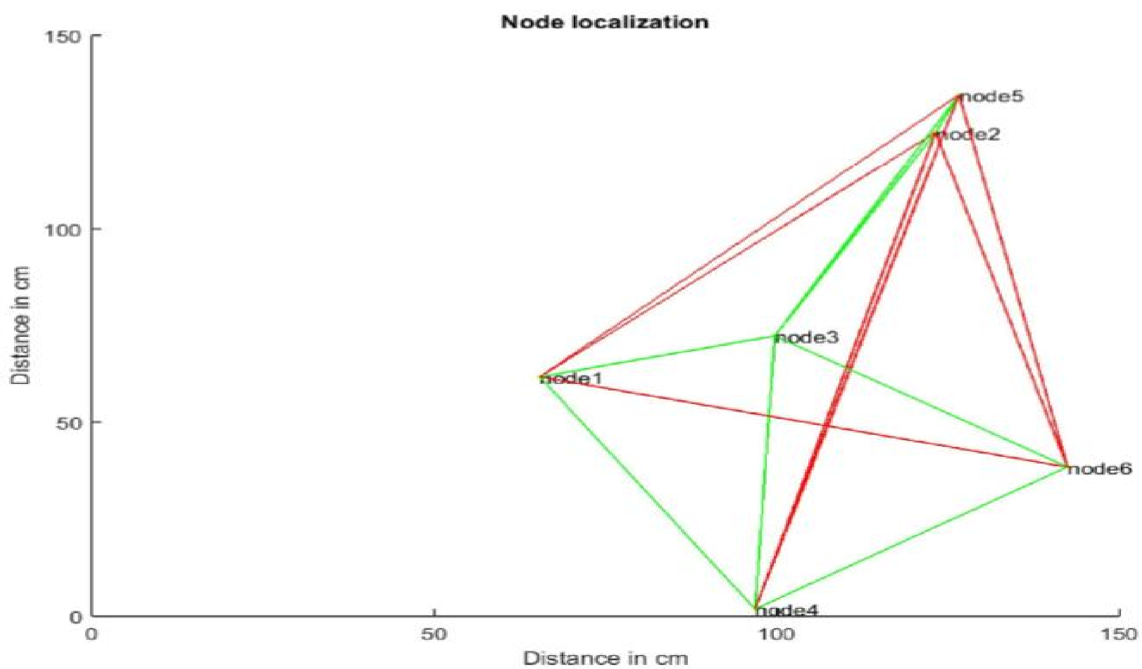

Figure 3-3: Random node deployment

❖ Calculating distance between node pairs and coordinator

After randomly generating nodes on the plane the next step is calculating the distance between each nodes and the coordinator. Using Euclidean algorithm and the value of nodes on the x and y coordinates value, the distance is calculated. In figure 3.3 a green line is used to show short distance which is less than 75cm and the red line shows a distance greater than 75cm.

Table 1 : Distance between node pairs and coordinator

Node Pairs	**Distance (cm)**
1-2	85.6401
1-3	35.9114
1-4	67.6729
1-5	95.1741
1-6	80.4471
2-3	57.6061
2-4	125.9178
2-5	10.2681
2-6	88.5481
3-4	70.5833
3-5	67.8456
3-6	54.4830
4-5	136.1085
4-6	58.5161
5-6	97.4131

❖ Selecting direct or cooperative transmission

As I mentioned in the introductory chapter, in WBAN there are two types of communication. These are direct and cooperative transmission. Direct transmission is takes place between the sensor node and the coordinator. Cooperative transmission uses a relay node as an intermediate between the sensor and the coordinator. In order to selecting the transmission mode, first a distance range is seated. Here 75cm is considered as a predetermine distance or range. If the distance between the sensor node and the coordinator is greater than or equal to the range, relay node is used as an intermediate and relays the data to the coordinator. But if the distance is less than the range the sensor node directly transmits to the coordinator.

For all node pairs and coordinator

$Node_i$, $node_j$ and coordinator

Distance = $\sqrt{|x_i - x_j|^2 + |y_i - y_j|^2}$

If Distance >= R

Use = cooperative transmission (sensor => relay => coordinator)

Else

Use = direct transmission (sensor => coordinator)

End

❖ Calculating path loss and energy dissipation

<u>Calculating path loss</u>

Path loss shows the relative strength between the transmitted power at the sending node and the received power at the receiver. The path loss at the sending and receiving node was calculated as a function of both distance and frequency using the formula:

PL = 20log10 (4πdf/c)……………………………………...................… Eq. (11)

Where: d is the distance between the sender and the receiver, f is frequency and c is speed of light.

<u>Calculating energy dissipation</u>

The radio propagation energy model used in this project was introduced by (Reusens E. et al 2009). ETx (k,d) =ETx- elec(k)+ETx-amp(k,d) ……………………....................…..Eq.(12)

ERx (k) = ERx – elec(k)ERx(k) = ERx – elec x k ……………..…..................Eq.(13)

Where: ETx is transmission energy in joules, ERx is energy consumed by the receiver in joules ETx-elec are energies required by the circuirity of transmitter and receiver in nJ/bit., Eamp is the energy required by the amplifier circuit in J/bit, K is the packet size in bits.

3.5. Reducing energy consumption during abnormal energy wastage

Wireless Body Area Network requires an operational frequency with many technical constraints and it is required to use an unlicensed band for transmission. Also with the choice of unlicensed operational frequency, there is a trade-off of increased interference due to multiple interfering sources using the same band, thus it is very much required to associate Cognitive radio with WBAN for optimized transmission and improving the performance of WBAN.

Wireless body area network requires transmitting real time body signals at regular short time intervals. It is very important that the transmission is made free of cost. But with the advantage of free operational frequency in unlicensed spectrum, we also have a trade-off of multiple technologies using the same or similar frequency in a very close proximity which surely will affect the transmission by increasing interference and occupying the transmission channel for most of the time which affects the transmission by WBAN network.

Hence it is very important to get this problem resolved. The best way is to utilize cognitive radio with WBAN so that interference can be reduced to the best possible extent improving the transmission ability of the system. The WBAN design selected is using 2.4GHZ for transmission. Thus other sources like Bluetooth, WLAN and ZIGBEE etc. are some of the possible interferers that should be kept in mind while designing an overall transmission system. So in order to resolve the interference problem appropriate spectrum sensing should be considered. In this paper energy detection sensing technique is used to reduce energy consumption occurred by interference.

Cognitive Radio (CR) is basically an intelligent radio that senses the transmission channel at very frequent basis and as the channel is free, and then it is allotted to a different source improving the efficiency of transmission. In WBAN abnormal energy wastage like collision, idle listening and over hearing can be occurred. This can be occurred because during the selection of channel for transmission important issues cannot be considered. For instance, issues like the availability of free channel, the probability of collision occurrence and so on.

