SPECTRUM SENSING SCHEMES FOR COGNITIVE RADIO NETWORKS

THESIS REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Electronics and Communications Engineering

By

Y.SAI KRISHNA (Roll No: 109EC0220)

V.NARAYANA (Roll No: 109EC0560)

Under the guidance of

Prof. POONAM SINGH

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

2009 – 2013

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, *"***spectrum sensing schemes for cognitive radio networks***"* submitted by **Y.SAI KRISHNA** and **V.NARAYANA** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics and Communication Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Prof. POONAM SINGH

Department of Electronics and Communication Engineering

National Institute of Technology

Rourkela – 769008

DATE:

ACKNOWLEDGEMENT

We take it a deemed privilege to express our sincere thanks to all concerned who have contributed either directly or indirectly for the successful completion of our thesis report on

“SPECTRUM SENSING SCHEMES FOR COGNITIVE RADIO NETWORKS” .

Primarily, we submit our gratitude & sincere thanks to our supervisor **Prof. Poonam Singh**, Department of Electronics and Communication Engineering, for her constant motivation and Support during the course of our work in the last one year. We truly appreciate and value her esteemed guidance and encouragement from the beginning to the end of this thesis. We are indebted to her for having helped us shape the problem and providing insights towards the Solution.

Y.SAI KRISHNA
Roll No: 109EC0220

V.NARAYANA
Roll No: 109EC0560

ABSTRACT

The growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum which is limited and precious resource. Cognitive radio is a promising technology which provides a novel way to improve utilisation efficiency of available electromagnetic spectrum. Spectrum sensing used to detect the spectrum holes (underutilised bands of the spectrum) providing high spectral resolution capability. In this report, studied of spectrum sensing techniques is presented. The issues and challenges involved in implementation of spectrum sensing technique energy detection are discussed in detail. We implemented matched filter spectrum sensing technique and studied about cyclostationary detection in spectrum sensing .we implemented OFDM in spectrum sensing techniques as OFDM solves many problems in cognitive radio.

KEYWORDS: OFDM, Matched Filter, Energy Detection, Cognitive Radio, Spectrum sensing, cyclostationary.

CONTENTS

LIST OF ACRONYMS

AWGN	Additive White Gaussian Noise
CR	Cognitive Radio
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
OFDM	Orthogonal Frequency Division Multiplexing
BPSK	Binary Phase Shift Keying
SNR	Signal to Noise Ratio
SS	Spectrum Sensing
ED	Energy Detection
MFD	Matched Filter Detection
PSD	Power Spectral Density
ISI	Inter Symbol Interference

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Cognitive radio (CR) technology is a new way to compensate the spectrum shortage problem of wireless environment. It enables much higher spectrum efficiency by dynamic spectrum access. It allows unlicensed users to utilize the free portions of licensed spectrum while ensuring no interference to primary users' transmissions. Cognitive radio arises to be tempting solution to the spectral congestion problem by introducing opportunistic usage of the frequency bands that are not heavily occupied by licensed users. FCC define cognitive radio as, "A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets". Hence, one main aspects of cognitive radio is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access. In cognitive radio terminology, PU can be defined as the user who has license to use a specific part of the spectrum. On the other hand, secondary users (SU) or CR users do have license to use the spectrum but can use the spectrum

Chapter 2

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

2.1 INTRODUCTION

A special type of multicarrier transmission known as orthogonal frequency division multiplexing (OFDM) is one of the most widely used technologies in current wireless communications systems. OFDM has the potential of fulfilling the requirements of CR totally or with minor modifications. Because of its attractive features, it has been successfully used in numerous wireless standards and technologies. So we believe that OFDM will play an important role in realizing CR concept as well by providing a proven, scalable, and adaptive technology for air interface. CR's have the ability to sense and be cautious of its operational environment, and accordingly dynamically adjust its radio operating parameters. To achieve this objective, the physical layer (PHY) needs to be greatly flexible and adaptable.

Conceptually, OFDM is a specialized FDM, the additional constraint being: all carrier signals exhibit orthogonality property. the sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other in OFDM,, meaning that cross-talk between inter-carrier guard bands and the sub-channels is eliminated are required. actually This simplifies the design of both the transmitter and the receiver; unlike conventional FDM, a separate filter for each sub-channel is not necessary The orthogonality also allows more spectral efficiency, with a total symbol rate is as same as the Nyquist rate for the equivalent baseband signal (i.e. near half the Nyquist rate for the double-side band physical pass band signal). Almost the whole available frequency band can be used. OFDM generally has a nearly 'white' spectrum, giving it benign electromagnetic interference properties with respect to other co-channel users.

2.2 OFDM THEORY

OFDM is a multicarrier technique which is used transmission over a dispersive channel. In ofdm technique the carriers are orthogonal, actually which make them independent of one another. We are basically using the flat fading channel. As delay spread is less than the duration of symbol.

SUB CARRIERS

Every sub carrier in OFDM system is having frequency that has an integer multiple of a fundamental frequency and every sub carrier is a Fourier component of the OFDM signal.

Equation for the sub carrier:

$$S(t) = \cos(2\pi f_c t + \theta_k)$$

$$= a_n \cos(2\pi n f_0 t) + b_n \sin(2\pi n f_0 t)$$

$$= (a_n^2 + b_n^2)^{1/2} \cos(2\pi n f_0 t + \varphi_n)$$

Where $\varphi_n = \tan^{-1}(b_n/a_n)$.

Total sum of the sub carriers will make the main OFDM signal so the equation of OFDM will be like-

$$S_B(t) = \sum_{n=0}^{N-1} \{ a_n \cos(2\pi n f_0 t) - b_n \sin(2\pi n f_0 t)\}.$$

ORTHOGONALITY CONDITION

We can assume that periodic signals are said to be orthogonal if their product over a period is equal to zero. Equation for checking orthogonality:

$$\int_0^T \cos(2\pi n f_0 t) \cos(2\pi m f_0 t) = 0,$$

In discrete domain:

$$S_B(t) = \sum_{n=0}^{N-1} \{ a_n \cos(2\pi n f_0 t) - b_n \sin(2\pi n f_0 t)\}.$$

Where $m \neq n$ for both the cases.

INTER CARRIER INTERFERENCE (ICI)

Due to the presence of frequency offset and Doppler Effect, then there might be a chance of loss of orthogonality of sub carriers. Interference occurs between the subcarriers. so this is known as inter carrier interference.

INTER SYMBOL INTERFERENCE

Inter symbol interference (ISI) is an unavoidable outcome of both wired and wireless communication system. ISI makes a system less efficient. The main cause of this kind of problem. It introduces error inside a system is multipath. So receiver and transmitter filter must be used to reduce this kind of problem and provide possible minimum error.

CYCLIC PREFIX

This is an addition of guard interval to the end of an OFDM symbol that is added to the front of the symbol in the transmitter, and is removed before demodulation at the receiving end. Main advantages of cyclic prefixes

• It acts as guard interval, which can eliminate the ISI from the previous symbol.

• It maintains the continuity of an OFDM signal.

INVERSE FOURIER TRANSFORM

In inverse Fourier transform, it takes the signal in frequency domain, and maps it into time domain. The time domain generally consists of a set of real values. The Fourier maps it into a frequency domain series. The IDFT consists of complex value, whose imaginary part is zero.

It is a linear transformation that can be applied at the transmitter end and DFT must be used at the receiver end to get the original signal. We can use IDFT to OFDM signal to get the time domain series. It also plays a major rule in forming a filter. Normally we can implement fast Fourier transform (FFT) instead of DFT and IDFT to reduce the system complexity and the computation speed will also much faster.

