East West University

Undergraduate Thesis Report
On
Study of Energy Detection Based On Spectrum Sensing in Cognitive Radio

Submitted to the Department of Electronics and Communications Engineering in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Electronics and Telecommunications Engineering

Prepared By

Arman Hossain ID# 2012-2-55-057

Mirza Hasibul Hasan ID# 2012-2-55-068

Superivised By

Sarwar Jahan

Senior Lecturer

Department of ECE, East West University

Spring 2016

Declaration

We, hereby declare that we have completed thesis on the project entitled **"Study of Energy Detection Based On Spectrum Sensing in Cognitive Radio"** as well as prepared a research report to the department of Electronics and Communications Engineering is partial fulfillment of the requirement for the degree of Bachelor in Electronics and Telecommunications Engineering under the course of 'ETE 498'.

We farther assert that the work presented in this report is our except where due reference or acknowledgement is presented as to the work of others.

Signature

…………………………… …………………………….

Arman Hossain
ID# 2012-2-55-057
Department of ECE, East West University

Mirza Hasibul Hasan
ID# 2012-2-55-068
Department of ECE, East West University

Approval of Supervisor

…………………………………

Sarwar Jahan
Senior Lecturer
Department of ECE, East West University

Approval

The thesis titled **"Study Of Energy Detection Based On Spectrum Sensing in Cognitive Radio"** submitted by Arman Hossain (ID# 2012-2-55-057) and Mirza Hasibul Hasan (ID# 2012-2-55-068) to the Department of Electronics and Communications Engineering, East West University, has been accepted as satisfactory for the partial fulfillment of requirements for the degree of Bachelor of Electronics and Telecommunications Engineering as approved as to its style and contents.

Approved By Supervisor:

……………………………….

Sarwar Jahan

Senior Lecturer

Department of ECE, East West University

Abstract

To cope up with the demand of user's traffic and availability of spectrum of wireless network, cognitive radio can pave the way to optimize them. Cognitive radio networks (CRN) deals with two types of users: one is primary users (PUs) or licensed users who have the higher priority to use a specific part of the spectrum and the other one is secondary users (SUs) or unlicensed users who have less priority of using spectrum. SUs use the spectrum in such a way that they do not cause interference with PUs. In cognitive radio network, different techniques (i.e. Energy detection, Cyclostationary Feature Detection, Matched filter, Cooperative Sensing, Waveform Based Sensing etc.) have been used to improve the performance of channel sensing. However, some of these techniques are vulnerable to malicious users and may not correctly follow sensing order of saving energy and/or time or to lunch denial of service attacks against the network. The performance of such a network solely depends on the accuracy of spectrum sensing, i.e. minimization of false alarm and maximization of detection. These two parameters are heavily affected by the presence of malicious users inside the network. In this paper we have studied cooperative sensing energy detection method of cognitive radio network and show the relation of bit error and signal to noise ratio (SNR) in Rayleigh fading channel. Also analyze the probability of miss alarm and probability of detection for different number of users.

Acknowledgement

We would like to express our heartiest and most sincere gratitude to our supervisor Sarwar Jahan, Senior Lecturer, Department of Electronics and Communications Engineering, East West University for his constant support, suggestions, encouragement, intelligent and guiding us to successfully complete our thesis work. He provided us with every bit of support he could manage. We were allowed to work on our own and whenever we lost our way, he guided us back to track with patience and interest.

We would like to thank all of the faculty members of ECE department for their kindness and support all these days. They helped us with their suggestion whenever we required their council. We thank our friends and batch-mates for helping us every possible way they can and always lifting us in tough situation.

We are thankful to our parents and family for their endless support and encouragement which always gave us hope and inspired us to work harder.

Thank you everyone.

Signature:

……………………

Arman Hossain

ID# 2012-2-55-057

Department of ECE, East West University

………………………

Mirza Hasibul Hasan

ID# 2012-2-55-068

Department of ECE, East West University

Authorization

We hereby declare that were the sole authoring soft his thesis. We authorize East West University to lend this thesis to other institution so are individuals for the purpose of scholarly research.

Arman Hossain

ID# 2012-2-55-057

Mirza Hasibul Hasan

ID# 2012-2-55-068

CONTENTS

Declaration II
Approval III
Abstract .... **IV**
Acknowledgement V
Authorization VI
List of tables VIII
List of figures IX

Chapter 1 : Introduction and fundamentals of Cognitive Radio 1
1.1 Introduction 2-4
1.2 History and Background of Cognitive Radio 4
1.3 Advantage of Cognitive Radio System 5-6
1.4 Feature of Cognitive Radio 7
1.5 Purpose of Cognitive Radio 7-8
Chapter 2 : Types of Cognitive Radio (CR) 9
2.1 Types of Cognitive Radio 10-11
2.2 Signal Detection techniques for spectrum sensing 11-12
Chapter 3 : Literature survey and Task of Cognitive Radio 13
3.1 Cognitive Cycle 14
3.2 Main function of Cognitive Radio 14-15
Chapter 4 : Spectrum Sensing 17
4.1 Spectrum Sensing in Cognitive Radio 18

4.2 Challenges in Spectrum Sensing....................18
4.3 Methodology 19
4.4 Use of Spectrum Sensing 19-22
4.5 Probability of false alarm (P_{FA}) and probability of miss detection (P_M) 22

Chapter 5 : Energy Detection 23
5.1 Definition 24-25
5.2 Methodology....................25
5.3 How it works....................25
5.4 System Model....................25-28
5.5 Advantage of Energy Detection 28-29

Chapter 6 : Result Analysis....................30
6.1 Optimization of Cooperative Spectrum sensing to minimize the total error rate ...31-36
6.2 Energy Detection Simulation 36-38
Chapter 7 : Types of Cognitive Radio (CR) ....
7.1 Conclusion....................39-40
APPENDIX A : MATLAB 41-51
References....................52-54

List of Tables

Table 3.1 Overview of available techniques for spectrum sensing 16
Table 6.1 Optimal number of 'n' CRs for different SNR and its error level 35

List of figures

Figure 1.1: SDR becomes the platform of choice for the Cognitive Radio………………..5

Figure 1.2: Spectrum Bands………………………………………………………….6

Figure 3.1: Cognitive Cycle 14

Figure 4.1: Cooperative spectrum sensing (CSS).. 22

Figure 5.1: Energy Detector 24

Figure 5.2: Block diagram of energy detection 25

Figure 5.3: Interference cause by shadowing uncertainty 29

Figure 5.4: Between miss detection and false alarm 29

Figure 6.1 (a): Total error probability for n=5 versus threshold when ED with SNR=10dB and L=10 samples at CR 31

Figure 6.1 (b): Optimization of Cooperative Spectrum sensing total error probability CRs threshold vs. total error rate when ED is used locally with SNR=10dB............................ 32

Figure 6.1(c): Total error probability for n=10 CRs versus threshold when ED is used with SNR=5dB and N=20 samples used at each CR 33

Figure 6.1(d): Total error probability for n=10 CRs versus threshold when ED is used with SNR=13dB and N=20 samples used at each CR 34

Figure 6.1(e): Total error probability for n=10 CRs versus threshold when ED is used with SNR=15dB and N=20 samples used at each CR 35

Figure 6.2(a): ROC curves for Energy Detection over Rayleigh fading channel(SNR=(20,25,30,35)dB and samples size L=10,15,20,25) 37

Figure 6.2(b): ROC curves for Energy Detection over Rayleigh fading channel for changing threshold at decreasing SNR=35dB (Pfa vs. Pm) 38

Figure 6.2(c): ROC curves for Energy Detection over Rayleigh fading channel for changing threshold (decreasing SNR=35dB, 30dB, 25dB) (Pfa vs. Pm) 38

Chapter 1

Introduction and fundamentals of Cognitive Radio

1.1 Introduction:

Cognitive radio (CR) is the most popular in wireless and mobile communication and it is network which is the next generation most essential in wireless communication system. Basically there are two types of users in cognitive radio. They are defined as licensed user, these are, (1)Primary User(PU) and (2)Secondary User(SU) .It enables in wireless communication to unlicensed users or secondary users (SUs) to exploit under-utilized spectrum (called white spaces)[1].The licensed users or primary users (PUs) so that bandwidth availability improves at the SUs, which helps to improve overall spectrum utilization. Collaboration is an intrinsic characteristic of CR to improve network performance. We are using Software Defined Radio (SDR) in CR technology [2]. It will change the way the radio spectrum is regulated. It will enable an early grow and successful results of cognitive radio which can affect many traditional businesses. Cognitive Radio is an adaptive intelligent radio and network technology that can automatically detect available channels in a wireless communication.

By convention licensed spectrum is allocated over long time periods and is meant to be used only by licenses. A government agency apportions license for spectrum use referred as the Fixed Spectrum Allocation (FSA) scheme. [3] With this, the radio spectrum is split into bands allocated to distinct technology based services e.g. mobile telephone, radio and TV broadcast on absolute basis. The FSA model guarantees exclusive use of the frequency spectrum by licensed users like primary user. As a consequence of the transition from regular voice only communication to multimedia type application demanding higher data rates and this plan will not have the capacity for emerging applications.[4]

However, studies show spectrum use is intense on certain portions while a significant amount remains underutilized. This is due in part to the fact that most carriers do not transmit at all times in all geographic locations where the license covers. Records from the FCC indicate spectrum allocated in the bands below 3GHz have a utilization range of 155 to 85%. [5]

Now a day the radio spectrum is being used in many sectors including mobile communications, medical and scientific research, cultural activities, aeronautical and marine communications, defense and emergency services etc. In that case, the number of users in radio spectrum services are communications and radio are increasing day by day and it is the most important for economic growth and many social activities and developing work . This is becoming obviously great effort in the wireless and mobile communication. At the same time spectrum sensing is facing some problem. So, Cognitive Radio Network (CRN) is the best solution for this problem. In cognitive radio there are two types of users, one is primary or licensed user who is mostly dependent on spectrum sensing and another one is secondary or unlicensed user which is less dependent in using spectrum. In cognitive network there are different types of spectrum sensing techniques [6]. These are,

1. Energy detection
2. Matched filter
3. Waveform sensing
4. Cooperative sensing
5. Cyclostationary feature detection etc.

These have been used for improving the performance of spectrum sensing. This is used for better performance against the network. In this network, there are different types of malicious users such as greedy users, unintentionally misbehaving users. The performance of spectrum sensing in the network i.e. minimization of false alarm and maximization of detection. These two parameters are heavily affected by the presence of malicious users inside the network.

In this present era, everything should be changed and updated. Although technology is being changed day by day, in future it is going to be on top. So many researcher to submit to change the technology and especially almost in wireless communication and other part of job. In the several work submitted, several researches stated that both of all time and frequency much have licensed spectrum unused. On the other hand traffic in wireless network tends to be burst. Spectrum sensing depends on the ability to use the unused spectrum. Cognitive Radio is the best solution for using the unused spectrum.CR is a very important technology for the new generation digital communications and its development is fundamental to guarantee an optimal use of the radio spectrum as wee economic and social benefits. Moreover, CR is a flexible system because it can change the communication parameters to adapt to channel conditions. Automatism and flexibility are possible because CR includes the Software-Defined Radio(SDR).The basic concept of SDR software radio can be configured or defined by the software so that a cheap and simple hardware. In this case, the function of cognitive radio actually includes the ability of a transceiver to determine its geographic location, encrypt or decrypt signals adjust output power, sense neighboring wireless devices in operation, identify a the user ,authorize its user. Mainly CR that new methods and algorithms can make fast and accurate.

The development of spectrum techniques enables the applications of CR in many areas like Cellular networks, Military usage, Emergency networks and TC white spaces etc.

