CROSS-LAYER DESIGN AND IMPLEMENTATION OF COGNITVE RADIO SYSTEM

NAME OF AUTHORS:

IBRAHIM BIN MOHIUDDIN 16141026

NAWSHIN ANIS 12110015

SARAFWAMIA AHMED 12110030

ZAKI ANAN 16141027

UNDER THE SUPERVISON OF:

DR. MD. MUHIDUL ISLAM KHAN

Department of Computer Science & Engineering

School of Engineering & Computer Science

BRAC University

DECLARATION

We, hereby declare that this thesis is based on the results found by ourselves. Materials of work found by other researcher are mentioned by reference. This Thesis, neither in whole or in part, has been previously submitted for any degree.

Signature of Supervisor

Dr. Md. Muhidul Islam khan

Signature of Author

Ibrahim Bin Mohiuddin

Nawshin Anis

SarafWamia Ahmed

Zaki Anan

ABSTRACT

Demand of ever-present wireless services requires the use of more spectrum resources. However, present wireless networks are segmented by a fixed spectrum allocation policy. This fixed allocation of spectrum has lead to unused or underutilized bandwidth (namely spectrum holes) where opportunistic spectrum sharing increased its efficiency.

To address this problem, cognitive radio is being uplifted as an emerging solution which uses intelligent technology to autonomously adapt in operating parameters in dynamic conditions. This paper starts with the illustrations of cognitive radio and classifications of spectrum sensing techniques which are then simulated by providing manual parameters through an algorithm in MATLAB. The simulation consist a set of dummy primary users who are set with specific bandwidth and using energy detection technique those spectrum bands are allocated dynamically to a set of secondary users during the idle period of the primary users. Lastly, a signal to noise ratio (SNR) manipulation has been implemented to observe how spectrum sensing is affected which in turn aided to understand spectrum allocation.

ACKNOWLEDGEMENT

This thesis was suggested by Professor Dr. Md. Muhidul Islam Khan, Chairperson, Department of Computer Science and Engineering, BRAC University. This is the work of Ibrahim Bin Mohiuddin, Nawshin Anis, SarafWamia Ahmed and Zaki Anan, students of BRAC University, studying Computer Science and Electrical and Electronic Engineering of Program Electronic and Communication Engineering from the year 2012. The document has been prepared as an effort to compile the knowledge obtained by us during these four years of education and produce a final thesis which innovatively addresses one of the issues of research in computer networking.

We also want to acknowledge Dr. Amitabha Chakrabarty, Assistant Professor, Department of Computer Science and Engineering, BRAC University, Dr. Tarem Ahmed, Assistant Professor, Department of Electrical and Electronics Engineering, BRAC University and our peer Ekramul Hoque who have consistently shown their interests in our work and assisted us in preparing the report.

TABLE OF CONTENTS

1 Chapter 1: INTRODUCTION	04
1.1 MOTIVATION	04
1.2 THESIS LAYOUT	04
2 Chapter 2: RELATED WORKS	05
3 Chapter 3: WIRELESS COMMUNICATION	06
3.1. A BRIEF HISTORY OF WIRELESS COMMUNICATION	06
3.2. CROSS-LAYER DESIGN	07
3.2.1. WIRELESS COMMUNICATION & CROSS-LAYER DESIGN	08
3.2.2. CROSS-LAYER DESIGN FOR COGNITIVE RADIO NETWORK	08
3.3. COGNITIVE RADIO	10
3.3.1. COGNITIVE CYCLE	11
4 Chapter 4: SPECTRUM SENSING	13
4.1. SPECTRUM SENSING FOR SPECTRUM REUSE13	13
4.2. SPECTRUM SENSING METHODS	15
4.2.1 TRANSMITTER DETECTION (Non-cooperative Detection)	16
4.2.1.1. MATCHED FILTER DETECTION	17
4.2.1.2. ENERGY DETECTION	18
4.2.1.3. CYCLOSTATIONARY FEATURE DETECTION	20
4.2.2. RECEIVER DETECTION (Cooperative Detection)	20
4.2.3. INTERFERENCE BASED DETECTION	21
5 Chapter 5: ENERGY DETECTION ALGORITHM	22
5.1. CODE OF PROBABLITY AND FALSE ALARM	23
5.2. SIMULATION OF COGNITIVE RADIO	24
5.3. RESULT	28
6. Chapter 6: CONCLUSION	34
REFERENCES	35

CHAPTER 1

INTRODUCTION

1.1. MOTIVATION:

In order to make the spectrum sharing more efficient the technology of spectrum reuse was carried out by Cognitive Radio. Spectrum sensing is the primary action taken by a Cognitive Radio which senses the spectrum holes to identify unused or underutilized spectrums. The process then holds the radio communication to manage the bandwidths dynamically. Thus the primary objective of this paper is to illustrate the classifications of spectrum sensing techniques focusing on energy detection technique and deducing lightweight algorithms to implement this technique.

1.2. THESIS LAYOUT:

The rest of this paper is organized as follows.

Chapter 2 discusses related work. Chapter 3 is on Wireless Communication where history of wireless communication, cross-layer design and cognitive radio (CR) has been discussed. Chapter 4 talks about spectrum reuse and classification of spectrum sensing. Lastly in chapter 5, we showed simulation of cognitive radio system at energy detection method with probability of detection and false alarm. Chapter 6 concludes this paper with a summary.

CHAPTER 2

RELATED WORKS

Growth of wireless users has turned the system of spectrum allocation a challenge. However, according to Federal Communication Commission (FCC) measurements a majority of the licensed frequency bands are unused or utilized less than 10%. The FCC has therefore encouraged the use of these licensed frequency bands to unlicensed wireless users for opportunistic spectrum sharing [1]. Thus, the technology of Cognitive radio was introduced. Before the introduction of CR spectrum division had caused waste of certain bandwidth as frequency was allocated in a fixed domain to all the wireless users. These unused or unutilized bandwidth are known as spectrum holes. Due to these spectrum holes unlicensed wireless users were deprived of bandwidth for communication.

This paper emphasizes on energy detection technique of spectrum sensing among the described techniques. The techniques include matched filter detection, Cyclostationary Feature Detection under the classification of transmitter based detection. Receiver Detection (Cooperative Detection) and interference based detection are two other classifications. We also discussed algorithm and showed simulations of a CR network and energy detection, specifying probability of detection and probability of false alarm.

CHAPTER 3

WIRELESS COMMUNICATION

3.1. A BRIEF HISTORY OF WIRELESS COMMUNICATION:

Wireless communication is the most important and widely used and researched topic of today's communication field. While electronic and electric media for communication has been a top research subject since early 1800s, the first demonstration of telegraphy was shown by Joseph Henry and Samuel F.B. Forse in 1832 after the discovery of electromagnetism by Hans Christian Oersted and Andre-Marie Ampere in early 1820's. US built telegraph networks on its East Coast and California in 1840's [2].

Maxwell predicted the existence of electromagnetic wave and postulated wireless propagation in 1867 which was proved by Heinrich Hertz in 1887. That was the first time a spark transmitter generated a spark in a receiver a several meters away. Within a few years, Branly developed coherer for detecting radio waves. Marcov and Popov started experimenting on radio-telegraph thereafter and Marconi demonstrated wireless telegraph to the English telegraph office on 1896. He patented complete wireless systems in his name the next year [3][2].

Wireless communication became the real phenomenon in 1900s. In 1901, Marconi successfully transmitted the radio signal across the Atlantic Ocean from Cornwall to Newfoundland. The next year, transmission of first bidirectional communication was established. The following year, Marconi was awarded the Nobel Prize in Physics.

J.A. Fleming and Lee DeForest patented diode and triode in their name in 1904 and 1906 respectively. The first commercial trans-Atlantic Wireless service using 30*100 m antenna masts was possible in 1907 and then there came the real wireless network era and beginning of the end of cable-based telegraphy. In 1915, voice was sent to San Francisco from New York without any wire. Five years later, Marconi discovered short wave radio which brought a new dimension [4].

In early 1920s, radio broadcast took place in commercial basis and radios were installed in police station and car. Before World war 2 use of radio got quite well expanded and during that time radio technology got developed rapidly. In 1949, FCC recognized mobile radio as a new class of service and after that mobile user got higher and higher day by day. In 1960s mobile telephone service was introduced and supported full-duplex, auto dial and auto trunking. Japan deployed the first cellular communication system in 1979 and advanced mobile phone system was deployed in 900 MHz band after a while [4].

US Digital phone system was introduced in early 1990s and IS-95 code-division multiple access (CDMA) spread- spectrum digital cellular system. Global System for Mobile Communication System (GSM) was deployed in 1994. 2000 was the year for third generation cellular system standards.

