MULTIBAND ENERGY SPECTRUM SENSING IN COOPERATIVE-COGNITIVE NETWORK

BY

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CERTIFICATE

We accept the work contained in this report as a confirmation to the required standard for the partial fulfilment of the degree of MS (EE).

Head of Department

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External Examiner

DEDICATION

TO

OUR PARENTS AND TEACHERS

WHO'S PERENNIAL HEARTY WISHES

AND PERPETUAL HELP HAVE

MADE US TO WITHSTAND

EVERY STRESS OF

LIFE

DECLARATION OF AUTHORSHIP

I hereby declare that content of this thesis is my own work and that it is the result of work done during the period of registration. To the best of my knowledge, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

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Ansar-Ul-Haq

ABSTRACT

Cognitive Radio is a promising technology that enables simultaneous sharing of spectrum via multiple users (i.e., primary and secondary users) through opportunistic access mechanism. This technology heavily relies on specific spectrum sensing algorithm which enables it to uniquely identify spectrum holes (i.e., vacant portions of spectrum) and thus allocating better spectrum portion to secondary users. Initially, the researchers developed spectrum sensing techniques for single spectrum band. However, recently multiband spectrum sensing schemes got significant popularity. In this thesis, we focused on multi-band spectrum sensing schemes in centralized cognitive radio network to cater interference that occurs due to the sudden appearance of primary users and increases overall system throughput as compared single spectrum sensing scheme. We have utilized diversity combining scheme to improve the detection capability of our proposed algorithm. Furthermore, we used a double threshold energy detection algorithm which reduced the probability of collision between primary and secondary users. Independent and randomly placed relays are used as observing units to analyze system's performance, whereas simulations are carried out using energy detection in rician fading environment. At the end we show all the important results of our proposed multi-band spectrum sensing which improves the system's performance as compared to single-band spectrum sensing.

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ABBREVIATIONS

CCN	Cooperative-Cognitive Network
MRC	Maximal Ratio Combining
FCC	Federal Communication Commission
CRN	Cognitive Radio Network
AF	Amplify and Forward
DF	Decode and Forward
EF	Estimate and Forward
PDF	Probability Distribution Function
LOS	Line of Sight
MIMO	Multiple Inputs Multiple Outputs
AAF	Amplify and Forward
DAF	Decode and Forward
SU	Secondary Users
PU	Primary Users
CR	Cognitive Radio
CC	Cognitive Centre
PDA	Personal Digital Assistant
TV	Television
PC	Personal Computers

CWC	Centre for Wireless Communications
CRAMNET	Cognitive Radio Assisted Mobile Ad Hoc Network
AWGN	Additive White Gaussian Noise
SNR	Signal to Noise Ratio
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
CS	Cyclic Spectrum
I/p	Input
O/p	Output
BPF	Band Pass Filter

Chapter 1

Introduction

CHAPTER 1. INTRODUCTION

1.1. Overview

In this growing world of data hungry gadgets, availability of spectrum remains a constant concern for the engineering sector. Many solutions are thus proposed every now and then in order to coop with this problem. In this paper our focus will be on comparing few of these important methodologies and presenting with pros and cons of each method, our intent is to bring about a clear understanding so the user can opt for the best available solution.

According to FCC in the complete spectrum there is a high congestion rate in the frequency ranging below 3 GHz, but contrary to that frequencies above 3 GHz and below 6 GHz, have very low utilization [1]. Previously the bandwidth allocation was static but the drastic increase in the data consuming wireless technologies demand for bandwidth has increased exponentially which has forced the bandwidth allocation authorities to change their fixed allocation technique to an adaptive one, which can efficiently utilize the frequency gapes in spectrum [2]. Cognitive radio technology is basically aimed at putting this underutilized spectrum to a good use by dynamically allocating spectrum to the incoming traffic, thus making overcoming the rigidness of the system. By employing an effective cognitive cycle a fair spectrum sharing scheduling can be achieved which depends upon the nature of user's application. Cognitive Radio is an important technology of the OSA (opportunistic Spectrum Access), this technology is layered over SDR which is renowned in learning from experience this adaptability and re-configurability of the system enables it to switch adaptively. In this two layered infrastructure the configuration is modified by an SDR unit while the cognitive radio is responsible for the intelligent detection of the users. To ensure the quality CR aims at improving Spectrum utilization and un-interrupted communication of CR and the licensed user [3].

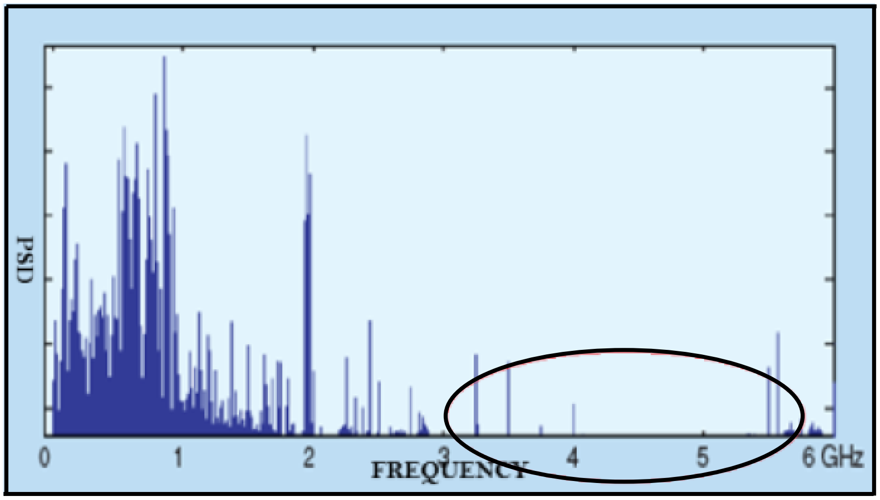

Figure 1.1 : Spectrum Utilization Measurement by FCC [2]

Cooperative spectrum sensing is normally used to identify spectrum holes but this technique comes with cost of cooperation overhead amongst the cognitive radio. Therefore if local spectrum sensing is enhanced this can reduce the cooperation overhead. When a cognitive radio scans through the spectrum it is called spectrum sensing , there are multiple techniques that are developed for spectrum sensing which include matched filter [4], and cyclo-stationary detection [5] and energy detection [5,7].

The key functions of CRNs are sensing of the spectrum, sharing of spectrum, its management and mobility. This is carried out by cognitive center which confirms the absence or presence of primary user (PU) in such a way that the performance of primary user should not be interrupted [8]. For improving the detection performance of cooperative radio networks, cognitive relays are used. These cognitive relays work on different types of transmission protocols such as; Amplify and Forward (A&F), Estimate and Forward (E&S), and Decode and Forward (D&F).

1.2. Problem Description

Research efforts in the field of cooperative-cognitive networks have focused on the effects of detection techniques on the overall performance of such networks. It has been established in research studies that noise uncertainty is high in energy detection. Multiple recent studies suggest that a lot of work done on single band energy. The focus of this research thesis is to investigating the performance of multiband energy spectrum sensing in cooperative-cognitive networks over various fading channels. As a result this methodology promises to deliver enhanced throughput and efficient network.

1.3. Thesis Objectives

Aims of the project are:

- To study and analyse the spectrum sensing by using energy detection technique in multiband cooperative cognitive network.
- Analysing the detection technique using double threshold energy detection.
- To analyse the result for multi hop network using the double threshold energy detection.
- To analyse the result for different number of users and for different sampling point.

1.4. Research Methodology

Noise ambiguity added at relays is a major issue in wireless communication. For such purpose relay transmission protocols are brought under consideration. Relay schemes are supposed i.e. amplify and forward (A& F). In A&F the signal at relay is amplified along with the noise added to it, which is not needed and we can have problem of false alarm and misdetection of Primary User (PU). The main idea of this research is to introduce multiband spectrum sensing technique due which sudden reappearance of PU shall not interfere with the SU transmission as the secondary user will be able to seamlessly handoff from one channel to another and because of that system throughput will be increases by accessing multiband. Simulations are carried out with Monte Carlo simulation, confined and clear results are taken which are shown in chapter 4 where each and every term is discussed in the thesis.

1.5. Thesis Organization

In chapter 2, literature are discussed which contain cooperative sensing, classification of cooperative sensing, transmission protocols for relays, cognitive radios and sensing techniques used in it. In chapter 3, modelling of channel, path loss, diversity techniques and combining algorithms are discussed. Chapter 4 comprises of spectrum sensing, its methods and implementation. Furthermore, in chapter 5 proposed system and the simulated results are shown. Future directions are given in Chapter 6.