But there are some problems with spectrum sensing in CR. Because maximum research focuses on spectrum sensing in CR. So, in theoretically detection algorithms not enough which the process of cognitive radio of spectrum sensing. In hardware test platform is required to test and check the performances of the CR networks. And in cognitive radio have interesting tested platform for radio network has been introduced by Eric Blossom that is called GNU radio. Later on, we will describe briefly.

1.2. History and background of Cognitive Radio:

The concept of cognitive radio was first proposed by Joseph MitolaIII in a seminar KTH (the Royal Institute of Technology in Stockholm) in 1998 and was published in an article by Mitola and Gerald Q.Maguire, Jr. in 1999.It was a novel approach in the wireless communication field. The sophistication possibility in a Software Defined Radio (SDR) has now reached the level where each radio can conceivably perform profitable tasks that help the user and help the network and help minimize spectral congestion. Radios are already demonstrating one or more of these capabilities in limited ways. To support the technologies and regulatory considerations three major applications make it cognitive radio. They are as follows:

1. Spectrum management and optimizations.
2. Interface with a wide variety of networks and optimization of network resources.
3. Interface with a human and providing electromagnetic resource to aid the human in their activities.

Many technologies have come together to result in the spectrum efficiency and cognitive radio technologies. These technologies represent a wide range of contributions up on which cognitive technologies may be considered as an application on top of a basic SDR platform which is implemented largely from digital signal processors and general-purpose processors (GPPs) built in silicon [7].

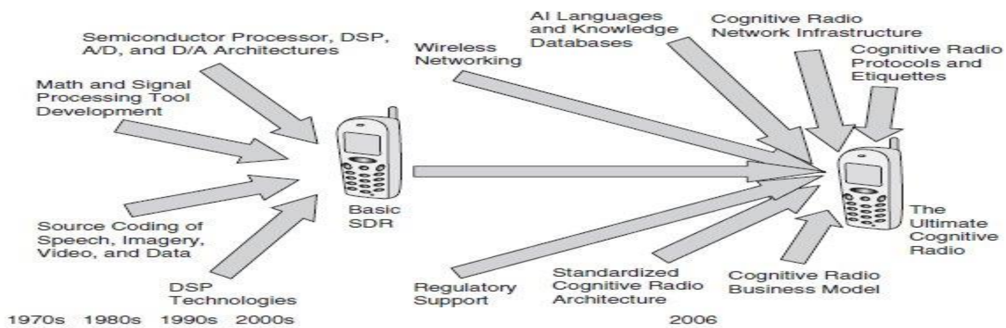

Fig 1.1: SDR becomes the platform of choice for the cognitive radio

1.3. Advantages of cognitive radio system:

There are lots of advantages of cognitive radio system which are given below:

- **Utilization of idle frequencies in white spaces:** National and international bodies assign different frequencies for specific uses. In most cases licensed users have the rights to broadcast over these frequencies. This frequency allocation process creates a band-plan. This band-plan assigns white spaces for technical reasons to avoid interferences. In this case, the frequencies are unused and they have been specifically assigned for a purpose such as a guard band. Most commonly although these white spaces exist naturally between using channels and since assigning nearby transmissions to immediately adjacent channels will cause destructive interferences to both. In addition to white space assigned for technical reasons, there is also an unused radio spectrum which has either never been used or is becoming free as a result of technical changes. A cognitive radio reconstructs those unused spectrums and makes them usable to the other users.

- **Adaptive communications:** Adaptive communication is form of communication which is tailored to someone’s needs and abilities. It is designed to provide people with the ability to communicate with others like as,
  - ✓ **Robust wireless systems (network switches):** It can monitor the spectrum and choose frequencies that minimize interference to existing communication activity.
  - ✓ **Dynamic spectrum access:** It has the strong ability to access free spectrum and able to modify it to use for the users who have the scarcity of spectrum.

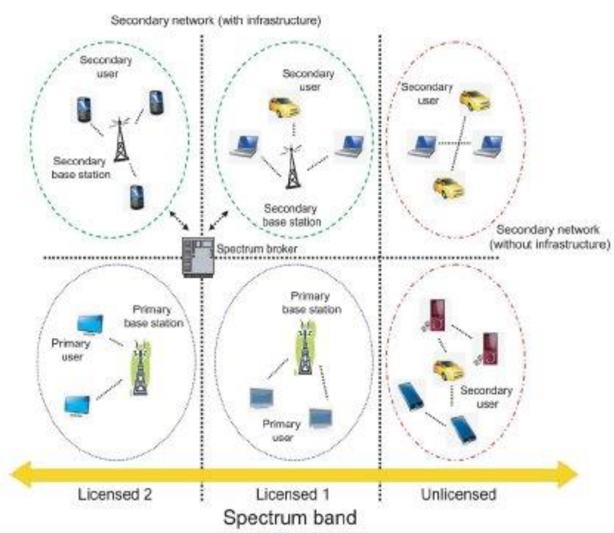

Fig: 1.2: Spectrum Bands [25]

- **On demand spectrum sharing, exchanges and merchandising:** On demand when there us any scarcity of unavailability of frequency CR can share, exchange or merchandising their frequency. The above fig 1.2 shows some of those situations where primary user are sharing spectrum with a secondary user through a spectrum broker. In fig 1.2 the primary user of licensed 1 and licensed 2 are sharing their network with secondary users and create a secondary network (with infrastructure). This network also exchanges the spectrum and creates a secondary network (without infrastructure) which is used by secondary unlicensed users.

1.4. Features of Cognitive Radio:

The following are the features of cognitive radio:

- **Frequency Agility:** Cognitive radio has this ability to change its operating frequency to optimize the usage certain conditions.
- **Dynamic Frequency Selection (DFS):** Cognitive radio has ability to sense signals from other nearby transmitters in the effort to choose an optimum operating environment.
- **Location Awareness:** CR provides the ability for a device to determine its location and the location of other transmitters. At first, it determines whether it is permissible to transmit at all and then to select the appropriate operating parameters such as the power and frequency allowed at its location.
- **Negotiated user:** A cognitive radio can incorporate a mechanism that enables the sharing of spectrum under the terms of a prearranged between a license and a third party.
- **Adaptive Modulation:** CR features with the ability of modify transmission characteristics and waveforms to exploit opportunities to use spectrum.
- **Transmit Power Control (TPC):** CR allows full power limits when it needs to transmit. But it can construct the transmitter power to a lower level to allow greater sharing of spectrum when higher power operation is not necessary.

1.5. Purpose of Cognitive Radio (CR):

- ✓ Identify the broad cognitive radio network technology vision and research opportunities.
- ✓ Define the required experimental infrastructure to carry out the science agenda.
- ✓ Define the boarder Impacts of cognitive radio network research and both in terms of social value and educational outreach programs.

The second and longer term opportunity is that of cognitive radio networks (CRNs), a term that refers to adaptive and self-organizing radio networks that are capable of responding to environmental changes such as interference, device density and end user application management.

CRNs with DSA capabilities have the potential for improving spectrum efficiency and wired network capacity while restricted forms of cognitive radio adaption and spectrum found in wireless network such as (Wi-Fi) [8].

1.6. Major research themes bring pursued by the community are identified in cognitive radio:

1. Spectrum policy alternatives and system models.
2. Spectrum sensing algorithms.
3. Cognitive radio architecture and software abstractions.
4. Cooperative wireless communication.
5. DSA technology and algorithms
6. Protocol architecture for CRNs.
7. Network security for CRNs
8. Cognitive networks and the internet[26]

Chapter 2

Types of Cognitive Radio (CR)

2.1. Types of Cognitive Radio:

Now we will describe about types of cognitive radio which has two types of radio network. These are [5],

(1) Full Cognitive Radio:

Cognitive radio is radio which takes every possible parameter into account.

(2) Spectrum Sensing Cognitive Radio:

Spectrum sensing cognitive radio is used for detecting channel only radio frequency considered. But now this time there are so many new solutions for cognitive radio. This new solution method for upcoming some new security threats. Such as followings:

Primary user emulation attacks (PUEs):

In Primary user emulation attacks ,attackers may transmit forbidden time slots and effectively emulate the primary user to make the protocol compliant SUs erroneous conclusion that the primary user are present. The primary user can be detected with high accuracy and low false alarm rate under primary user emulation attacks.

Spectrum sensing data falsification attacks (SSDF):

In these types of attacks in cognitive radio, the attackers send false observations and intentionally or unintentionally, to the fusion enter (FC) and let the FC make the wrong decision.

Then we know the there are two types of users in cognitive radio network but analytically we see that there are some users beside primary user (PUs) and secondary user (SUs).

- **Malicious user (MUs):** Malicious user is actually not providing service for other. This user makes some confusion

- to other user. These types of attacks send false observation to confuse other user .This is FC causing extensive DoS (Denial of Service) attacks making a CRN hop from band to band. Malicious users are harmful user for cognitive radio.
- **Unintentionally misbehaving users (UMUs):** These types of users report faulty observations for spectrum availability which is not for their subjective consciousness. But the malfunction of their software or hardware. This is called unintentionally misbehaving user.
- **Greedy users (GUs):** Greedy users always send false report to others. This attack mainly attitude like as UMUs but it continuously send false report to other user .It is specific spectrum hole is occupied by incumbent signals that force all other users to vacate the specific band (spectrum hole) in this user.

2.2. Signal Detection techniques for spectrum sensing:

Now we will talk about the different types of primary signal detections in cognitive radio [10]. These are,

1. Energy Detection(ED)
2. Matched Filter(MF)
3. Cyclostationary Feature Detection
4. Co-operative Sensing(CS)
5. Waveform Based Sensing

Energy Detection (ED): To simplify the matched filtering approach and one has to perform non-coherent detection through energy detection. This sub-optimal technique has been extensively used in radiometry. An energy detector can be implemented similarly to a spectrum analyzer by averaging frequency holder of a Fast Fourier Transform (FFT).Samples are required to meet a probability of detection due to non-coherent processing

Matched Filter (MF): The best way to detect the signals with maximum SNR is to use a matched filter. It is the most important skill is the low time needed but it needed some properties. This method includes the demodulation. Matched filter basically used for the PUs detecting. When the transmitted signal is known matched filter is the optimal solution for detecting PUs.This method is useful for dedicated receivers like in TV transmission [9].

Cyclostationary Feature Detection (CFD): CFD is the detection which proprieties that varies periodically with time which is called cyclostationary features. This type of detection exploits the periodicity in the received primary signal to identify the presence of the PUs signal. Spectral Correlation Function is defined as,

$$S_x^{\alpha}(f)=\lim_{\substack{T\to\infty \\ \Delta t\to\infty}} \frac{1}{\Delta t}\int_{-\Delta t}^{+\Delta t}\frac{1}{T}X_T\left(t,f+\frac{\alpha}{2}\right)X_T^{*}\left(t,f-\frac{\alpha}{2}\right)dt$$

Where,

X_T=Fourier Transform

α=Cycle frequency

Co-operative Sensing (CS): Co-operative sensing detection is detectors PUs signal reliable co-operating with other users. These detection techniques better in a system process when problem arises in fading and shadowing and noise uncertainty. Co-operative sensing mainly decreases the probability the misdetection and false alarm. This is also do the hidden the primary user problem and also decrease the sensing time [10].

Co-operative sensing was used for the improvement of the network of the sensing as the presence of a primary user not detected by a single cognitive radio due to shadowing, fading, propagation losses and interference effect. In cognitive radio, co-operative sensing arises some security concerns that have been discussed in the literature. Cognitive network may contain some malicious users that could attack the network and corrupt the spectrum security sensing. Two types of malicious attacks are generally considered in co-operative sensing. These are,

1. Incumbent Emulation Attack(IE)

2. Spectrum Sensing Data Falsification(SSDF)[17]

Waveform Based Sensing (WBS):WBS has many patterns in cognitive radio like preambles,midmbles,regularly transmitted pilot patterns etc. and these are utilized by the wireless system that synchronize.