3.5.1. Flowchart of the system

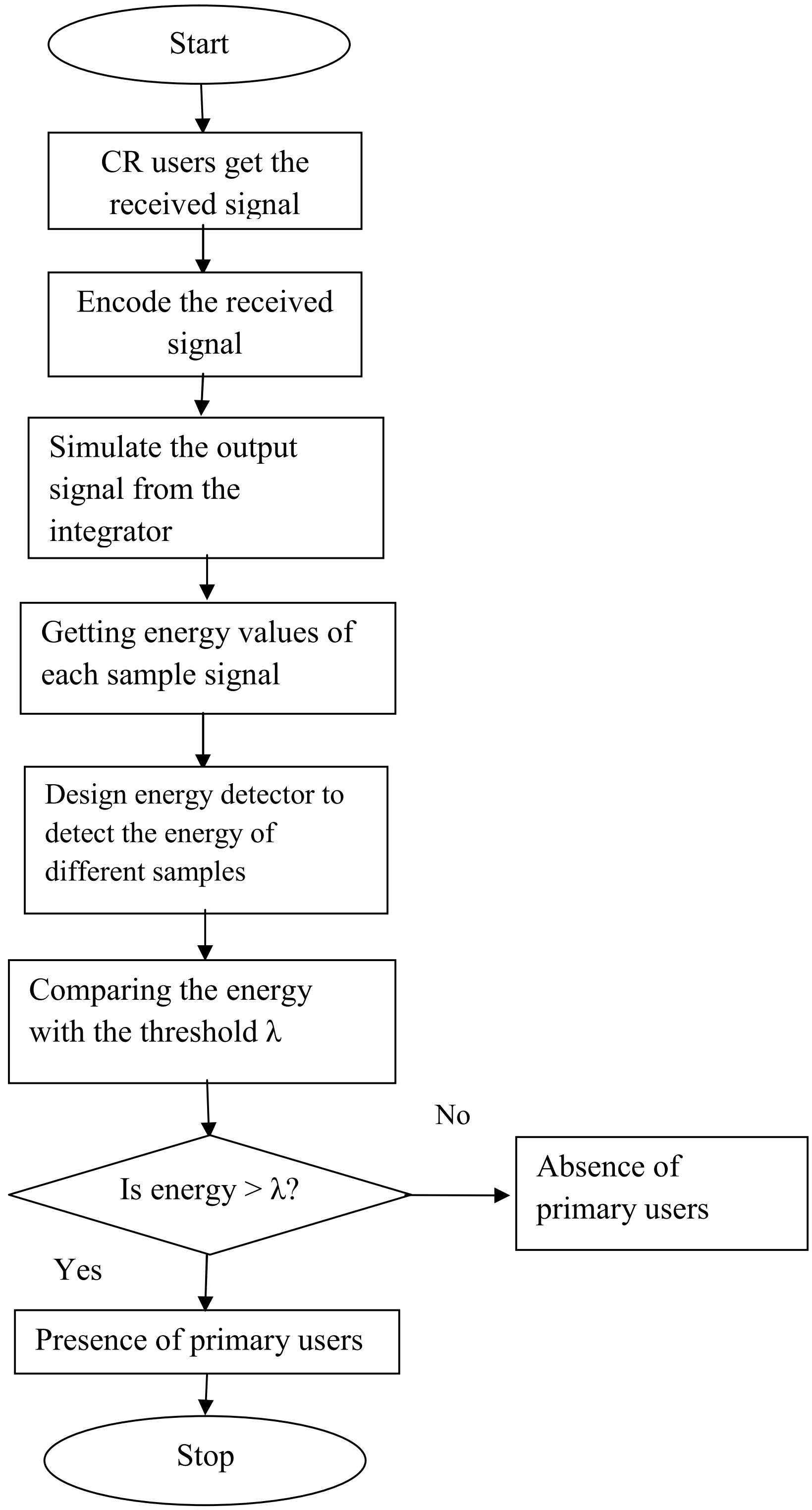

Figure 3-4: Flowchart of the system

3.5.2. Model Components

Additive White Gaussian Noise: - Additive white Gaussian noise (AWGN) is a type of noise which exists in the communication channels generally. In an AWGN channel model, we always assume that there's no any other distortion or effects from other sources. There will be always AWGN during the transmission of signals in CR network.

Q-function: - is a convenient way to express right-tail probabilities for Gaussian random variables. For x∈R, Q (x) is defined as the probability that a standard normal random variable (zero mean, unit variance) exceeds x:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt \quad \text{.......................................} \text{Eq. (14)}$$

By using Q-function we will derive the false alarm probability and the threshold, the former will be expressed in terms of the Q function and the latter will be expressed in terms of the inverse of the Q function.

Signal to Noise Ratio: - in analog and digital communications, signal to noise ratio (SNR) is defined as the ratio of signal power to the noise power. It indicates signal intensity relative to background noise. When the ratio is higher than 1:1, it indicates there's more signals than noise

In CR networks, to determine the spectrum availability, CR user need statistical information on the received primary signals, so the minimum SNR is the least signal level needed to decode the received signals. The false alarm probability pf can be derived in terms of the Q function, expressed as follows:

$$p_f\ (w, t_s) = Q(\frac{\lambda - 2t_s\ w\sigma n^2}{\sqrt{4t_s\ w\sigma_{n^4}}}) \quad \text{.......................................} \text{Eq. (15)}$$

The false alarm probabilities vary with the W and the observation time. We can get the threshold as:

$$\lambda = \sqrt{4t_s w\sigma n^4}\, Q^{-1}(P_f) + 2t_s w\sigma n^2 \quad \text{.......................................} \text{(Eq 16)}$$

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Introduction

As described in the previous chapters this study aims to optimize the network lifetime of WBAN. Hence, in order to enhance the network life time of nodes the study focuses on mainly in reduction of energy consumption during transmission time and abnormal energy wastage.

The result and discussion chapter presents in two sections. Section 4.2 presents discussion of findings on energy reduction during transmission time and section 4.3 presents discussion of findings on energy reduction during abnormal energy wastage using CR.

4.2. Discussion of findings on energy reduction during transmission time

By following the procedure which is presented in section 3.4.3 in chapter 3 the result will be discussed as follows. MATLAB was used to randomly generate the nodes using 150 cm plane. The reason of using 150 cm plane is by considering the average height of a person is 150 cm. Then the nodes are randomly placed on that plane. As shown in figure 3-3 in chapter three, there are six nodes placed on the plane. Node 6 was considered as the coordinator node and the rest five nodes considered as both sensor and relay node.

The next step was calculating a distance between each nodes and the coordinator. In order to calculate the distance, Euclidean algorithm and the value of XY coordinate plane were helpful. The distance between each node is presented in table 1 in chapter three.

Then distance algorithm which is mentioned in section 3.4 in chapter 3 is used to make a connection between the sensor nodes and the coordinator. Here the range or the predetermine distance is set to 75 cm. If the distance between the sensor and the coordinator is less than or equal to 75 cm, the sensor node sends the sensed data directly to the coordinator. Otherwise, relay node is used to send sensed data to the coordinator.

The distance was measured between the sensor nodes and the relay as well as the coordinator. In this study 2.4GHz frequency band is used as it is freely available and mostly used band in WBAN design.

4.2.1. Performance metrics

Path loss calculation: - path loss shows the relative strength between the transmitted power at the sending node and the received power at the receiver. The path loss at the sending and receiving node was calculated as a function of both distance and frequency using the formula.

$PL = 20\log10\ (4\pi df/c)$ Where d is the distance between the sender and the receiver, f is frequency and c is speed of light.

Table 2: path loss and distance data from MATLAB

Distance (cm)	**Path loss (dB)**
0.10	-45.9559
10.10	46.3465
20.10	60.1102
30.10	68.1863
40.10	73.9233
50.10	78.3762
60.10	82.0160
70.10	85.0942
80.10	87.7613
90.10	90.1142
100.10	92.2192
110.10	94.1236
120.10	95.8623
130.10	97.4618
140.10	98.9429

A plot of path loss versus distance shows that an increase in path loss along with increasing in distance as shown in figure below:

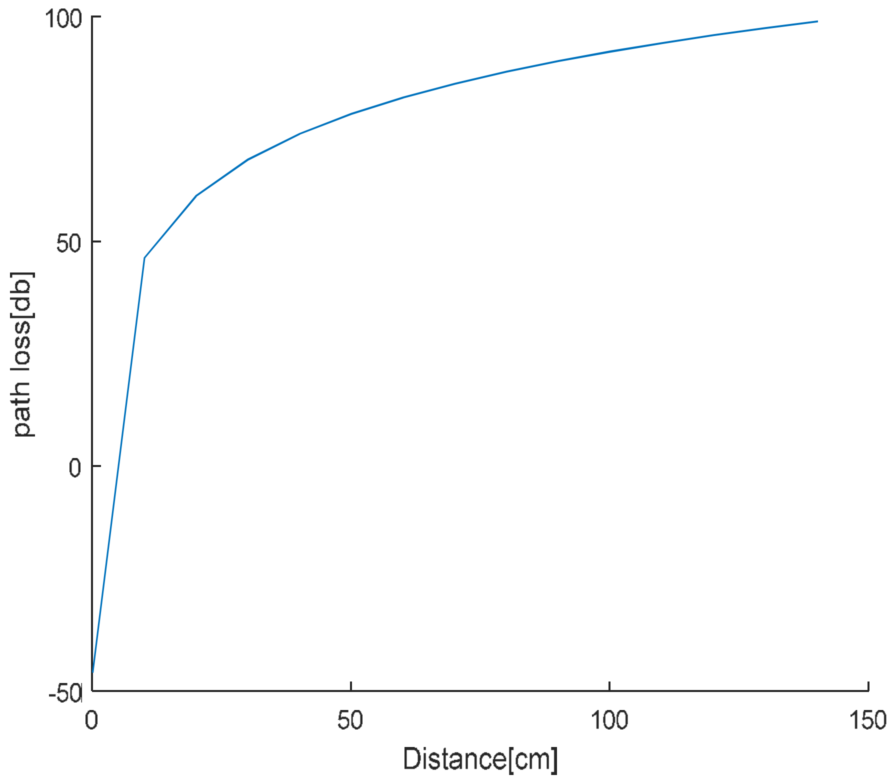

Figure 4-1: Path loss versus distance graph

From the result of the simulation it is concluded that a steady rise in path loss with increase in distance between the sensor and the coordinator. This implies that when a relay node is used, the interference on the signal due to free space path loss is reduced thus enhancing energy reduction during transmission.

Energy dissipation: - is loss of energy to transmit data from the transmitter to the receiver.

Table 3: Transmitter energy and distance data from MATLAB

Distance (cm)	**Transmitter energy (nJ)**
0	0.0061
10	20.9859
20	257.9027
30	1.1688e+03
40	3.4581e+03
50	8.0651e+03
60	1.6155e+04
70	2.9115e+04
80	4.8547e+04
90	7.6264e+04
100	1.1429e+05
110	1.6485e+05
120	2.3038e+05
130	3.1351e+05
140	4.1707e+05

A plot of transmitter energy versus distance shows that energy dissipation at the transmitter energy will be increased as increasing distance as shown in figure below:

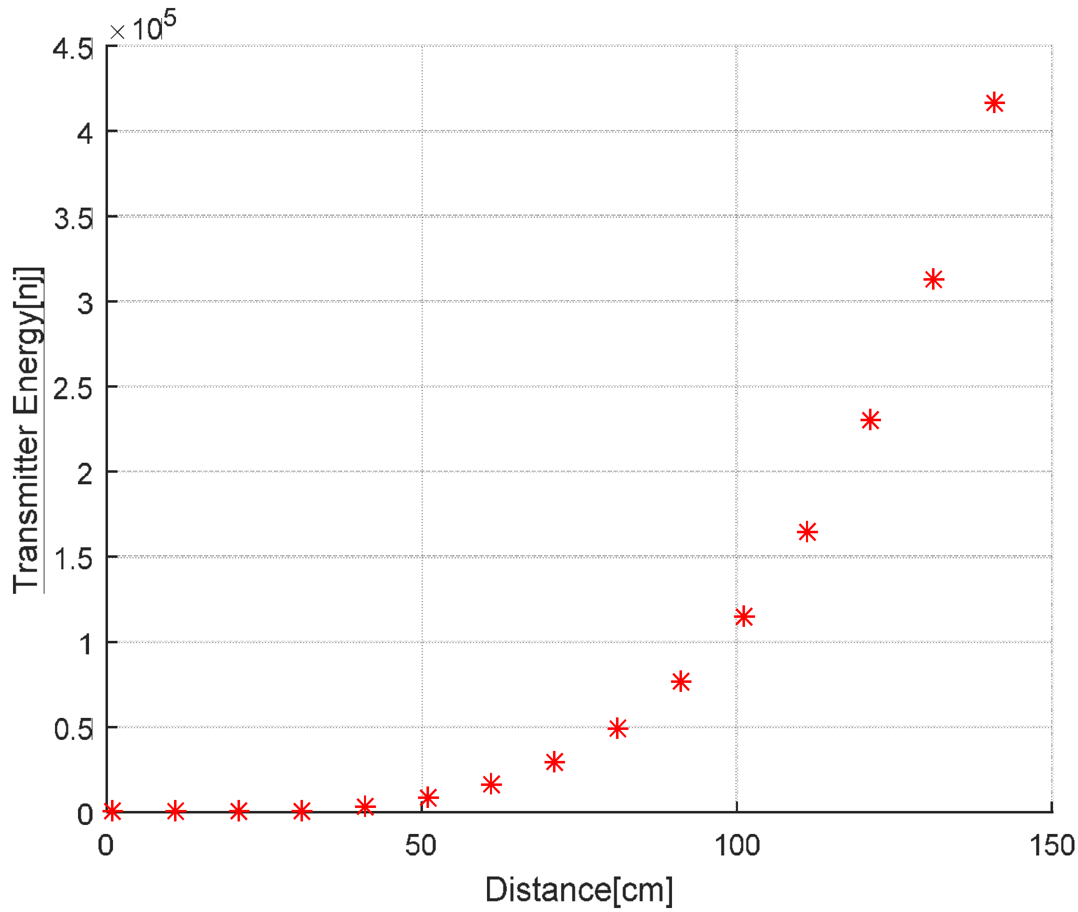

Figure 4-2: Transmitter energy versus distance graph

4.3. Discussion of findings on energy reduction during abnormal energy wastage

As we discussed before abnormal energy wastage can be occurred mainly by interference. Interference in WBAN can be occurred when many spectrum users can use one spectrum at a time. Therefore, in order to reduce energy consumption during abnormal energy wastage cognitive radio network is a great advantage.

As we know that CR promises the secondary users access the spectrum which is allocated to a primary user, so avoiding interference to potential primary users is a basic requirement. Therefore we should detect the primary user status through the continuous spectrum sensing.

❖ Simulating the Signal in MATLAB

Here encode the signal in MATLAB to simulate the output signal. It consists of the energy values of each samples' signal. Then encode energy detector to calculate the energy of each samples. Comparing the energy detected with the threshold, and then determines the presence or the absence of the primary users. The parameters, the false alarm probability and the threshold are the important parameters in CR networks; the false alarm probability should be kept as small as possible to avoid underutilization of transmission opportunities.

❖ Encode the output signal from the integrator

We can encode the output signal using: sig=sqrt(sigmas^2+sigman^2)*randn(100,N). Where sigmas^2 is the variance of the signal waveform, sigman^2 is the variance of AWGN and randn distributes random numbers and arrays.

Then we set the values of the parameters to simulate the signal; SNR=-10dB, bandwidth W=1*10^5, observes time Ts=1*10^-2sec, samples N=2*Ts*W, variance of the noise σn^2 =1*10^-12 and variance of the received signal $\sigma s^2 = (\sigma n^2 * 10^{-1})^2$.