Chapter 2

Literature Review

CHAPTER 2. LITERATURE REVIEW

COOPERATIVE NETWORKS

2.1. Overview

When a signal propagates from the sender to receiver, there are a lot of hurdles in the path of its propagation. As, a result the signal becomes distorted. Examples are attenuation, delay, distortion and fading. Due to different reflectors in the environment, fading occurs. When the two copies of original signal are combined at the receiver side, in phase, constructive interference occurs. And we get our required information signal. In case of destructive interference, the two copies are combined out of phase and we lost our information. Different signals propagate on different paths to the destination (receiver) which is called multipath propagation. Destructive interference decreases the signal power, SNR and may fail the communication process. We have to remove these effects in order to obtain our required information signals. Diversity is the best option against these hurdles. Diversity is the process in which we transmit different copies of the same signal to the receiver. At receiver, we have different copies so easily we can take out our information. Different forms of diversity are used to deal with successfully the multipath fading.

2.2. Fading

When we have destructive interference at the receiver side, we lost our original information. This process is called fading. This brings a change in the signal power and Signal to noise ratio. The different copies that are received have different delay time and phase shift. The fading may be caused due to two reasons, Multipath propagation and shadowing from different objects. We overcome the Multipath fading through diversity.

2.2.1. Non-Selective Fading

During transmission, the propagating signal has a different bandwidth than the coherent bandwidth of the channel. When it is greater in case of channel than the transmitted Signal, then such fading is called Non-Selective Fading or also known frequency Non-Selective Fading. During this fading, all the components of useful signal spectrum reduced equally. It is also called flat fading. Signal to noise ratio is greatly affected by frequency non-selective fading.

2.2.2. Selective Fading

In some cases, the spectrum gets distorted by reducing only some of the spectral components. Such type of fading is called selective fading or frequency selective fading. In this type of fading, the bandwidth of transmitted signal has greater than the bandwidth of the channel. Different frequency components have different fading degrees. We also take into account the relative motion of the objects in this type of fading. At receiver, the signal must be contingent upon the relative phase difference, delay and motion [9].

2.2.3. Path Loss and Fading

Both path loss and fading distort the transmitted signal to a greater extent. Fading is the multiplicative of path loss. While taking to be the case of plane earth model, path loss is proportional to 1/R2. It should be noted that, the path loss is considered constant for the complete transmission for a constant distance (nearly) between the transmitter and receiver. The power which is attenuated at the destination (Receiver) side is proportional to 1/R4. Different key measures are used to overcome the path loss and fading e.g. Cross band and rout diversity etc. In wireless communication network, path loss can measure using path loss exponent. Range of its value is from 2 to 6. Different value for different environments is show in table 1. Path loss is expressed in dB and can be calculated using the following formula [10]

$$L = 10 * \mathrm{n} * \log10(\mathrm{d}) + C \qquad (2.1)$$

Where L is the path loss in decibels, n is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which accounts for system losses.

Table 2.1: Value of Path Loss Exponent for Different Environment

Environment	Path loss exponent (n)
Free space	2
Urban area	2.7-3.5
Suburban area	3-5
Indoor (line of sight)	1.6-1.8
Obstructed in building	4-6

2.3. Channel Modeling

When a signal propagates though a wireless medium, it becomes out of the shape due to some negative qualities of the channel. Different types of fading channels are used. Some of them are following.

2.3.1. Additive White Gaussian Noise

The signal transmitted from source towards destination is affected by certain amount of noise. This noise is called AWGN. The channel which transmitted the signal from source to destination is a frequency band which is the uniform distribution of certain amount of frequencies [11].

2.3.2. Rayleigh Distribution Fading Channel

Its name occurred due to Lord Rayleigh. Rayleigh distribution is represented as the least favourable case. We don't consider the line of sight communication in it. The distribution of phase and power are taking into account here. The phase distribution is always the same and free from external control of amplitude, while the power distribution is exponential in nature. When value of the Rice Factor K in rician fading moves toward the infinity then we have no Line of Sight component Rayleigh distribution is equal rician [12].

2.3.2.1. The Rayleigh Probability Distribution Function

For the independent components of h (t) probability density function of amplitude is given as [12]:

$$r = |h| = \gamma \tag{2.2}$$

$$f(r) = \left(\frac{r}{\sigma^2}\right) e^{-\left(\frac{r^2}{2\sigma^2}\right)} \quad where\ r \geq 0 \tag{2.3}$$

2.3.3. Rician Distribution Fading Channel

In this type of fading the signal arrive from multiple paths to at destination. From upcoming signal path at least one path is changing. Interference is produce due to multipath in rician fading channel.

2.3.3.1. The Rician Probability Distribution Function:

$$f(r) = \frac{2(k+1)r}{\Omega} e^{\left(-k-\frac{(k+1)r^2}{\Omega}\right)} j_0\left(2\frac{\sqrt{k)k+1)}r}{\Omega}\right) \quad \text{where r} \geq 0 \tag{2.4}$$

Here J_0 is the Modified Bessel function, have zero order. K is called the Rise factor. The Rayleigh distribution is equal to Rician distribution whenever the value of K approaches to Infinity. In such case we should have no line of sight component [13].

2.3.4. Nakagami-m Distribution Fading Channel

This distribution is also known as Nakagami-m Distribution. It is somehow related to gamma distribution. In case of Nakagami Distribution, there are two important parameters. One is m which is called shape factor and other is Ω which is known as controlling spread.

2.3.4.1. The Nakagami-m Probability Distribution Function:

$$f(r) = \frac{2m^m r}{\Gamma(m)\Omega^m} r^{2m-1}\, e^{(-\frac{m}{\Omega}r^2)} \quad \text{where r} \geq \tag{2.5}$$

The function Γ (.) is called "Gamma function" where the factor m is called "Shape Factor" and Ω is called controlling spread. It is actually the generalized form. Using this fading channel we can describe the other two rician and Rayleigh fading channel as well. When shape factor $m = 1$ then nakagamai-m fading channel is nearly equal to Rayleigh fading channel and when m is increasing then it approaches to rician fading channel model [14].

2.3.5. Suzuki Model

Suzuki model is the most advanced probabilistic distribution which most similar to the real world. Suzuki model is the combination of Log-normal and Rayleigh model. Shadowing effect is also considered in this model. In this model we take mean value of both log-normal and Rayleigh fading channel and then we take square of both the values. After that we pass that signal through low pass filter and after that add both signals to get Suzuki distribution signal. Implementation of suzuki model is shown in Figure 2.1 [15].

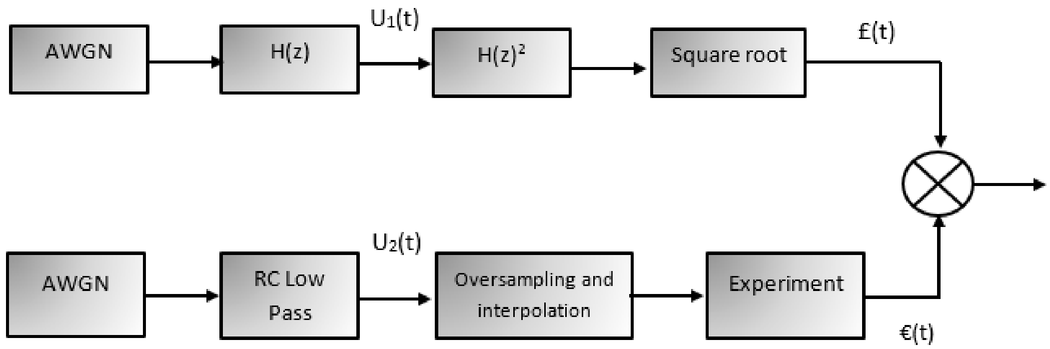

Figure 2.1: Implementation of Suzuki Model Path Loss [15]

Well considered factor in designing of any for radio communication system. Attenuation of the signal when it is transmitted through channel (either guided of non-guided) from sender towards the receiver. Path loss fades the EM waves that travel in the nearby atmosphere. Different types of losses are presented below:

- Absorption
- Free-space
- Reflection
- Diffraction

2.3.6. Absorption Losses

Opaque medium or cloudy medium between sender and receiver, then absorption losses occurs. Like losses in communication between satellite and user due to clouds.

2.3.7. Free-Space

This type of loss is prominent when there is no obstacle in LOS communication between the sender and receiver. Only distance is considered as function of attenuation. Examples are Satellite communication and micro wave links. Path loss for free space varies directly to the square of distance between sender and receiver.

2.3.8. Reflection

The bouncing back of signal with different angles from obstacles is called reflection. It happens when wavelength of signal is very short as compare to dimension of obstacle. Due to reflection multiple copies of signal are received at the Receiver which are added or subtracted. When this phenomenon happens then some part of energy from signal is absorbed by obstacle we call it Reflection losses.