Incumbent Emulation Attack (IE): IE is the attack in which malicious users know the characteristics of the primary signal and transmit a signal with similar characteristics so that other secondary users would believe that primary user is present.

Spectrum Sensing Data Falsification (SSDF): In SSDF, malicious user send false sensing information intentionally.

Chapter 3

Literature survey and Task of Cognitive Radio

During the literature survey we came across lot of research papers and surveyed from these. And also journals are covered related about this thesis. Some of the topics are discussed here.

3.1. Cognitive Cycle:

A basic cognitive cycle begins with radio scene analysis and identifying the spectrum holes which is shown in figure 2.1.In addition it also performs channel estimation for the channel capacity, channel state, transmitted power, transmitted frequency, issued signal to transmit power control and manage the spectrum management. And the cycle establishes connection with a proper initial handshake with the receiver. The rules and by which these capabilities are related are included in a reactive sequence and illustrated in figure 3.1 is called cognitive cycle.

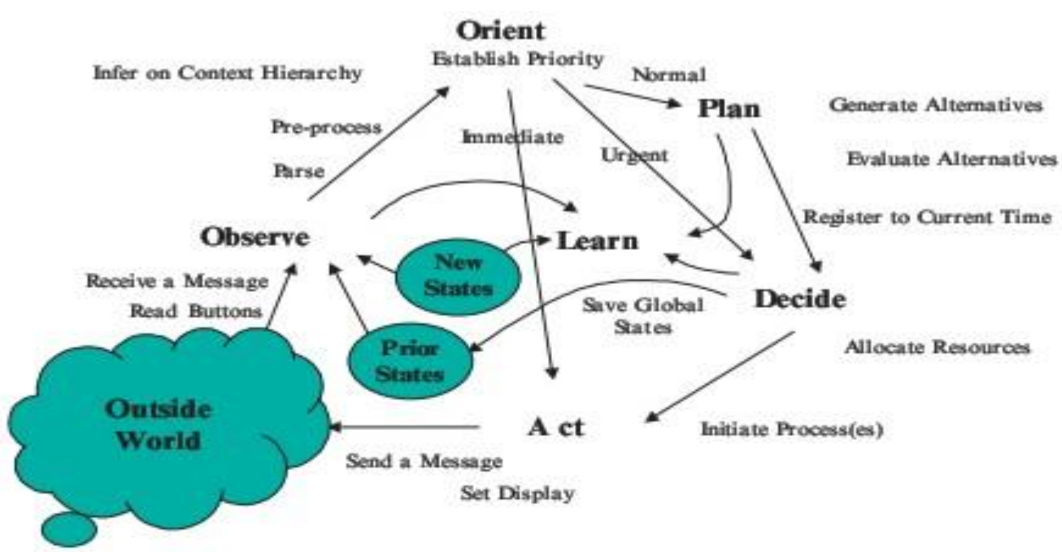

Fig. 3.1: Cognitive Cycle

3.2. Main function of Cognitive Radio:

There are various kinds of cognitive radio. Cognitive Radio is classified depending on the set of paramters.These parameters are chosen from transmission and reception changes and for historical reasons. One of them is known as Full Cognitive Radio (‘Mitola Radio’) in which every possible parameter is observable by a wireless node. Another one is Spectrum Sensing Cognitive Radio. In this type of cognitive radio only the radio frequency spectrum is considered.

On the component of the spectrum availability by Cognitive Radio can be classified into two types. First one is Licensed Band Cognitive radio which cognitive radio is capable of using bands assigns to licensed users and apart from unlicensed bands, Another one is Unlicensed Band Cognitive radio which can only utilize the only unlicensed parts of radio frequency spectrum.

We will now discuss about the main function of cognitive radio. The followings are the major functions of Cognitive Radio are,

(a) Spectrum Sensing: An essential capability of the CR is spectrum sensing i.e. the capability of timely sensing spectrum holes. This is also the basis and precondition for CR application. In order not interfere with LU when CU uses a spectrum hole to communicate and it has to quickly detect the presence of the LU and timely exit from a related band or continues to use the band for communication if the interference threshold is not exceeded.

(b) Spectrum management: Spectrum analysis and spectrum decision are the most important tasks to be carried out during spectrum management.

(C) Spectrum Mobility: This is should be ensure seamless operation and most exchange operating frequencies accordingly.

(d) Spectrum Sharing: Spectrum scheduling method takes care of sharing the available spectrum.

Incumbent Emulation Attack (IE): IE is the attack which malicious users know the characteristics of the primary signal and transmit a signal with similar characteristics so that other secondary users would believe that primary user present.

Spectrum Sensing Data Falsification (SSDF): In SSDF, malicious user send false sensing information intentionally.

Table 3.1: Overview of available techniques for spectrum sensing [11].

Spectrum Sensing Technique	Advantage	Disadvantage
Matched Filter	1.BestinGaussian knowledge 2. Need shorter sensing duration. 3. Less power consumption.	1.Requires a prior info on PU transmissions, and extra hardware on no des for synchronization with PU.
Energy Detection	1. Requires the least amount of computational power of nodes.	1. Requires longer sensing duration. 2. Higher power consumption. 3. Accuracy highly dependent on noise level variations.
Cyclo-stationary Feature Detection	1. Most flexible to variation in noise levels.	1. Requires a prior knowledge about PU transmissions. 2. Requires high computation capability on nodes.
Cooperative Sensing	1.Recommendedbythe FCC. 2.Guaranteesa Pre-determined interference to PU is not exceeded.	1. Requires knowledge of location PU and imposes polynomial calculations based on these locations.

Chapter 4

Spectrum Sensing

4.1. Spectrum Sensing in Cognitive Radio:

The definition of Full CR implies Intelligent Signal Processing (ISP) at all layers of the OSI model and this is not possible to at this moment. There are two principles problems that design hardware with the ability to intelligently make decisions based in own local environment and to develop SDR technologies to enable full reconfigure ability. Cause of the cognitive science is in its infancy.

These problems are not solved for many years and a device capable of operating in any frequency band up to 3GHz without the need for right front-end hardware including antenna will not available before 2030.By the way true cognition and fully flexible radio technology may not be needed. A simpler intelligence at the physical layer coupled with lower degrees of ISP and provide the significant benefits over traditional types if radio. This CR is classified spectrum sensing cognitive radio because of its main function is spectrum sensing. Actually it is based on the spectrum sensing by the CR focus on the increasing the spectrum efficiency in specific bands. Now this time some elements of CR are used in the current radio systems. Adaptive Frequency Hopping (AFH) is included in the Bluetooth standard avoid interference with other wireless technologies in the 2.4GHz unlicensed radio spectrum [12].

4.2. Challenges in Spectrum Sensing:

To realize a spectrum sensing cognitive radio as well as benefits at old radio systems is a fundamental step makes a full CR so spectrum sensing is an important object for research world. Spectrum sensing is not an easy problem to solve. Actually it should be formulated as a class of optimizing that arises in cognitive networks to maximize the spectrum efficiency. Normally multipath fading would normally be expected to interfere with the signals between the target under detection and CR. So it is difficult to understand if a signal does not exist or it is reduced by a bad channel. This problem is called ‘hidden PU’ [12] because a SU could transmit in an apparent hole of spectrum that on contrary hides a PU signal. In CR, spectrum sensing time is fast as possible. At last we can forget about the CR network consists of multiple SU and PU and thus interference between SU can occur so that detection system becomes unreliable. Cooperative sensing is recommended for solving these problems but definitive solution does not exist yet.

4.3. Methodology:

In spectrum sensor we detect on the basis of a binary hypothesis test on whether or not there are any primary signals in a particular channel. The channel is ideal under the null hypothesis and busy under the alternate [6]:

$$H_0(ideal) \ \ vs. \ \ H_1(busy)$$

- in ideal scenario, the received signal is essentially the ambient noise in the RF environment, and under the busy scenario, the received signal would consist of the primary user's (PU) signal and ambient noise [6]; thus
- $$\begin{aligned} H_0 &: \quad y(k) = w(k) \\ H_1 &: \quad y(k) = s(k) + w(k) \end{aligned}$$
- For k=1,………, n where n is the number of received samples, $w(k)$ represents ambient noise, and $s(k)$ represents the PU signal.
- In practice the unlicensed users need to continuously monitor the activities of the licensed users to find the spectrum holes (SHs), which is defined as the spectrum bands that can be used by the SUs without interfering with the PUs which is called spectrum sensing [7-9]. There are two types of SHs, namely temporal and spatial SHs , respectively. Temporal SH is defined as there is no PU transmission during a certain time period and SU can use the spectrum for transmission. When the PU transmission is within an area is called a spatial SH and the SUs can use the spectrum outside of that area.

4.4. Uses of Spectrum Sensing:

By convention, licensed spectrum allocated over long time periods and is meant to be using licenses. Actually in this licensed for government agency apportions license for spectrum use in referred to as the Fixed Spectrum Allocation (FSA) scheme. And also radio spectrum is split into bands in technology based services e.g. mobile telephony, radio and TV broadcast on absolute basis. The FSA model guarantees exclusive use of the frequency spectrum by licensed user i.e.

primary user (PU) [18].On the other hand it should also to be transition from voice communication to multimedia type applications demanding higher data rates, this plan will not have the capacity for emerging applications. From the FCC frequency allocation chart occupied by useable spectrum by government and commercial operators and leaving bandwidth for future wireless communication systems [13].

In the circumstances here should also take spectrum use intense on certain portions in significant value. This is due in part to the fact that most carriers do not transmit at all times in all geographic locations where the license covers.

Now we discussed about restrictions of frequency spectrum that allow exploiting the available spectrum are required. So, Dynamic Spectrum Access (DSA) was proposed to solve this inefficiency challenge. With this concept, licensed radio spectrum is optimized by secondary users that opportunistic spectrum access (OSA) of the frequency bands not occupied by the primary or licensed user. Hats why in Next Generation (xG) network is the Cognitive Radio (CR).The Cognitive Radio is an intelligent radio platform with the ability to exploit its environment to increase spectral efficiency and capacity.CR technology is envisaged to enable identification use and management of vacant spectrum known as spectrum holes or whitespaces [14].

Here also effect at acceptable level secondary users will sense the spectrum to detect whether it is available or not. Spectrum sensing is the most reliable sensing and integral function. The challenge then is that the procedure needs to have as little delay as possible so that once channels are available, transmissions should occur right away. In that time, little false detection would be expected.

There exist three spectrum sensing (SS) techniques in literature. These are the matched filter, cyclostationary feature and energy detection method. Both the matched filter and cylcostationary feature based detection concern knowledge of a signal which is not always obtained in practical scenarios. These two techniques require a significant amount of time to detect a signal. Energy Detection (ED) is widely feasible and it don’t need prior knowledge of the primary signals and has the least complexity .The ED method actually the energy of a received signal to decide the signal is noise or primary user's signal.

It is noticed that if failure in the performance of spectrum sensing implies a missed opportunity secondary users to utilize the white space of the spectrum sensing in the primary users [15].

It is essentials secondary users and primary users from unintended interference. The ED technique with the general purpose of sensing the spectrum for different wireless communication systems. Here mainly we should work based on Energy Detection(ED).

This is the study about the performance of energy detection for spectrum sensing. Both of the single detector and nodes of cooperative detectors will be explored.