In 1998 and 1999 the concept of cognitive radio was proposed by Joseph Mitola 111 in a seminar at KTH and published an article accordingly. It was one of the most novel approaches towards wireless communication. Cognitive radio is considered as an objective towards which a product characterized radio stage ought to advance: a completely reconfigurable remote handset which consequently adjusts its correspondence parameters to network and client requests. After the beginning of cognitive radio era there has been lot of works on improving and increasing the efficiency and intelligence of the system and IEEE is working relentlessly to make it better and better. The goal is to making the system intelligent enough so that the spectrum can be optimized or fully used [2].

3.2. CROSS-LAYER DESIGN:

Cross-layer design is a break from the OSI model where interchanges between layers are strictly limited. The cross layer methodology transports feedbacks and data progressively by means of the layer limits to foster efficiency for e.g. traffic or other limitations of necessities and resources by any control data to another layer yet that layer specifically influenced by the distinguished insufficiency.

In the first OSI model, strict limits between layers are implemented, where information are kept entirely inside of a given layer. Cross layer streamlining uproots such strict limits to permit communication between layers by allowing one layer to get to the information of another layer to trade data and stronger connection. For instance, knowing about the current physical state will offer channel allocation scheme or automatic repeat request (ARQ) technique at the MAC layer in enhancing tradeoffs and accomplishing throughput expansion [7][8].

3.2.1. WIRELESS NETWORK & CROSS-LAYER DESIGN:

There are a number of limits of wireless network following the OSI model that restricts communication between layers. Such as - rapid variation in channel, time varying fading, co-channel interference, vicious traffic, mobility, dynamic topology.

Cross layer design allows to pass more information by blurring, transferring and interchanging data and boundaries. As cross-layer design directly does the coupling between physical layer and upper protocol layers it can respond to channel selection and channel variation. Moreover, cross-layer helps OSI model to deal with complexity and scalability. Moreover there are different approach and architecture for wireless networks as well. It allows information to flow upward or downward, coupling layers and even merging them [5][6].

3.2.2. CROSS-LAYER DESIGN FOR COGNITIVE RADIO NETWORK:

Cognitive radio is profoundly agile wireless platform able to do independently picking parameters in light of winning impedance conditions. Adding to that, cognitive network is a network that follows a procedure that can see the present system condition, and after that arrangement, choose and follow up on those conditions. The system can gain from these adjustments and use them to make future choices, all while considering the end-to-deciding objectives.

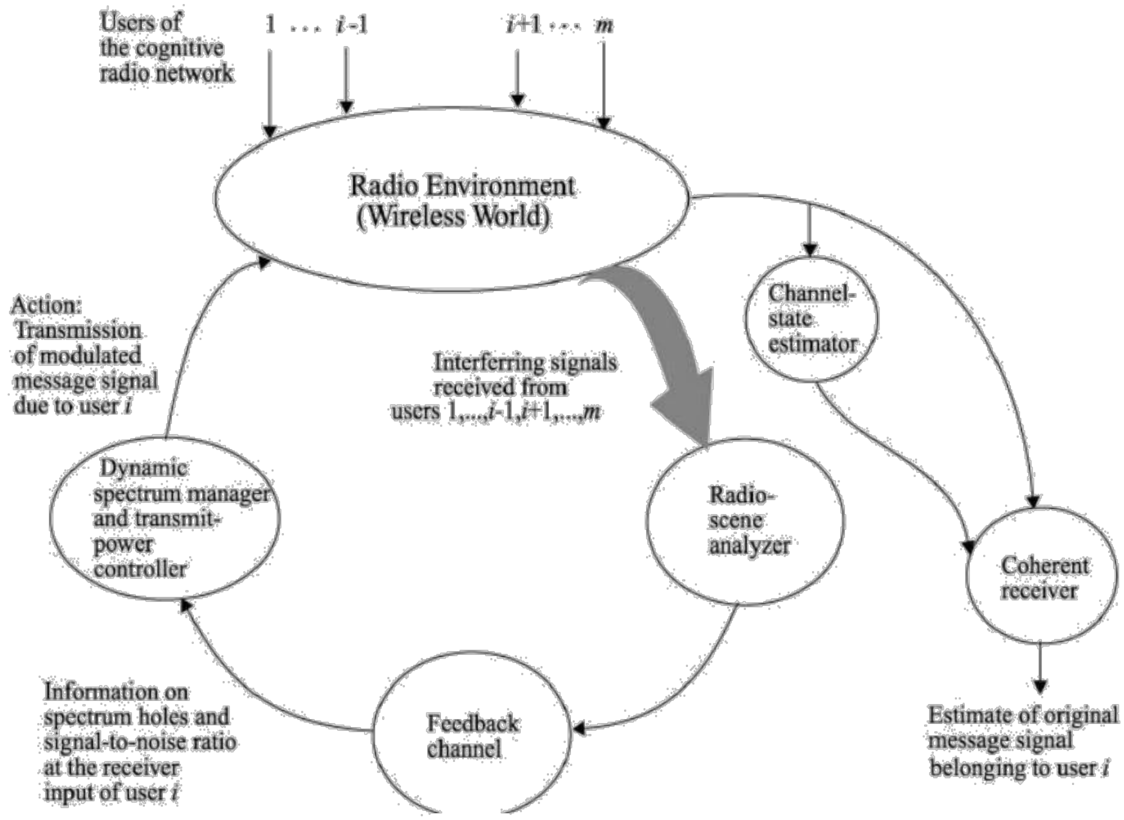

Figure 1: Cognitive Radio process [7]

As a cognitive engine senses and acknowledges the situation in the network, it works on that basis with simultaneous optimization of multiple parameters and merging OSI model layers. This optimization is done according to the condition of internal operating parameter across the layers of wireless device to meet the demand and increase efficiency with least resource [7][8] .

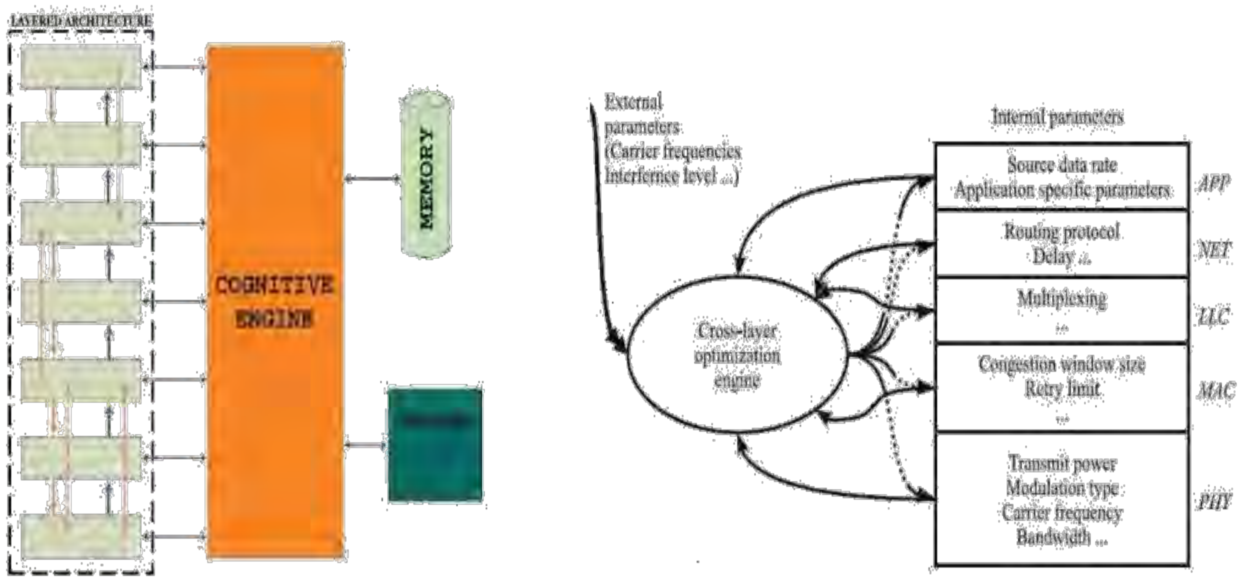

Figure 2: Cross Layer Design in Cognitive Radio Engine

3.3. COGNITVE RADIO:

This chapter emphasizes on the definition of a cognitive radio. The word “cognitive” implies self-learning. As a header, it can be said that cognitive radios have a combination of idea on the declarative and procedural overview of a self-aware system [9].

Self awareness defines that the cognitive radio should have knowledge about basic facts about radio and with the help of that knowledge it should be able to communicate with other elements. Therefore a radio uses RKRL (Radio Knowledge Representation Language) to undergo these tasks. The radio hardware contains modem, INFOSEC module, baseband protocol processor and user interface whereas the radio software contains SDR[9].SDR is a software defined radio system where components that were previously enacted in hardware are instead enacted with the help of software on a personal computer or embedded system. As a result, an SDR system can create a radio which can both transmit and receive variety of radio protocols which is completely dependent on the software being used.The radio uses RKRL frames to do interfacing of reasoning capability and software of cognitive radio and resolve the radio control problems [9].

