QUALITATIVE COMPARISON OF CYCLOSTATIONARY BASED SENSING TECHNIQUES IN COGNITIVE RADIO

Project Report submitted in partial fulfillment of the requirement for the degree of

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under the Supervision of

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to

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Certificate

This is to certify that project report entitled **Qualitative comparison of cyclostationary based sensing technique** in cognitive radio submitted by Shivangi Kulshrestha (081124), Harjapjit Bakshi (081108), Pulkita Garg (081096) in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Date: 01/06/2012

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Abstract

Today, the network providers are dealing with an acute shortage of available spectrum for general communication purposes. This is mainly due to ineffective utilization of the radio frequency spectrum. To further complicate matters, there are more data users and data-using devices than ever. As of mid-2011, the number of data-using devices such as smart phones and tablets actually is quite high. Additionally, users are using more data than ever before with no signs of slowing. It is estimated that demand for data will increase by more than 50 times just in the next five years. All while the amount of available spectrum remains the same, creating a very real and very serious spectrum crunch. While solutions exist, there are techniques coming up to solve this problem and make the device faster and more agile. One such technique is taken up in this report.

Cognitive Radio, built on a software-defined radio, is defined as an intelligent wireless communication system that is aware of its environment.It is a transceiver that automatically changes its transmission or reception parameters, in a way where the wireless communications can have spectrum agility in terms of selecting available wireless channels opportunistically. The main process is also called dynamic spectrum management. The general technique is to sense the idle time of a particular spectrum and allot the spectrum to a secondary user (unlicensed) while the primary user (licensed) is inactive. Thus it can be identified as an opportunistic unlicensed access to the idle frequency bands across the licensed RF spectrum.

This requires an efficient identification of spectrum holes and a clear separation of information signal from noise through various detection techniques. There have been various standardized techniques which have been associated with cognitive radio as of today. The techniques are matched filter detection, energy based detection and Cyclostationary detection. The first two techniques have been succeeded by a more agile and efficient algorithm which is Cyclostationary feature detection. This detection scheme

has been proven beneficial for all types of transmissions. Not just that, it has come up with various offshoots to provide the best result for a particular data transmission. In this report we outline our work on the basic four of the offshoots of Cyclostationary based spectrum sensing techniques, namely: Single cycle sensor with Gaussian Noise, Single cycle sensor in Non-Gaussian noise, Multi-cycle sensor with Gaussian Noise and Multi-cycle sensor in Non-Gaussian noise. This provides for the ground work for the other offshoots which are more complex. We have simulated thesetechniques in MATLAB and tested them for different SNR scenarios.For a better comparison between the three spectrum sensing techniques, we have also simulated the former-matched filter and energy detection technique in MATLAB. There are also other parameters which have been considered bringing forth a more detailed evaluation. First, we have proven how Cyclostationary is better than the other two techniques, i.e. matched filter technique and energy based detection. In the second phase of our work we have compared different offshoots within each other.

Other than this, we have worked on certain tradeoff conditions that are essential in the practical implementation of any of these techniques. These conditions would help in designing such transmitters and receivers with more efficiency and better performance. Keeping in mind, the present scenario of dearth of spectrum, our work contributes majorly to the mobile communication world.

CHAPTER 1

INTRODUCTION

1.1 Current Spectrum Scenario

The radio frequency spectrum is a limited natural resource to enable wireless communication between transmitters and receivers.The use of this radio spectrum is governed by various government agencies. The ITU (International Telecommunication Union) at the UN level, TRAI (Telecomm Regulatory Authority of India) in India, FCC (Federal Communications Commission) in US and other such agencies are responsible for information and communication technologies. It coordinates the shared global use of the radio frequency spectrum. They license segments to particular users in geographic areas and the rest are left open for service providers to use as long as they abide by certain regulations.