Following this paper, there is a one section talking about system model of Energy Detection(ED).Here is the expression for probability of detection and false alarm will be derived respectively .Also discussed about signal detector over fading and non-fading channels. It is also provide the Rayleigh and Nakagami-m fading channels.

Energy detection approach was where signals are assumed deterministic and exact noise variance is known before hand. Sampling theorem applied to estimate the received signal energy and chi-square statistics of the resulting sum of the squared Gaussian random variables and signal detection is reduced to a simple identification problem [16].

ED analysis has been considered with several modifications in literature. An adaptive scheme to explore ED based spectrum sensing is proposed. The model consists of a PU transmitting a QPSK modulated signal within a 200 KHz bandwidth. Sampling frequency is set 8 times the bandwidth and a 1024-point FFT is used to compute the received signal energy. Results suggest execution of spectrum sensing on emergence of the PU in the wake of the sensing time. However, from the choice of bandwidth under consideration, this study is restricted to frequency modulated (FM) signals. Numerical analysis of the ED method over fading channels.

In expression for the probability of detection (P_D) for energy detection over Nakagami fading channels only. Relating expression for number of samples sensing time to SNR for a given P_D and P_{FA} in this channel were deduced.[18].

When the narrowband energy detector nodes to sense multiple channels is considered. For this the detector works with a preset factor where the past primary user based on user action.

Within this context, each cooperating node employs energy detection locally, while sharing the raw sensed information with other node(s). This is dependent on the cooperative scheme adopted. Common cooperative spectrum sensing (CSS) schemes include centralized, decentralized and relay-assisted arrangement of nodes[19]

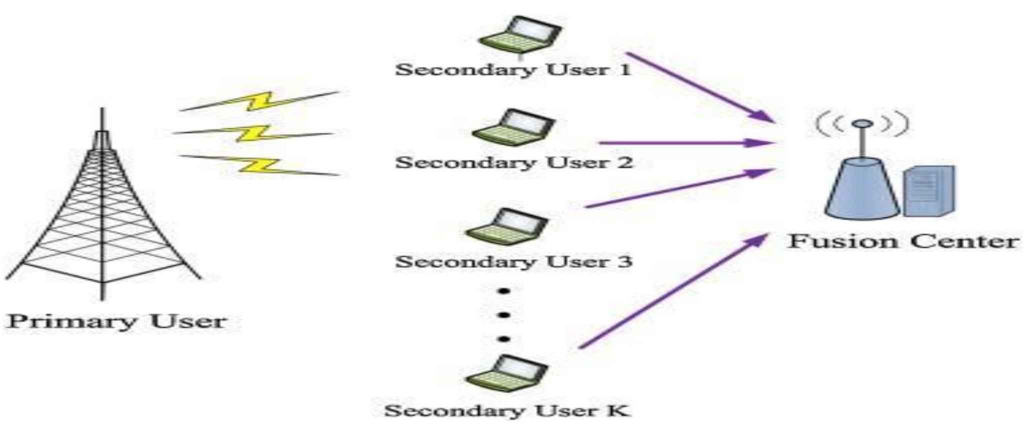

Fig 4.1: Cooperative spectrum sensing (CSS)

4.5. Probability of false alarm (P_{FA}) and probability of miss detection (P_M):

There are two types of error in spectrum sensing such as false alarm and miss detection. The probability that the signal when present will be detected is called probability of detection. The probability of a noise fluctuation which is mistaken for a signal is called probability of false alarm. Under utilization of the spectrum sensing of the primary users and secondary users can be determined by these false alarm and miss-detection[20].

Chapter 5

Energy Detection (ED)

5.1. Definition:

This is basic and common detection to spectrum sensing since it has low computational and execution complexity. This is non-coherent detection method that detects Pus signal base on the sensing energy. Actually energy detection sets a threshold according to the noise and comparing with input of the energy detection data stream. This detector shown in fig 1 which requires minimal information such as the signal bandwidth and carrier frequency. In this diagram there are so many methods to use in the energy detection to detect the primary user. The ED mainly do the presence of a signal comparing the received energy with a known threshold derives the noise of signal[21].

For the ED we can take an input signal which selects the bandwidth by a BPF and it is sampled. Then it is use the implementation for FFT (Fast Fourier Transform), and then the absolute value sampled is squared. At last we compared with between output of the integrator and threshold. It is the presence or absence primary user can be detected. In the energy detector architecture, FFT provides size of the resolution bandwidth and good detection of narrowband signals. This is considered high cost and long FFT need which depend on many hardware and sensing time [22].

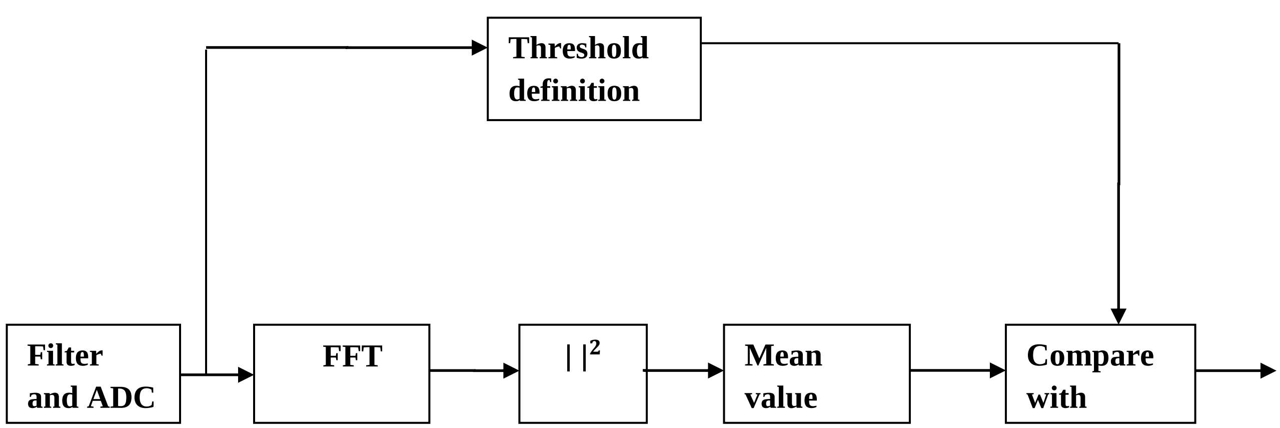

Fig 5.1: Energy Detector

A preamble is a known sequence that us transmitted in the beginning of each burst.

A midamble is the sequence that is transmitted in the middle of the burst.

This waveform based sensing techniques is only apply on the system a known signal pattern and it is WBS[23].

5.2. Methodology:

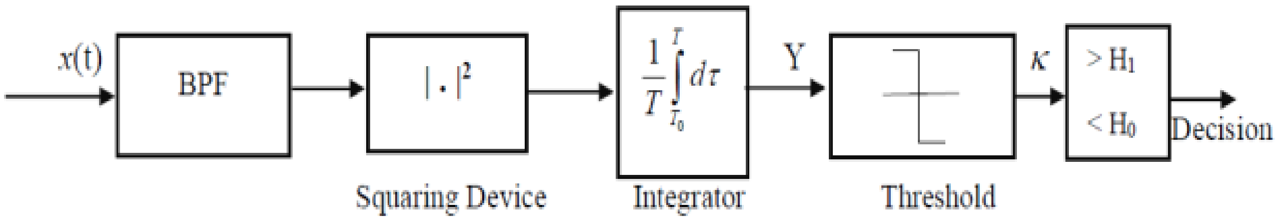

Fig 5.2: Block diagram of energy detection

5.3. How it works:

- In implementing energy detection, the received signal x (t) is filtered by a band pass filter (BPF).
- This is following by squaring law device.
- The band pass filter serves reduce the noise bandwidth.
- Noise at the input to the squaring device possesses a band limited and it is flat spectral density.
- The output of the integrator is energy of the input and it is the squaring device over the time interval T.
- Then the output signal from the integrator the is called decision statistic Y and is compared with threshold (k) which determine the absence or presence of a primary (licensed) user signal
- Decision used for the band is made by comparing the detection statistic to a threshold value, k from figure 1 show the energy detection diagram [21][23].

5.4. System Model:

Now, we should follow the analytically process then determine the signal x(t) is reduced to and identification problem and formalized as an hypothesis test.H_0 and H_1.H_0Implies absence where as H_1 denoted presence of the signal represented by

$$x(t) = \begin{cases} n(t), & H_0 \\ h * s(t) + n(t), & H_1 \end{cases} \quad (1)$$

Where,

X (t) =Received sample signal or (whitespace sample).

n (t)=Additive noise (zero-mean and variance σ^2).

h=Channel gain between the primary signal transmitter and the detector.

s (t)=The transmitted signal to be detected.

Now, using energy detector, a test statistic is computed from discrete samples of the channel under investigation.

$$Y=\sum_{k=1}^{M} |x[n]|^2 \tag{2}$$

Where,

Y=Test statistic at the energy detector node.

M=The number of sample under test.

It is assumed that the ED node is normally distributed with zero mean and unity variance.

From, equation (2) ,the distribution of the received signal energy at the ED node is written as[22],

$$Y = \begin{cases} \chi_{2d}^2, & H_0 \\ \chi_{2d}^2(2\gamma), & H_1 \end{cases} \tag{3}$$

Where,

χ_{2d}^2 =Central chi-square distribution.

$\chi_{2d}^2(2\gamma)$=Non-central chi-square distribution.

d=the time bandwidth product at the node.

γ=The non-centrality parameter equal to the signal to noise ratio. i.e

$$\gamma=\frac{E_s}{N} \tag{4}$$

The PDF for a chi-squared distribution is,

$$f_Y(y) = \begin{cases} \frac{1}{2^d\Gamma(d)} y^{d-1} e^{-\frac{y}{2}}, & H_0 \\ \frac{1}{2}\left(\frac{y}{2\gamma}\right)\frac{d-1}{2} e^{-\frac{2\gamma+y}{2}} I_{d-1}(\sqrt{2\gamma y}), & H_1 \end{cases} \quad (5)$$

Where,

Γ(.)=Gamma function.

I_v(.)=The v-th order modified Bessel function of the first kind.

Although the approximate solution for the P_D and P_{FA} over an AWGN is presented. However this is computationally complex. From equation (4) closed form expressions for both P_D and P_{FA} for ED over additive white Gaussian noise (AWGN) channel is derived [22].

P_DIs the probability that H_1 is selected when a signal is present for threshold k,P_D and P_{FA} defined as,

$$P_D = P(Y > k|H_1) \quad (6)$$

$$P_{FA} = P(Y > k|H_0 \quad (7)$$

Expressing P_D and P_{FA} in terms of the PDF yields

$$P_{FA}=\int_k^\infty f_Y\,(y)dy \quad (8)$$

From equation (4),

$$\Gamma(d,x)=\int_x^\infty t^{d-1}e^{-t}dt$$

$$P_{FA} = \frac{1}{2^d\Gamma(d)}\int_k^\infty (\frac{y}{2})^{d-1} e^{-\frac{y}{2}}dy \quad (9)$$

Substituting $\frac{y}{2}$=t with changed limits and expressing equation (8) in terms of the gamma function; defined by

$$\Gamma(d,x)=\int_x^\infty t^{d-1}e^{-t}dt$$

The P_{FA} is described by,

$$P_{FA}=\frac{\Gamma(d,\frac{k}{2})}{\Gamma(d)} \quad (10)$$

From equation (10) that P_{FA} is dependent on two parameters; the time-bandwidth product d, and threshold value, k. Hence P_{FA} is not related to SNR.