3.3.1. COGNITIVE CYCLE:

The cognition cycle is described in a simpler form through the following figure:

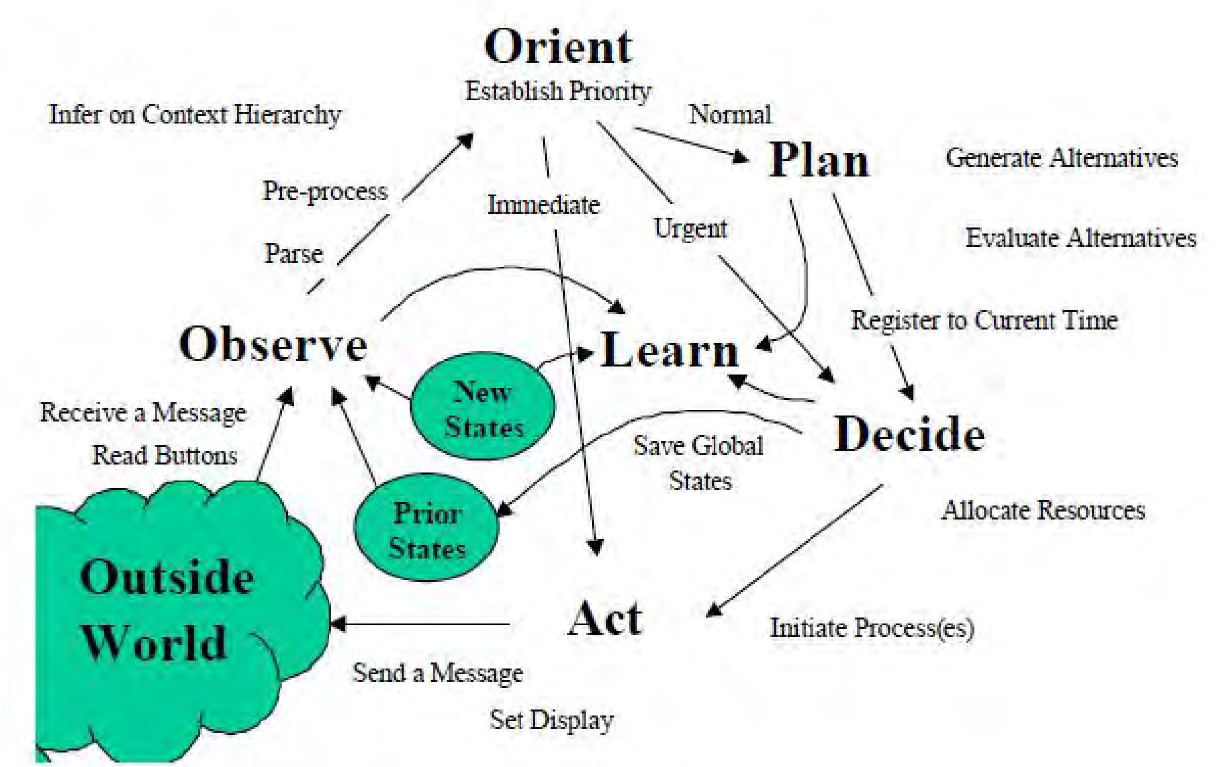

Figure 3: Simplified Cognition Cycle [9]

Any change in the environment as detected stimulus may enter the cognitive radio and further give a corresponding result as a response. The simple cycle being of the following actions: observation, orientation, planning, decision making and then action(s). These phases also require machine learning which is complex to compute, thus cognitive radio has “sleep and prayer epochs”.

During a sleep epoch the radio is not in use rather it processes machine learning algorithms. Any stimulus while the cognitive radio is in the wake cycle on any of the sensors starts a new primary cognitive cycle. The cognitive radio starts parsing any incoming information streams including RF-LAN or other short-range wireless broadcasts, weather channel, stock ticker tapes e.t.c. In this observation phase it also accumulates information on location, temperature, and light level sensors, etc. to gain knowledge of the user's communications context. The orientation step is based on priority of the stimulus. The path level "Urgent" accomplishes a reallocation of resources. For example: parsing of input to searching alternate RF channels, though normally incoming network message would generate a "plan" ("Normal" path). The next step generally plans whether to send it to the "Learning" or "decide" phase. The "Decide" phase makes a selection process among the candidate plans. The radio screens to make a choice and then alerts the user to an incoming message like a pager or to defer the interruption later. "Acting" uses effectors modules to initiate the selected process. Learning functions to observe and plan [9].

CHAPTER 4

SPECTRUM SENSING

4.1. SPECTRUM SENSING FOR SPECTRUM REUSE:

The technology used in spectrum reuse is cognitive radio which consists of three essential components.

(a) Spectrum Sensing.

(b) Dynamic spectrum management.

(c) Adaptive communications.

Cognitive Radio was identified as a useful candidate for opportunistic spectrum sharing by a Notice of Proposed Rule Making issued by FCC in December 2003 [10].

(a)Spectrum Sensing: Secondary users have to sense and monitor the radio spectrum environment to search for frequency bands which are not used by the primary user [10]. The unused frequency bands are known as spectrum holes, whose usage are temporally enabled by the CR. Spectrum holes can be categorized into temporal Spectrum holes and spatial spectrum holes.

Temporal Spectrum holes: During the time of sensing the bands are unoccupied by PUs. Thus in the current time slot this band can be used by the SUs. This does not require complex signal processing.

Spatial spectrum holes: This band of the spectrum is unoccupied by the PUs at some spatial areas. Thus, SUs can occupy this as well as outside of these areas. This requires complex signal processing algorithms unlike temporal spectrum sensing [11].

Spectrum holes can be classified into three types in terms of power spectra of incoming RF:

1. **Black spaces:** these are dominated by high-power "local" interferences at some time.
2. **Grey spaces:** these are partially dominated by low-power interferences.
3. **White spaces:** except for white Gaussian noise these are free of RF interferences.

(a) **Black spaces and white spaces:** It can be used by unlicensed users when accurate sensing techniques are used. However, black spaces can not be used since it will cause interference with PUs.

The CR moves to another spectrum hole if the band is used more by a PU as shown by figure below.

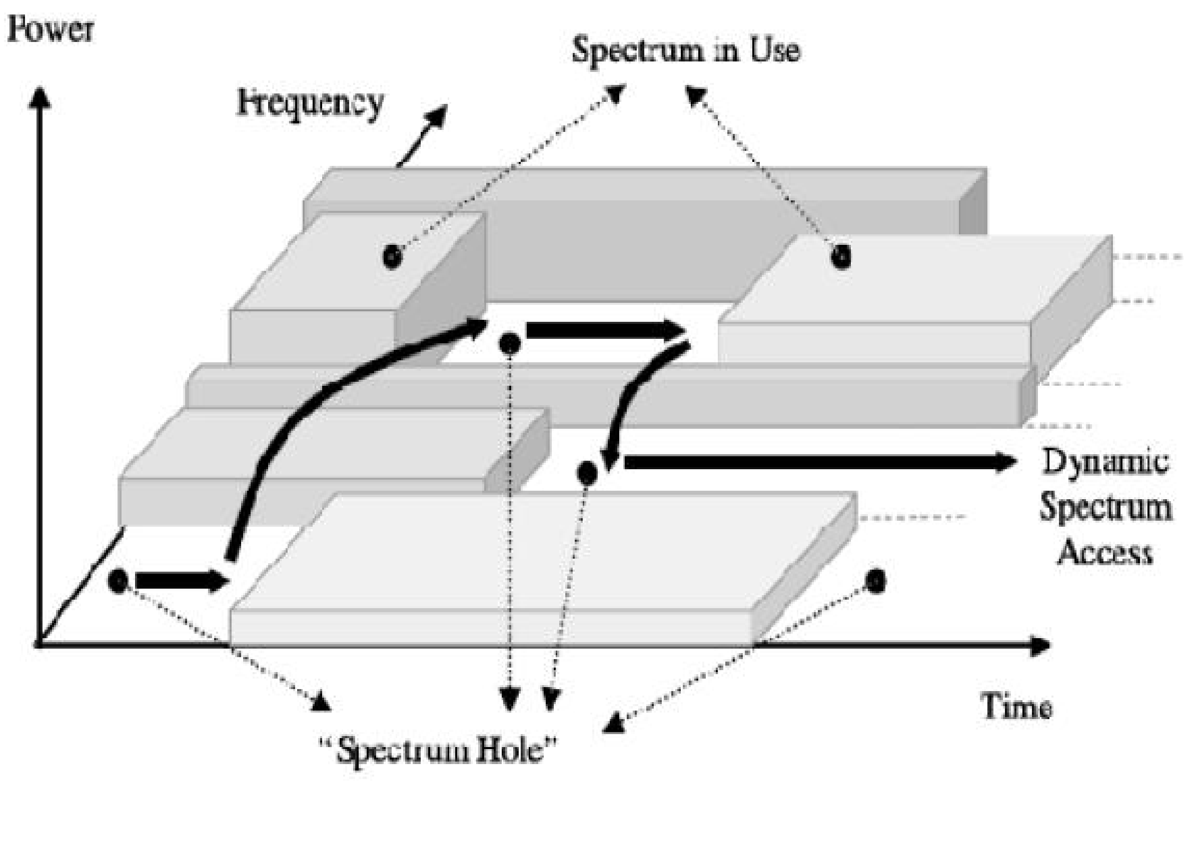

Figure 4: Spectrum Holes [11]

(b) Dynamic spectrum management: The best among the available bands are dynamically selected by the CR for communications [10].