MODULATION AND DEMODULATION IN OFDM

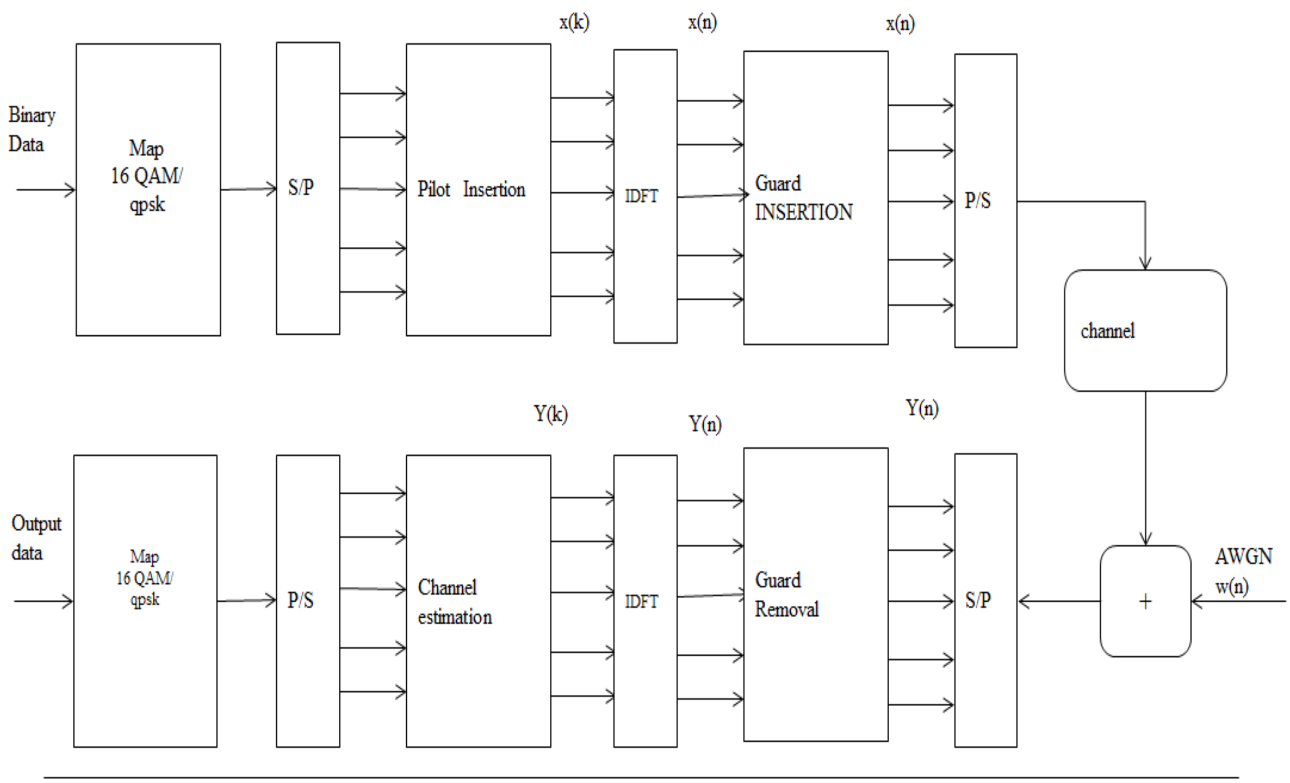


Fig 2.1 Block Diagram of OFDM Technique

MODULATION

By modulation the signal wave is transformed in order to transmit it over the communication channel in order to minimize the effect of noise. This is done to ensure that received data can be demodulated to give back the original data. In this system, the high data rate information is divided into small sets of data which are placed orthogonal to each other and this is achieved by modulating the data by some modulation technique like QPSK, QAM, BPSK and MSK after modulation, IFFT is performed on the modulated signal further processed by passing through a parallel to serial converter to remove ISI we use cyclic prefix

COMMUNICATION CHANNEL

Channel is required to pass the data through it. The data signal will be distorted by the presence of the noise. There may be addition of additive white Gaussian noise, that affect the signal to noise ratio (SNR).mean square error is affected by the added carrier offset.

DEMODULATION

It is the technique by which the modulated data signal will be transformed in to the original data.at First the modulated data is passed through a low pass filter. There after that the cyclic prefix is removed and FFT is applied to it to convert it into frequency domain. There uses a serial to parallel converter .The bit error rate and signal to noise ratio is calculated to compare the original signal and the signal received at the receiver end.

2.3 OFDM BASED COGNITIVE RADIO

Many problems a raised with high bit rate communications will be overloaded by a multi carrier modulation technique called OFDM the major of which is time dispersion and The data bearing symbol stream is split into these streams are transmitted on different sub carriers. Several lower rate streams and as the splitting increases the symbol duration by the number of orthogonally overlapping carriers (subcarriers) only a small portion of the neighboring symbols affected by the multipath echoes extending the OFDM symbol with a cyclic prefix (CP) is used to remove the remaining inter symbol interference. Using this method, OFDM reduces the need for complex equalizers and dispersion effect of multipath channels encountered with high data rates. Then the other advantages of OFDM include high robustness against narrowband interference (NBI), spectral efficiency, scalability, and easy implementation using fast Fourier transform (FFT).

WHY OFDM IS A GOOD FIT FOR CR

OFDM's flexibility together with underlying sensing and spectrum shaping capabilities and adaptively make it probably the best transmission modulation technology for CR systems. Now proceeding, we explain how OFDM can fulfill these requirements and we present some of the requirements for CR.

2.4 ADVANTAGES OF OFDM SYSTEM

- Intersymbol interference is eliminated by introducing guard band.
- Perfectness and robustness in multipath environment.
- OFDM can tolerate the effect of delay spread.
- OFDM is resistant to fading.
- Data rate is higher. It can be varied using different modulation schemes at the baseband.

2.5 DISADVANTAGES OF OFDM SYSTEM

- Need the correction at the receiver, as Sensitive to frequency offset.
- Input signal power is more when compared to Output signal power
- Complex IFFT/FFT process is going on.
- Use the system becomes complex by guard interval.

Chapter 3

SPECRUM SENSING SCHEMES

3.1 SPECTRUM SENSING

Cognitive radio (CR) technology solves the issue of spectrum underutilization in wireless communication better way. Cognitive radios are designed in order to provide highly reliable communication for all users of the network, wherever and whenever needed and to facilitate effective utilization of the radio spectrum to its maximum extent .show relatively low utilization of the licensed spectrum which is mainly due to inefficient fixed frequency allocations rather than any physical shortage of the spectrum. This observation has lead the regulatory bodies to search a method where secondary (unlicensed) systems are allowed to opportunistically utilize the unused licensed bands commonly called them as white spaces. CR network can change its transmitter parameters based on interaction with environment in which it operates. Cognitive radio includes four major functional blocks: spectrum management, spectrum sharing, spectrum sensing and spectrum mobility.

A major challenge in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and come out of the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users. This method is called spectrum sensing. Spectrum sensing and estimation is the fast and major step to implement CR system. We can categorize spectrum sensing techniques into direct method, which is considered as frequency domain approach, here the estimation is carried out directly from signal and indirect method, which can be described as time domain approach, where the estimation is done by using autocorrelation of the signal.so many ways are there , and other way of categorizing the spectrum sensing and estimating methods are by making group into model based parametric method and periodogram based nonparametric methods. Other way of classification depends on the need of spectrum sensing as stated below Spectrum Sensing for Spectrum Opportunities.

PRIMARY TRANSMITTER DETECTION In this model, the detection of primary users is verified based on the received signal at Cognitive radio users. This method includes matched filter (MF) based detection, covariance based detection, energy based detection method, radio identification based detection, waveform based detection, cyclostationary based detection scheme, radio identification based detection and random Hough Transform based detection.

3.2 SPECTRUM SENSING TECHNIQUES

Sensing spectrum is the most important factor of cognitive radio, which is important step that needs to be performed for communication to take place. A number of techniques have been developed for detecting whether the primary user is present in a particular frequency band of the spectrum. Some particular characteristics of the signal to identify the signal even its type or some approaches use the signal energy. Some of the most common schemes employed for Spectrum Sensing are

• Energy Detection

• Cyclostationary Feature Detector

• Matched Filter Detection

Among the above three methods energy detection is popular till now, but the major problem with energy detection method is that the poor performance under low SNR conditions and also no proper difference between primary users and noise. Rather the MF maximizes the SNR the electromagnetic radio spectrum we have is a limited natural resource and getting crowded day by day due to increase in wireless devices and apps. Because of the static allocation of the spectrum it has been also found that the allocated spectrum is underutilised. Also, the conventional approach to spectrum management is very easy in the sense that each wireless operator is assigned an exclusive license to operate in a certain frequency spectrum. With most of the useful radio spectrum already allocated, so it is difficult to find vacant bands to either to enhance existing ones or to encourage new service. In order to overcome this situation, we come up with a means for developed utilization of the spectrum creating opportunities for dynamic spectrum access.