2.3.9. Diffraction

The bending over of signals through obstacles is called diffraction. Losses happen when the obstacle edges are sharp. Phase and angle of obstacles cause the signal to bend at different angles.

2.4. Diversity

Fading causes distortion in the signal strength and power. To deal with fading a co-channel interference successfully we use diversity. Different types of diversity techniques are used. The degree of progress in development with any diversity technique is contingent upon the un-correlation amount between the diversity and main channels.

When the sender transmits different copies of the same signal to destination, then receiver has multiple copies of the same signal [16]. These different components are then get together to take out our required information. Different techniques are discussed here [17-18].

2.4.1. Frequency Diversity

Frequency diversity uses extra spectrum that’s why it is banned in many countries. It is not very efficient in spectrum point of view. Lower and high frequency bands are used frequency diversity. This technique is just unwanted use of spectrum. In frequency diversity, multiple copies of the original signal are transmitted, having different frequency at the same time.

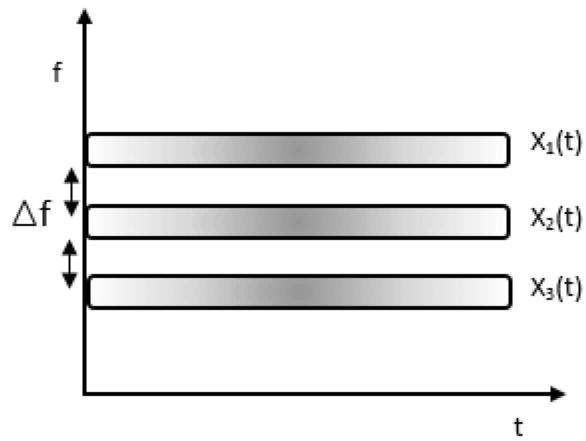

Figure 2.2: Frequency Diversity

2.4.2. Time Diversity

Just like in frequency diversity, here also different copies of the original signal are transmitted but have different time slots. All the copies have the same frequency. It is shown in figure 2.3.

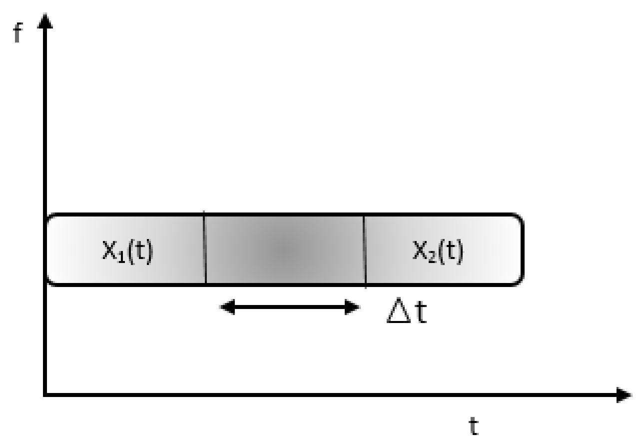

Figure 2.3: Time Diversity

2.4.3. Space Diversity

This technique is very expensive, requiring two antennas and higher tower. Being spectrum efficient, it is considered to be the best option against multipath fading. Two vertical antennas are used in space diversity, they are placed in such manner that one has maximum power and other has minimum. The multipath fading causes phase cancellation on main path. But due to the vertical position of two antennas the diversity path is not affected. In space diversity we transmit the same signal through different antennas at same frequency and time. This technique is also known as “Multiple Inputs Multiple Outputs”, (MIMO). It is shown in the given fig.

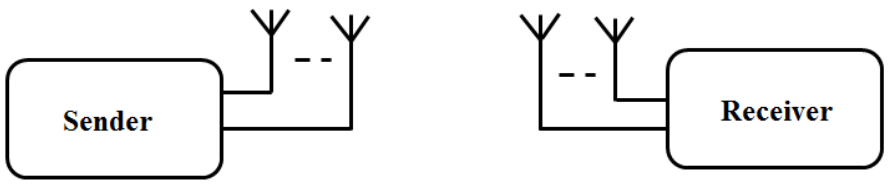

Figure 2.4: Space Diversity

2.4.4. Polarization Diversity

Electric and magnetic components are transverse to each other and to propagation path. In polarization diversity we altered these two components, which carry the different copies of the original signal. Both the Electric and magnetic components are vertical to each other so we get orthogonal type of polarization.

2.4.5. Angle Diversity

In angle diversity, direct and indirect delayed waves have different angles of arrival. We use directional antennas to transmit different copies of the same signal, having different angles of separation. The directional antennas produced the multipath signals. However, at the destination side for separating these multiple angular components, we use highly directional antennas.

2.4.6. Multiuser Diversity

In this diversity, first we define the opportunistic user scheduling at either the sender or receiver side. During scheduling, the transmitter on the basis of channel quality selects the best user among all. Receiver provides information about the channel quality to the transmitter.

2.5. Diversity Combining Schemes

List of combining techniques are given below:

- Maximal Ratio Combining (MRC)
- Selection Combining
- Square-Law Combining (SLC)
- Equal-Gain Combining (EGC)
- Scanning

2.5.1. Maximal-Ratio Combining

In this method the signal is amplify with high SNR, each copy from multiple relay has separate receiver. The copies of signal from different receivers are then co phase and added together and multiplied with weighted signal to form one signal. In space diversity this method is used. The final received signal for MRC is [14]

$$Y_{MRC} = \sum_{i=0}^{n} w_i * Y_i \tag{2.6}$$

2.5.2. Selection Combining

In this method more than one copy of signal received at receiver. The signal copy which is high SNR is selected and then demodulated for further process. This method is very simple and less complex [19].

2.5.3. Square-Law Combining

In this method the signal which coming from multiple relay are squared and added together at receiver. In this method phase estimation is not considered which is the only different between SLC and MRC. The final received signal for SLC is [20]

$$Y_{SLC} = \sum_{i=0}^{n} Y_i \tag{2.7}$$

2.5.4. Equal-Gain Combining

This method is simplest form of MRC. Like in MRC the signal coming from different path are co-phased and added together to form one signal at receiver. The probability of a signal at receiver with adequate SNR is still high but not like as in MRC [21].

2.5.5. Scanning

It is also known as feedback combining technique. This method is low complexity, then selection combining. It scans for the signal with SNR greater than the predefined threshold value. Comparator is used to compress the signal for the sake of high SNR signal. Process is repeated till the SNR of receiving signal is greater than pre-defined SNR. It is the simplest of all combining techniques as only one receiver is required.

2.6. Cooperative Transmission Protocols

There are three different type of protocols are used for transmission.

- Amplify and forward
- Decode and forward
- Compress and forward

We have only used amplify and forward transmission protocol in for relaying scheme. Processing is different in each case.

2.6.1. Amplify and Forward

As the name shows, in this type, the received signal is first amplified by the relay and then sends towards its required destination. We use this transmission when we have limited computing time and time delay. It is used for analogue signals communication. The attenuated signal from the transmitter is amplified and sends toward the destination. Unfortunately, it also amplifies the received noise. As compared to decode and forward it takes less delay during processing [22-23]

2.6.2. Decode and Forward:

In this type, the relay first deciphers the received signal. After that encodes it again. Its main advantage is that it does not amplify the received noise. But as compare to amplify and forward it takes more delay time which is not acceptable. Symbol by symbol it encodes the received message signal [24].

2.6.3. Estimate and Forward:

In [25], saving power is the concern of the author and he is suggesting estimate and forward protocol (E&F). It's simplified form of D&F relay. E&F doesn't detect any error in the signal. When it encoded at receiver side original signal will be extracted

COGNITIVE RADIO

2.7. Overview

With the recent abrupt growth in communication, wireless technologies have also increased intensively. Conventionally spectrum licensing schemes are based on static spectrum license, which results in severe underutilization of the valuable frequency spectrum. So this static model of spectrum allocation presents a great challenge for the resourced wireless network to fulfill the requirement of the rapidly increasing wireless networks [26]. To solve this problem of spectrum underutilization a more flexible and dynamic model is required. So it was proposed to solve this problem by cognitive radios. In this model, the unlicensed user is allowed to use the spectrum resources of licensed user under specific conditions [27]. In this cognitive radio based dynamic spectrum allocation model, the spectrum rights is owned by the primary user, while the unlicensed user (secondary user) can share this spectrum in the absence of the primary user in an opportunistic manner. So to find out spectrum holes and to check whether the primary user is using the spectrum or not a sensing technique is required. Hence Spectrum sensing is extremely important in cognitive radios, because it has to sense the spectrum and find out the spectrum holes for the use of the secondary users. There are different types of spectrum sensing techniques are used like energy detection, match filter detection and cyclostationary feature detection. Energy detection is the most simple and reliable of these techniques because it gives very good detection probability in a very short time [28]

2.8. History

Joseph Mitola III for the first time introduced the concept of cognitive radio in a workshop at Royal Institute of Technology in 1998. The frequency allocation body including the FCC find out that the expensive radio spectrum is not utilized most of the time, and the spectrum is idle most of the time. If we take an example, cell system groups are most widely used in all parts of the planet, hence its frequency spectrum band is over-burden. While other frequency bands like military, paging frequencies and many others are not extensively used. As these bands are not utilized efficiently and there are spectrum holes so to efficiently utilize the available spectrum and to cover these spectrum holes the concept of unlicensed users were introduced. This standard was given the name of cognitive radio. In January 2010 at University of Oulu, the primary telephone was implemented with cognitive radio system.