With the recent boom in personal wireless technologies, the unlicensed bands have become crowded with frequency allocations for everything from wireless networks to digital cordless phones. The Federal Communication Commission estimates that the variation of use of licensed spectrum ranges from 15% to 85%, whereas according to Defense Advance Research Program Agency(DARPA) only 2% of spectrum is in use in the US at any given moment.In other words, a huge portion of the allocated spectrum is used sporadically, leaving a large portion of spectrum unused for large instants of time leading to spectrum under-utilization.This problem can be solved by dynamically looking at a spectrum as a function of both time and space.

Cognitive radios, based on software defined radio have emerged as an efficient solution to the under-utilization of the spectrum. These radios help in sensing when the spectrum is inactive by smartly sensing and adapting to the changing environment by altering their transmitting parameters. This radio allows the secondary users(unlicensed users) to borrow unused radio spectrum from primary licensed users while the spectrum is idle. By sensing to the environment a cognitive radio is able to fill the idle spectrum(spectrum hole) and allocate it to the secondary user without causing harmful interference to the licensed user.To do this, the cognitive radio needs to continuously sense the spectrum it is using for it to detect the reappearance of the primary user. The cognitive radio must withdraw immediately from the spectrum once the presence of primary user is detected in order to avoid interference.After scanning the radio spectrum, the following three situations were estimated:

- Few frequency bands in the spectrum are crowded/overloaded.
- Other frequency bands are used partially.
- Remaining frequency bands are used very rarely.

1.2 Main Objective

Our focus area of work is the evaluation of Cyclostationary based spectrum sensing technique and its offshoots in the presence of noisy environment to detect the spectrum holes.

In this report we outline our work on four of the offshoots of cyclostationary based spectrum sensing techniques, namely: Single cycle sensor with Gaussian Noise, Single cycle sensor in Non-Gaussian noise, Multi-cycle sensor with Gaussian Noise and Multi-cycle sensor in Non-Gaussian noise. We have simulated the four techniques and along with the other 2-enerdy detection and matched filter sensing techniques using MATLAB and the results are shown in this report. Also, a comparison of the performances of the various techniques has been included, based on trade-offs between noise interference, multiple secondary users, etc.

1.3 Other related terms and definitions

a. **Radio**:- It is a technology that is used for the transmission and receiving of information in the form of electromagnetic waves(radio waves).

b. **Radio waves**:-These are electromagnetic radiations lying in the radio frequency range from about 3 KHz to 300 GHz and travel at the speed of light.They are made to carry information by varying the amplitude, frequency , and phase of the wave within a frequency band.

c. **Radio spectrum**:-It is the part of the electromagnetic spectrum corresponding to radio frequencies which includes frequencies lower than 300 GHz and higher than 3 KHz. Different portions of the radio spectrum are used for different purposes and applications.A band is a small portion of the entire spectrum, set aside for a common purpose.

d. **Software**:-A set of instructions that are executed by a programmable process or a device which can be modified.
e. **Software defined Radio**:-A SDR is a radio that includes a transmitter in which the operating parameters including the frequency range, modulation type or maximum radiated or conducted output power can be altered by making a change in software without making any hardware changes. SDR is used to minimize hardware requirements; it gives user a cheaper and reliable --solution. But it will not take into account spectrum availability.
f. **Cognitive Radio**:- Cognitive radio is an intelligent adaptive radio system that is aware of its capabilities , its surrounding environment and has the ability to learn and act as per the user's requirement.
g. **Transmitter**:- It is an electronic device that has the ability to generate and radiate radio waves with the help of an antenna.
h. **Receiver**:-It is an electronic device that receives the radio waves transmitted by the transmitter. It extracts and converts the information contained in those waves into usable form. It is also used with an antenna

1.4 Thesis Layout

The first chapter offers a look into the current spectrum scenario, outlines our main objective and gives a thesis layout. The second chapter gives literature on Cognitive Radios, with the third chapter defining Spectrum Sensing and detailing on its classifications. The fourth chapter lays out a detailed theory on cyclostationary feature detection, our primary area of work. Finally, we have included our implementation and further research work on tradeoffs for system design of cognitive radios.