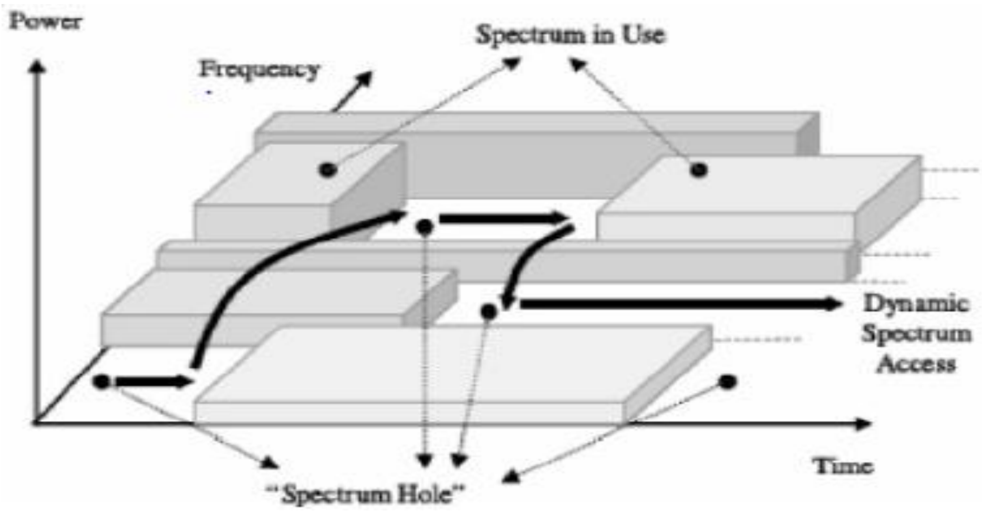


Fig 3.1 Illustration of spectrum white space

3.3 Classification of Spectrum Sensing Techniques

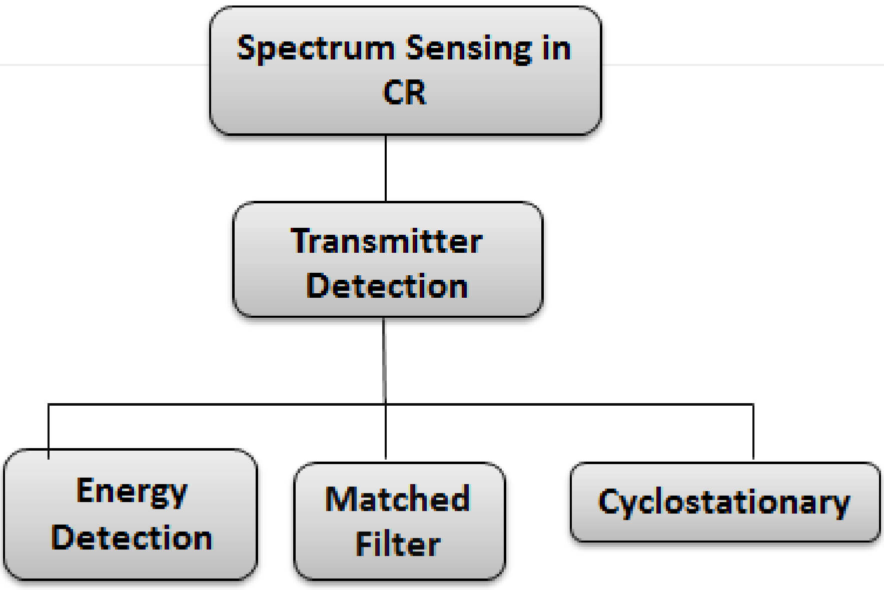


Fig 3.2 SHOWS THE DETAILED CLASSIFICATION OF SPECTRUM SENSING TECHNIQUES.

They are broadly classified into three main types, cooperative sensing and interference based sensing, transmitter detection or non-cooperative sensing. Transmitter detection technique is again classified into energy detection, matched filter detection scheme and cyclostationary feature detection method.

Primary Transmitter Detection

3.3.1 Energy Detection

It is a non-coherent detection method that finds the primary signal based on the technique is Shown below

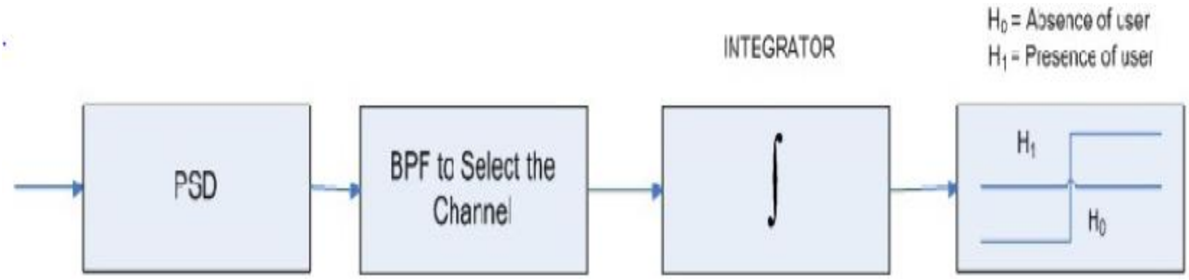


Fig 3.3 **The block diagram of energy detection**

In this scheme, signal is allowed through band pass filter of the bandwidth W and is integrated over time interval. The outcome from the integrator block is then compared to a precalculated threshold. This comparison is used to find the existence or absence of the primary user. The threshold value of energy detection can be fixed or variable based on the channel conditions and threshold value depends on snr ratio. The ED is called to be the Blind signal detector because it ignores the structure of the signal and properties of the signal. It estimates the presence of the signal by comparing the energy received with a known threshold derived from the statistics of the noise derived from SNR. Logically, signal detection can be reduced to formalize as a hypothesis test, a simple identification problem.

$$y(k) = n(k)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..H_0$$

$$y(k) = h*s(k) + n(k)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots H_1$$

Where y (k) is the sample to be analyzed at each instant k and n (k) is the noise of variance. Let y (k) be a sequence of received samples k _ {1, 2….N} at the signal detector, then a decision rule can be stated as,

$$H_0\ldots\ldots if\ \varepsilon < v$$

$$H_1\ldots\ldots\ldots if\ \varepsilon > v$$

Where 2e = E y (k) the estimated energy of the received signal and is chosen to be the variance of noise _2. However ED is always is having a number of disadvantages

i) Sensing time may be high is taken to achieve a given probability of detection.

ii) Detection performance is related to the uncertainty of noise power.

iii) Energy Detection cannot be used to distinguish primary signals from the secondary CR user signals. As a result CR users need to be refrained and tightly synchronized from the transmissions during an interval called Quiet Period in cooperative sensing.

iv) To detect spread spectrum signals ED cannot be used.

3.3.2 Matched Filter

Introduction to Matched Filter:

The decision making on whether the signal is present or not can be known if we pass the signal through a filter, which will stress the useful signal sig(t) and quash the noise w(t) at the same time. Such a filter which will peak out the signal component at some instant and smother the noise amplitude at the same time has to be designed. This will give a sharp contradiction between the signal and the noise, and if the signal sig (t) is present, the output will come out to have a large peak at this instant. If the signal is missing at this instant, no such peak will appear. This arrangement will make it feasible to decide whether the signal is present or absent with less probability of error. The filter which finished this is called as matched filter.

Main intention of the filter is, to minimise the noise component and to maximise the signal component at the same moment. So this is clearly equivalent to maximizing the signal amplitude to the noise amplitude ratio at some instant at the output. It proves more suitable if we go for square of amplitudes. So the matched filter is designed in such a way that it should maximize the ratio of the square of signal amplitude to the square the amplitude of noise.

PROPOSED WORK

In the proposed work, IEEE 802.11a signal has been produced based on the standard specification parameters. The actual data points available for transmission is converted from serial to parallel form.

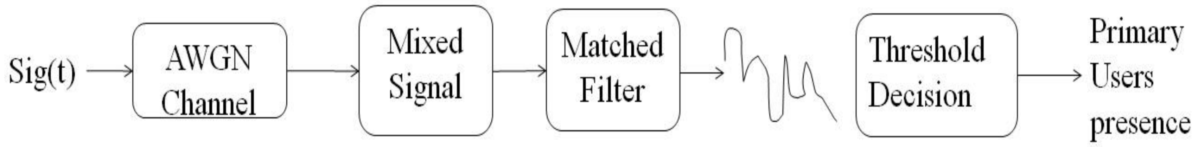
Then modulate the resulted data. This modulated data is exposed to Inverse fast Fourier transform operation and the preambles are added as per IEEE 802.11a standard. This data is passed through AWGN channel.

Let us assume sig(t) be the transmitted signal, w(t) is the channel noise, sig(t) + w(t) will be the received signal, which is given as the input to the matched filter and sig0(t)+w0(t) be the output of the filter. Let the impulse response of matched filter's be h(t). It had been demonstrated that, impulse response of the optimum system is the mirror image of the desired message signal sig (t) about the vertical axis and shifted to the right until all of the signal sig(t) has entered the receiver. It should be understood that the matched filter is optimum of all linear filters. The signal component at result of the filter, at the observing moment tm is given by

sig0(tm) = 1/2π_(s (ω)) 2 (1)

sig0(tm) = E (2)

Hence the output signal component has high amplitude of magnitude E, which is nothing but the energy of the signal sig (t). The maximum amplitude is not dependent of the waveform sig (t) and relays only upon it's enter



. Fig 3.4 THE SPECTRUM SENSING BLOCK USING MATCHED FILTER

Here the transmitted signal is allowed through the channel where the additive white Gaussian noise is getting added to the signal and outputted the mixed signal. The matched filter is getting this mixed signal as input. The impulse response convolved with the matched filter input and the matched filter output is then compared with the threshold for primary user detection. The threshold of a signal, determined with the impulse response of the matched filter and the matched filter output is then compared with the threshold for primary user detection. The threshold of a signal, determined by two possible ways has been mentioned here. One way is to find the energy of the signal and make it to half, fix it as a threshold. Another way is to calculate the standard deviation of the signal by computing the mean and use it as threshold. Of the two methods, the first one is theoretically proved to be optimal. . Once the threshold is fixed, presence of signal is determined based on the following decision rule.

rxd (t) > a: signal present

rxd (t) < a: signal absent

Here rxd (t) is the matched filter output given by

rxd (T) = sig0 (T) +w0 (T)

From eqn.(2)

rxd (T) = E + w0 (T)

If primary user signal is absent, then received signal be indication of only noise.

rxd (T) = w0 (T)

Matched Filter Detector

Where Q (.) is the Gaussian complementary distribution function. **Matched Filter Detector**

For the MFD, the decision statistic is given by

$T_{MFD}= \sum_{n=0}^{N-1} z(n) * x(n)$, where z(n)= 2sqrt(Ps)cos(2*pi*f_0*n)

Is the deterministic signal of interest with energy (**E**)

$$\mathbf{E} = \sum_{n=0}^{N-1} z(n)^2$$

$$P_{D,A.M.F.D} = Q(\frac{T_{MFD} - E}{\sigma_W \sqrt{E}})$$

$$P_{F.A.M.F.D} = Q(\frac{T_{MFD}}{\sigma_W \sqrt{E}})$$

Where Q (.) is the Gaussian complementary distributions function.