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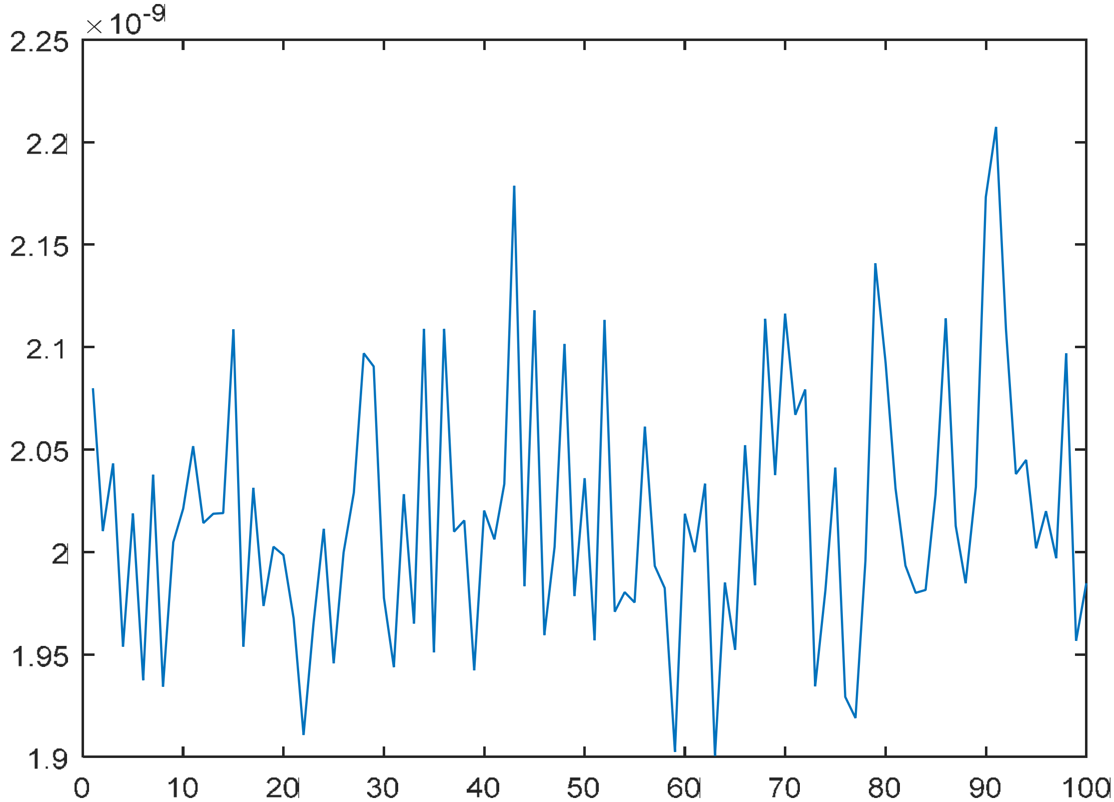

Figure 4-3: output signal with AWGN

The above figure shows that different signal's energy at different samples. On the X-axis different samples are found and on the y-axis different signal's energy in dB are shown.

- ❖ Encode the energy detector

Set up the energy detector in MATLAB to detect and compare the output signal which is simulated in the previous section with threshold. The idea of the energy detector is to detect the energy of the different sample's signal and then comparing the energy with the threshold to see if there is primary user or not.

So we can encode the threshold (lamda) as:

lamda = sqrt(4*Ts*W*sigman^4)*qfuncinv(Pf) + 2*Ts*W*sigman^2 in matlab, where: qfuncinv is the inverse Q-function.

Then compare the threshold lamda (λ) with each sample's energy E:

If E > λ, it means the spectrum is occupied by primary users and we get 1 detection.

If E < λ, it means the spectrum is idle and we get 0 detection.

Then we set the values of the parameters to calculate the threshold or lamda and to detect the presence or absence of primary user and sum all the samples which are detected. SNR=-5dB (for example), pf=0.01 and samples N=100.

Through the detection we get the each sample's energy and the threshold lamda = 0.2147. Comparing with the detections, there is 75 sample's energy greater than threshold so there are 75 spectrums occupied and there are 75 detections. As we know that the minimum SNR is the least signal level needed to decode the received signals. So SNR maybe influence the result.

❖ SNR and Detection

In CR networks, to determine the spectrum availability, CR user need statistical information on the received primary signals, so the minimum SNR is the least signal level needed to decode the received signals. As increasing the SNR value number of detections also increases. We will change the SNR and then repeat the simulation to see the relationship between the SNR and the detections.

As we can see from the table below with the increasing of the SNR (from -10 dB to 0) the detections we get also increased. So the SNR influences the detections. It indicates that with the increasing of the SNR, the more spectrums which are occupied we can detect.

Table 4: SNR versus detection

SNR (dB)	Detections
-10	3
-9	6
-8	6
-7	11
-6	34
-5	75
-4	100
-3	100
-2	100
-1	100
0	100

4.4. Performance metric measurement

The performance of the spectrum sensing technique can be measured by the performance metric values. These values determine the presence and absence of primary users in the model. The following parameters are used to measure the performance of energy detector:

- Probability of false alarm
- Probability of miss detection
- Probability of detection and
- The receiver operating curve (ROC)

Probability of false alarm (P_f): the probability of deciding the signal is present while H_0 is true. In the context of cognitive radio networks, a false alarm yields undetected spectrum holes [10]. So a large P_f contributes to poor spectrum usage by secondary users.

Probability of miss detection (P_{md}): the probability of deciding the signal is absent while H_1 is true. Large P_{md} introduces unexpected interference to primary users [10].

Probability of detection (P_d): the probability of deciding the signal is present when H_1 is true.

The receiver operating curve (ROC): measures the sensitivity of the detector and can be used in binary hypothesis. Currently the application of this curve has become much popular [10]. The ROC curve is widely applicable in signal detection and it shows the tradeoff between probability detection and false alarm probability.

4.5. Comparisons of energy detector and matched filter spectrum sensing techniques

Energy detector is based on the transmitter detection to deduce whether there is a signal from primary transmitter which is present in a spectrum or not. Energy detector simplifies the matched filter to perform non-coherent detection. It detects the received signals' energy to compare with the threshold and then deduce the status of the primary signals. It has low computational and execution complexities, so it is the most widely used techniques in spectrum sensing.

Energy detector based spectrum sensing is employed for both in inband and wideband spectrum sensing whereas matched filter based spectrum sensing employed for only inband sensing [34]. A matched filter based spectrum sensing has high computational complexity and implementation cost in comparison to the energy detector based spectrum sensing. Being coherent technique in a matched filter based spectrum sensing each SU require PU information storage in its database whereas energy detector has no such information requirements [34].

Based on the performance metric stated in section 4.4 this section provides a comparison between energy detector and matched filter based spectrum sensing in order to show the performance of energy detector.

The figure 4-4 shows a plot of SNR versus probability of detection at the value of false alarm probability P_{fa} = 1e-08 in energy detector method. The graph shows that as the value of SNR increase the probability of detection also increase. When the value of SNR becomes near to 8 db, the value of probability of detection becomes 1. So we can achieve high value of probability of detection at low SNR value.