CHAPTER 2

CYCLOSTATIONARY PROPERTIES OF A SIGNAL

2.1 Stationarity

If $\{X(t)\}$ is a random process which is Gaussian in nature, its value at time, for instants t_1 and t_2 would be given by the joint Gaussian PDF equation.

$$f_{xx}(x,y) = \left(1/2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}\right)\exp\{-\left(\frac{X-mX}{\sigma X}\right)^2 - 2\sigma\left(\frac{X-mX}{\sigma X}\right)\left(\frac{Y-mY}{\sigma Y}\right) + \left(\frac{Y-mY}{\sigma Y}\right)^2\}$$

A general N-fold probability density function which completely describes the random process is a necessity in our studies. Such probability density function depends on N time instants $t_1, t_2 \ldots tn$. In certain PDFs, the time origin is immaterial. Such random processes are known as stationary. Or in other terms, *statistically stationary in the strict sense.* For these processes, means and variances are independent of time, and correlation coefficient (covariance) depends only on the time difference.

Any kind of noise is stationary in nature. This is the very basis of cyclostationary detection.

2.2 Correlation and Power Spectral Density

The autocorrelation function, as a statistical average is ergodic in nature. The Fourier transform of the autocorrelation function is the power spectral density S(f).

The Wiener-Khinchine theorem is a formal statement of this result for stationary random processes, for which.

$$R(t_1, t_2) = R(t_2 - t_1) = R_{xx}$$

For such processes, previously defined as wide sense stationary, the power spectral density and the auto correlation functions are Fourier pairs.

$$S(f) \leftrightarrow R(xx)$$

2.3 Power Spectral Density

Consider a particular sample function of a random process. To obtain a function giving power density versus frequency using the Fourier transform.

The time average power density over the interval $[-T/2, T/2]$ is computed. Since, the time average power density depends on the particular sample function chosen, the operation is preferably performed on an ensemble and the limit is taken as $T \rightarrow \infty$ to obtain the distribution of power density with frequency. This is defined as power spectral density.

2.4 Properties of an autocorrelation Function

Time averages are replaced by statistical averages in case of autocorrelation function.

2.4.1 The first property states that $|R_{xx}| <= R(0)$ for all time delays.

2.4.2 The second property states that $R(-t) = R(t)$. the proof of this property is quiet easy.

$$R(\tau) \triangleq \overline{X(t)X(t+\tau)} = \overline{X(t'-\tau)X(t')} \triangleq R(-\tau)$$

2.4.3 The third property states that when delay is close to infinity the autocorrelation is equal to the dc power of the signal. If in case, the original signal does not contain any periodic component.

$$\lim_{|\tau|\rightarrow\infty} R(\tau) \triangleq \lim_{|\tau|\rightarrow\infty} \overline{X(t)X(t+\tau)} \cong \overline{X(t)}\,\overline{X(t+\tau)} = \overline{X(t)}^2,$$

where $|\tau|$ is large.

2.4.4 The fourth and the most important property is that if the signal $X(t)$ is periodic, the autocorrelation function of the signal will also be periodic in nature.

CHAPTER 3

COGNITIVE RADIO: AN OVERVIEW

3.1 Introduction

Cognitive radio is a key technology that allows the proper utilization of spectrum and its allocation in a dynamic manner.The term 'Cognitive Radio' is defined by S. Haykin (Haykin, 2005) as follows:

"Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment, and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters(e.g., transmit power, carrier frequency, and modulation strategy) in real time, with two primary objectives in mind:

- *Highly reliable communication whenever and wherever needed.*
- *Efficient utilization of the radio system."*

The term cognitive radio was first suggested by Joseph Mitola (Mitola & Maguire, 1999).He defines the cognitive radio as a radio driven by a large store of a priori knowledge, searching out by reasoning ways to deliver the service the users want. The cognitive radio is a reconfigurable device with its platform as Software Defined Radio(SDR).Cognitive radio is also defined as a software defined radio with a cognitive engine brain.It uses software defined radio as well as adaptive radio in order to adjust its behavior so that the desired objective can be achieved.