2.9. Definition

"Cognitive radio (CR) is a form of wireless communication, in which a transceiver can smartly sense the wireless spectrum that are used for communication and the others which are not, and change the transmission parameters to the channels that not in use while avoiding the occupied ones".

2.10. Cognitive Radio Network Components

A cognitive radio network communication is divided into three basic components as follows:

- Primary network
- Secondary network
- Spectrum broker

2.10.1. Primary Network

It is the most important and a crucial component of the cognitive radio network because the spectrum resources of the primary network are used in the whole system. It is composed of two parts a primary user and a primary base station. Basically the primary is actually the owner of the spectrum that is being utilized by the system. The primary user gets the frequency spectrum and pay for it. Hence it is also called the licensed user of the given frequency spectrum. In a cognitive radio networks primary user is unaware of the activities of the secondary user or any other secondary users. While Base Station is a Static network component and is responsible to control the access of the primary users to the spectrum resources. It also has the spectrum license [27].

2.10.2. Secondary Network

It is the part of the cognitive radio which is actually getting benefit from the network. It is also composed of two parts, a Secondary user and a secondary base station. Secondary users are those users which uses the vacant frequency spectrum of the primary user in an opportunistic manner [29]. Hence it is using the resources of a licensed user, so it is essential that there should be no interference in the communication of the primary user. As soon as the primary user approaches the frequency channel, secondary users need to free the channels abruptly and move into another vacant channel. So to keep an eye on the primary user activity and to find out vacant channels it needs a continuous detection mechanism which is performed by the cognitive center. The instant any free channel is detected, the transmission parameters of the secondary users is shifted to that free channel. While the secondary base station is a static Network component of the cognitive radio, which provides single hop connection of the secondary users SU.

2.10.3. Spectrum Broker

It is one of the most important component of the cognitive radio Networks. It most important function is to govern the access of the spectrum in the cognitive networks. It also provides sharing of the spectrum and distributes the spectrum resources among the different devices. So it keeps the information of the available frequency spectrum resources so it is a kind of centralized server [29]. Based on the functionality and the context in which the device is used, it takes different names such as Bandwidth Broker [30], Spectrum Policy Server [31], Regional spectrum broker [32] or simply the broker.

2.11. Cognitive Cycle

- Spectrum sensing
- Spectrum analysis
- Spectrum decision

2.11.1. Spectrum Sensing

The basic responsibility of the CR is to access the spectrum in an opportunistic manner. So it has to sense the spectrum regularly so that when the spectrum is not occupied by the primary user the secondary user may use it [27].

2.11.2. Spectrum Management

The CR is responsible to allocate the best of the available spectrum to the secondary user. And it should make sure that the spectrum is vacant in the presence of the primary user. And move the secondary user to any other available band [27].

2.11.3. Spectrum Sharing

CR also has to provide a spectrum sharing method among several users. It is the responsibility of the CR to provide best available spectrums to all the secondary users [27].

2.12. Sensing Techniques

In cognitive system, sensing of spectrum is one the upmost criteria. There are many ways through which spectrum can be sensed [33]. Following are some of them.

- Energy detection
- Matched Filter detection
- Cyclo-stationary Feature detection

2.12.1. Energy Detection

It is used widely, having its own features. It is also known as visionless signal detector because it ignores the signal shape (structure). It cooperates on the idea that at receiver side energy of the signal is always greater than energy of the noise. Here, we defined a proper threshold, on the basis of which the signal presence is detected. We compare the received energy with the known threshold. If the signal energy received has more energy than our defined threshold, then signal is present or vice versa. The block diagram of energy detector is shown in Figure 2-5 [34].

Advantages

Energy detection method is become very popular. As compared to other methods it has numerous advantages. It is the simplest technique. It takes less processing time during its operation and is low computational. More, its implementation costs are very low.

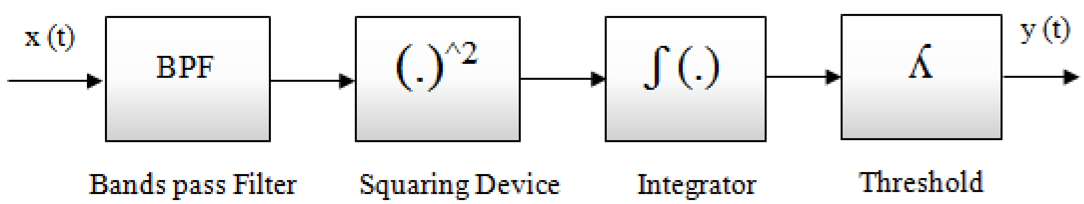

Figure 2.5: Block Diagram of Energy Detection [34]

2.12.2. Matched Filter Detection

Match filter is always considered the best linear filter which contains much knowledge of transmitted signal. It is use for primary user detection. SNR can be reached at the maximum level through match filter detection at the output side. For high processing gain it takes less time as compared to other techniques. It is considered as desired filter in case of AWGN. It operates on the principle of convolution. The match convolves the signal (received signal) with our defined threshold. Through this we can decide about the presence of primary user. The block diagram of matched filter is shown in Figure 2-6 [35].

Advantages and Disadvantages:

Its main advantage is that it takes less consuming time for deciding about the miss probability detection and the probability of false alarm. Its consuming power is very large. For each signal, a dedicated receiver is requires by cognitive radio. Moreover, it is not used in multi-waveform detection case.

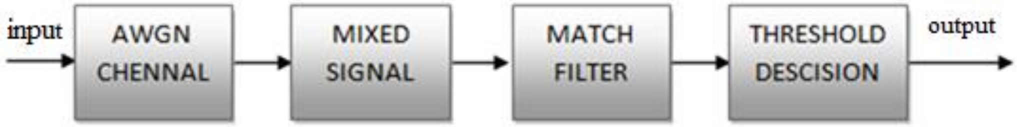

Figure 2.6: Block Diagram of Matched Filter Detection [35]

2.12.3. Cyclo-Stationary Feature Detection

In this method, we use the cyclo-stationary features of received signals in order to detect the primary user. The cyclo-stationary signals are those signals which have periodic function autocorrelation. Decision about the presence of primary user is performed on the basis of cyclic frequencies scanning. We have two cases, if cyclic spectrum for certain cyclic frequency is less than the threshold, then we has no signal. If it is greater than the threshold level then it will show the presence of signal. White Gaussian noisy channel is used for detection performance. Cyclo-stationary detection performance is not good as compared to energy detection technique. Its performance is strong to uncertain noise. Primary user signal can be detected at low SNR ratio. For this we use Information about the received signal. The block diagram is shown in Figure 2-7 [36].

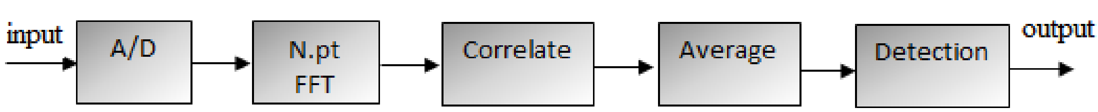

Figure 2.7: Block Diagram of Cyclostationary Detection [36]

Chapter 3

Methodology

CHAPTER 3. METHODOLOGY

Some of the most popular and common sensing techniques that are wildly used for cognitive Networks are discussed in chapter 2 Such as match filter detection, the cyclostationary Feature detection, Energy detection and the Fuzzy logic based Detection [37]. Each one of these techniques has different ways of sensing the spectrum but they have some common features as well. Like both match filter and cyclostationary Feature Detection are Coherent Detection. Coherent detection is a type of detection in which the output depends on the input original signal; the detected signal is matched and compared with the copy of original signal that is transmitted.

These are very useful methods of detection in CRNs with higher signal to noise ratio (SNR) which requires knowledge about the signal which is transmitted due to which they require a lot of time for their processing especially the cyclostationary feature detection. The energy detection is the non-coherent type of detection.