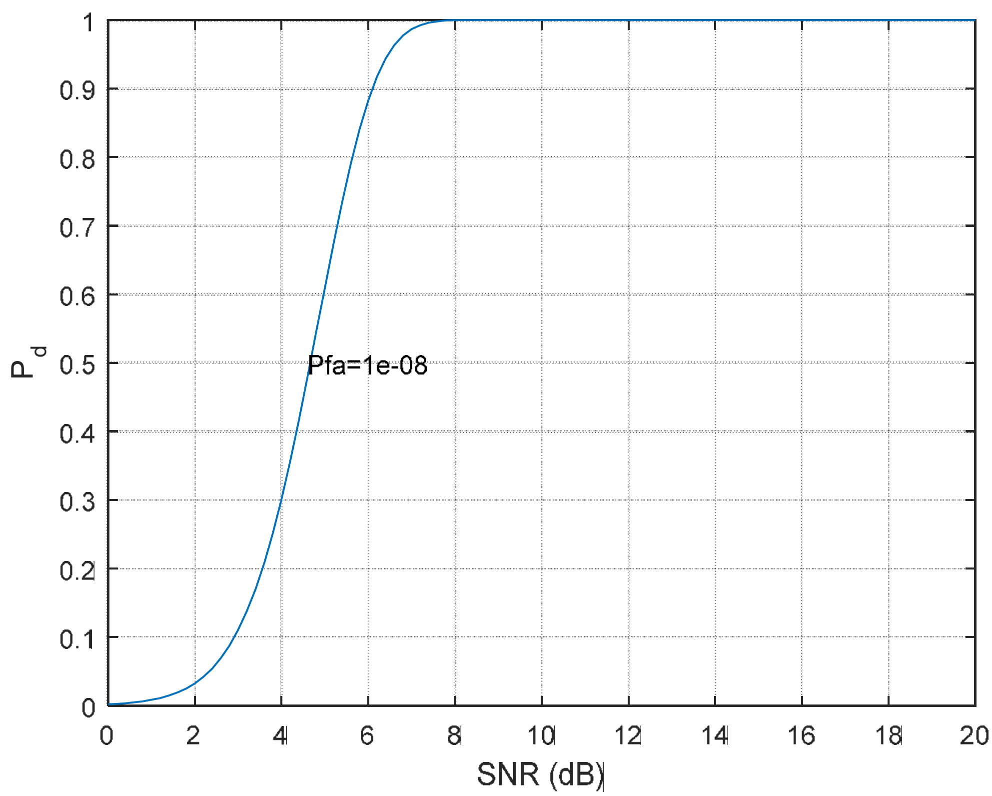

Figure 4-4: Probability of detection versus SNR in energy detector

The figure 4-5 below shows a plot of probability of detection versus SNR in matched filter based spectrum sensing method at the same probability of false alarm P_{fa} = 1e-08. When we set the value of SNR to 8 db the value of probability of detection becomes almost 0.63. As shown in the graph as the value of SNR increase from 0 db to 20 db, the value of probability of detection not equal to 1. So in matched filter spectrum sensing we cannot achieve high value of probability of detection in low value of SNR.

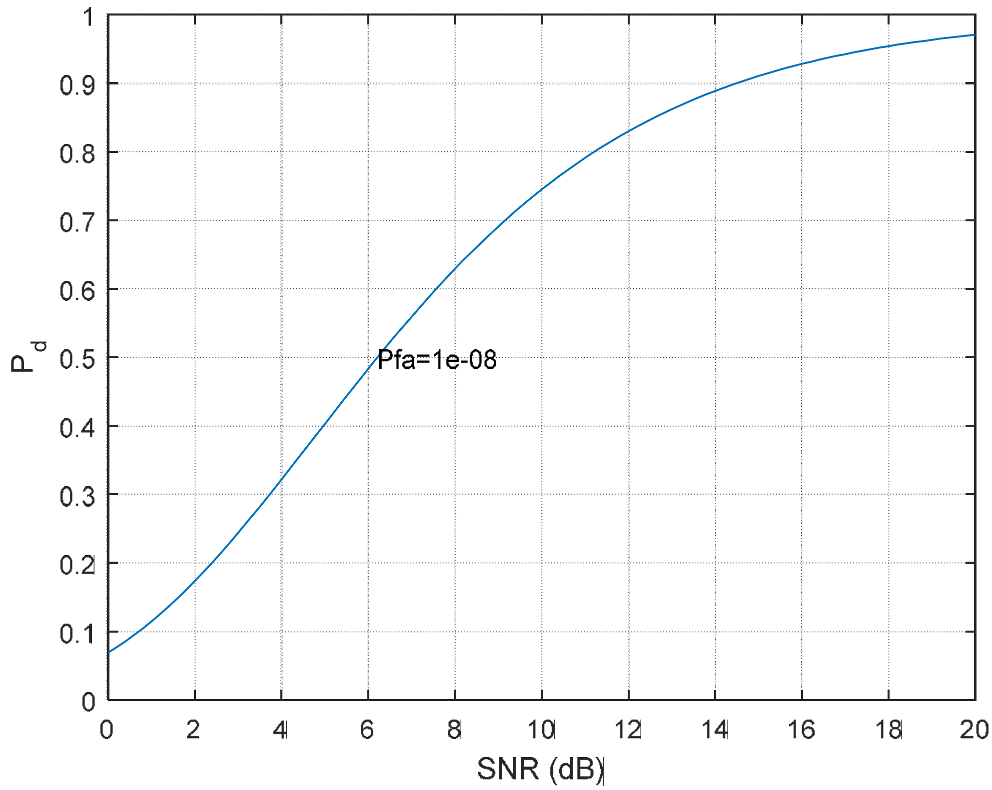

Figure 4-5: Probability of detection versus SNR in matched filter

The figure 4-6 below shows a comparison of both energy detector and matched filter based spectrum sensing method. The plot shows the comparison of both sensing techniques at the same probability of false alarm P_{fa} = 1e-08 and we get the following ROC (Receiver operating characteristics) curve. By concluding graph we can say that energy detector method is more effective than matched filter method at low value of SNR.

As shown in the graph the proposed energy detection based spectrum sensing performs better in the low value of SNR than that of matched filter spectrum sensing technique. One of the performance metric is probability of detection in which increasing the value of probability of detection in low value of SNR. We conclude that we can achieve high probability of detection at low value of SNR in the proposed energy detection.

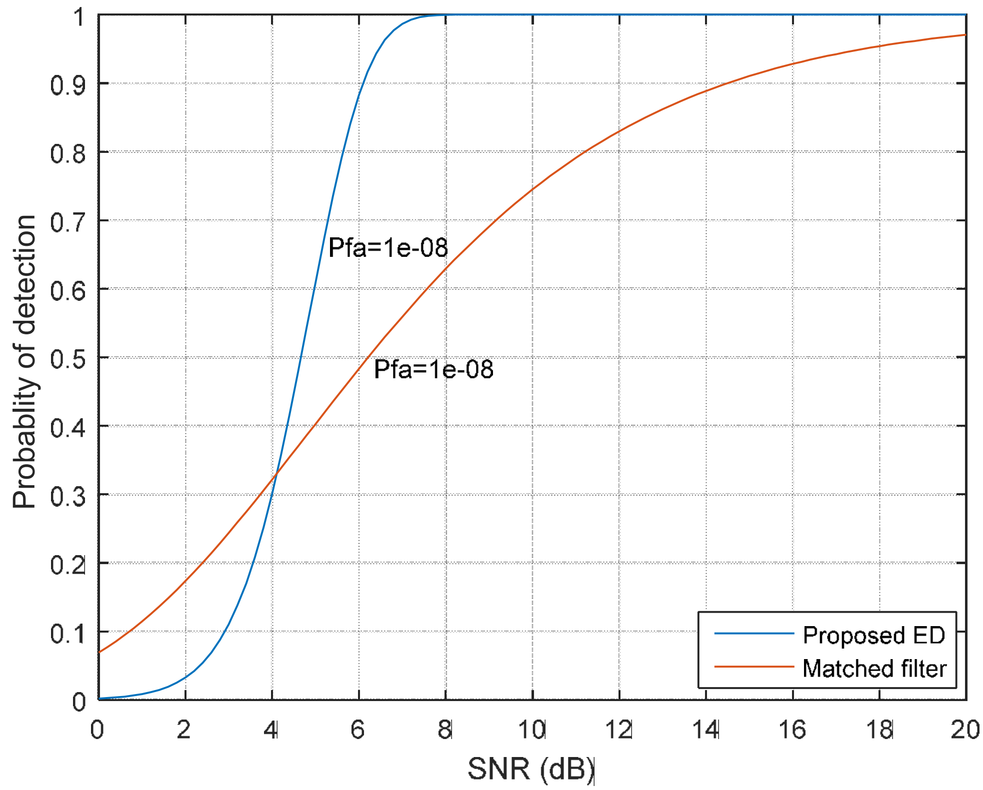

Figure 4-6: Probability of detection versus SNR in both energy detector and matched filter

Figure 4-7 shows that as the number of samples increases probability of detection also increases and SNR get improved. So energy detector is also used to improve SNR in wireless communication. At low SNR energy detection has more efficiency than matched filter method. So energy detection method gives more probability of detection and also the value of SNR will be improved. The graph shows the number of samples versus SNR required for detection. As the number of samples increases from 1 to 10 the value of SNR required for detection should be increased greatly in order to improve the performance of spectrum sensing technique.