To help improve the usefulness and effectiveness of the wireless communication, cognitive radio has enabled a number of capabilities that include the following functions:

- To exploit locally vacant or idle unused radio channels in order to provide new ways to access the spectrum.
- Roam across borders and perform self-adjustment to stay in compliance with all local radio operations and emissions regulations.
- Negotiate as a broker on behalf of the radio user with multiple service providers to give network access best matched to the user needs at the lowest cost.

- Adapt itself without user intervention to save battery power or to reduce interference to other users.
- Make use of location awareness to ensure that radio emissions do not interfere with licensed broadcasters.
- Understand and follow the actions and choices taken by their users to become more responsive and anticipate user needs over time.
- Formulate and issue queries, one radio to another.
- Execute commands sent by another radio.
- Fuse contradictory or complementary information

3.2 Cognitive radio network

The concept of cognitive radio can be further extended into the idea of a cognitive radio network.The cognitive radio network can be described as an intelligent multiuser wireless communication system having the following abilities:

i. To be able to perceive the outside world also referred to as the radio environment by giving each user's receiver the authorization to sense the surrounding environment continuously.

ii. To learn from the surrounding environment and accordingly adapt in response to the differences in that environment

iii. To allow communication among various users through co-operation in a self-organized manner.

iv. To limit the communication resources among those users.

v. To create the experience of self-awareness

3.3 Characteristics of Cognitive Radio

Cognitive radio dynamically selects the frequency of operation and also dynamically adjusts its transmitter parameters. The main characteristics of cognitive radios are Cognitive Capability, Agility and Flexibility.

- **Cognitive Capability:**

  Cognitive capability refers to the ability of radio to capture or sense information from its environment and perform real time interaction with it. This cognitive capability can be explained with the help of three characteristics:

Spectrum Sensing: -The spectrum sensing performs the task of monitoring and detection of spectrum holes.

Spectrum Analysis :- The spectrum analysis will estimate the characteristic of detected spectrum hole.

Spectrum Decision:- Cognitive radio predicts its own capabilities first for example the data rate, the transmission mode, and the bandwidth of the transmission. After that the appropriate spectrum band is selected from spectrum holes determined in spectrum sensing. Once the operating spectrum band is determined, the communication can be performed over this spectrum band. However, since the radio environment changes from time to time, the cognitive radio should be aware of the changes of the radio environment.

If some primary user wants to communicate on the spectrum band, which is in the use of cognitive radio then the spectrum mobility function is invoked to provide a seamless transmission. Any environmental change during the transmission such as primary user appearance, user mobility, or traffic variation can activate this adjustment.

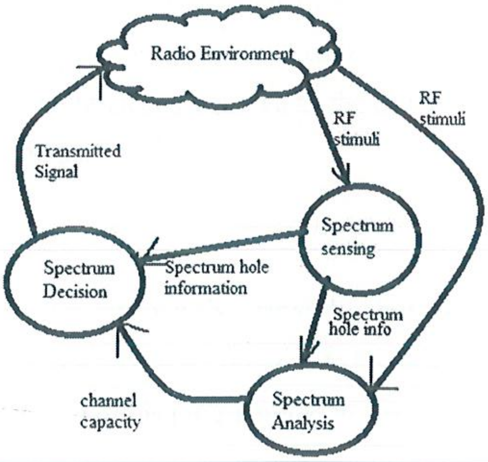

Figure 1:Cognitive Capability

- **Flexibility:**

Flexibility refers to the ability that allows the cognitive radio to adjust its parameters like link, operating frequency, modulation and transmission power at run time without any modifications in the hardware components. We can use different technologies depending on their spectrum availability with the same hardware. An example is a cell tower that can operate in the cell band for telephony purposes but change its waveform to get telemetry from vending machines during low usage, or other equally useful, schedulable, off-peak activity. The same band is used for two very different roles, and the radio characteristics must reflect the different requirements, such as data rate, range, latency, and packet error rate.