3.3.3 Cyclostationary Feature Detection

Cyclostationary feature detection needs high computation complexity, the best detection point is determined through simulation analysis on different detection points, and then we intend combination detection method using multiple detection points to obtain better performance. Output validate the effectiveness of the suggested method Cyclostationary feature detection can be able to have high detection probability under low SNR, actually, it requires high computation complexity.

In reality, based on channel and a given location, the licensed users' signal parameters are known and the SNR is changing gradually, so we assume that we can obtain the licensed users' signal type and SNR before making detection. Using of the licensed users' prior knowledge like properties of signal, we only makes detections in some specific frequencies and cycle frequencies, and multiple combine detection points to increase the performance further. And then given the PD required by licensed users, the probability of false alarm (PFA) under different SNRs is implemented. Through the threshold adjustment, we decrease the PFA to make better use of spectrum hole when the SNR is high and increase the PFA to avoid interference to the licensed users when the SNR is low.

The principle of cyclostationarity

Modulated signals are in general coupled with repeating spreading, cosine carrier, , over-sampling etc., outcome in built-in periodicity. When the signal's mean and autocorrelation exhibit periodicity, i.e., mx (t + T) = mx (t),

$$Rx\,(t + T, u + T) = Rx\,(t, u)$$

We name this signal a second order cyclic statistics process. The auto-correlation of signal x(t) is given a

$$R_x\,(t, \tau) = \lim_{N\to\infty} \frac{1}{2N+1} * \sum_{n=N}^{N} x\left(t + \frac{\tau}{2} + n * T\right) * x\left(t - \frac{\tau}{2} + nT\right)$$

As Rx (t, τ) is periodic with period T0, it can be expressed as a Fourier series representation

$$R_x\,(t, \tau) = \sum_{m=-\infty}^{\infty} Rx^{m/T}(\tau)\, e^{j2\pi mt/T}$$

$$Rx^{\alpha}(\tau) = \left(\frac{\mathbf{1}}{\boldsymbol{T}}\right) \int_{-\infty}^{\infty} Rx(t, \tau) e^{-j2\pi\alpha t} dt$$

Where is the second-order cycle frequency equals to the spectrum coherence function (SCF) can be obtained from as

$$\mathbf{Sx}^{\boldsymbol{\alpha}}(\boldsymbol{f}) = \int_{-\infty}^{\infty} Rx^{\boldsymbol{\alpha}}(\tau) \boldsymbol{e}^{-\boldsymbol{2\pi f}\tau}\, d\tau = \frac{1}{T} X\left(f + \frac{\alpha}{2}\right) * x\,(f-\alpha/2) - 4$$

Where x (f) is the Fourier transform of signal x (t) from (4) we can find that S_x (f) is the correlation of the signal spectrum different types of signals have different spectrum correlation features. The SCF of the Gaussian white noise is given. These figures illustrate that the SCF of BPSK signal is different from the SCF of Gaussian white noise and cyclostationary features can be used for signal detection under low SNR environment.

The SCF of the Gaussian white noise is defined. These figures clears that the SCF of BPSK signal is different from the SCF of Gaussian white noise and cyclostationary features can be used for signal detection under low SNR environment.

Implementation

SCF of noise Implementation Usually, the cyclostationary detection needs high computation complexity and can't meet the real-time operation that required by spectrum sensing for cognitive radio.so as to reduce the complexity,

Suggests to make detection in axis f=0 and axis α=0. And he also points out that when $f_c=f_s/4$, the detection point f=0, $\alpha=2f_c$ performs best , here f_s denotes the sample rate however , from we can find that the points $\alpha=+-m/T_0$, $f=f+-f_c$ also have peaks , which can be demonstrated.

Here, we assume that the characteristics of licensed users' signals are known and detect these signals under specific points. We take time-domain averaging and frequency-domain smoothing to obtain SCF as follows

1) Finding points of cycle frequency and carrier frequency that we need to analyse.

2) Get M groups of data with length of N, calculate FFT for each group of data

$X_m(K) = \sum_{n=0}^{N-1} Xm(n)e^{-j2\pi nk/N}$

Where $X_m(K)$ is the FFT of M th data group

3) Compute power spectrum density (PSD)

$S_m(k) = \frac{1}{N} X_m(k)\, Xm^*(k)$

Where $S_m(k)$ denotes the PSD of the signal from m-th group of data.

4) Compute SCF

$\mathbf{Sm}^{\alpha i}(\boldsymbol{K}) = \frac{1}{N} Xm\left(K + \frac{\alpha i}{2}\right) * Xm\,(k-\alpha i/2)$

Where $\mathbf{Sm}^{\alpha i}(\boldsymbol{K})$ denotes the PSD of the signal from m- th group of data

5) Frequency domain smoothing

$$\mathrm{Sm}^{\alpha i}(K)_{\Delta f} = \frac{1}{P}\sum_{P=-(P-1)/2}^{(P-1)/2} \mathrm{Sm}^{\alpha i}(K+P)$$

Where P is spectrum domain smoothing factor $\mathrm{Sm}^{\alpha i}(K)\Delta f$ *is* the i-th detection pint from mth group of data after spectrum domain smoothing.

6) Compute test statics

$$I_m(\alpha i) = \frac{\mathrm{Sm}^{\alpha i}(K)_{\Delta f}}{[S\left(K-\frac{\alpha i}{2}\right)*S(k+\alpha i/2)]^{1/2}}$$

$$I(\alpha i) = \frac{1}{M}\sum_{m=1}^{M} Im\ (\alpha i)$$

$$I(\alpha) = \sum_{i=1}^{D}(Wi)I\ (\alpha i)$$

Where I_m (α_i) is the test statistics at i-th detection point that we obtain from m-th group of data, I (α_i) is the test statistics at i-th detection point and I (α) is the overall test statistics. D is the number of point in decision, w_i is the weight at i-th detection point.

7) Detection decision

If $I(\alpha) < \lambda$ No signal

$I(\alpha) > \lambda$ Signal exist

Where λ is threshold determined by P_{FA}

Spectrum sensing based on cyclostationarity in cognitive radio is studied. The second-order cyclic analyses built-in in modulated signals is used to detect the signals. Because of high complexity of cyclostationary feature detection and so we choose to detect specific frequencies and cyclic frequencies based on the signal's feature to decrease complexity greatly. We collate the detection performance of different points to find the best detection points through simulation analysis and propose to combination detection method using multiple detection points to get better performance.