In all these types of techniques energy detection the simplest type of detection scheme that is most widely used because in case of energy detection, detection probability is much better than others at high SNR values and in a very short period of time [38]. Energy detection is based on a very simple principle, it finds out the received signal energy at the output and then compare it value with a predefined value and based on the result it decides whether the primary user is present or not [39]. The predefined value is called a threshold. There are two terms widely used in energy detection technique, the probability detection Pd, it is the probability of affirming the presence of licensed user (Primary user) when it is actually using the spectrum and the False Alarm Probability Pf, it is the probability if affirming the presence of the licensed user (Primary user) when it is actually not being used by primary users. The higher the detection probability the better the lessened band protected from the secondary user while the primary user is there.

3.1. Energy Detector Structural Design

Energy detector is composed of three parts a spectrum analyzer an oscilloscope and a computer. Basically a spectrum analyzer is used to measure the power of the spectrum of any given signal. But here it is used to measure the amplitude of the input signal versus frequency. We can analyze the spectrum of any signal through it. Its result is displayed on an oscilloscope which is connected to it. There are two axis one the horizontal and the other is vertical axis. Frequency is represented on the horizontal axis while the vertical axis is used for amplitude of the signal [40].

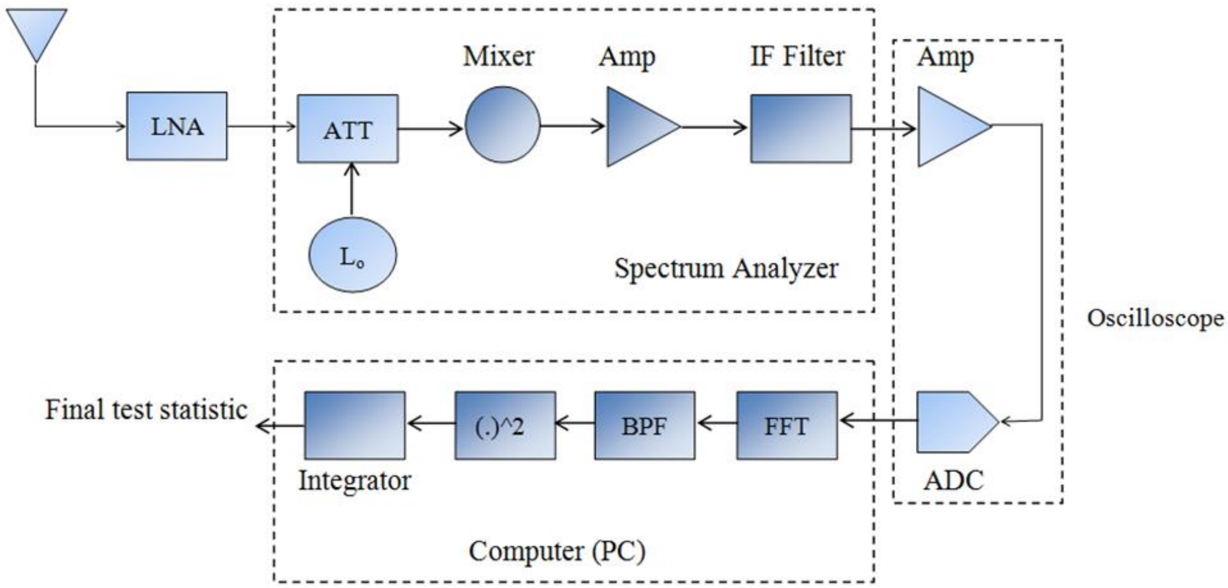

Figure 3.1: Energy Detector Prototype [40]

3.2. Multi-Band Spectrum

We consider sub channels (k) which are non-overlapping and are obtained by division of primary communication channel over a multi-band channel. Occasionally these sub channels (k) are underutilized and are not occupied by primary users; in such circumstances these channels are available for secondary users for specific period of time.

Detection of vacant channel problem on sub channel k, can be modeled as a choice between H(0,k) and H(1,k), the former choice translates as absence of primary user shown by (0), whereas later represents presence of primary user depicted by (1). Figure 3-2, depicts sparse presence of primary users over a multiband channel spectrum. Underlying hypothesis vector represents the sub channels which forbid or allow access of spectrum in opportunistic manner.

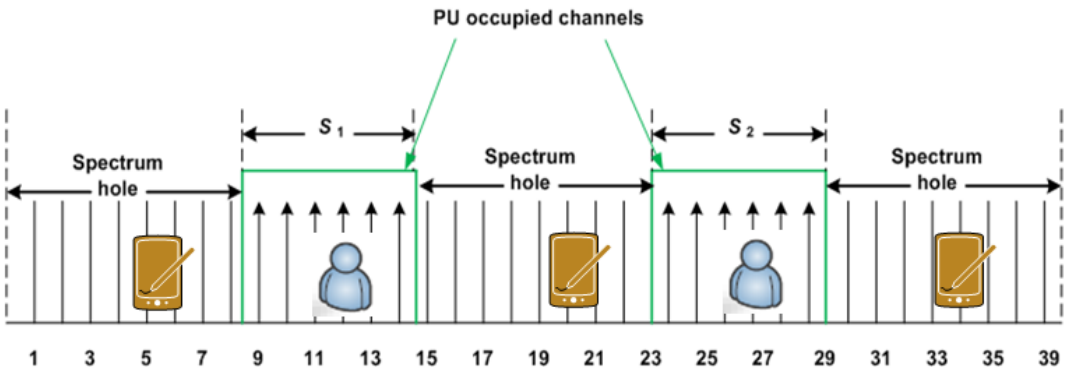

Figure 3.2: Schematic Diagram of a Multiband Channel

The main task of spectrum sensing is to sense the multi-band k channels and identify the channels which are not used by the primary user and vacant for opportunistic use. For this we use energy detection spectrum sensing technique.

3.2.1. Serial Spectrum Sensing

In serial spectrum sensing one energy detector is used to sense the multiple channels one at time.

3.3. System Model

Let us consider a wireless Cooperative-Cognitive Network as shown in the Figure 3-3. The given system model is composed of three different components a primary user, a cognitive centre CC and intermediate node i.e the secondary users. The secondary users also work as a relays. In this case the relays are operated as Amplify and forward. The intermediate nodes transmit the signals from the primary users to the cognitive centre CC. there is also a direct path from the primary user to the cognitive centres in which the transmission of the signal is effected by the relays.

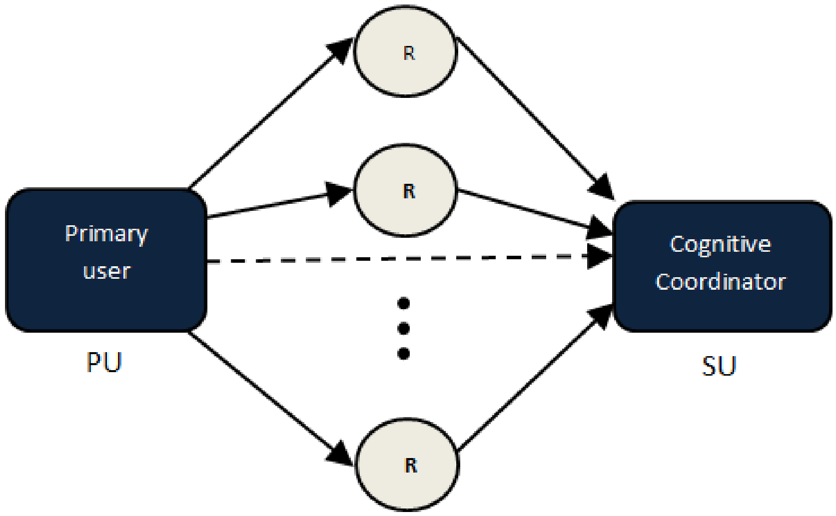

Figure 3.3: System Model

The intermediate nodes vary from system to system different number of relays can be used depending upon the system requirement. There different kind of fading channels which can be used. In our case we have used rician fading channel. As signals are received at the output through different paths i.e the relay paths or the direct path so there are multiple copies of the original signals are being received at the CC. These signals are combined through different diversity techniques. Here we have used square law combining technique for it to get a single signal from the multiple copies at the cognitive centre.

3.4. Single Threshold Energy Detection

Figure 3-4 shows a very simple representation of the Single energy detection algorithm. In this algorithm a single predefined (Threshold) value is used for detection. The output of the CC is compared with this value to find out the presence of the primary users. Let suppose y (t) is the output of the transmitted signal. If this output signal y (t) is greater than the threshold value then it means the presence of the primary user and that the secondary user can't use the spectrum at that given time. It is shown by H1. But when the output signal y (t) is lesser than the threshold value then it shows the absence of the primary users and the secondary user is free to utilize the spectrum at the given time. It is shown by H0.