P_DIs obtained from the cumulative distribution function (CDF) of Inform equation (4) as,

$$P_D=1-F_Y(y) \quad (11)$$

Now the even number if degrees of freedom (2d in this case) CDF of Y is described by

$$F_Y(y)=1-Q_d(\sqrt{\psi},\sqrt{y}) \quad (12)$$

From equation (10) and (11), P_D for and energy detector over AWGN channel can be evaluated form;

$$P_D=Q_d(\sqrt{2\gamma}\sqrt{k}) \quad (13)$$

In real communication system, signals take more than a path between the transmitter and receiver. Fading can distributed models that explored uncertainties encountered in a channel server as tools for studying multipath and path loss features. So, these are the Rayleigh and Nakagami channel fading models [22].

By averaging the conditional P_D in the AWGN case (given equation (12) over the SNR fading distribution, closed form expression for the P_D in Rayleigh fading channels is expressed as;

$$P_{D_{Ray}}=e^{-\frac{k}{2}}\sum_{n=0}^{d-2}\frac{1}{n!}(\frac{k}{2})^n+(\frac{1+\gamma}{\gamma})^{d-1}[e^{(-\frac{k}{2(1+\gamma)})}-e^{(-\frac{k}{2})}\sum_{n=0}^{d-2}\frac{1}{n!}(\frac{k\gamma}{2(1+\gamma)})] \quad (14)$$

In the expression P_{FA}will not changed under all fading channels, since P_{FA} is independent of SNR (shown in equation (10).

The Rayleigh fading model considers urban multipath features, especially effects of the ionosphere and troposphere. It describes the statistical time varying nature of the received envelope of a flat fading signal or the envelope of an individual multipath component[14][24]

<u>5.5. Advantage of Energy Detection:</u>

The implementation of the energy detector makes it favorable candidate for spectrum sensing task. And the performance of the energy detection is highly susceptible to noise level uncertainty Noise level uncertainty means where situation of the noise variance is only approximately. Remarkable noise uncertainty can be arisen from e.g. thermal noise [19].

The noise uncertainty causes problem especially in the case of energy detection because it is not easy to set the threshold properly without the knowledge of the accurate noise level. Energy detector cannot differentiate between modulated signals, noise, and interference. Thus it cannot benefit from adaptive signal processing for canceling the interference.

Advantage of energy detection is written down below,

1. The performance of energy detector on shadowing/fading environments degrades clearly and secondary users may need to cooperate in order to detect the presence of primary users.

2. Where an obstacle prevents the secondary user from detecting the presence of the primary user and the secondary user starts to transmit, from figure (4.3).

3. The secondary user's transmission causes interference to a primary user who is communicating with the hidden primary user that was not visible.

4. The challenge of the energy detection is used to choose the right threshold for detection. But the problem is presented figure (4.4) where the probability density functions of the received signal with and without primary signal can be seen. If we want to probability of missed detection very low so the probability of false alarms increases and this would result in low spectrum. And if the probability of false alarm low then the result of missed detection probability high and which increase the interferences to the primary users [25].

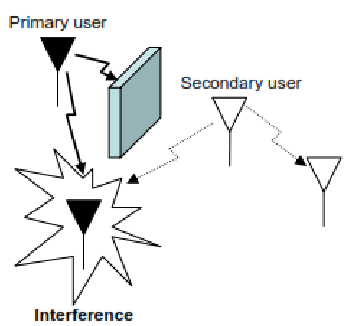

Fig 5.3: Interference cause by shadowing uncertainty

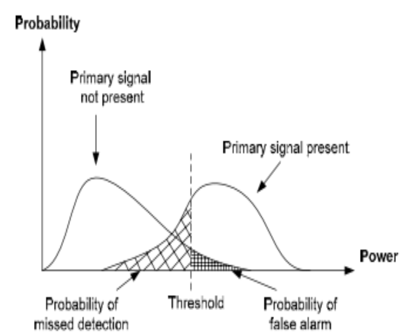

Fig 5.4: Between miss detection and false alarm

Chapter 6

Result Analysis

6.1.Optimization of Cooperative Spectrum sensing to minimize the total error rate:

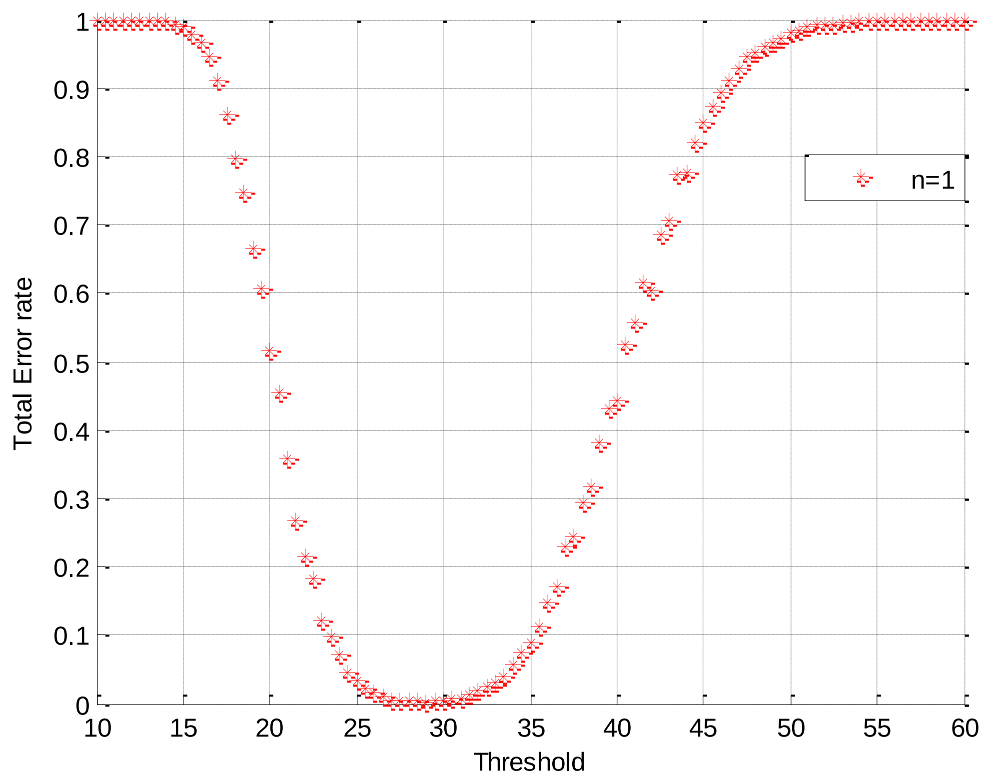

Fig 6.1(a): Total error probability for n=5 versus threshold when ED with SNR=10dB and L=10 samples at CR

From figure 6.1(a), shows the total error probability versus the threshold for SNR=10dB and n=5 using ED technique.

Here local spectrum sensing technique is ED and the local SNR=10dB and N=20 samples are used for this spectrum sensing. From figure 6.1(b) shown the threshold vs. total error rate using ED technique[25].

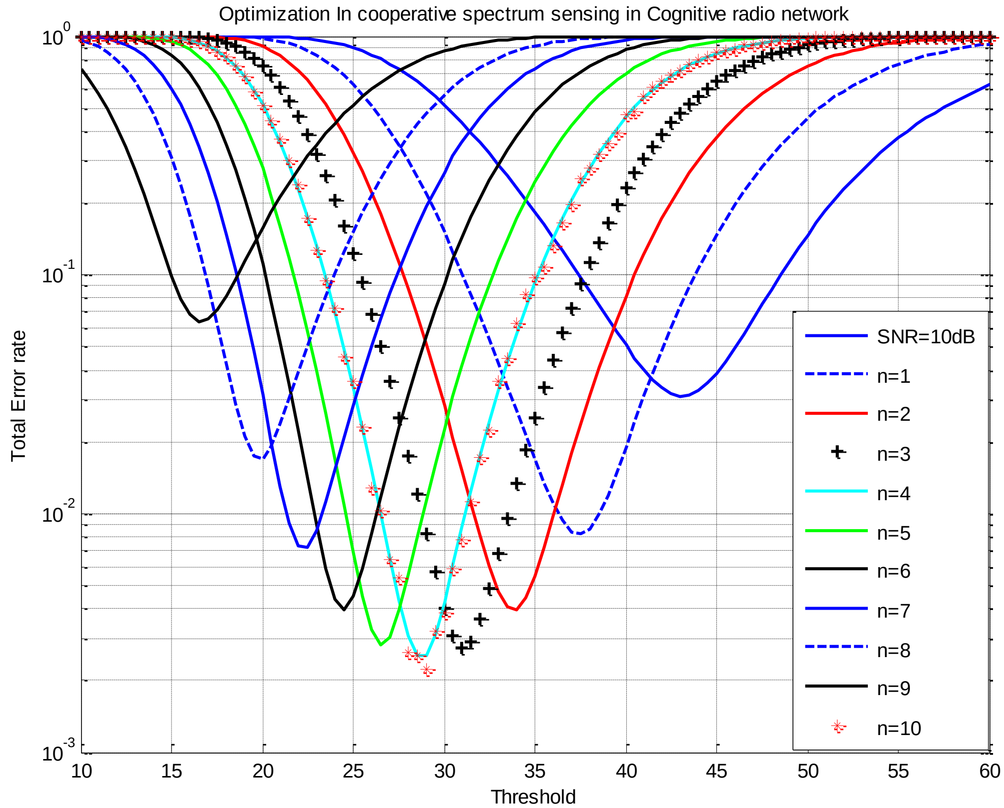

Fig 6.1(b): Optimization of Cooperative Spectrum sensing total error probability CRs threshold vs. total error rate when ED is used locally with SNR=10dB

From figure 6.1(b), shows the total error probability versus threshold for different number of n=1, 2, 3, 4 ….k and out of CRs that controls the fusion rule using ED technique. If we compare the different curves that represent the total error for different number of n in figure 6.1(a). We observe there are difference in the performance through using n=1 to 10 and as an n=10 fusion rule. Here n=10 which represent 'AND' fusion rule and give high total error rate compared to the other curves; it is found that the minimum total error in n=5 are the same value of SNR and threshold.

In this figure, we get the optimum value of 'n' out of 'K' CRs. We vary threshold value from 10 to 40 and for different SNR values (0dB, 5dB, 10dB) ,we found optimal value of 'n' from optimal voting rule. From graph we conclude that for low threshold value with low SNR, the required number of CR's is more. We increase threshold value with low or same SNR then we requires very less number of CR. And also SNR increases the optimal value of n increases. E.g. If SNR=0dB and threshold=33 then optimal value of n is 1.That is with 1 CR we can achieve low error rate [20][25].

For high threshold value, optimal value of n is small, so for high threshold value with number of CR's, we get probability of missed detection false alarm probability. Also the probability reduces by decreasing SNR value for small number of 'n' in a AWGN channel.