(c) Adaptive communications: Opportunistic and best use of the ever-changing spectrum is made by the CR by configuring its transmission parameters (carrier frequency, bandwidth, transmission power, etc) [10]. Spectrum mobility is also required to move these spectrum bands when the PU has control of a certain band [12].

4.2. SPECTRUM SENSING METHODS:

Spectrum sensing, the most important aspect of CRs enables it to detect the availability of wideband spectrum in real-time. It also determines spectrum characteristics across space, time, frequency and code, which includes acquiring the signal waveform, modulation, bandwidth and carrier frequency

The multidimensional sensing opportunities of a cognitive radio are as follows:

(1) Frequency: division of the available frequency bands into smaller bands for the SUs for opportunistic usage.

(2) Time: availability of frequency band at a certain time.

(3) Geographical area: availability of frequency band in certain geographical area.

(4) Code: based on various coding schemes it is the availability of non-intrusive simultaneous transmission [12].

The classification of spectrum detection techniques are shown in Figure:

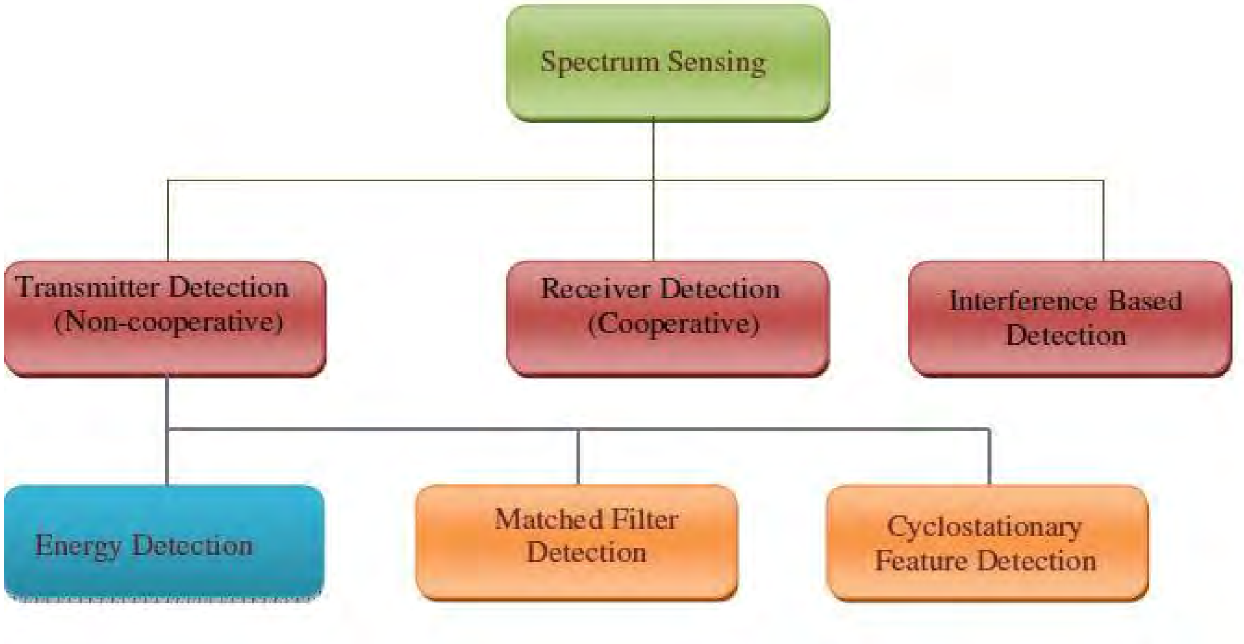

Figure 5: Spectrum Sensing Classification [11]

4.2.1 TRANSMITTER DETECTION (Non-cooperative Detection):

The presence or absence of the PU in a specified spectrum must be independently detected by the CR. A model is described by [10], the signal detected by the SU is:

Ho:y(t)= w(t)

H1: y(t)= w(t) +h.x(t)

Where the hypothesis Ho corresponds to "no signal transmitted"; H1 corresponds to "signal Transmitted"; y(t) is received signal; x(t) is transmitted signal; w(t) is an Additive White Gaussian Noise (AWGN) with zero mean and variance n2, and h amplitude of chan (Channel coefficient).

Such proposed methods include matched filter detection, energy detection, and cyclostationary feature detection [11].

4.2.1.1. MATCHED FILTER DETECTION:

Matched-filtering sensing acts as an excellent detector when the receiver is completely aware of the primary transmitted signal. The receiver correlates the received signal to a complex, conjugate, time-reversed version of itself and maximizes the SNR and compares between the final output of matched filter and predetermined threshold. In order to do so the receiver should have complete insight of the bandwidth, operating frequency, modulation type, pulse shaping and frame format. Therefore, the performance of the matched filter deteriorates when the information about the transmitted signal is not accurate. When the receiver has complete and accurate knowledge then this method performs efficiently and is able to find out the probability of detection in the shortest possible time [11].

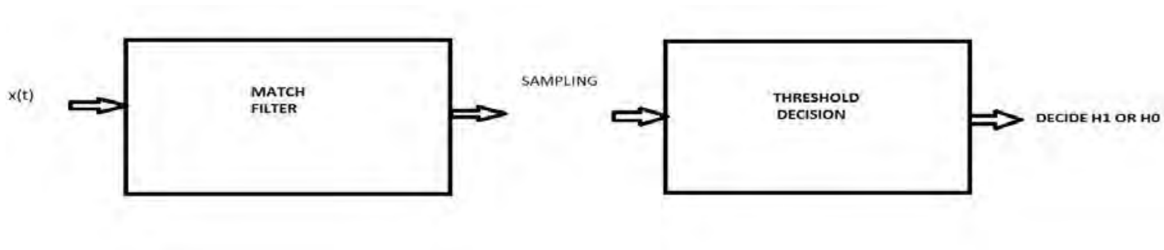

Figure 6: Matched Filter Detection

The advantage of matched filtering is that it requires a very short time to attain a certain probability of false alarm or probability of missed detection. The matched filter required less time to achieve high processing gain due to coherency. However, the disadvantage of matched filtering is that it requires perfect knowledge of the primary user which is typically not possible and so it restricts the robustness of matched-filtering sensing [13]. Another disadvantage of this technique is that it consumes large amount of power since it is a very complex technique [14].

The figure below shows the probability of detection for various SNR values and probability of false alarms.

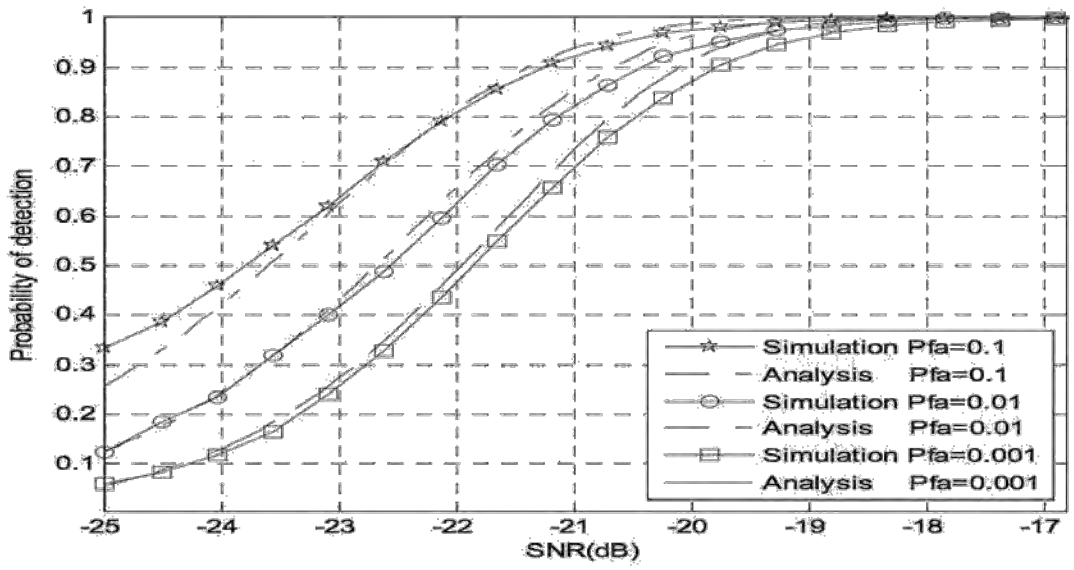

Figure 7: Probability of detection for various SNR values and probability of false alarms [11]

Based on the figure we can say that matched-filter detection performs well at low SNRs as well as providing low probability of false alarms [12].