- **Agility**

Agility is the ability to change the spectral band in which a device will operate. Cell phones have rudimentary agility because they can operate in two or more bands (e.g., 900 and 1900 MHz). Combining both agility and flexibility is the ultimate in "adaptive" radios because the radio can use different waveforms indifferent bands. Specific technology limitations exist, however, to the agility and flexibility that can be afforded by current technology. The time scale of these adaptations is a function of the state of technology both in the components for adaptation as well as the capacity to sense the state of the system. These are classically denoted as the observable/controllable requirements of control systems.

- **Reconfigurability**

Spectrum awareness is provided by cognitive capability but reconfigurability allows the radio to be programmed dynamically in accordance to the environment surrounding it.To be more specific, the cognitive radio is programmed to transmit and receive on a large range of frequencies.

3.4 Main functions of Cognitive Radio

The main functions of cognitive radio are as follows:

i. **Spectrum Sensing:**

   This is a common function of cognitive radio. It is used to detect unused spectrum, also known as spectrum holes, and allocate it to an unlicensed user for use while it is not being used by the primary licensed user.

ii. **Spectrum management:**

   The best available spectrum band is decided to meet the requirements of the user without creating any interference to primary user. It is also used to estimate for how long the spectrum hole can be used by the unlicensed user.

iii. **Spectrum mobility:**

   It is the process when a user that is using a particular frequency band wants to change its frequency of operation. It tries to maintain seamless communication during the transmission of a particular user to a better spectrum.

iv. **Spectrum sharing:**

   It allows multiple users to coexist in the same region of spectrum. It decides how to fairly distribute the available spectrum fairly among all secondary users.

3.5 Cognitive radio applications

A cognitive radio can adapt to the needs of the user by sensing its environment i.e. by sensing the spectrum. Theoretically the radio spectrum is said to be infinite but practically due to the desirability of certain spectrum portions it is finite. No spectrum that that is licensed to a particular user is used at all instants and remains idle for a large amount of time. Hence, usage of spectrum efficiently is one of the major concerns in the world of communication. A promising solution to this is Cognitive Radio. A cognitive radio intelligently detects the unused portion of a spectrum and assigns it to another user temporarily. Cognitive radio has other capabilities too, which includes location identification, sensing the spectrum use of a neighboring system, changing the frequency on which it is operating as well as altering transmission parameters.

The cognitive radio is more beneficial over a conventional radio. It has the following advances due to which it is has many applications:

i. Improving spectrum utilization & efficiency
ii. Improving link reliability
iii. Less expensive radios
iv. Advanced network topologies
v. Enhancing SDR techniques
vi. Automated radio resource management

Cognitive radio applications are classified into 3 broad categories which are as follows:

1) Spectrum access applications

Access to the spectrum or a RF band is limited by regulatory constraints, but research in this field has shown that when examined as a function of frequency, time and space, its occupancy is low. Cognitive radio senses the unused spectrum through a dedicated sensor and hence may create increased opportunities for spectrum access.

2) Authentication applications

A cognitive radio learns the identity of the user(s). This application can hence prevent unauthorized users from using the CR.

3) Military/Emergency services

One of the direct applications of cognitive radio is for the military and public safety users.Cognitive radio offers them the necessary interoperability and quality of service. Since cognitive radios have the capability to adapt and adjust themselves, they can communicate between and among different standards at the same time.