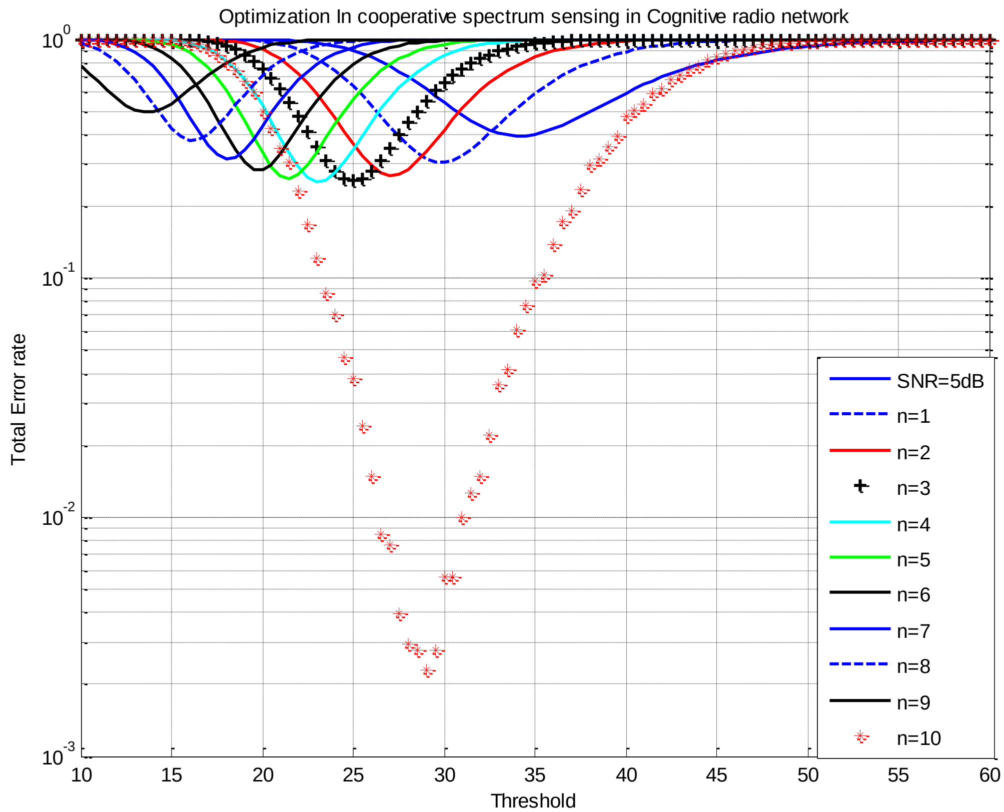

Fig 6.1(c): Total error probability for n=10 CRs versus threshold when ED is used with SNR=5dB and N=20 samples used at each CR

From figure 6.1(c), here changing the SNR to see the changing of the different curve for n=10.It is shown the figure threshold vs. total error rate and the error level is $10^{-0.6}$ and number of cognitive radio is 4 or 5

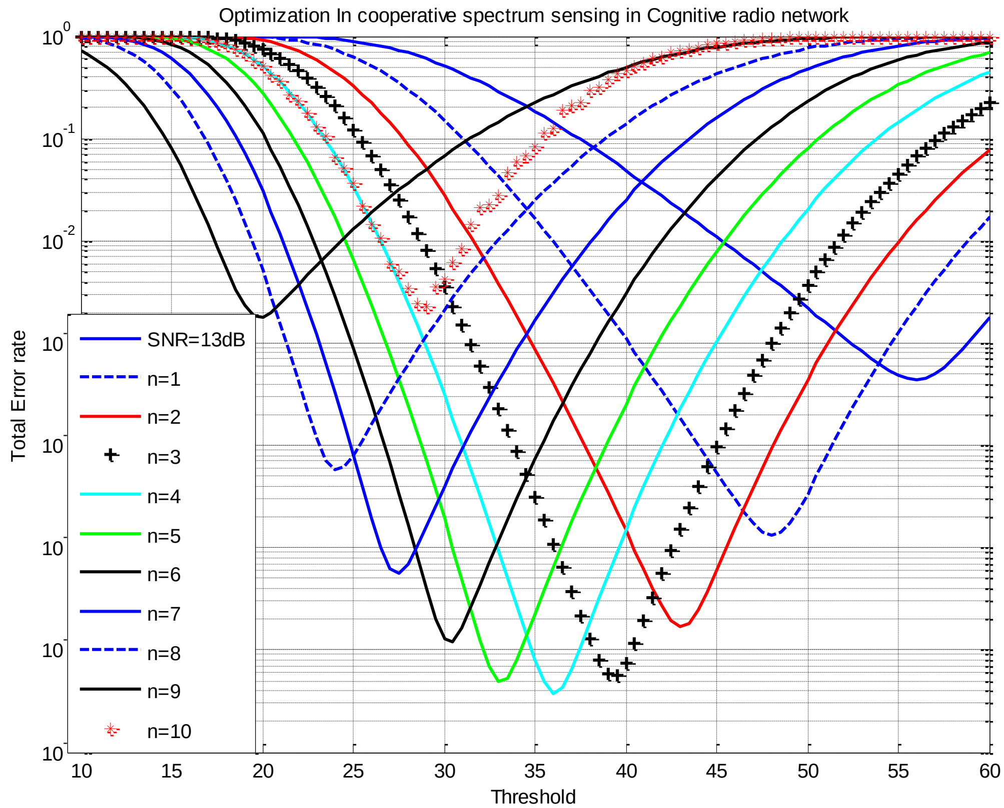

Fig 6.1(d): Total error probability for n=10 CRs versus threshold when ED is used with SNR=13dB and N=20 samples used at each CR.

From figure 6.1 (d), here changing the SNR to see the changing of the different curve for n=10.It is shown the figure threshold vs. total error rate and the error level is $10^{-6.5}$ and number of cognitive radio is 5 or 6

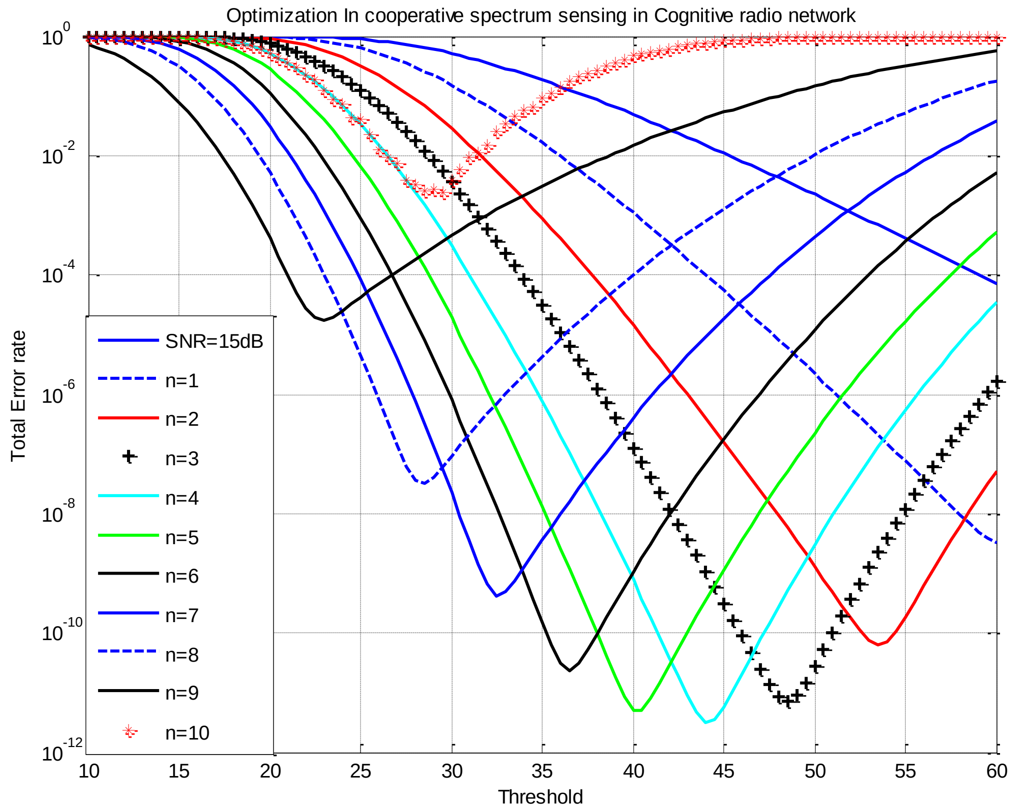

Fig 6.1(e): Total error probability for n=10 CRs versus threshold when ED is used with SNR=15dB and N=20 samples used at each CR.

Table 5.1: Optimal number of 'n' CRs for different SNR and its error level

No	SNR in dB	Error level (Minimum)	Number of Cognitive Radio User
1	5	$10^{-0.6}$	4 or 5
2	10	$10^{-2.6}$	5
3	13	$10^{-6.4}$	5 or 6
4	15	10^{-11}	6

Table 1 shows the optimal fusion rule and minimum error when SNR is varied and the ED is used with number of samples (i.e. N=20).The improvement in the performance by increasing the total number for different SNR at CRs at fixed N .For example min error=0.2511 when SNR=5dB and CRs=4 or 5.The increase in SNR causes decrease the minimum error and variation in CRs. We also find out the value of different SNR=17,18 or 20 for user of cognitive radio is increased.

6.2. Energy Detection Simulation:

It is the energy detection performed over a Rayleigh channel exhibits a tough detection performance.

From figure 6.2(a), we get the concept of energy detection of Rayleigh channel is improved performance achieved by less number of samples (L).

1) It is increased the false alarm depend on the SNR value.

2) If SNR value is increased so false alarm is increased.

3) On the other hand when SNR value is less so false alarm is decreased. Energy signal increases for a given number of samples L.

4) False alarm is depending on the SNR value. When SNR value is increased then minimum error level is 10^5 that Rayleigh channel become low now of user of cognitive radio.

5)This is the complementary ROC over Rayleigh fading channel for average SNR values of 20-35 dB and time bandwidth product different for different sample u=L/2 and sample size L=10-25 is as shown in Fig 6.2(c).

6) From P_M -P_{FA} plot, it is observed that the slopes are low for P_M<0.1 and 10dB increase in SNR (from 15dB to 25dB) has an decreases in missed detection probability (reducedP_D).

7) It is apparent that energy detection executed over a Rayleigh channel exhibits a tough detection performance [26][27].

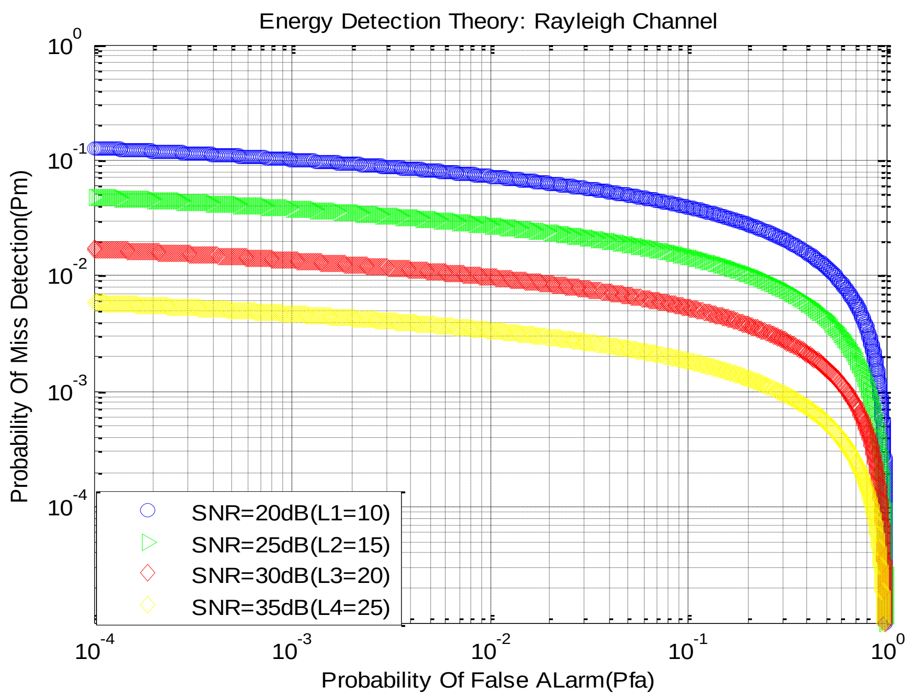

Fig 6.2(a): ROC curves for Energy Detection over Rayleigh Fading channel(SNR=(20,25,30,35)dB and samples size L=10,15,20,25).