4.2.1.2. ENERGY DETECTION:

The main purpose of spectrum sensing is to efficiently detect the radio users without much complexity and false alarms in the shortest possible time. Various spectrum sensing techniques include energy based sensing, cyclostationary feature-based sensing, matched filter-based sensing and other sensing techniques. Different techniques have different approaches based on their advantages and disadvantages. In this paper we are mainly going to focus on energy-based spectrum sensing. The energy based spectrum sensing technique detects the primary users very efficiently and this process can be used effective with analog and digital signals which is at the RF/IF stage or at the baseband. In order to detect a radio signal we consider the following assumptions and conclusions:

r(t)=v(t); under H0

r(t)=hs(t)+v(t); under H1……………..(1)

Here r(t) is the complex baseband of the detected radio signal, s(t) is the received primary user signal, v(t) is the additive band limited Gaussian noise is the channel component with amplitude and phase shift (h=0).Therefore, an energy detector cannot differentiate between the detected radio signal and the noise signal when the signal-to-noise ratio is very low. The energy detector produces the most favorable outcome when s(t) is zero mean complex Gaussian.

The energy detectors calculate the energy metric of a detected signal over a certain time period T over N samples, where T=NTs and Ts is the signal sampling period.

From the equation (1),the energy detector is defined by

$$\xi = \int_{t0}^{t0+T} r(t)\widehat{r}(t)\, dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Here,r(t)is the complex conjugate of r(t) and t0 is an arbitrary starting time.[13]

Then,the signal-to-noise ratio is defined by

$$\rho = (\alpha^2) \div (\sigma^2[t2 - t1]) \int_{t1}^{t2} s(t)\widehat{s}(t)dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

It is assumed that the detected signal, s(t) is present within the time t1<tt2

Considering discrete signal r[n]=r[nTs],the energy detection is defined by

$$\xi = Ts \sum_{n=0}^{N-1} r[n]\widehat{r}[n] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Here. N is the ‘total number of samples. Since T is the total sensing time, the time bandwidth product is TBw= NTsfs = NTs(1/Ts)=N.

There are N number of real component samples and N number of imaginary component samples and therefore a total of 2N samples. The detection principle can be defined as:

d={0; $\xi < \lambda$

d={1; $\xi \geq \lambda$

Here, defines the threshold.

4.2.1.3. CYCLOSTATIONARY FEATURE DETECTION:

Cyclostationary feature detection is a method used to detect primary user transmissions by using the cyclostationary features of the received signals [11]. Modulated signals are coupled with sine wave carriers, pulse trains, repeating spreading, hoping sequences or cyclic prefixes which result in built-in periodicity. These modulated signals are referred to as cyclostationary since their statistics, mean and autocorrelation display periodicity [10]. Moreover, cyclostationary detector can differentiate the modulated signal from the additive noise. Instead of power spectral density (PSD), cyclic detection is used to detect the signals which are present in a given spectrum [11]. PSD is real-valued one dimensional transform whereas, spectral correlation function (also known as cyclic spectrum) is two dimensional transform [10]. Cyclostationary based sensing exploits the cyclostationary features of the received signal by using the cyclic correlation function to detect primary users' signals. The correlation function gives peak values when the cyclic frequency is equal to the transmitted signal's fundamental frequency [12]. Cyclic frequencies can be considered to be known or it can be obtained to be used as features for determining the transmitted signals [11]. The disadvantage of this method is that it needs to work with all the frequencies in order to develop the spectral correlation function which ends up being very lengthy and complicated calculations. However, cyclostationary can be intentionally included to the transmitted signal so that the spectrum sensing can be improved [11].

4.2.2. RECEIVER DETECTION (Cooperative Detection):

Cooperative sensing occurs for a group or network of CRs where they share the sensing information they attain for PU. Eventually this results in a more accurate spectrum sensing over the cognitive radio location. Cooperative sensing has an improving performance especially in the fading shadowing and noise uncertainty. In the figure 8 we can see multipath blurring, shadowing and recipient's instability. As appeared in the figure, CR1 and CR2 are inside the transmission range of the PU transmitter (PU TX) but CR3 is outside the range of PU transmitter. Because of different weakened duplicates of the PU signal and the obstruction by a house, CR2 experience multipath and shadow blurring such that the PU's signal may not be recognized properly . In addition, CR3 experiences the beneficiary instability issue since it is ignorant of the PU's transmission and the presence of the essential beneficiary (PURX). Therefore, the transmission from CR3 may meddle with the gathering at PU RX. On the off chance that CR clients, the greater part of which watch a solid PU signal like CR1 in the figure, can collaborate and share the detecting results with different clients, the joined agreeable choice got from the spatially gathered perceptions can conquer the inadequacy of individual perceptions at each CR client.

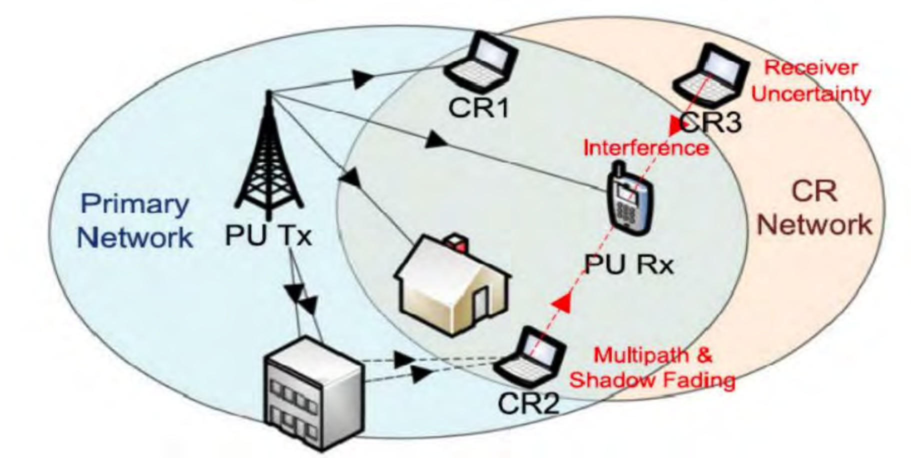

Figure 8: Receiver Detection [11]

4.2.3. INTERFERENCE BASED DETECTION:

Two signals are considered (signal ‘A’ and signal ‘B’) and the process is based on the assumption that if signal A interferes with signal B then signal B will be within the communication range of signal A. Therefore the signal can be detected by examining the interference with the detector’s signal [11].

CHAPTER 5

ENERGY DETECTION ALGORITHM

This code is to plot receiver operating characteristic curve for simple energy detection, when the primary signal is real Gaussian signal and noise is additive white real Gaussian. Here, the threshold is available analytically.

In this code first of all we took a variable "L" with value 1000 which is primary signal also known as real Gaussian signal. "snr_dB" is Signal noise ratio in decibels. To convert it from decibel simple signal noise ratio we used "snr" which is equal to 10^ (snrDB/10) as SNR (db) = 35 = 10 log (SNR).

Probability of false alarm is Pf.

To minimize the risk we did 1000 Monte Carlo simulations (Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values—a probability distribution—for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions.)

Noise "n" is random value between 1 and L with mean 0 and variance 1. Main signal is square root of main signal multiplied by random noise value. Then we add primary user signal "s" and noise "n" which is the strength of the signal which received at SU*. Energy of received signal over N samples is square of absolute value of received signal "y". "energy fin" test statistics for the energy detection by summing up different value of energy from different values. We used theoretical value of threshold, refer, Sensing Throughput Tradeoff in Cognitive Radio, Y. C. Liang [10]. Then we checked whether the received energy is greater than threshold, if so, increment Pd (Probability of detection) counter by 1.