From the comparison of energy detection and matched filter spectrum sensing, as the number of samples increases the value of SNR required for detection should be increase in order to increase the access of getting free channels for transmission. So energy detection achieves high performance in improving SNR required for detection.

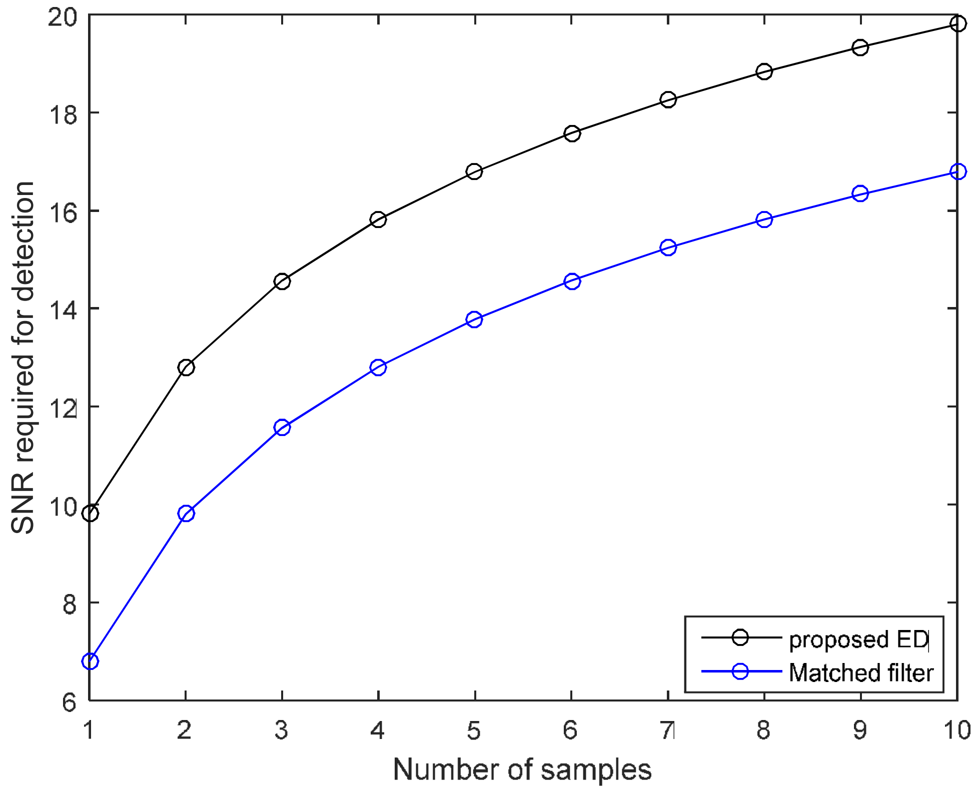

Figure 4-7: Number of samples versus SNR required for detection

As shown in the figure 4-8 below, we can say that as the number of samples increases probability of detection increases and detection threshold get improved. So energy detector is also used to improve detection threshold compared to matched filter. Improving detection threshold helps in increasing the chance of getting free channels for transmission.

As the number of samples increase the value of detection threshold should be increased in order to get unused channel or spectrum for the use of SU. From the graph below when the number of samples is 1, the value of detection threshold is 3 in the energy detection method. But in matched filter spectrum sensing when the number of samples is 1, the value of detection threshold is 2 which is less than the value in energy detection. So the proposed energy detection has high performance in enhancing detection threshold than matched filter.

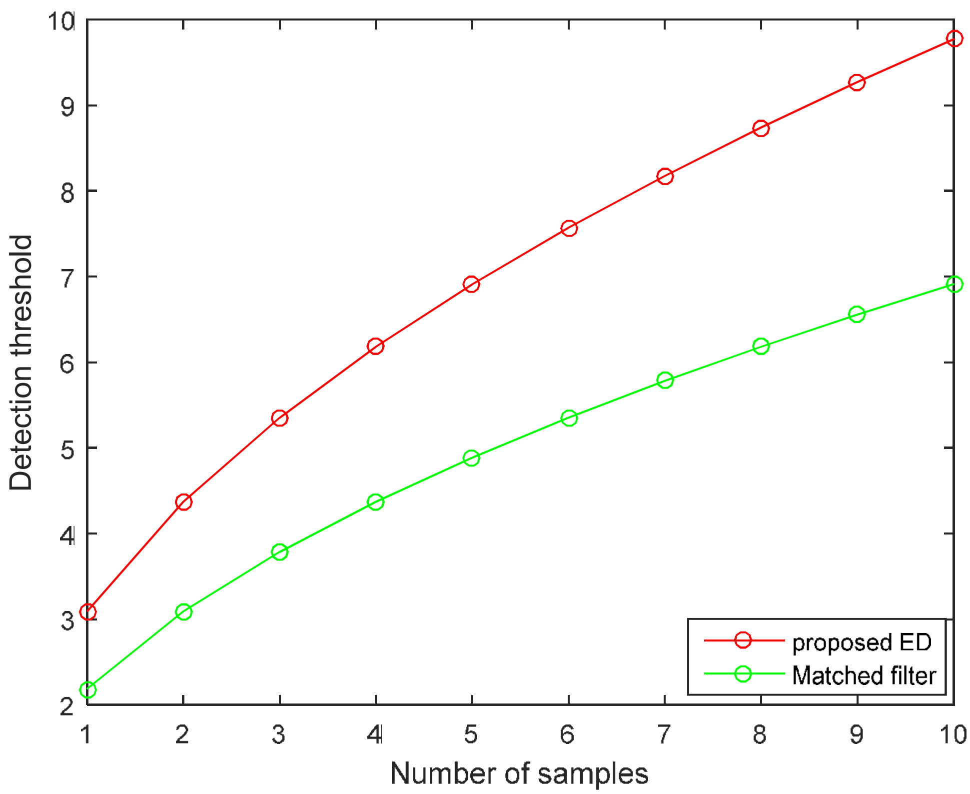

Figure 4-8: Number of samples versus detection threshold

Figure 4-9 shows a graph of probability of false alarm and probability of miss detection for the proposed energy detector. From the theory we can understand that large value of probability of miss detection introduces unexpected interference to primary users. So the value of probability of miss detection should be kept small as possible.

The graph is a Receiving operating characteristics (ROC) curve shows the probability of false alarm versus the probability of miss detection. The value of miss detection should be kept as small as possible in order to increase the performance of spectrum sensing technique. From the graph as the value of probability of false alarm comes to 1, the value of probability of miss detection becomes zero.