From 6.2(a), it is shows the changing SNR value for changing curve. Different SNR for different curve in different samples of Here SNR value is 20dB , 25dB, 30 dB, 35 dB and sample value is L=10,15,20,25.

In this figure see that different SNR for change the probability of miss detection (P_M) and probability of false alarm (P_{FA}) is constant.[28]

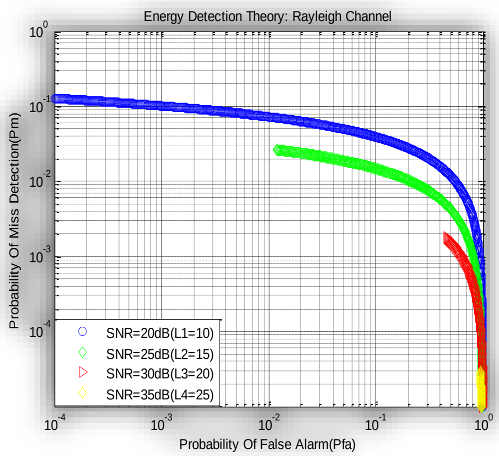

Fig 6.2 (b): ROC curves for Energy Detection over Rayleigh fading channel for changing threshold at decreasing SNR=35dB (P_{FA} vs.P_M).

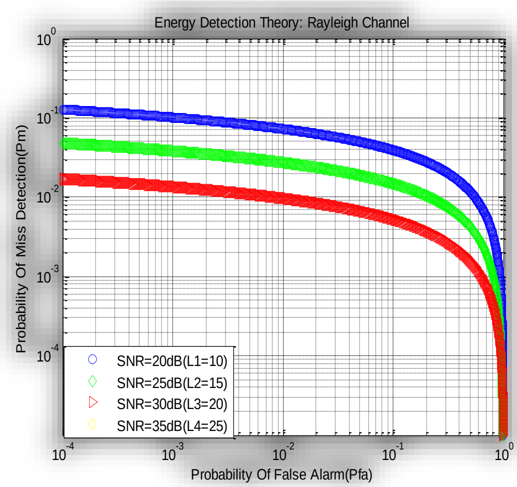

Fig 6.2 (c): ROC curves for Energy Detection over Rayleigh fading channel for changing threshold (decreasing SNR=35dB,30dB,25dB) (P_{FA} vs. P_M).

From fig 6.2 (b), decreasing threshold value in same time changing also SNR value. In the last figure 6.2(a) seen that the yellow curve is decreasing for changing the threshold point. In this figure we see that the threshold range is much decreasing for SNR=35dB then yellow curveis not shown in there.

So decreasing threshold for changing the curve. Threshold range is different curve for different like threshold=0:0.01:100, 0:0.01:100, 0:0.01:50, 0:0.01:30 in that range of curve become decreasing in P_{FA} vs. P_M.

From Figure 6.2(c), we see that the figure shows the decreasing the value of P_{FA} from P_M and we should change the value of threshold for decreasing the P_M. Here show the how can change the curve in decreasing the value of threshold. Here threshold value decreasing like as previous figure 6.2(c)[29].

Chapter 7

Conclusion

In this paper, the performance of an energy detector as related to detecting underutilized or unoccupied spectrum was evaluated. From a theory based sampling method energy detection performance is studied for an unknown signal transmitted over fading and non-fading channels. Chapter 4 and 5 explained the target studio of the energy detection in cognitive radio basically . Here we also explained about architecture of CR MATLAB code of the detector is also presented in this chapter. During the simulation, we faced various types of problems for the detection of path loss. One of the major problems we faced is when the CR user increases much then the probability of detection becomes saturated in a certain value of probability of false alarm. This is one of the limitations of Energy Detection Cognitive Radio.

We also discussed about the cooperative sensing with energy detection using formula and modeling the system. We analyzed the system with optimum rule for minimum error rate and K/2 is optimal value. Also, optimization of threshold has been done with minimum values of probability of missed detection and false alarm probability. We analyzed that Energy Detection less probability of missed detection and false alarm probability so that spectrum allocated correctly to secondary user.

In our paper ,it has been shown that as the cognitive radio is increased and the probability of miss detection signals be significantly increased. It has been shown that as the cognitive user is increased, the probability of miss detection canals be significantly increased. It may also be seen that using only a less users to help us to obtain better detection probability compare dousing all the users in the network. We also discussed how the users must be taken into consideration for the cooperative spectrum sensing Energy Detection.

Appendix A: MATLAB code

1) Energy detection theory: Rayleigh Channel

Here is the M-files to show energy detection signal are presented.

First function to generate the signal.

a)

```
clc
close all
clear all
L = 10; % Number of sensing samples to be taken
snr_db = 20; % Average SNR in decibel for Rayleigh channel
snr = 10.^(snr_db./10);
thresh = 0:0.01:100; % Threhsold
Pf= 1- gammainc(thresh./2, L./2); % Calculation of probability of false alarm
pd = [];
A = snr./(1 + snr);
u = L./2; % Time-Bandwidth product
forpp = 1:length(Pf)
n = 0:1:u-2;
term_sum1 = sum((1./factorial(n)).*(thresh(pp)./2).^(n));
term_sum2 = sum((1./factorial(n)).*(((thresh(pp)./2).*(A)).^(n)));
pd(pp) = exp(-thresh(pp)./2).*term_sum1 + (1./A).^(u-1).*(exp(-thresh(pp)./(2.*(1+snr))) - exp(-
thresh(pp)./2).*term_sum2); % Probability of detection
end
loglog(Pf,1-pd,'rd') % ROC curve
grid on
xlim([10^-4 1])
```

```
ylim([10^-5 1])
legend('SNR=20dB')
xlabel('Probability Of False ALarm(Pfa)')
ylabel('Probability Of Miss Detection(Pm)')
title('Energy Detection Theory: Rayleigh Channel')
```

b)

```
clc
close all
clear all
L = 2; % Number of sensing samples to be taken
snr_db = 50; % Average SNR in decibel for Rayleigh channel
snr = 10.^(snr_db./10);
thresh = 0:0.01:100; % Threhsold
Pf= 1- gammainc(thresh./2, L./2); % Calculation of probability of false alarm
pd = [];
A = snr./(1 + snr);
u = L./2; % Time-Bandwidth product
forpp = 1:length(Pf)
n = 0:1:u-2;
term_sum1 = sum((1./factorial(n)).*(thresh(pp)./2).^(n));
term_sum2 = sum((1./factorial(n)).*(((thresh(pp)./2).*(A)).^(n)));
pd(pp) = exp(-thresh(pp)./2).*term_sum1 + (1./A).^(u-1).*(exp(-thresh(pp)./(2.*(1+snr))) - exp(-
thresh(pp)./2).*term_sum2); % Probability of detection
end
loglog(Pf,1-pd,'rd') % ROC curve
grid on
xlim([10^-4 1])
```

```
ylim([10^-5 1])
legend('SNR=50dB')
xlabel('Probability Of False ALarm(Pfa)')
ylabel('Probability Of Miss Detection(Pm)')
title('Energy Detection Theory: Rayleigh Channel')
```

c)

```
clc
close all
clear all
L1 = 10; % Number of sensing samples to be taken
snr_db = 20; % Average SNR in decibel for Rayleigh channel
snr = 10.^(snr_db./10);
thresh = 0:0.01:100; % Threhsold
Pf= 1- gammainc(thresh./2, L1./2); % Calculation of probability of false alarm
pd = [];
A = snr./(1 + snr);
u = L1./2; % Time-Bandwidth product
forpp = 1:length(Pf)
n = 0:1:u-2;
term_sum1 = sum((1./factorial(n)).*(thresh(pp)./2).^(n));
term_sum2 = sum((1./factorial(n)).*(((thresh(pp)./2).*(A)).^(n)));
pd(pp) = exp(-thresh(pp)./2).*term_sum1 + (1./A).^(u-1).*(exp(-thresh(pp)./(2.*(1+snr))) - exp(-
thresh(pp)./2).*term_sum2);% Probability of detection
end
loglog(Pf,1-pd,'bo')% ROC curve
grid on
```

```
xlim([10^-4 1])
ylim([10^-5 1])
hold on
L2 = 15; % Number of sensing samples to be taken
snr_db = 25; % Average SNR in decibel for Rayleigh channel
snr = 10.^(snr_db./10);
thresh = 0:0.01:100; % Threhsold
Pf= 1- gammainc(thresh./2, L2./2); % Calculation of probability of false alarm
pd = [];
A = snr./(1 + snr);
u = L2./2; % Time-Bandwidth product
forpp = 1:length(Pf)
n = 0:1:u-2;
term_sum1 = sum((1./factorial(n)).*(thresh(pp)./2).^(n));
term_sum2 = sum((1./factorial(n)).*(((thresh(pp)./2).*(A)).^(n)));
pd(pp) = exp(-thresh(pp)./2).*term_sum1 + (1./A).^(u-1).*(exp(-thresh(pp)./(2.*(1+snr))) - exp(-
thresh(pp)./2).*term_sum2);% Probability of detection
end
loglog(Pf,1-pd,'g>')% ROC curve
grid on
xlim([10^-4 1])
ylim([10^-5 1])
hold on
L3 = 20; % Number of sensing samples to be taken
snr_db = 30; % Average SNR in decibel for Rayleigh channel
snr = 10.^(snr_db./10);
thresh = 0:0.01:100; % Threhsold
```

```
Pf= 1- gammainc(thresh./2, L3./2); % Calculation of probability of false alarm

pd = [];

A = snr./(1 + snr);

u = L3./2; % Time-Bandwidth product

forpp = 1:length(Pf)

n = 0:1:u-2;

term_sum1 = sum((1./factorial(n)).*(thresh(pp)./2).^(n));

term_sum2 = sum((1./factorial(n)).*(((thresh(pp)./2).*(A)).^(n)));

pd(pp) = exp(-thresh(pp)./2).*term_sum1 + (1./A).^(u-1).*(exp(-thresh(pp)./(2.*(1+snr))) - exp(-
thresh(pp)./2).*term_sum2);% Probability of detection

end

loglog(Pf,1-pd,'rd')% ROC curve

grid on

xlim([10^-4 1])

ylim([10^-5 1])

hold on

L4 = 25; % Number of sensing samples to be taken

snr_db = 35; % Average SNR in decibel for Rayleigh channel

snr = 10.^(snr_db./10);

thresh = 0:0.01:100; % Threhsold

Pf= 1- gammainc(thresh./2, L4./2); % Calculation of probability of false alarm

pd = [];

A = snr./(1 + snr);

u = L4./2; % Time-Bandwidth product

forpp = 1:length(Pf)

n = 0:1:u-2;

term_sum1 = sum((1./factorial(n)).*(thresh(pp)./2).^(n));
```

```
term_sum2 = sum((1./factorial(n)).*(((thresh(pp)./2).*(A)).^(n)));

pd(pp) = exp(-thresh(pp)./2).*term_sum1 + (1./A).^(u-1).*(exp(-thresh(pp)./(2.*(1+snr))) - exp(-thresh(pp)./2).*term_sum2);% Probability of detection

end

loglog(Pf,1-pd,'yd')% ROC curve

grid on

xlim([10^-4 1])

ylim([10^-5 1])

legend('SNR=20dB(L1=10)','SNR=25dB(L2=15)','SNR=30dB(L3=20)','SNR=35dB(L4=25)')

xlabel('Probability Of False ALarm(Pfa)')

ylabel('Probability Of Miss Detection(Pm)')

title('Energy Detection Theory: Rayleigh Channel')
```

2)Optimization In cooperative spectrum sensing in Cognitive radio network

Here is the M-files to show cooperative spectrum sensing in cognitive radio signal are presented.