5.1. CODE OF PROBABILITY OF DETECTION & FALSE ALARM:

```
clc
close all
clear all
L = 1000;
snr_dB = -10; % SNR in decibels
snr = 10.^(snr_dB./10); % Linear Value of SNR
Pf = 0.01:0.01:1; % Pf = Probability of False
Alarm for m = 1:length(Pf)
m
i = 0;
for kk=1:10000
n = randn(1,L);
 s = sqrt(snr).*randn(1,L);
y = s + n;
energy = abs(y).^2;
energy_fin =(1/L).*sum(energy);
thresh(m) = (qfuncinv(Pf(m))./sqrt(L))+ 1;
if(energy_fin >= thresh(m))
i = i+1;
end
end
Pd(m) = i/kk;
end
plot(Pf, Pd)
```

```
hold on

thresh = (qfuncinv(Pf)./sqrt(L))+ 1;

Pd_the = qfunc(((thresh - (snr + 1)).*sqrt(L))./(sqrt(2).*(snr + 1)));

plot(Pf, Pd_the, 'r')

hold on
```

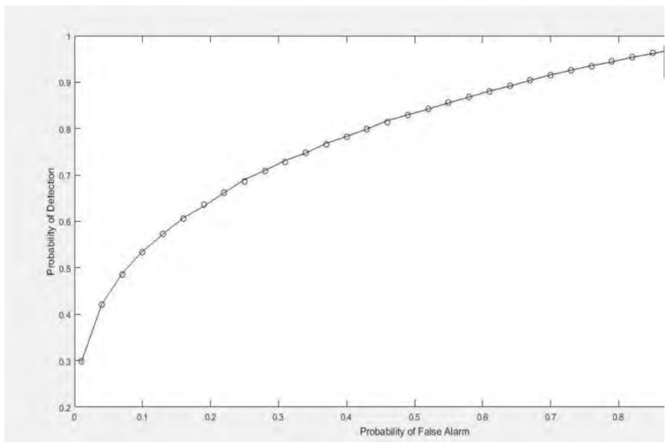

Figure 9: Probability of False Alarm vs Probability of Detection

5.2. SIMULATION OF COGNITIVE RADIO SYSTEM:

We have taken 5 carrier frequencies Fc1 = 1000, Fc2 = 2000, Fc3 = 3000, Fc4=4000 and Fc5 = 5000 keeping the client message/information signal recurrence as 1000.

x = cos(2*pi*1000*t)//each client's base band information signal

When client 1's information arrive, it is regulated at the main transporter Fc1, correspondingly as the second client's information arrives, it is tweaked at the second bearer Fc2, so on till fifth client is allocated the Fc5 band. On the off chance that any client's information is not introduce his recurrence band stays vacant which is known as a Spectral Hole.

```
in_p = input('\nDo you want to enter first primary user Y/N: ','s');

        if(in_p == 'Y' | in_p == 'y')

        y1 = ammod(x,Fc1,Fs);
```

```
        end
in_p = input('Do you want to enter fifth primary user Y/N: ','s');
        if(in_p == 'Y' | in_p == 'y')
        y5 = ammod(x, Fc5, Fs);
        end
```

When the entire task is finished we add every one of the signs to make a transporter sign which will be broke down for unfilled openings as the channel.

```
y = y1 + y2 + y3 + y4 + y5;
```

Presently we'll appraise the power spectral density of our bearer signal utilizing the periodogram(); capacity and the qualities are put away in an array Pxx. Pxx is the appropriation of power per unit frequency. This value is then put away in a dsp information item and afterward plotted.

```
Pxx = periodogram(y);
        Hpsd = dspdata.psd(Pxx,'Fs',Fs);
        plot(Hpsd);
```

- Hs = DSPDATA.<DATAOBJECT>(...) returns a DSP data object, Hs, of type specified by DATAOBJECT. Some common data objects are
- msspectrum - Mean-square Spectrum (MSS) data object
- psd - Power Spectral Density (PSD) data object
- pseudospectrum - Pseudo Spectrum data object

We got a five focuses for all clients in the exhibit Pxx which increased by 10000 ought to be above 8000 if there's no ghostly opening. //this only a perception which is working as such, the specialized viewpoints will be tended to later in the presentation.

```
chek1 = Pxx(25).*10000;

        chek2   =   Pxx(46).*10000;

        chek3   =   Pxx(62).*10000;

        chek4   =   Pxx(89).*10000;

        chek5 = Pxx(105).*10000;
```

Now if there’s another client entering the channel, we'll check the cluster Pxx, at certain area and allocate client the main ghastly hole as coded beneath.

```
if(chek1 < 8000)

        disp('Assigned to User 1 as it was not present.');

        y1 = ammod(x1,Fc1,Fs);

        elseif (chek2 < 8000)

        disp('Assigned to User 2 as it was not present.');

        y2 = ammod(x1,Fc2,Fs);

        elseif(chek5 < 8000)

        disp('Assigned to User 5 as it was not present.');

        y5 = ammod(x1,Fc5,Fs);

        else

        disp('all user slots in use. try again later,');
```

Then we have the slot emptying algorithm which will empty the already occupied bands by asking user to choose a slot and executing the following code:

```
in_p = input('\nDo you want to empty first user’s slot Y/N: ','s');
        if(in_p == 'Y' | in_p == 'y')
        y1 = 0;
        end
in_p = input('Do you want to empty fifth user’s band Y/N: ','s');
        if(in_p == 'Y' | in_p == 'y')
        y5 = 0;
        end
y = y1 + y2 + y3 + y4 + y5;
```

And then we repeat the above plotting procedure that was done after the assignments. To add noise to our signal we have used the simpler awgn(); function.

```
noise_in = input('Do you want to add noise effect? [Y/N]:  ','s');
        if(noise_in == 'Y' | noise_in == 'y')
        figure
        Y = awgn(y,0.01);
        Pxx1 = periodogram(Y);
        Hpsd = dspdata.psd(Pxx1,'Fs',Fs);
        plot(Hpsd);
```

To weaken our sign the framework requests the rate of lessening required took after by the plot of the constricted carrier signal. The rate isolated by hundred is subtracted from 1 and the staying number is increased with the sign.

```
temp = input('Do you want to attenuate the signals? [Y/N]: ','s');
        if(temp == 'Y' | temp == 'y')
        aF = input('Enter the percentage to attenuate the signal:  ');
        figure
        tem = aF/100;
        tm = 1-tem;
        Yf = y.*tm;
  plot(Yf);
```

5.3. RESULT:

We've outlined our framework to have 5 distinctive frequency channels and every User is relegated a specific frequency band. When we run our project it'll request that include a User and relegate it a specific band in ascending order.

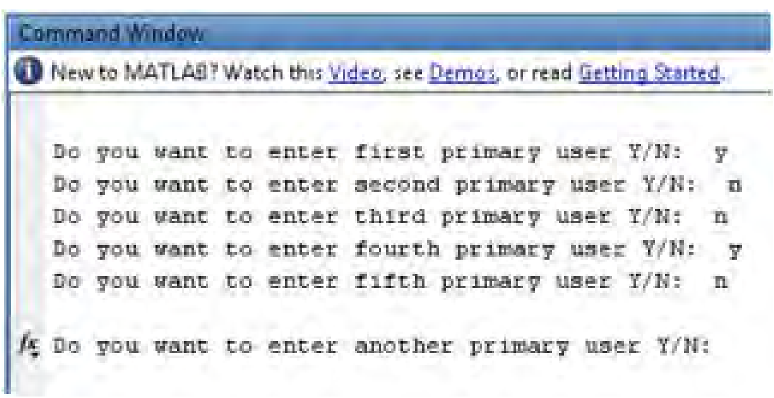

Figure 10: Creating Primary Users

Here we haven't entered User 2, 3 and 5; therefore their particular groups are still un-assigned. We can see them underneath in the power spectral density graph of our carrier signal.

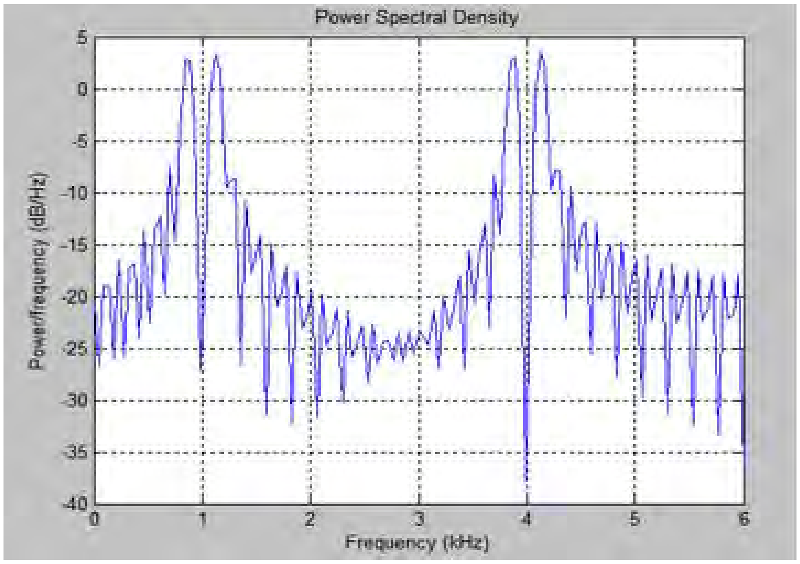

Figure 11: Power Spectral Density for User 1 and User 4

Now we will add another new User in the system. The system will search first available spectrum hole and allocate it for the new User. As User 2 was not sending any data the first available spectrum hole after User 1, the reserved band for the User 2 will be allocated for the new user.