Chapter 4

SIMULATIONS AND RESULTS

4.1 OFDM

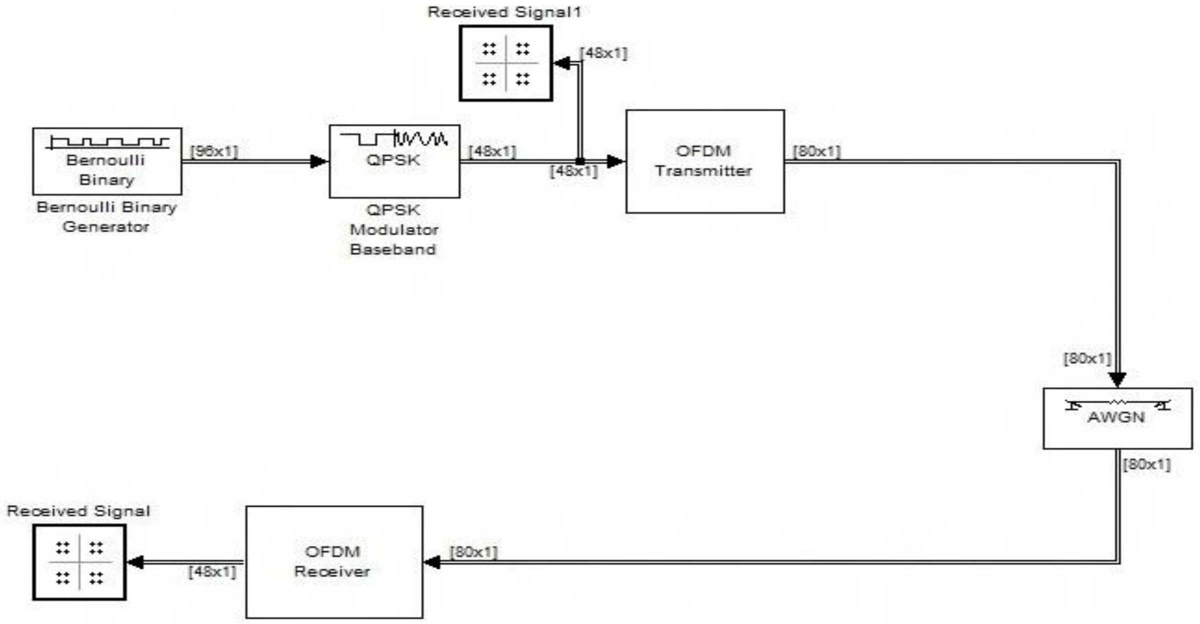


Fig 4.1(a) SIMULINK MODEL OF AN OFDM SYSTEM

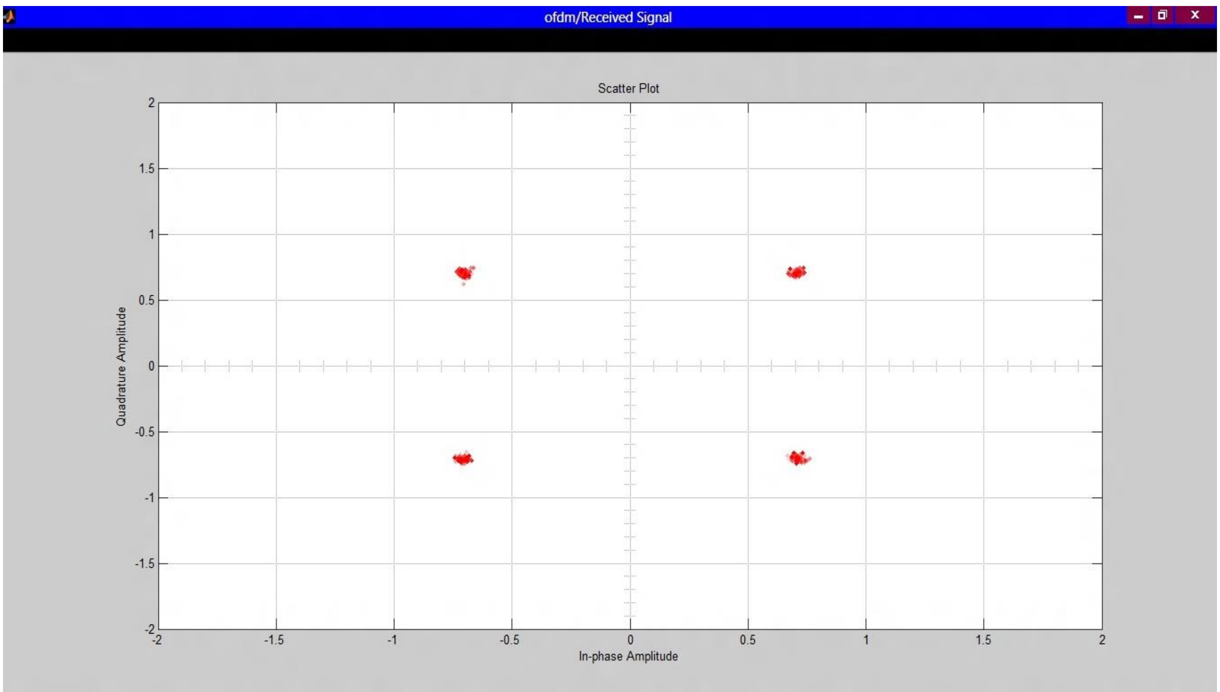


Fig 4.1(b) OFDM RECEIVED SIGNAL

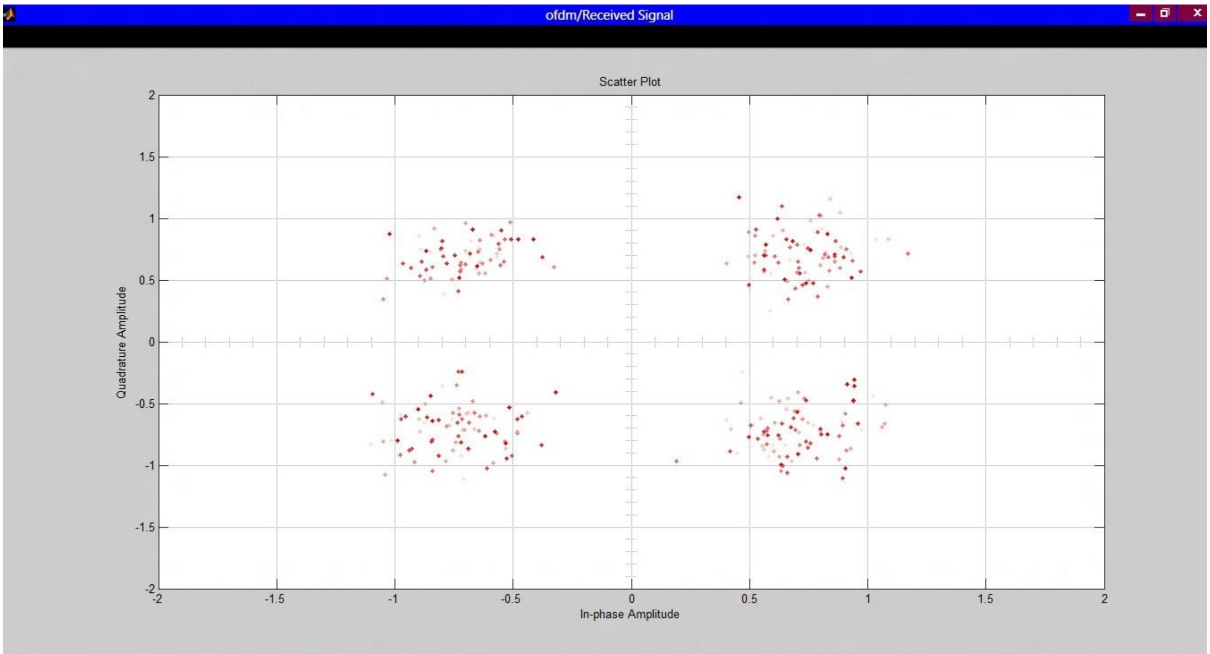


Fig 4.1(c) OFDM RECEIVED SIGNAL AT 10 dB

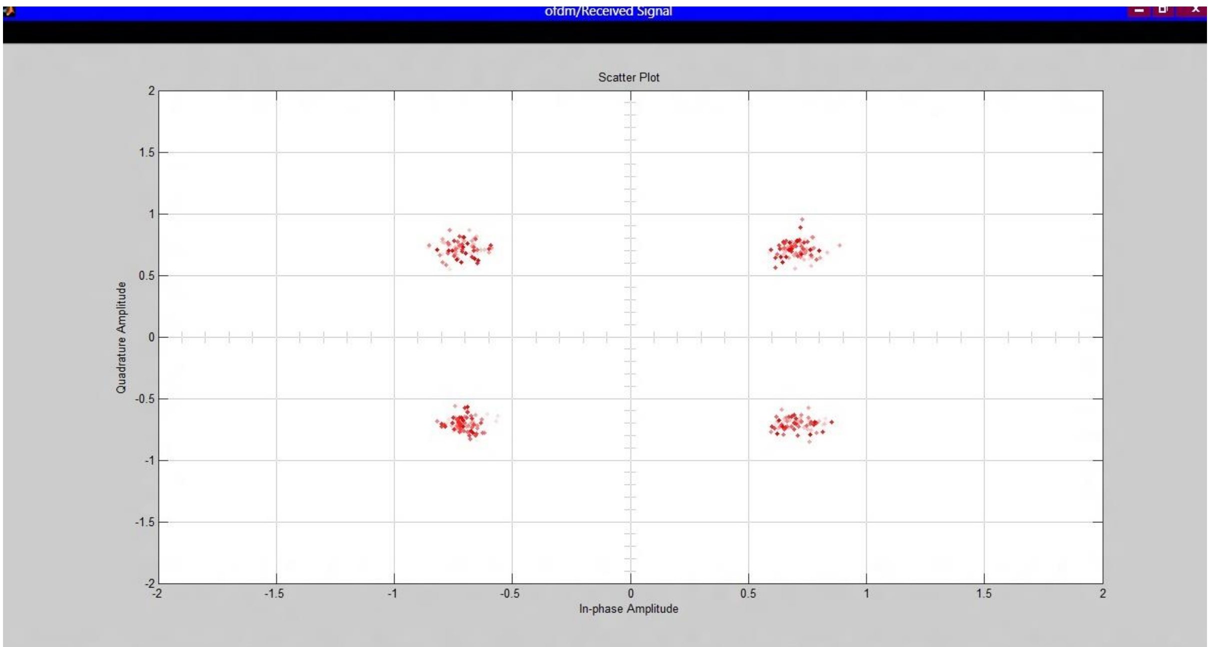


Fig 4.1(d) OFDM RECEIVED SIGNAL AT 20 dB

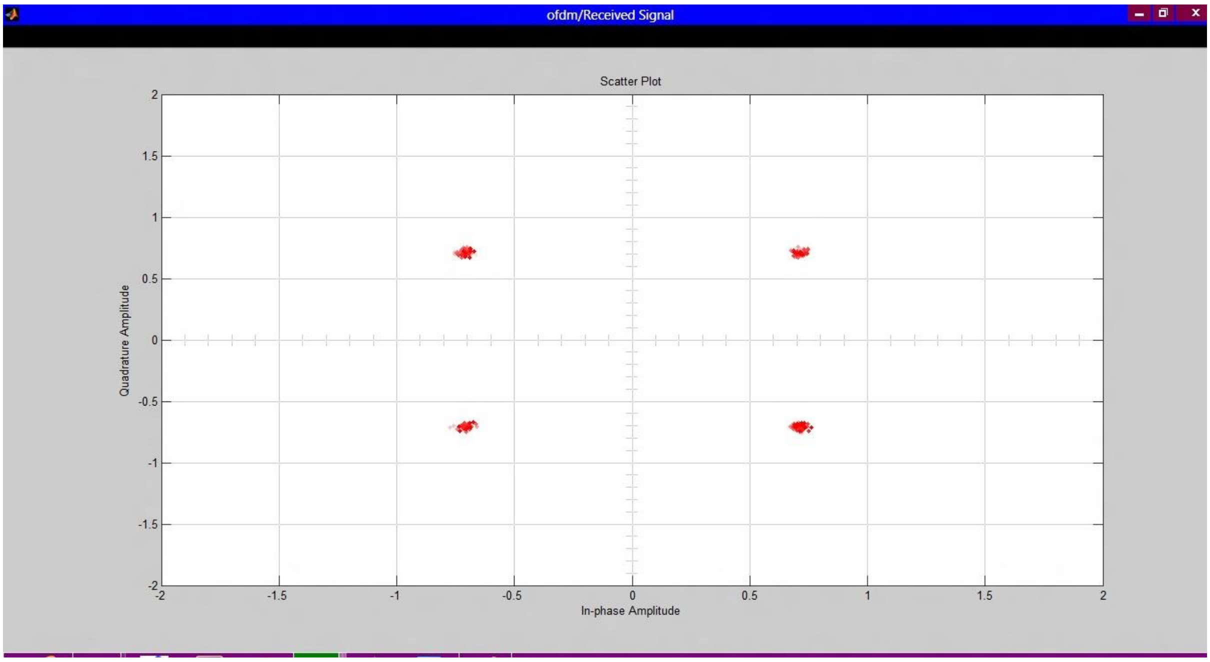


Fig 4.1(e) OFDM RECEIVED SIGNAL AT 30 dB

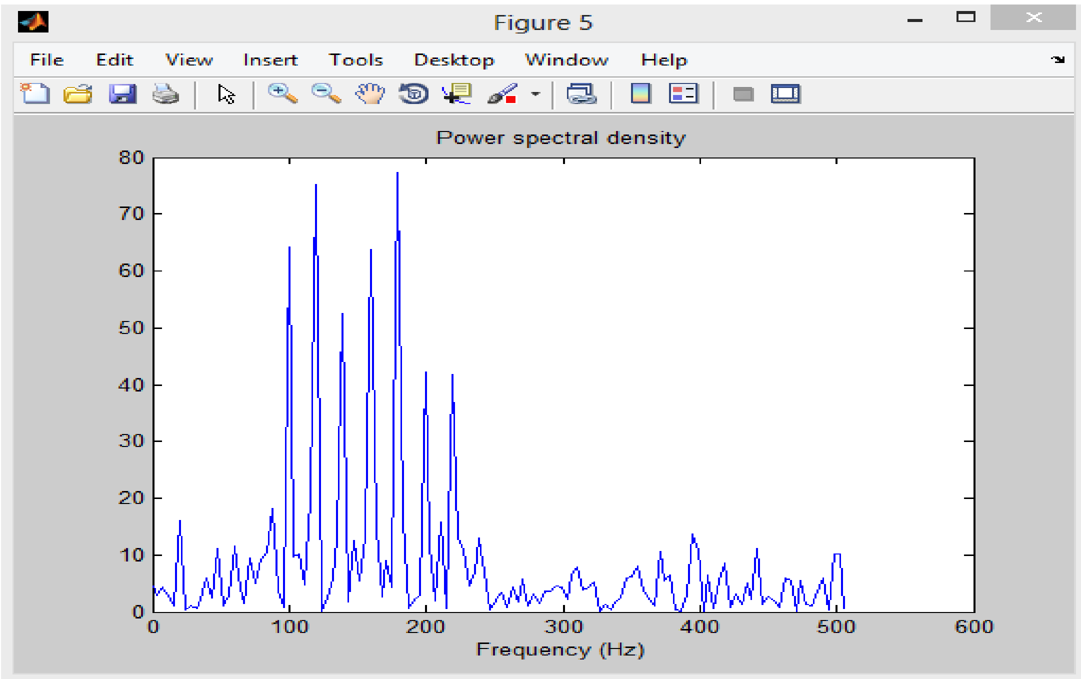


Fig 4.2 POWER SPECTRAL DENSITY (PSD) OF A SIMPLE ENERGY DETECTOR

4.2 ENERGY DETECTION

This is the graph plotted between probabilities of false alarm vs. probability of detection at some specific SNR values. Here we assume some values from 0 to 1 or probability of false alarm and for each value we find threshold value by using the threshold value we find the simulated and theoretical probability of detection

For simulation

We use SNR value -12db

Constant, u=1000

- The threshold function used in analysing energy detection method is

  Th(i)=gammaincinv(1-pfa(i),u)*2

  pfa means probability of false alarm

- Theoretical function for probability of detection in energy detection method is

Pd_theory (i) = marcumq (sqrt (pn*2*u), sqrt (Th (i)), u);