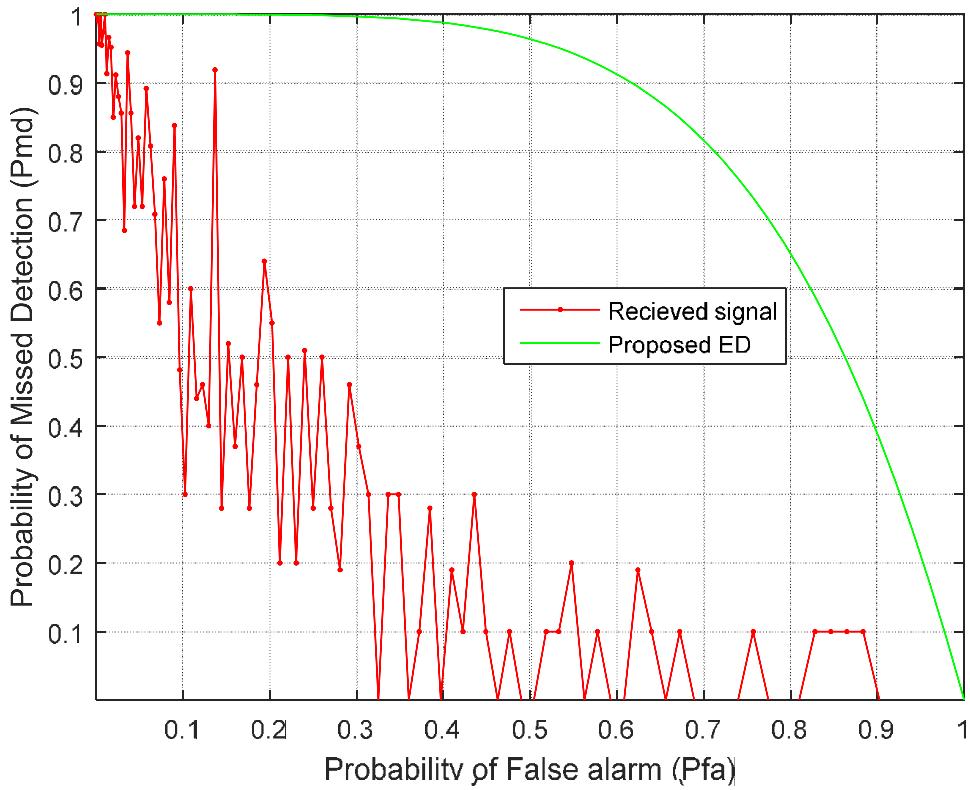

Figure 4-9: ROC graph of Probability of miss detection versus probability of false alarm

Figure 4-10 shows a graph of probability of false alarm and probability of miss detection for the proposed energy detector. From the theory we can understand that large value of probability of miss detection introduces unexpected interference to primary users. So the value of probability of miss detection should be kept small as possible.

The graph is a Receiving operating characteristics (ROC) curve shows the probability of false alarm versus the probability of miss detection. The value of miss detection should be kept as small as possible in order to increase the performance of spectrum sensing technique.

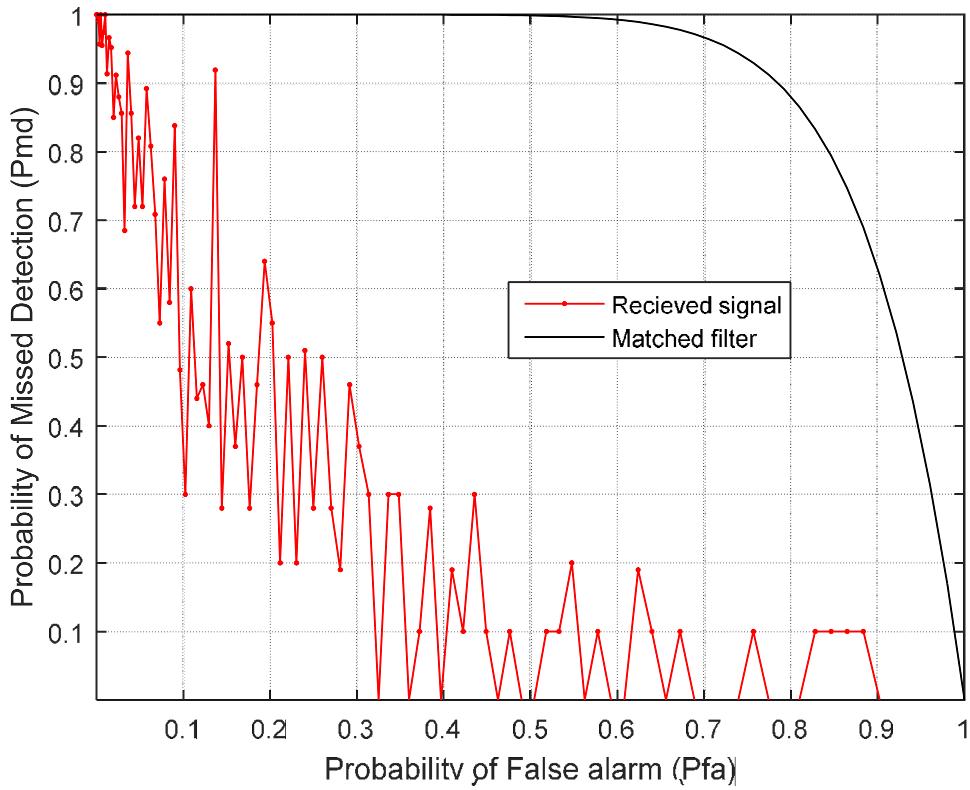

Figure 4-10: ROC graph of Probability of miss detection versus probability of false alarm

Figure 4-11 is a ROC curve graph of probability of miss detection and probability of false alarm. From the simulation result as the value of false alarm probability increase towards 1, the miss detection value of energy detector decrease to 0. If we set the probability of false alarm to 0.5, the miss detection value will be almost 0.9625 in energy detector. Whereas in matched filter, for same value of false alarm probability the corresponding miss detection value was almost 1. This implies energy detector reduce the miss detection value compared to matched filter.

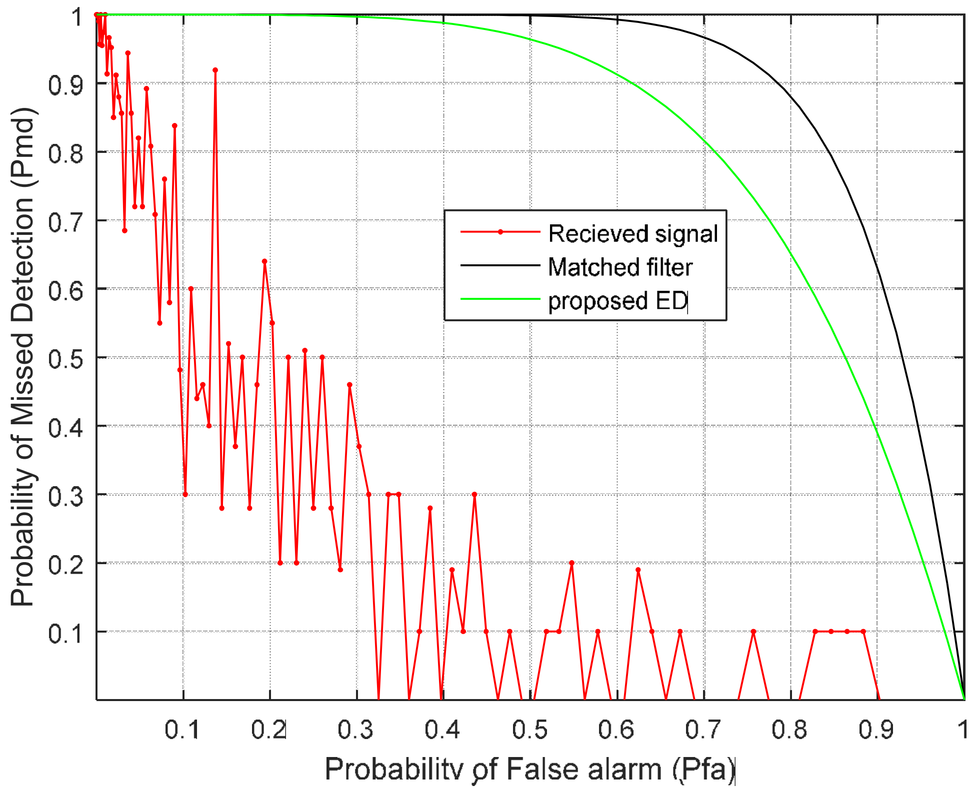

Figure 4-11: ROC graph of Probability of miss detection versus probability of false alarm

Receiving operating characteristics (ROC) curves are useful for analyzing energy detector based spectrum sensing method performance, for coherent system. We used the ROC SNR function to analyze the effectiveness of energy detection for various SNR values. In addition to this, we also reviewed the improvement in energy detection performance achieved by multiple samples. Finally, I used the ROC SNR and ROC Pfa functions to analyze energy detector performance when using for both coherent and non coherent system.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this research project, I proposed optimizing network lifetime of WBAN through cognitive radio. As I discussed before, the main problem in WBAN is high energy consumption during transmission time and abnormal energy wastage. To overcome this problem, I proposed the solutions in to two parts.