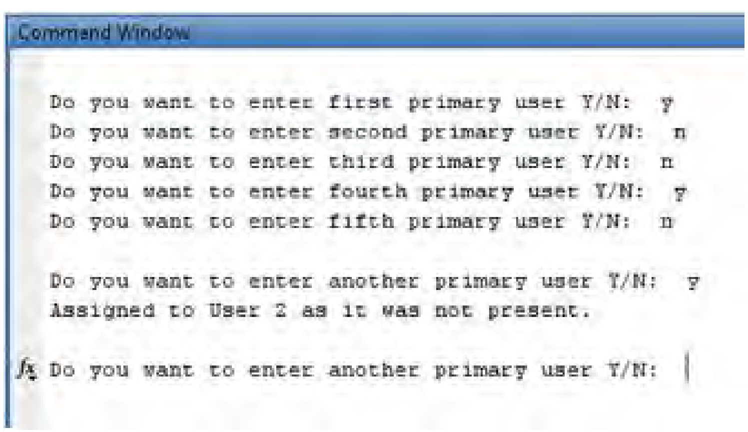

Figure 12: Prompt User Creation

We can see that first spectral hole is now filled with data of new User. The spectral hole was reserved for User 2.

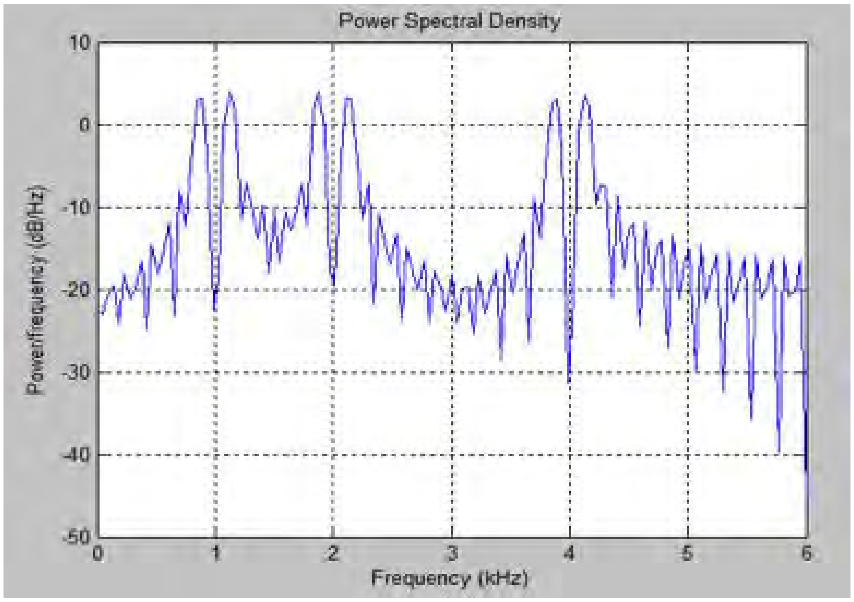

Figure 13: Power Spectral Density due to presence of User 1, 2 and 4

Adding another user in the system will give Spectral gap of User 3 to the new user.

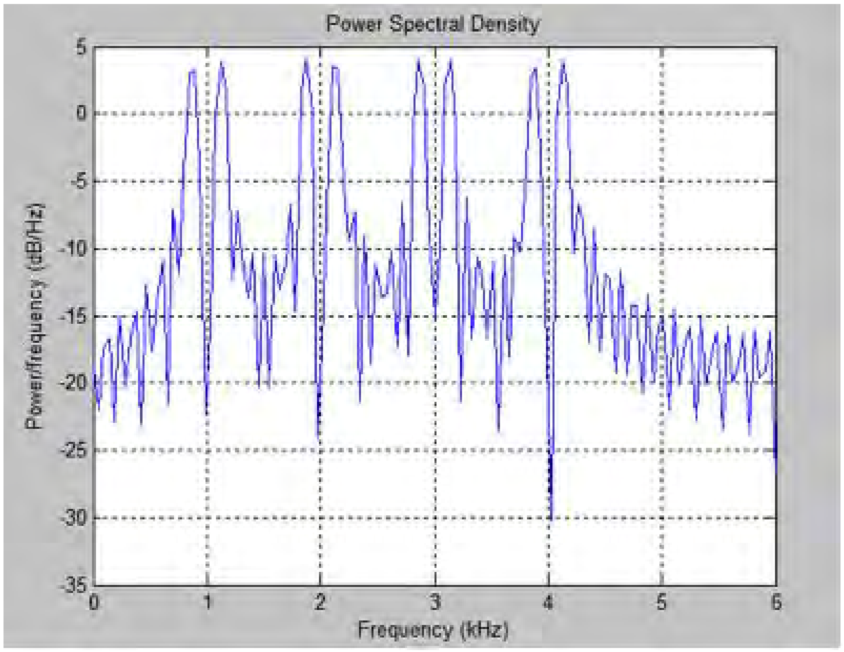

Figure 14: Power Spectral Density due to presence of User 1, 2, 3 and 4

Now feel the last slot with another user. The power spectral density chart is now showing all the frequency bands are in use.

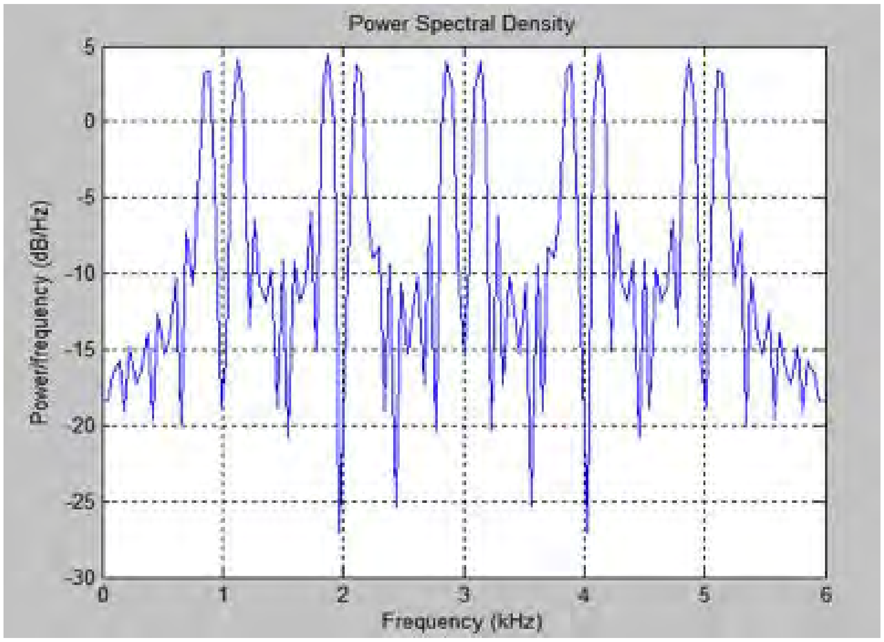

Figure 15: Power Spectral Density due to presence of all the 5 users.

Now system will not take any other user and will be able to free up the slot as shown below.

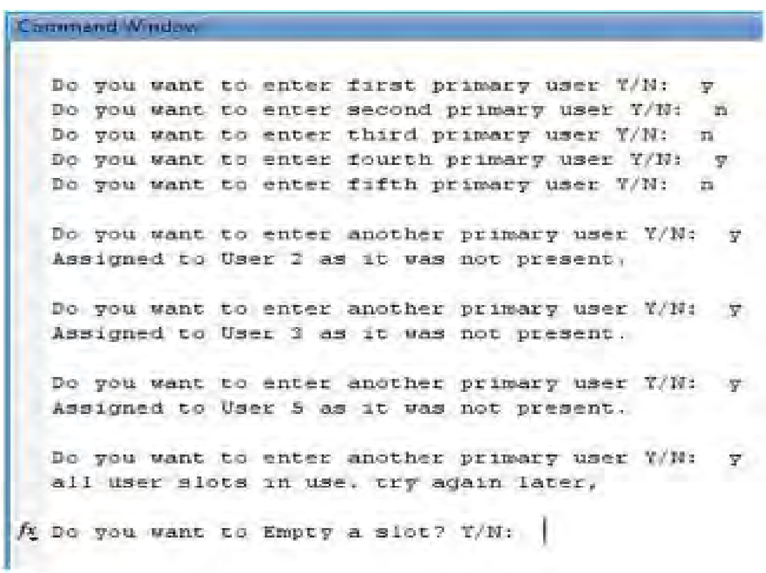

Figure 16: Occupied Slots

In our system we can add noise and attenuation parameter to analyze the channel characteristics.