Here pn =noise power

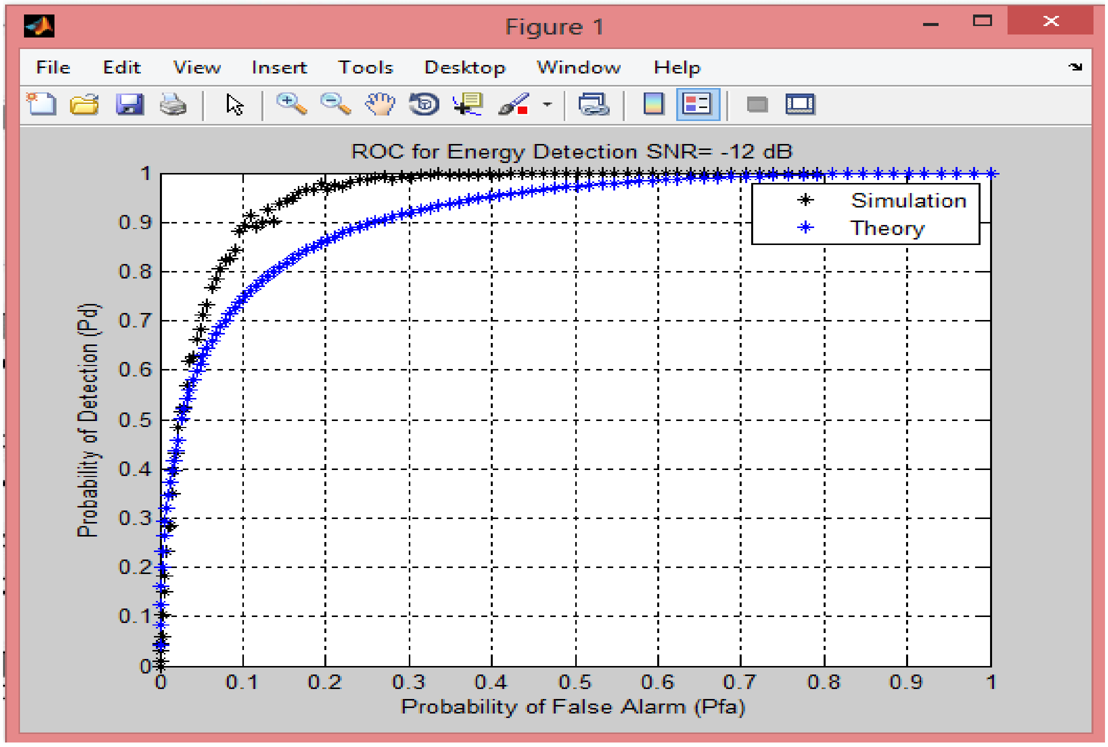


Fig 4.3.ROC FOR ENERGY DETECTION

4.3 MATCHED FILTER

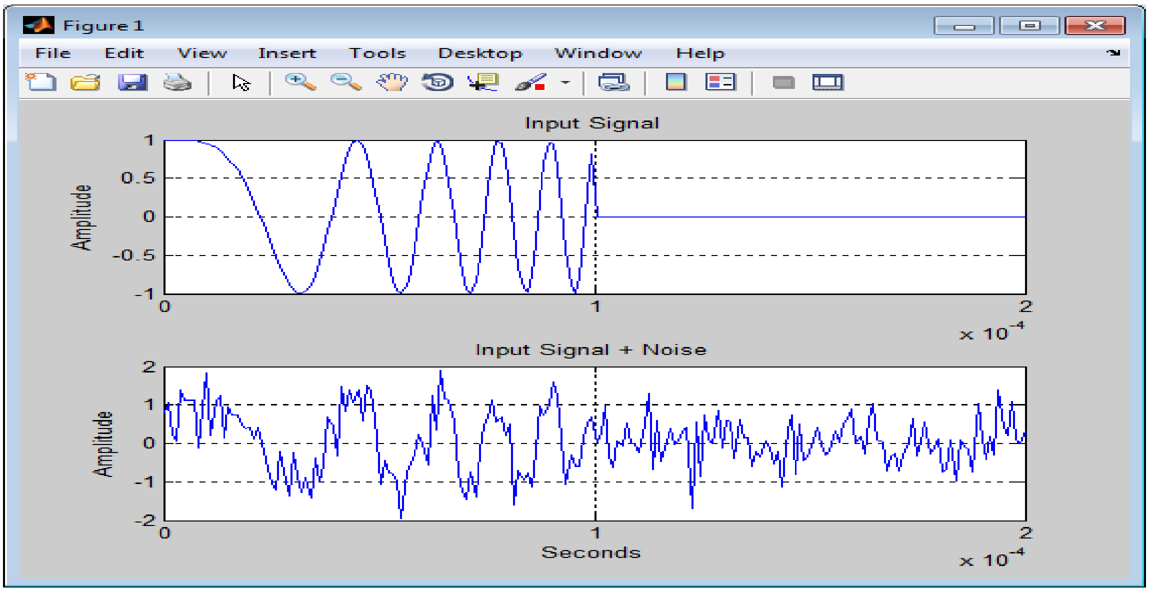


Fig 4.4(a) LINER FM WAVEFORM AND NOISE MIXED INPUT SIGNAL

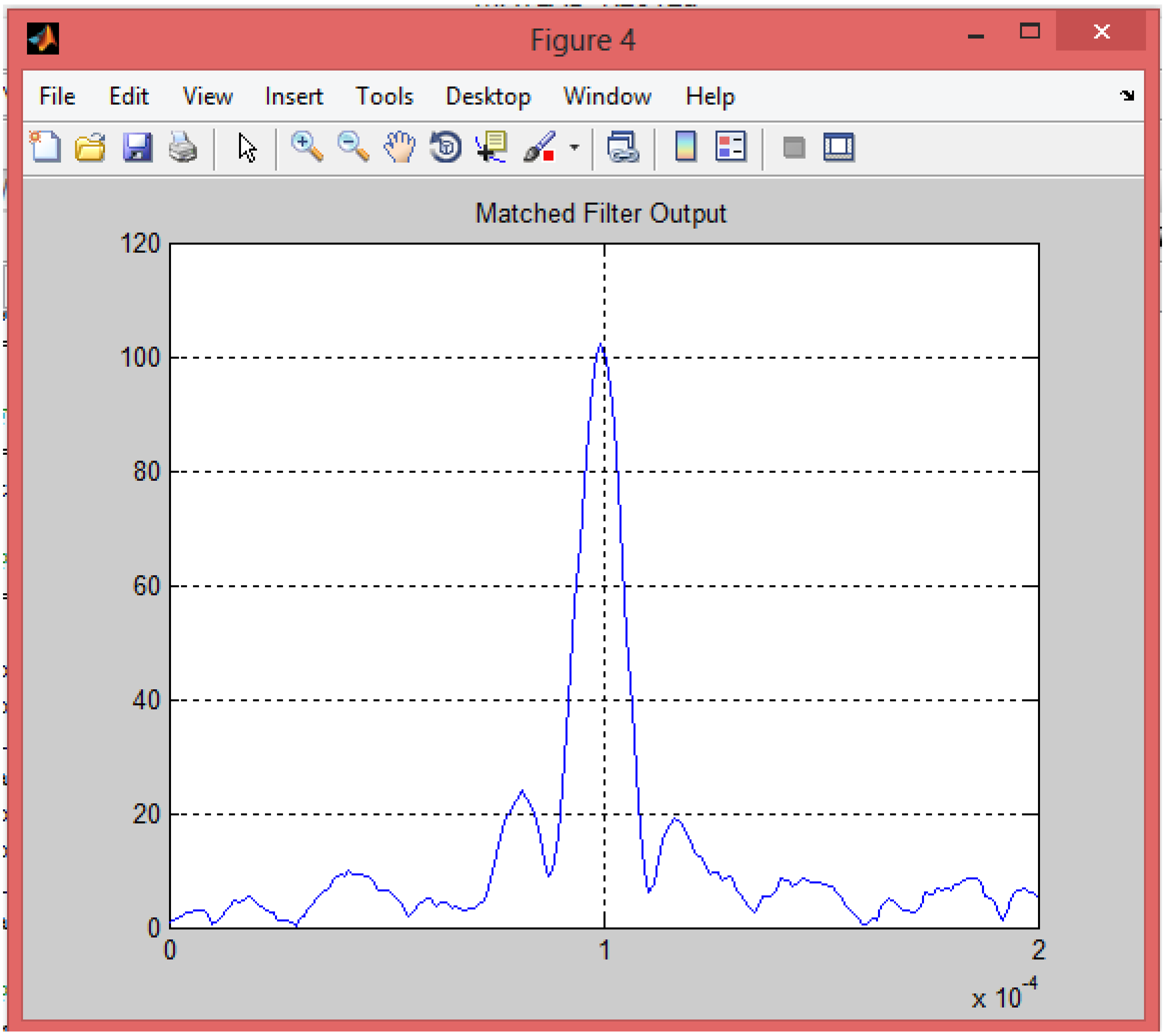


Fig 4.4(b) MATCHED FILTER OUTPUT.

4.4 OFDM Based Matched Filter

- we apply ofdm modulation techinique to the input data points
- we used 64 data points and block size of ofdm is 8
- modulation technique is qpsk