3.6 Advantages and Limitations of Cognitive radio:

3.6.1 Advantages of Cognitive Radio:

Cognitive radios are expected to be powerful tools for mitigating and solving general and selective spectrum access issues. They are believed to be the key technology required to improve the utilization of spectrum and prevent it from getting wasted.The following are the advantages of cognitive radio:

1. A cognitive radio is a software defined radio along with the intelligence, awareness, learning and observational capabilities.It adjusts its operations in order to meet the QoS required by different users and services.
2. A cognitive radio proves greater spectrum efficiency through improved spectrum access. It is a technology that provides dynamic, opportunistic spectrum access. It can sense the idle spectrum bands and by dynamically altering its operating parameters, it makes use of the available vacant bands in an opportunistic manner.
3. Cognitive radio reduces as well as simplifies the tasks needed to set up and use a radio.A cognitive radio is aware of its user's goals and priorities and hence could simplify the operation of radios.Using cognitive functionality the burden of technical know-how on thepart of the user is significantly reduced.
4. By increasing the user throughput and system reliability it improves the wireless data network performance. Wireless sensor networks employ fixed spectrum allocation scheme. A wireless network can either operate in an unlicensed band or can lease the licensed spectrum. This involves high cost. Also the unlicensed bands are used by various other devices such as PDA's, Bluetooth devices and so the network experiencesan overcrowded spectrum band. Opportunistic spectrum access provided by cognitive radio can be used to maximize the performance of the network .
5. More adaptability and less coordination required between wireless network.

3.6.2 Limitations of Cognitive radio:

a) Denial of Service Attacks- ADoS attack is an act of preventing authorized access to a system resource or the delaying of system operations and functions. It is the denial of communication to legitimate users- the CRs- even when the system resources such as unused frequencies- are available. There are two types of DoS attacks- *denial* and *induce attacks.*

- Denial attacks prevent communication through placing victim CR into one of the following states:

  i. All available spectrum appears to be occupied by licensed (primary) transmitters.
  ii. Location information is unavailable or has too low accuracy.
  iii. Sensor is unavailable or has incorrect measurements.

iv. The cognitive engine cannot connect to the radio.

v. The operating system cannot connect to the cognitive engine.

- Induce class of DoS vulnerabilities is when CR is stimulated to cause interference with a licensed transmitter. While the result is not an immediate DoS, it may cause permission policies to be tightened or eliminated potentially denying service over the long term. A CR may cause interference with a licensed transmitter under one or more of the following conditions:

  i. The licensed spectrum appears unoccupied.

  ii. The location is incorrect.

  iii. The sensor provides incorrect measurements.

  iv. The commands to the T_x/R_x are incorrect.

b) Software reliability

- CR must be able to detect the presence of un-decodable signals. Just knowing the modulation scheme and codebooks is nearly useless.
- Even small noise uncertainty causes serious limits in detectability

CHAPTER 4

SPECTRUM SENSING

4.1 Introduction

The ultimate objective of the cognitive radio is to obtain the best available spectrum through Cognitive Capability, Flexibility and Agility as described above. Since there is already a shortage of spectrum, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users. The cognitive radio enables the usage of temporally unused spectrum, which is referred to as a *spectrum hole* or *white space*. If this band is further used by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference.

The cognitive capability of a cognitive radio enables real time interaction with its environment to determine appropriate communication parameters and adapt to the dynamic radio environment.

In spectrum sensing a cognitive radio senses the radio environment, finds available spectrum band, estimates interference temperature of the radio environment and detects spectrum holes.

4.1.1 Interference temperature

The idea of interference temperature was introduced for quantifying and managing interference.Interference temperature is a measure of the RF power generated by undesired emitters along with noise which is present in the receiver per unit bandwidth. By regulating the received power, a cognitive radio is able to measure the current interference environment and hence adjusts its frequency band to prevent harmful interference to the licensed users. After obtaining the interference temperature two important limits can be estimated:

- The maximum level where any signal exceeds the threshold
- The minimum level where any signal below it can be neglected and the band can be declared as empty or unused, hence be assigned to a secondary user.