Part 1: in the first part of the study reducing energy consumption during transmission time is presented. The model uses an optimum distance to place a relay for transmitting signals from nodes beyond the predetermine distance. The simulation showed that the nodes uses lower energy to send signals through a relay and short distance. Based on the simulation result, path loss was affected greatly by distance. As the distance increased more and more the path loss become higher.

Part 2: the second part of the study was reducing energy consumption during abnormal energy wastage through cognitive radio is presented. The model uses dynamic spectrum access (DSA) technology for allocation of spectrum to the users in order to reduce interference. An energy detector technique is used to detect the energy of different sample's signal and then comparing the energy with the threshold to see if there are primary users or not. Also the study presents how the SNR influences the detections and presents the suitable SNR for the energy detector.

Energy detector is based on the transmitter detection to deduce whether there is a signal from primary transmitter which is present in a spectrum or not. Energy detector simplifies the matched filter to perform non-coherent detection. It detects the received signals' energy to compare with the threshold and then deduce the status of the primary signals. It has low computational and execution complexities, so it is the most widely used techniques in spectrum sensing. But it also has some disadvantages. Energy detector cannot distinguish between modulated signals, noise and interference. Furthermore, a threshold we used will be easily influenced by unknown or changing nose levels, so the energy detector will be confused by the presence of any inband interference. Thirdly, CR users cannot perform the sensing tasks and transmission at the same time.

During the simulation result in getting the energy of 100 samples and calculates the false alarm probability. It is different from the theory value we take. So the SNR can be considered as an important factor to influence the detections. By changing the value of the SNR, we get the relationship between the SNR and the detections, from the diagram, we can see from -4 dB to 0, SNR makes the energy detector performs best.

5.2. Recommendations

As a recommendation wireless body area network is a broad area of study in this recent time. There are many research studies on enhancing the performance of WBAN. For further study in the future I recommend:

- Performing adequate studies on security and reliability issues
- Implementing energy detection in other programming language
- Enhancing the performance of WBAN through applying different spectrum sensing techniques

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APPENDICES

Appendix A

Energy of each sample in -5dB

0.2076	0.2092	0.2202	0.2245	0.2108	0.2280	0.2100	0.2213	0.2207	0.2137
0.2297	0.2199	0.2226	0.2239	0.2175	0.2241	0.2076	0.2286	0.2300	0.2226
0.2171	0.2211	0.2194	0.2200	0.2188	0.2298	0.2176	0.2156	0.2211	0.2286
0.2197	0.2234	0.2329	0.2331	0.2232	0.2115	0.2146	0.2094	0.2151	0.2237
0.2281	0.2211	0.2094	0.2207	0.2140	0.2210	0.2335	0.2335	0.2218	0.2264
0.2204	0.2266	0.2306	0.2186	0.2255	0.2279	0.2327	0.2144	0.2205	0.2016
0.2153	0.2206	0.2340	0.2339	0.2164	0.2095	0.2003	0.2112	0.2154	0.2175
0.2131	0.2172	0.2150	0.2136	0.2287	0.2254	0.2176	0.2227	0.2167	0.2191
0.2308	0.2273	0.2207	0.2289	0.2245	0.2140	0.2238	0.2148	0.2350	0.2153
0.2095	0.2127	0.2210	0.2050	0.2246	0.2068	0.2158	0.2350	0.2085	0.2128

Appendix B

MATLAB code for calculating path loss along with increasing distance

```
>>clear all;
>> f=2.4*10^9
f =
   2.4000e+09
>> c=3*10^10
c =
   3.0000e+10
>> pi=3.14
pi =
    3.1400
>> d=[0.1:10:150]
d =
  Columns 1 through 4
    0.1000   10.1000   20.1000   30.1000
  Columns 5 through 8
   40.1000   50.1000   60.1000   70.1000
  Columns 9 through 12
   80.1000   90.1000   100.1000   110.1000
  Columns 13 through 15
  120.1000   130.1000   140.1000
>> PL=20*log((4*pi*d*f)/c)
```

```
PL =

  Columns 1 through 4

  -45.9559   46.3465   60.1102   68.1863

  Columns 5 through 8

   73.9233   78.3762   82.0160   85.0942

 Columns 9 through 12

   87.7613   90.1142   92.2192   94.1236

  Columns 13 through 15

   95.8623   97.4618   98.9429

>> figure;hold;

Current plot held

>> plot(d,PL)

>> xlabel('Distance[cm]')

>> ylabel('path loss[db]')

>>
```

Appendix C

Detecting the energy of each sample in -10dB

```
>> W=1e+5;
>> Ts=1e-2;
>> N=2*Ts*W;
>> sigman=1e-6;
>> %SNR=-10dB
>> sigmas=sigman*(10^(-10/10));
 >> sig=sqrt(sigmas^2+sigman^2)*randn(100,N);
>> pf=0.01;
 >> lamda=sqrt(4*Ts*W*sigman^4)*qfuncinv(pf)+2*Ts*W*sigman^2;
>> for i=1:100
ss=sig(i,:);
en(i)=sum(ss.^2);
en
 lamda
 z(i)=en(i)-lamda;
 end
en =
    1.0e-08 *
  Columns 1 through 5
    0.2040    0.1957    0.2015    0.2095    0.2029
  Columns 6 through 10
    0.1967    0.2027    0.2136    0.2010    0.1935
```

Columns 11 through 15

0.1886 0.2014 0.1882 0.2122 0.2060

Columns 16 through 20

0.2066 0.2080 0.2032 0.1920 0.2085

Columns 21 through 25

0.2021 0.1973 0.1970 0.1961 0.2119

Columns 26 through 30

0.2149 0.2057 0.1976 0.2019 0.2027

Columns 31 through 35

0.2046 0.2018 0.2033 0.1878 0.2136

Columns 36 through 40

0.2000 0.2133 0.1957 0.2059 0.1913

Columns 41 through 45

0.1976 0.2117 0.2078 0.1922 0.1909

Columns 46 through 50

0.2031 0.1958 0.2086 0.1954 0.1956

Columns 51 through 55

0.2053 0.2052 0.1981 0.2111 0.2098

Columns 56 through 60

0.2043 0.1943 0.1939 0.1914 0.2011

Columns 61 through 65

0.2051 0.1974 0.2106 0.1998 0.2005

Columns 66 through 70

0.2023 0.1977 0.2009 0.2000 0.1938

Columns 71 through 75

```
   0.2025    0.2032    0.2013    0.2036    0.2005

  Columns 76 through 80

   0.2024    0.2099    0.2111    0.2246    0.2024

  Columns 81 through 85

   0.2187    0.2057    0.1976    0.1906    0.2078

  Columns 86 through 90

   0.1937    0.1995    0.2053    0.1979    0.1990

  Columns 91 through 95

   0.2089    0.2012    0.1968    0.1947    0.2049

  Columns 96 through 100

   0.1947    0.1957    0.2043    0.1863    0.2070

lamda =

   2.1471e-09

>> detect=z>=0;
>> sum(detect)

ans =

     3

>>
```