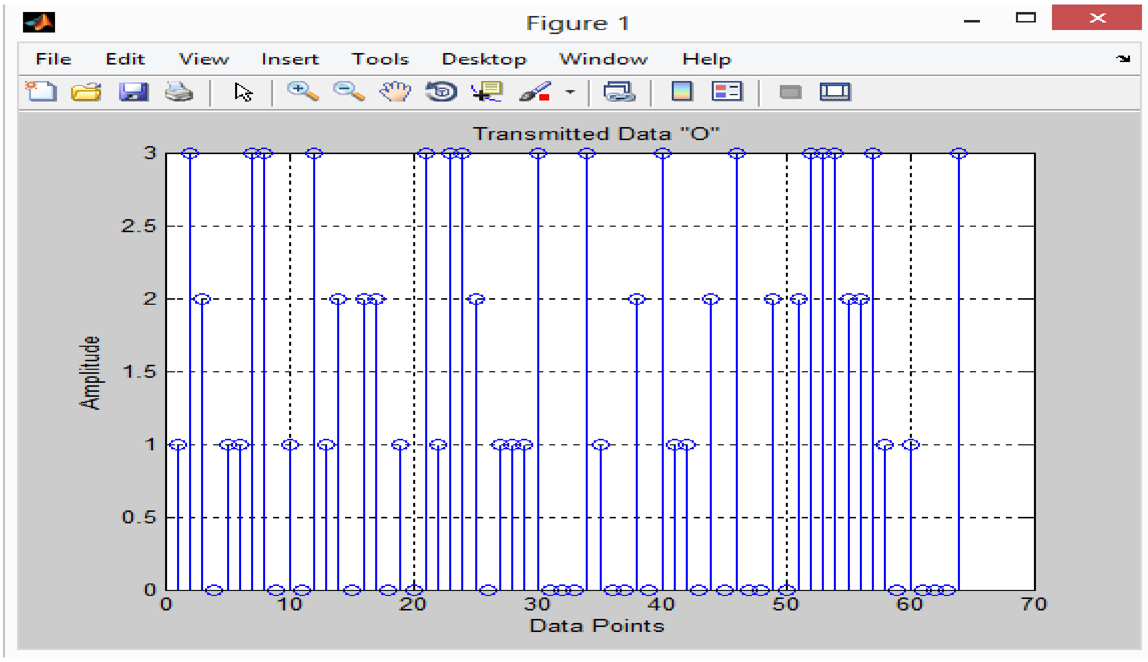


Fig 4.5(a) INPUT DATA POINTS

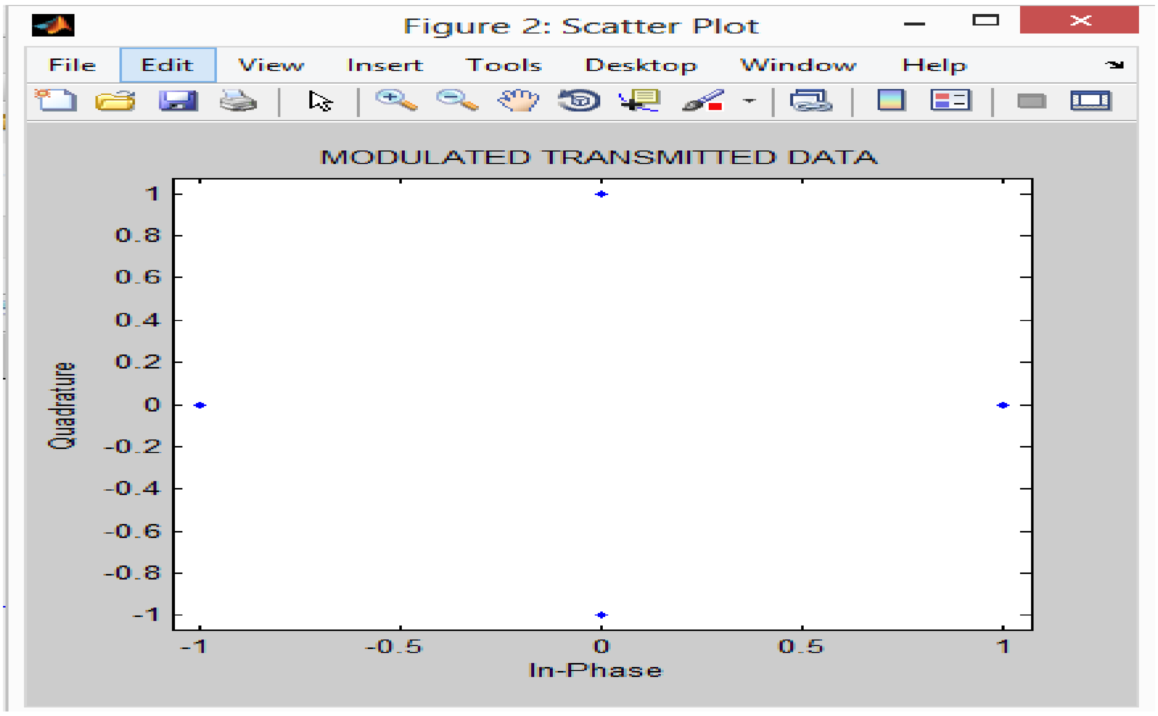


Fig 4.5(b) QPSK MODULATED DATA POINTS

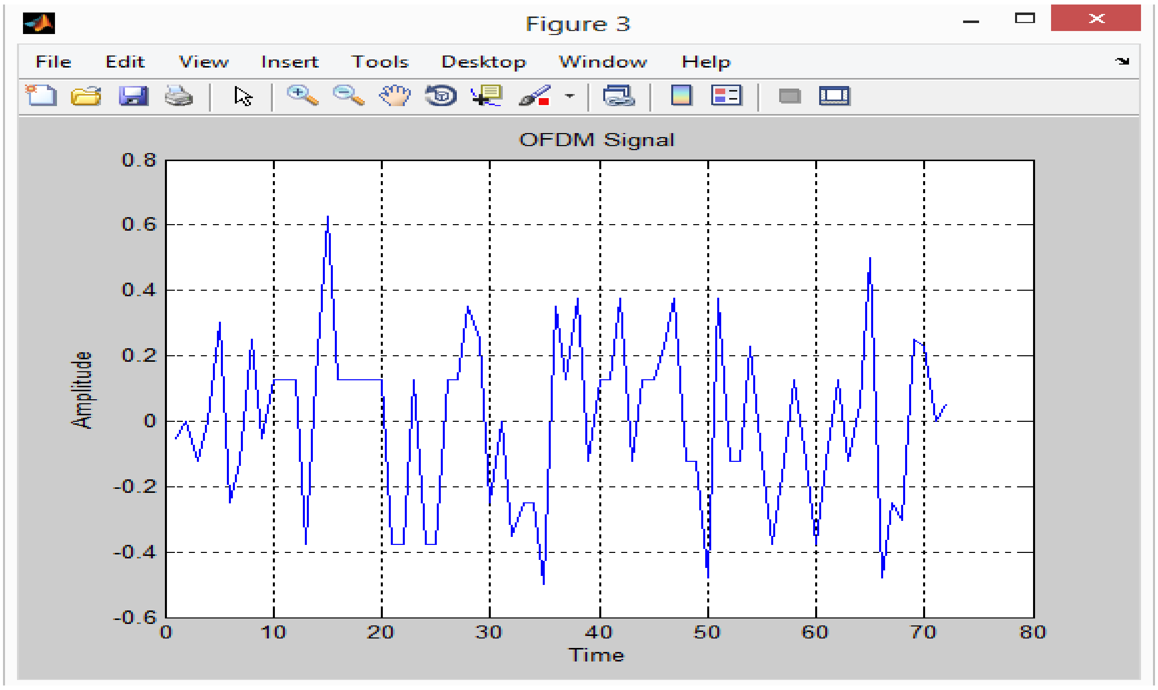


Fig 4.5(c) GENERATED OFDM SIGNAL

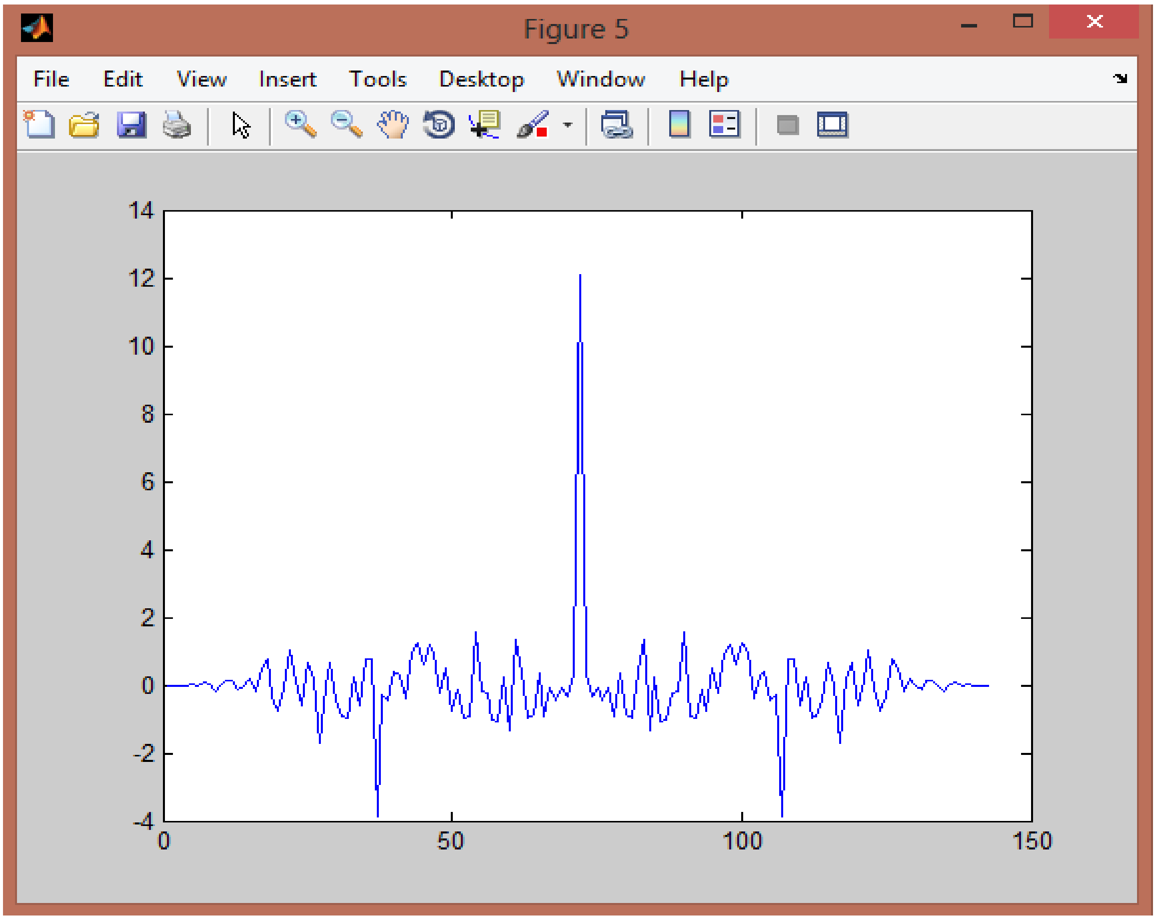


Fig 4.5(d) MATCHED FILTER OUTPUT.

Chapter 5

DISCUSSION

The threshold function used in analysing energy detection method is Th (i) =gammaincinv (1-pfa (i), u)*2 pfa means probability of false alarm ,Theoretical function for probability of detection in energy detection method is Pd_theory(i)=marcumq(sqrt(pn*2*u),sqrt(th(i)),u); Here pn =noise power

ROC curves are used to plots of the probability of detection vs. the probability of false alarm in energy detection. The probability of detection varies based on SNR, false alarm probability. When SNR increases, the detection probability increases. Matched Filter can be used when signal features are known before.

A matched filter can detect only a particular frequency signal one way is to estimate the energy of the signal and reduce it to half, fix it as a threshold. Another way is to compute the standard deviation of the signal by computing the mean and use it as threshold. Each sensing technique had its own advantages and disadvantages. As, Matched filter detection improved SNR, but required the prior information of PU for better detection. Energy detection had the advantage that no prior information about the PU was required. But did not perform well at low SNR, there was a minimum SNR required after which it started working.

We studied Cyclostationary feature detection performed better than both, matched filter detection and energy detection. Cyclostationary feature detection outperformed other two techniques. However, its processing time very large and implementation was complex.

Chapter 6

CONCLUSION

we analyzed the performance of spectrum sensing technique energy detection, the spectrum sensing results are gathered in terms of probability of false alarm (Pf), probability of PU detection alarm (Pd), for a specific SNR. we analysed the performance of spectrum sensing technique matched filter for OFDM modulated signal .Matched filter and cyclostationary feature techniques both require prior information of PU and implementation Is complex, while energy detector does not require PU information, easy to implement, and speed of operation.

REFERENCES

1. Beibei Wang and K. J. Ray Liu, “**Advances in Cognitive Radio Networks: A Survey**”, *IEEE journal of selected topics in signal processing vol .5, Feb 2011*.
2. Tevfik Y¨ucek and H¨useyin Arslan, “**A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications**”, *IEEE communications survey & tutorials, vol .11, first quarter 2009.*
3. Deepa Bhargavi and Chandra R. Murthy “**Performance Comparison of Energy, Matched-Filter and Cyclostationarity-Based Spectrum Sensing**”, *M. E. Thesis, Indian Institute of Science, India*, may-2010.
4. Shiyu Xu, Zhijin Zhao, Junna Shang, “**Spectrum Sensing Based on Cyclostationarity**” Workshop on Power Electronics and Intelligent Transportation System,2008.
5. Ashish Bagwari,"**Comparative performance evaluation of Spectrum Sensing Techniques for Cognitive Radio Networks**" Fourth International Conference on Computational Intelligence and Communication Networks 2012
6. S.Shobana, R.Saravanan, R.Muthaian **"Matched Filter Based Spectrum Sensing on Cognitive Radio for OFDM WLANs**" S.Shobana et al. / International Journal of Engineering and Technology (IJET).