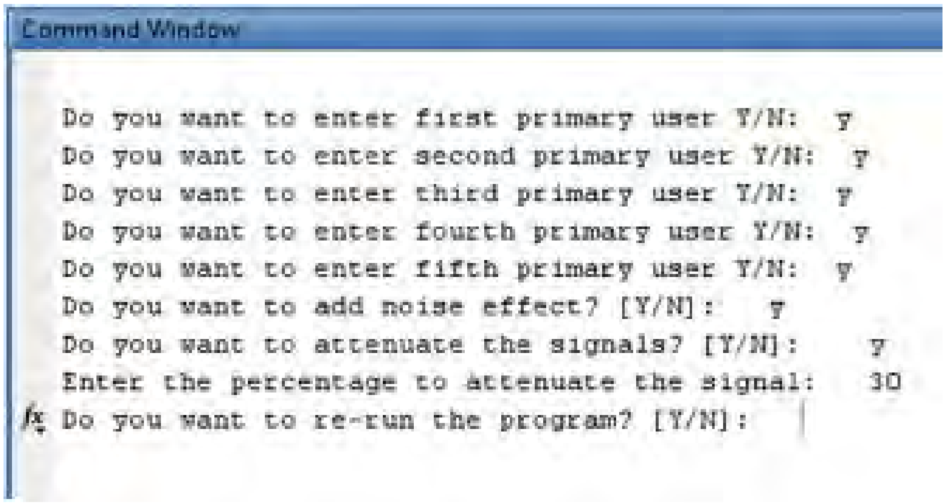

Figure 17: Prompt Noise and Attenuation

The result of adding noise and attenuation parameter is shown below.

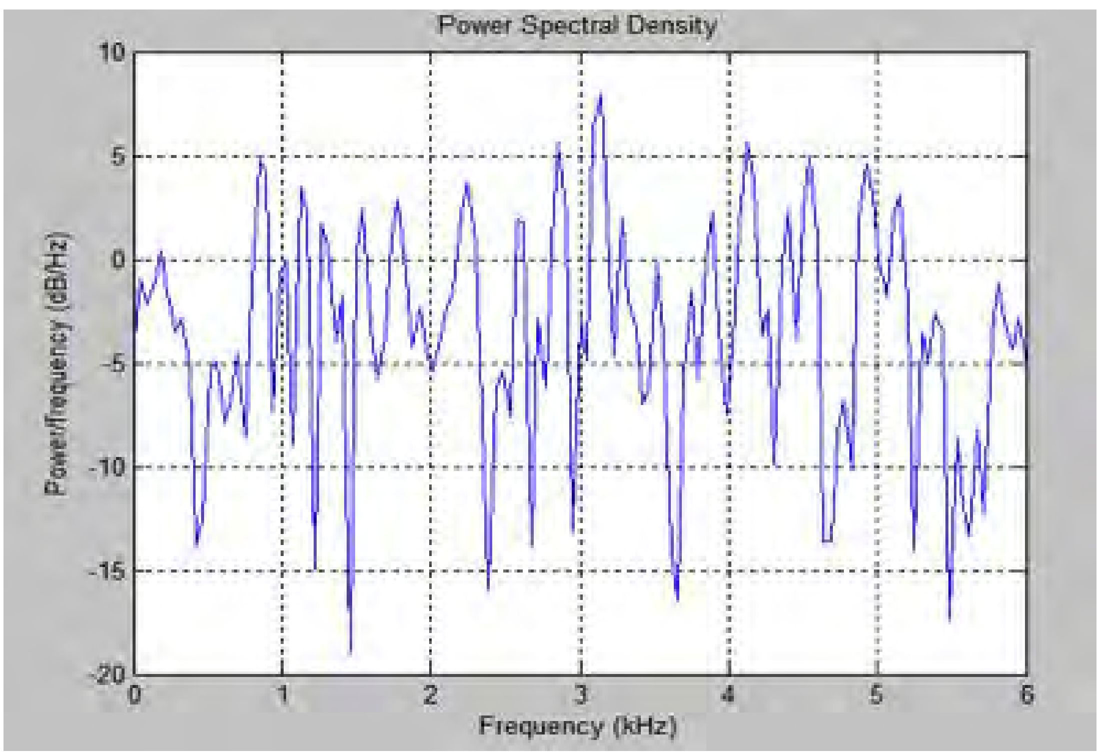

Figure 18: Noisy Channel's Power Spectral Density Graph

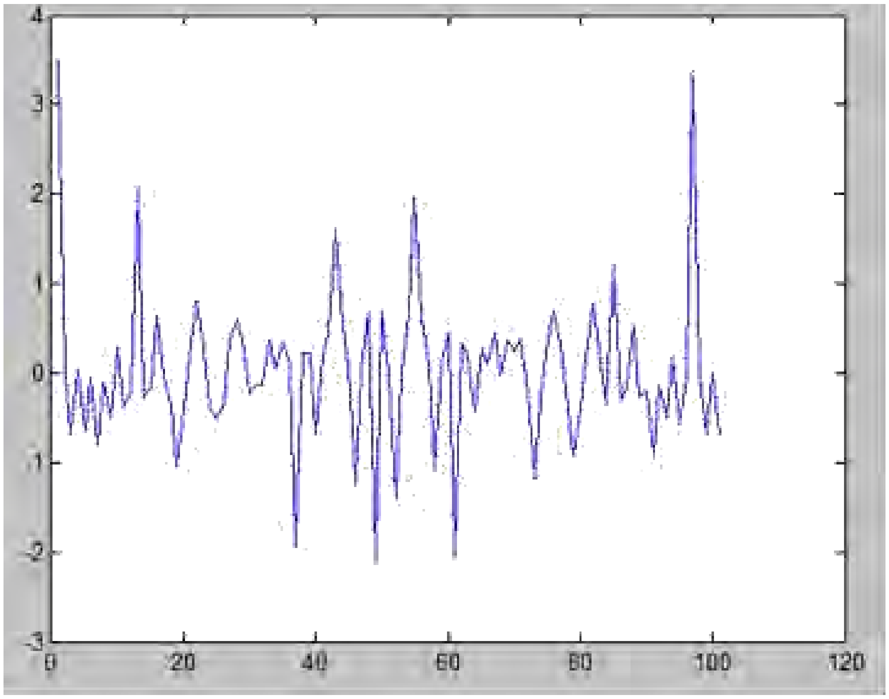

Fig: Noisy & attenuated Carrier’s Power Spectral Density Graph

This test helps us to build idea how decisions is taken on the basis of power spectral density of the channel which can be used cognitively to find out the available gaps those can be assigned to new incoming users thus improving the overall channel throughput.

CHAPTER 6

CONCLUSION

Spectrum is a very valuable resource in wireless communication systems, and it has been a focal point for research and development efforts over the last several decades. Cognitive radio, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept. One of the important elements of cognitive radio is sensing the available spectrum opportunities. In this paper the spectrum opportunity and spectrum sensing technique has been simulated in MATLAB in order to understand how the basis of a cognitive system works, Various aspects of the spectrum sensing task are explained in detail. Several sensing methods are studied and collaborative sensing is considered as a solution to some common problems in spectrum sensing. This paper opens the platform for further analysis in estimation of spectrum usage in multiple dimensions including time, frequency, space, angle and identifying opportunities in developing algorithms in future usages and applications.

REFERENCES:

[1]A. Ghosh and W. Hamouda, "Cross-Layer Antenna Selection and Channel Allocation for MIMO Cognitive Radios", IEEE Transactions on Wireless Communications, vol. 10, no. 11, pp. 3666-3674, 2011.

[2]M. Kumar and R. Kakani, "The Telecommunication Revolution", 2016.

[3]"History of Wireless Communication", Wirelesscommunication.nl, [Online]. Available: http://www.wirelesscommunication.nl/reference/chaptr07/history.htm. [Accessed: 16- Apr-2016].

[4]J. Shea, 2016.

[5]S. Pandit and G. Singh, "An overview of spectrum sharing techniques in cognitive radio communication system", Wireless Netw, 2015.

[6]. J. Zhang, "Defining Cross-Layer Design for Wireless Networking", 2014.

[7] S. Shabdanov, P. Mitran and C. Rosenberg, "Cross-Layer Optimization Using Advanced Physical Layer Techniques in Wireless Mesh Networks", IEEE Transactions on Wireless Communications, vol. 11, no. 4, pp. 1622-1631, 2012.

[8] V. Kawadia, P.R. Kumar, "A cautionary perspective on cross-layer design", in: IEEE Wireless Communications, Volume 12, Issue 1, Feb. 2005.

[9] J. Mitolla iii, "An Integrated Agent Architecture for Software Defined Radio", 2000.

[10] X. Liu, Q. Jing, Y. Jia, W. Zhong and Y. Guan, "Sensing-throughput tradeoff for cooperative multiple-input single-output cognitive radio", Int. J. Commun. Syst., vol. 28, no. 5, pp. 848-860, 2013.

[11] M. Abdulsattar, "Energy Detection Technique for Spectrum Sensing in Cognitive Radio: A Survey", IJCNC, vol. 4, no. 5, pp. 223-242, 2012.

[12] S. parsons, "Literature Review of Cognitive Radio Spectrum Sensing EE 359 Project",Stanford University, 2014.

[13] T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications", IEEE Communications Surveys & Tutorials, vol. 11, no. 1, pp. 116-130, 2009.

[14] B. Jariwala1 and V. Manilal2, "A Survey: A Cognitive Radio for Wireless Communication”", e-ISSN: 2278-2834,p- ISSN: 2278-8735, vol. 9, no. 1, , 2014.