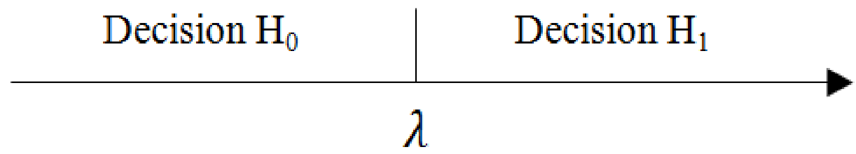

Figure 3.4: Single Threshold ED Algorithm [20]

'P_d', 'P_f' and 'P_m' can be calculated as [20]:

$$P_d = p\{\, y(t) > \lambda \mid H_1 \,\} = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{3.1}$$

$$P_f = p\,(Y > \lambda \mid H_0) = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \tag{3.2}$$

$$P_m = p\{\, y(t) \le \lambda \mid H_1 \,\} \tag{3.3}$$

Equation '3.3' can also be written

$$P_m = 1 - P_d \tag{3.4}$$

In above equation γ represent the SNR, λ represent the predefined threshold value, '$Q_u(.\,,\,.)$' is a generalized Marcum Q-Function, 'u' shows the Time bandwidth factor while '$\Gamma(.)$' and '$\Gamma(.,.)$' shows Gamma and incomplete Gamma function respectively. In this case the Collision Probability 'P_c' between the PU and CC is same as the missing probability 'P_m'.

3.5. Double Threshold Energy Detection

Due to some limitation of the Single threshold energy detection like interference with the primary user and noise uncertainty, a new algorithm was proposed to cope up these shortcomings i.e Double Threshold Energy Detection algorithm. Figure 3-5 shows a very simple schematic representation of the Double Energy Detection Algorithm. As the name, Double Threshold Energy detection shows this algorithm shows two threshold values for detection. The two thresholds represented by (λ_0 *and* λ_1) reduces the noise uncertainty. So in the case the output signal will be compared with both the threshold values. If the output $y(t)$ is greater than λ_1 then it shows the availability of the primary user and the secondary user cannot use the spectrum.

And if output $y(t)$ is lesser than the threshold value λ_0 then it shows that the primary user is not present and the spectrum can be utilized by the secondary user. As shown in the Figure 3-5 as H_1 and H_0 respectively. But when the output signal $y(t)$ is in between the two threshold values (λ_0 *and* λ_1) it means that the result is invalid and the spectrum should be detected and sensed again.

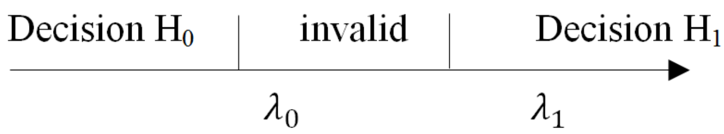

Figure 3.5: Double Threshold ED Algorithm

For double-threshold energy detection the formula for 'P'_d', 'P'_f' and 'P'_m' can be calculated as [20, 41]:

$$P'_d = p\{ y'(t) > \lambda_1 \mid H_1 \} = Q'_u \left(\sqrt{2\gamma'}, \sqrt{\lambda_1} \right) \tag{3.5}$$

$$P'_f = p\,(y'(t) > \lambda_1 \mid H_0) = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \tag{3.6}$$

$$P'_m = p\{ y'(t) \leq \lambda_1 \mid H_1 \} \tag{3.7}$$

Equation '3.7' can also be written as

$$P'_m = 1 - P'_d \tag{3.8}$$

Also the Probability Collision is given as [20]:

$$\begin{aligned} P'_c &= p\{ y'(t) < \lambda_0 \mid H_1 \} \\ &= 1 - p\{ y'(t) > \lambda_0 \mid H_1 \} \\ &= 1 - Q'_u \left(\sqrt{2\gamma'}, \sqrt{\lambda_0} \right) \end{aligned} \tag{3.9}$$

3.6. Multiple Relay Communication

Any number of intermediate nodes can be used as the Relays denoted by "ri" for the wireless communication systems, where *i*=1, 2, 3,….., *N* generally. The signal received at i-th Relay from the PU is given as:

$$y_{sri} = h_{sri}x + n_{sri} \tag{3.10}$$

Where "h_{sri}" is the channel response for *i*-th link between source and relay and "n_{sri}" is the noise added in the each signal at different *i*-th links from source to the relay node.

Now the different signals "y_{rid}" received at the destination from *i*-th Relay or link is given by relation as:

$$y_{rid} = A_{ri}h_{rid}y_{sri} + n_{rid} \tag{3.11}$$

Where "h_{rid}" is the channel response for the *i-th* link from *i*-th Relay to the destination CC, "n_{rid}" is the noise added in the signal at each *i*-th link from *i*-th Relay to the destination and "A_{ri}" is the amplification factor for each of the *i-th* Relay which is given as:

$$\mathrm{A_{ri}} = \sqrt{\frac{\mathrm{E_p}}{\mathrm{E_p}|\mathrm{h_{sri}}|^2 + \mathrm{N_0}}} \tag{3.12}$$

For multiple Relays the total end-to-end SNR is given as:

$$\gamma = \frac{1}{\mathrm{N_0}}\left(\sum_{i=1}^{N}\frac{\mathrm{E_{pri}E_{rid}}\left|\mathrm{h_{pri}}\right|^2 |\mathrm{h_{rid}}|^2}{\Omega_{\mathrm{pri}}\mathrm{E_{pri}} + \mathrm{N_0}\ \frac{\mathrm{E_{rid}}}{\Omega_{\mathrm{pri}}\mathrm{E_{pri}} + \mathrm{N_0}}\ |\mathrm{h_{rid}}|^2 + 1}\right) \tag{3.13}$$

Where "E_{pri}" and "E_{rid}" are the energies of the signals from PU to *i-th* Relay and from *i-th* relay to the destination respectively.

Chapter 4

Evaluation

CHAPTER 4. EVALUATION

4.1. System Setup

In this section, we present the simulation results for different scenarios that we have taken for analysis and comparison. Table.4-1 highlight the key simulation parameters for simulation model which shown in Fig.6. For simulation, we used rician fading channel and amplifying and forward scheme at relay. The parameters which we used in our simulation model are:

Table 4.1: Simulation Parameter

S/N	Parameter	Value
1	Time bandwidth factor	1
2	Noise power (σ^2)	1
3	SNR	-15 to 25dB
4	Threshold (λ)	0-40
5	Lower threshold λ_0	0.8 λ
6	Upper threshold λ_1	1.2 λ

4.2. Simulation Result

Our simulation results are given below. These simulation results are for rician channel environment. We use matlab simulator to plot our simulation results. Simulation result include throughput vs. SNR, plot between probability of detection (P_d) vs. SNR, probability of collision (P_c) vs. SNR for different number of channels and sampling points. Furthermore, we also plot comparison between single band and multiband energy spectrum sensing as well as single & double threshold energy detection.

4.2.1. SNR Verses Throughput

SNR Verses throughput is shown in Fig 4.1. Result shows that the throughput of our proposed system increases as SNR are increases. Furthermore, when we increase number of channels the system throughput increases.