First function to generate the signal.

```
clc;

close all;

clear all;

%This program is for optimization of spectrum sensing in

%Cognitive radio network.

N=20;

j=1;

tt=[];

err2=[];

Pmi=[];

Pdc=[];

error=[];
```

```
err1=[];
K=10;
snr=10;
Qd=0;
Qf=0;
tt=10:0.5:60;
vec=['-+','-o','-v','-d','->','-x','-s','-<','-*','-^'];
for n=1:1:10
s=ones(1,N);
w=randn(1,N);
u=N/2;                  %Time-delay bandwidth product
for t=10:0.5:60
Qd=0;
Qf=0;
SNR=10^(snr/10);   %for linear scale
a=sqrt(2*SNR);
b=sqrt(t);
Pd = marcumq(a,b,u );         % AVG. PROB OF DETECTION(computes the generalized
Marcum Q)
Pf = gammainc((t/2),u,'upper');% AVG. PROB OF FALSE ALARM(compute incompelete gamma
function)
Pm=1-Pd;                % AVG. PROB OF MISSED DETECTION OVER AWGN
for l=n:1:K
Qd=Qd+(factorial(K)*(Pd^l)*((1-Pd)^(K-l))/(factorial(l)*factorial(K-l)));
Qf=Qf+(factorial(K)*(Pf^l)*((1-Pf)^(K-l))/(factorial(l)*factorial(K-l)));
end
Qm=1-Qd;
err=Qf+Qm;
```

```
err1=[err1 err];
end
end
l=1;
i=1;
for j=1:1:10
semilogy(tt,-err1(i:i+100),vec(l:l+1),'LineWidth',1.5)
i=i+101;
l=l+2;
hold on;
end
grid on;
ylabel('Total Error rate');
xlabel('Threshold');
%----------------------Energy Detection----------------------------------------
n=5;
rel=10000;
tt1=10:0.5:60;
er1=[];
for t=10:0.5:60
Pdc=0;
Pfc=0;
Qd=0;
Qf=0;
Qm=0;
fori=1:1:rel
SNR=10;
```

```
snr=10^(SNR/10);
s=ones(1,N);
w=randn(1,N);
vari=var(w);            %variance of noise
Es=sum(s.^2);
N02=(Es)/(2*snr);
x1=s+w;
x2=w;
W=1;                    %Time-delay bandwidth product
E0=(sum(x2.^2))/((W*N02));
E1=(sum(x1.^2))/((W*N02));
if E1>t
Pdc=Pdc+1;
else
end
if E0>t
Pfc=Pfc+1;
else
end
end
Pd=Pdc/rel;
Pf=Pfc/rel;
for l=n:1:K
Qd=Qd+(factorial(K)*(Pd^l)*((1-Pd)^(K-l))/(factorial(l)*factorial(K-l)));
Qf=Qf+(factorial(K)*(Pf^l)*((1-Pf)^(K-l))/(factorial(l)*factorial(K-l)));
end
Qm=1-Qd;
```

```
er=Qf+Qm;
er1=[er1 er];
end
hold on;
semilogy(tt1,-er1,'*r')
grid on;
ylabel('Total Error rate');
xlabel('Threshold');
legend('n=1','n=2','n=3','n=4','n=5','n=6','n=7','n=8','n=9','n=10','n=5 by modelling');
title('Optimization In cooperative spectrum sensing in Cognitive radio network')
```

3) Energy Detection

Here are the M-files to show energy detection signal are presented.

First function to generate the signal

```
n=5;
rel=10000;
tt1=10:0.5:60;
er1=[];
for t=10:0.5:60
Pdc=0;
Pfc=0;
Qd=0;
Qf=0;
Qm=0;
for i=1:1:rel
SNR=10;
snr=10^(SNR/10);
s=ones(1,N);
w=randn(1,N);
vari=var(w);          %variance of noise
Es=sum(s.^2);
N02=(Es)/(2*snr);
x1=s+w;
x2=w;
W=1;              %Time-delay bandwidth product
```

```
E0=(sum(x2.^2))/((W*N02));
E1=(sum(x1.^2))/((W*N02));
if E1>t
Pdc=Pdc+1;
else
end
if E0>t
Pfc=Pfc+1;
else
end
end
Pd=Pdc/rel;
Pf=Pfc/rel;
for l=n:1:K
Qd=Qd+(factorial(K)*(Pd^l)*((1-Pd)^(K-l))/(factorial(l)*factorial(K-l)));
Qf=Qf+(factorial(K)*(Pf^l)*((1-Pf)^(K-l))/(factorial(l)*factorial(K-l)));
end
Qm=1-Qd;
er=Qf+Qm;
er1=[er1 er];
end
hold on;
semilogy(tt1,er1,'*r')
grid on;
ylabel('Total Error rate');
xlabel('Threshold')
;legend('n=1','n=2','n=3','n=4','n=5','n=6','n=7','n=8','n=9','n=10','n=5 by modelling');
```

References

[1] I. Mitola, J. Maguire, G. Q., "Cognitive radio: making software radios more personal." Personal Communications, IEEE. vol . 6, no. 04, pp. 13-18, Aug 1999.

[2] R. Chen, JM park J Reed, "Defense against primary user emulation attacks in cognitive radio networks." IEEE J. Selected Areas Commun. vol. 26, pp. 25-37, 2008.

[3] S. D. Tanuja and S. Dina, "Spectrum Sensing Algorithm for Cognitive Radio Networks for Dynamic Spectrum Access for IEEE 802.11 af standard," International Journal of Research and Reviews in Wireless Sensor Networks (IJRRWSN), vol. 2, pp. 77 - 84, March 2012.

[4] E. Axell, G. Leus, E. G. Larsson, and H. V. Poor, "Spectrum sensing for cognitive radio ; state-of-the-art and recent advances.," IEEE Signal Processing Magazine, vol. 29, pp. 101-116, 2012.

[5] M. A. McHenry, P. A. Tenhula, D. McCloskey, D. A. Roberson, and C. S. Hood, "Chicago spectrum occupancy measurements & analysis and a long-term studies proposal," Proceedings of the first international workshop on Technology and policy for accessing spectrum, pp. 10-12, 2006.

[6] Fatty M. Salem, Maged H. Ibrahim, and I. I. Ibrahim, "Energy Detection Based Sensing for Secure Cognitive Spectrum Sharing in the Presence of Primary User Eulation Attack." IEEK Transaction on Smart Processing and Computing, vol. 2, no. 6, pp. 357-366, Dec. 2013.

[7]Cognitive Radio Technology by Bruce A.Fette

[8]Future Directions in Cognitive Radio Network Research Edited by: Peter Steenkiste,

Douglas Sicker, Gary Minden, DipankarRaychaudhuriMarch 9-10, 2009

[9] R. Tandra and A. Sahai,"Fundamental limits on detection in low SNR under uncertainty" In Proc. of IEEE International Conference on Wireless Networks, Communication and Mobile Computing, vol. 3, pp. 464-469, June, 2005.

[10] TevfikYucek and HuseyinArslen, "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications." IEEE Communication Surveys & Tutorials, vol. 11, no. 1, First Quarter, pp. 116-130. 2009.

[11]Aldo Buccardo "A Signal Detector for Cognitive Radio System"

[12] S Haykin, DJ Thomson, JH Reed, "Spectrum sensing for cognitive radio." Proc IEEE. vol. 97, no.5, pp. 849-877, 2010.

[13] [17]S. Anand, Z. Jin and K. P. Subbalakshmi, "Analytical Model for Primary User Emulation Attacks in Cognitive Radio Networks," New Frontiers in Dynamic Spectrum Access Networks, 3rd IEEE Symposium, pp. 1-6, E-ISBN : 978-1-4244-2017-9, Chicago, IL DySPAN, 2008.

[14] James D.Gadze',Oyibo,A.$Michael^2$,Ajobiewe,N.$Damidola^3$" A performance study of Energy Detection Based Spectrum Sensing for Cognitive Radio Networks"

[15] D. Cabric, S. Mishra and R. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," In Proc. Asilomar Conf. on Signals, Systems and Computers, vol. 1, no. 1, pp. 772-776, Nov 2004.

[16] S. Mishra, A. Sahani and R. Brodersen, "Cooperative sensing among cognitive radios." IEEE International Conference on Communications, 2006 ICC '06 vol. 4 pp. 1658-1663, June, 2006.

[17] J. Wei and X. Zhang, "Two-tier optimal-cooperation based secure distributed spectrum sensing for wireless cognitive radio networks." INFOCOM IEEE Conference on Computer Communications Workshops, vol. 58, pp. 1-6, Mar 2010.

[18] R. Chen, J. M. Park, Y. Hou and J. Reed, "Toward secure distributed spectrum sensing in cognitive radio networks." Communications Magazine, IEEE, vol. 46. no. 4, pp. 50-55, Apr 2008.

[19] Mai Abdelhakim, Lei Zhang, JianRen and Tongtong Lei, "Cooperative sensing in cognitive networks under malicious attack," Speech and Signal Processing (ICASSP), vol. 11, pp. 3004-3005, 2011.

[20] Gaurav G. Bhosale 1, Dipak B. Khandgaonkar 2and J. Christopher Clement Student, School of Electronics Engineering, VIT University, Vellore - 632014, TamilNadu, India1Student, School of Electronics Engineering, VIT University, Vellore - 632014, TamilNadu, India2 Professor, School of Electronics Engineering, VIT University, Vellore - 632014, TamilNadu, India3"Cognitive Radio Networks: Optimization of Cooperative Spectrum Sensing to minimize the total error rate.

[21] Kostylev,"Energy detection of a signal with random amplitude," In Proc. of IEEE International Conference on Communication, vol. 4, no. 11, pp. 11-17 October 2012.

[22] H. Wang, L. Lightfoot and T. li, "On phy-layer security of cognitive radio: Collaborative sensing under malicious attacks," 44th Annuual Conference on Information Sciences and Systems (CISS), pp. 9-12, Mar 2010, Princeton, NJ.

[23] T. Yucek and huseyienArslan, "Spectrum characterization for opportunistic cognitive radio system" In Proc. IEEE Military Commun. Conf. Washintog. D.C USA., vol. 11, no. 1, pp. 1-6, Oct. 2009.

[24] D. Datla, R. Rajbanshi, A. M. Wyglinski, and G. J. Minden, " Parametric adaptive spectrum sensing framework for dynamic spectrum access networks." In Proc. IEEE Int.

Symposium on New Frontiers in Dynamic Spectrum Access Networks, Dublin, Irland, pp. 482-485, Apr. 2007.

[25] A Ghasemi, ES Sousa,"Spectrum sensing in cognitive radio networks: Requirements, challenges and design trad-offs." IEEE Commun Mag. vol. 46, no.4, pp. 32-39, 2008.

[26] J Ma, GY Li, BH Juang, "Signal processing in cognitive radio." Proc IEEE, vol. 97, no. 5, pp. 805-823, 2010.

[27] P. Zhang," In the development of wireless cognitive science", Chin. Sci. Bull. vol. 57, pp. 3661-3661, 2012.

[28] Lu Lu, Xiangwei Zhou, UzomaOnunkwo and Geoffrey Ye Li, "Ten years of research in spectrum sensing and sharing in cognitive radio." EURASIP Journal on Wireless Communications and Networking, vol. 48 pp 1-16, 2012.

[29] Hanwu, Zebing Feng, Zhiqin Wei, Zhiyong Feng and Ping Zhang, "Security management based on trust determination in cognitive radio networks." EURASIP Journal on Advances in Signal Processing, vol. 28, pp 1-16, 2014.