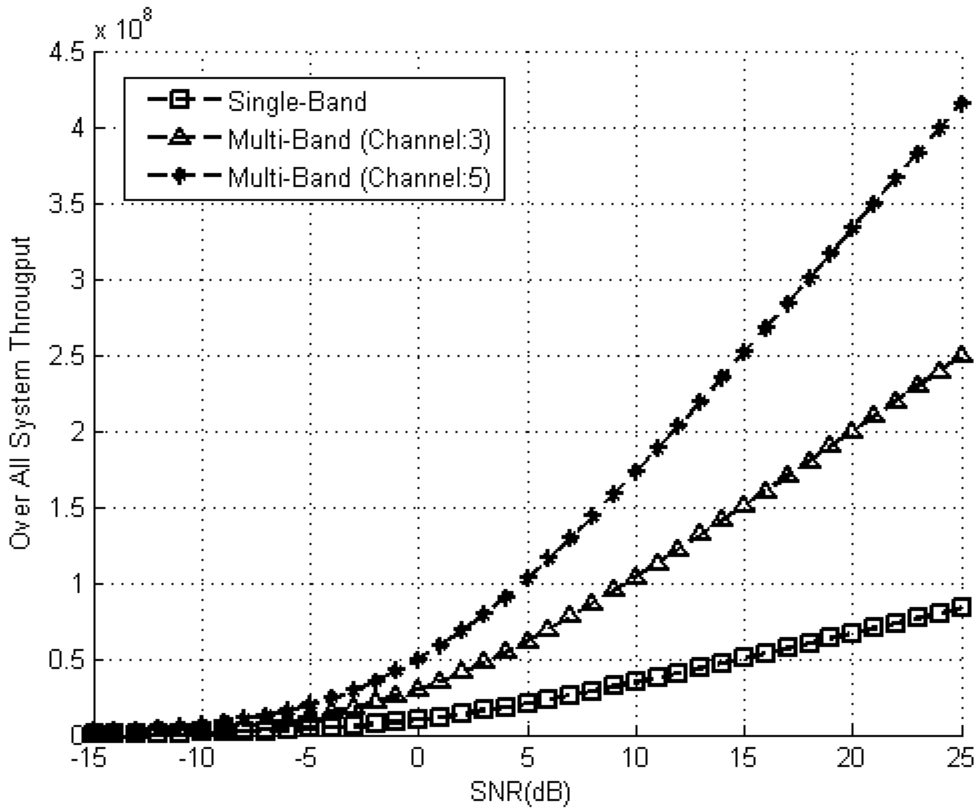

Figure 4.1: Overall System Throughput vs SNR

4.2.2. Detection Probability Verses Throughput

Detection probability verses throughput is shown in Fig 4.2. Result shows that the throughput of our proposed system increases as detection probability are increases. We also see that our proposed algorithm better then single-band spectrum sensing technique.

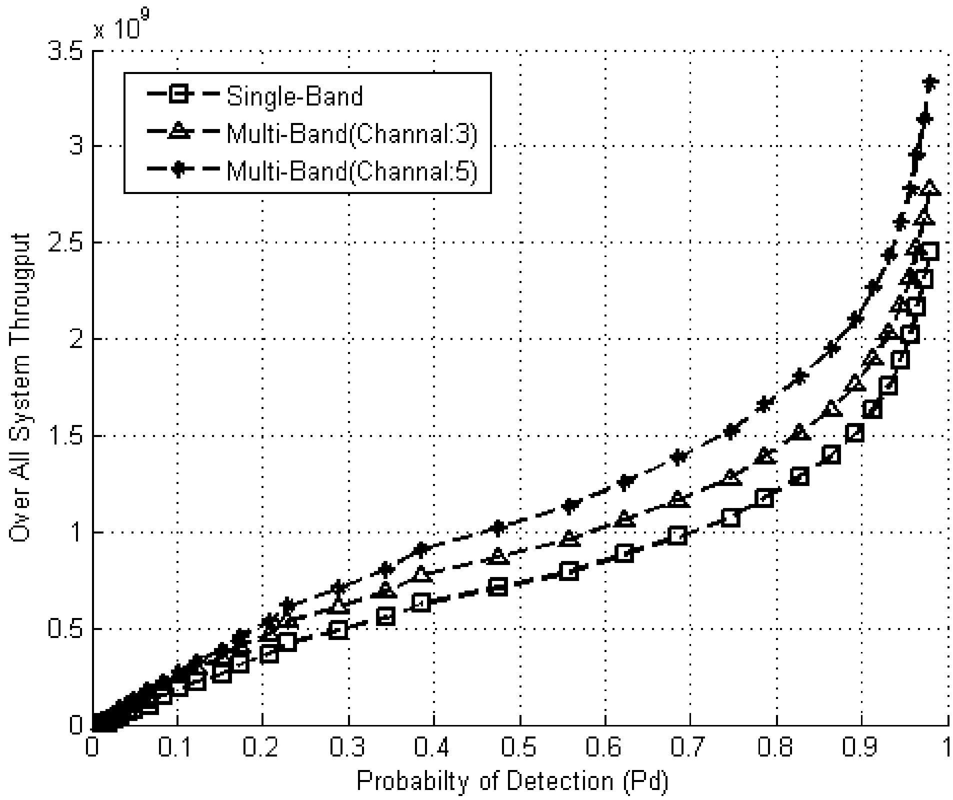

Figure 4.2: Overall System Throughput vs Detection Probability

4.2.3. PU Activity Verses Throughput

PU activity verses throughput is shown in Fig 4.3. Result shows that the throughput decreases when PU activity increases. When PU activity is zero its mean that primary users is absent and spectrum is free. As result secondary users uses spectrum and throughput of the system is maximum. As PU activity increases throughput of is decreases because the spectrum is utilized by primary users.

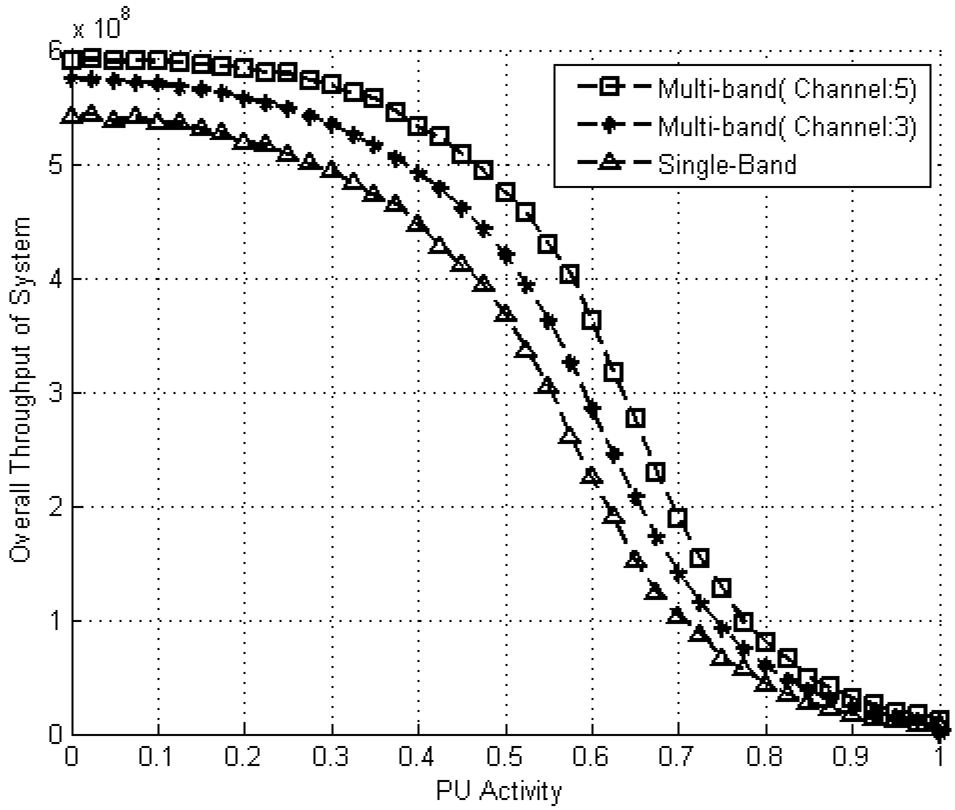

Figure 4.3: Overall System Throughput vs PU Activity

4.2.4. SNR Verses Probability of Detection (P_d)

SNR Verses probability of detection is shown in Fig 4.4. Result shows that the P_d increases as SNR are increases. From Fig 4.4, we see that our algorithm increases P_d as we sampling point increases. For example, at SNR =10, P_d increases from 47% to 87% when sampling point increases from 2 to 6.

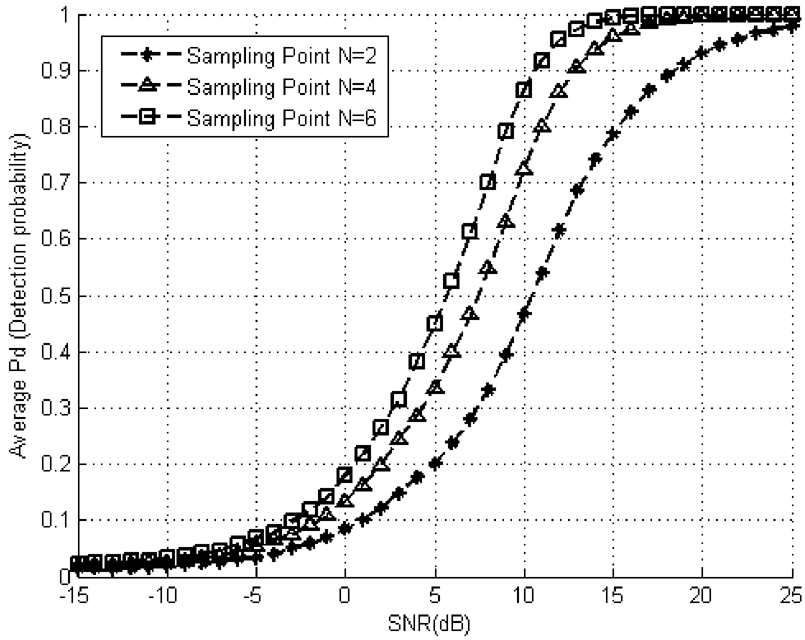

Figure 4.4: Probability of Detection vs SNR for Different Sampling Points

4.2.1. SNR Verses Probability of Collision (P_c)

Fig 4.5 and Fig 4.6 shows that probability of collision between the PUs and SUs across different value of SNR. Fig 4.5 shows that the P_c between PU and SUs decreases as SNR increases. Also our algorithm improves P_c when number of channel increases. For example, at $\text{SNR} = 10$, P_c decreases from 53% to 40 as number of channels increases from 3 to 10.

Also from Fig 4.6, the P_c decreases as sampling point increases. For example, at $\text{SNR} = 10$, P_c decreases from 55% to 13% as sampling point increases.

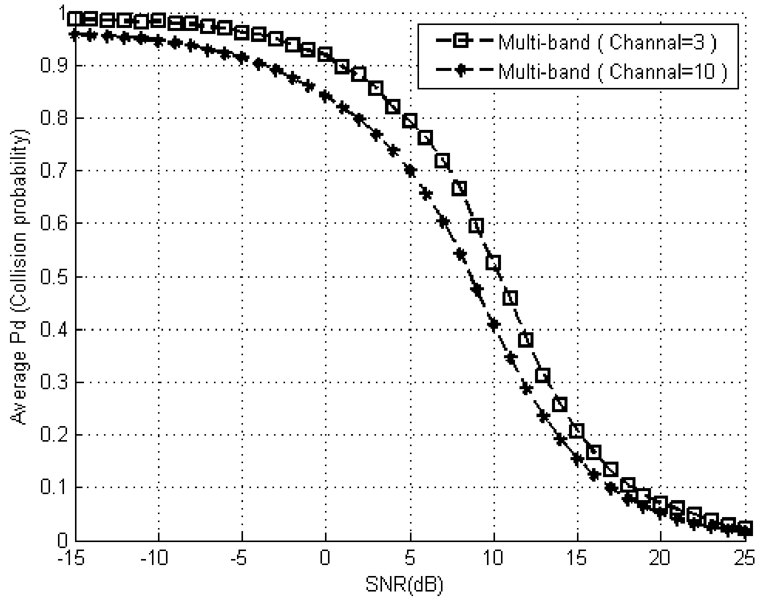

Figure 4.5: Probability of Collision vs SNR for Different Channel

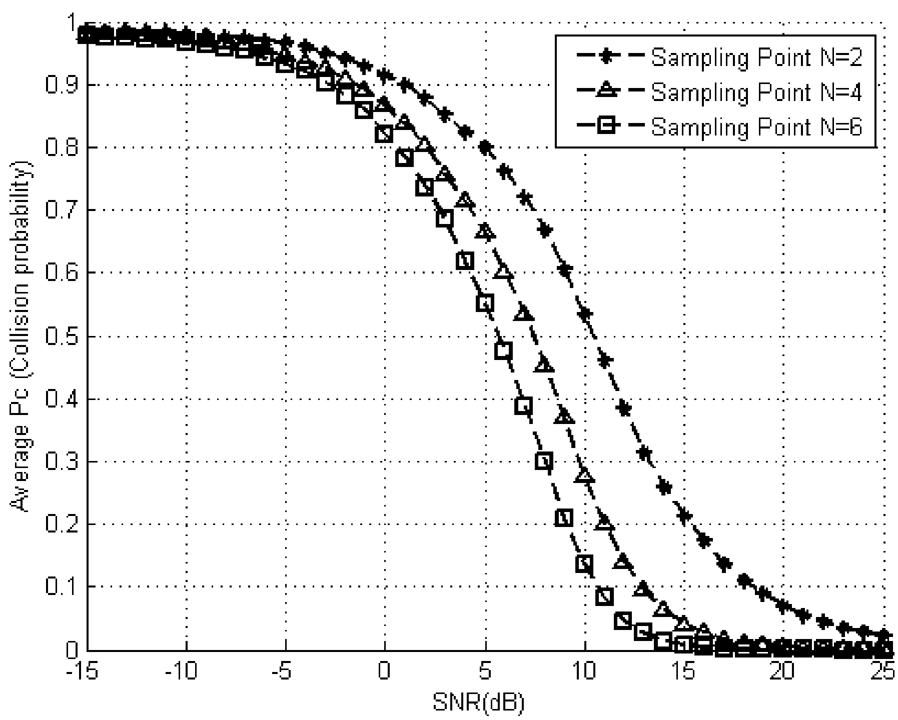

Figure 4.6: Probability of Collision vs SNR for Different Sampling Points

4.1. Single Threshold Verses Double Threshold

4.1.1. Probability of Collision Verses Lamda (λ)

Collision probability between the PU and SUs across different lamda values is shown in the Fig 4.7. The results show that the P_c decreases for double threshold energy detection. For example, at λ =20, R3; P_c for single threshold energy detection is 60% which is decreased to 43% for double threshold energy detection

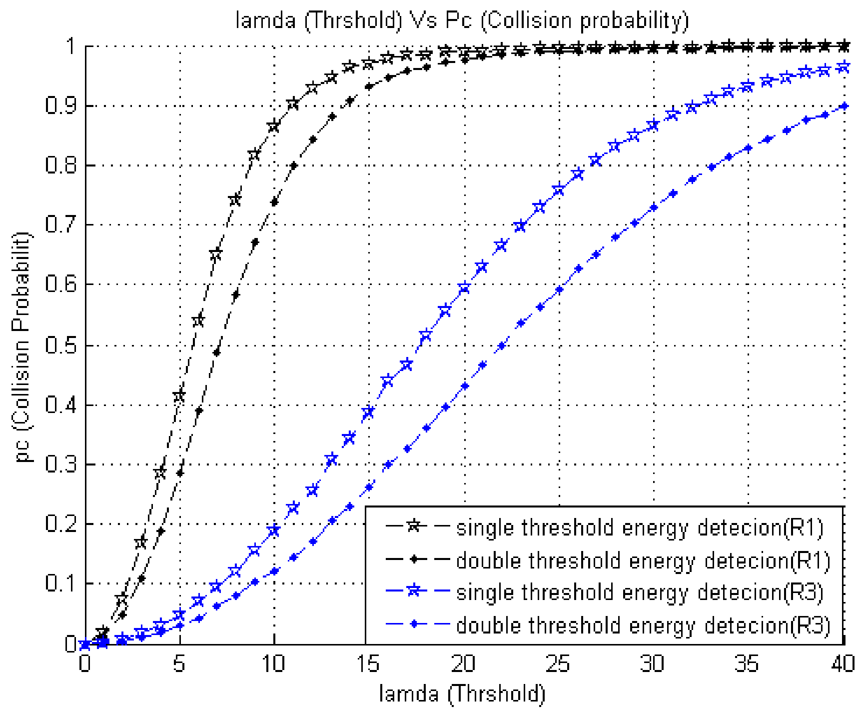

Figure 4.7: Probability of Collision (Pc) vs Threshold (λ)

Chapter 5

Conclusions and Future Work

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

5.1. Conclusions

In this thesis, we proposed a navel multiband spectrum sensing due to which sudden reappearances of PU shall not interfere with the SU transmission as the secondary user will be able to seamlessly handoff from one channel to another. Furthermore, diversity combining technique is incorporated at the cognitive centre to improve the detection performance of the energy detection algorithm and double threshold energy spectrum sensing to reduce the collision probability between PU & SU. For reliability enhancement, we use different number of relays for cognitive centre. Simulation results show that the overall system throughput increases for our proposed scheme as compared to single-band spectrum sensing. Also detection probability and collision probability improved for our proposed multi-band spectrum sensing. Also our proposed algorithm increase overall system throughput as probability of detection increases. The system throughput is maximum when primary user activity is zero and vice versa.

Simulation results also demonstrate 13% & 40% reduction in collision probability when increased number of channels and sampling point respectively. Multi-band spectrum sensing also increase 40% detection probability as we increase number of sampling point. At the end, double threshold and single threshold energy detection compression shows that the collision between PU and SUs are reduced 17% as compared to single threshold energy detection algorithm.

5.2. Future Works

In this thesis, we use serial energy multi-band spectrum sensing technique and SLC diversity technique at receiver to add all the signals coming from all direction and in future we will study other different multi-band spectrum sensing techniques as well as different combining techniques at cognitive centre.

In future, we will also work on following areas for this system:

- Implement multiband cognitive cooperative in heterogeneous network
- Implementation of Double threshold energy detection on OFDMA-based multi-user multiband cognitive-cooperative network.

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