4.1.2 Spectrum Holes

A spectrum hole is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not utilized by that user. Primary users are those who hold the licensed channels or primary bands.

As said above radio scene analysis includes two functionality. These two stages are performed periodically. The interference temperature is suggested to be estimated for the whole targeted frequency ranges. Then depending on the current interference and the interference temperature on the previous iterations all channels can be classified into three types of spectrum holes:

- White spectrum holes, which are fully not used.
- Gray spectrum holes, which are partially used.
- Black spectrum holes, which are fully used.

After the sensing operation is completed, the users are allowed to access freely the white holes and partially use the gray holes in such a way that does not disturb the primary user. But they will not use the black holes, because the black holes are assumed to be fully used and any extra use will interfere with the ongoing communication in them.

4.2 Conventional Spectrum sensing

Since cognitive radio is an intelligent wireless communication radio device, it should be able to sense the environment and also adapt itself to optimize the spectral utilization.Spectrum sensing is an important element in cognitive radio since it must be performed before allowing a secondary unlicensed user to access a vacant licensed spectrum. It is based on a binary hypothesis test which is as follows:

$$H_0 : x(t) = n(t)$$

$$H_1 : x(t) = n(t) + s(t)$$

Where x(t) is the complex signal received by the cognitive radio, s(t) is the transmitted signal of the primary user, n(t) is the noise. H_0 represents the null hypothesis that no primary user is present, only noise is present and H_1 is the alternate hypothesis that a primary user signal exists.

The key metric in spectrum sensing are the probability of correct detection (P_d).

$$P_d = prob\{decision = H_1/H_1\}$$

Two errors can occur while sensing the spectrum. The first is the probability of false alarm(P_f), i.e., detection of signal when the channel is actually vacant, no primary user is present. This happens when the cognitive incorrectly senses noise as the primary user signal.

$$P_f = prob\{decision = H_1/H_0\}$$

The second is the probability of misdetection (P_m) ,i.e, when the cognitive radio labels an occupied spectrum as vacant. This happens when the radio is not able to sense the signal due to its low signal to noise ratio or when the primary user signal is very weak.

$$P_m = prob\{decision = H_0/H_1\}$$

4.3 Spectrum Sensing methodologies

Number of attributes must be included in any cognitive radio spectrum sensing technique.These are used to ensure that spectrum sensing undertaken meets the requirements of a specific application. These also ensure that the cognitive radio system avoids interference to other users as well as maintains its own performance.These methodologies and attributes are:

i. **Spectrum sensing bandwidth:** -A number of issues are associated with spectrum sensing bandwidth. The first is on how many channels will the system sense effectively whether or not they are occupied. If the system does not sense other channels apart from the one which is in use it will not know about the alternative channels that can used should the current one become occupied. The actual reception bandwidth also needs to estimated. A narrow bandwidth reduces the system noise floor and hence improves the sensitivity, but a sufficiently wide bandwidth is required to detect the unused channels for transmission

ii. **Transmission type sensing**:- The system should be capable enough to identify the transmission of the primary user of the channel. It also must identify the other transmissions in the same system such as those of spurious signals, etc.

iii. **Spectrum sensing accuracy:**- The spectrum sensing technique being used must be able to detect the presence of any other signal so as to reduce the rate of false alarms.

iv. Spectrum sensing timing window:- The spectrum sensing technique should allow time slot so as to enable the detect other signals when it is not transmitting.

4.4 Classification of spectrum sensing techniques

The main challenge to the Cognitive radios is the spectrum sensing. In spectrum sensing there is a need to find spectrum holes in the radio environment for CR users. However it is difficult for CR to have a direct measurement of channel between primary transmitter and receiver.

A CR cannot transmit and detect the radio environment simultaneously, thus, we need such spectrum sensing techniques that take less time for sensing the radio environment.

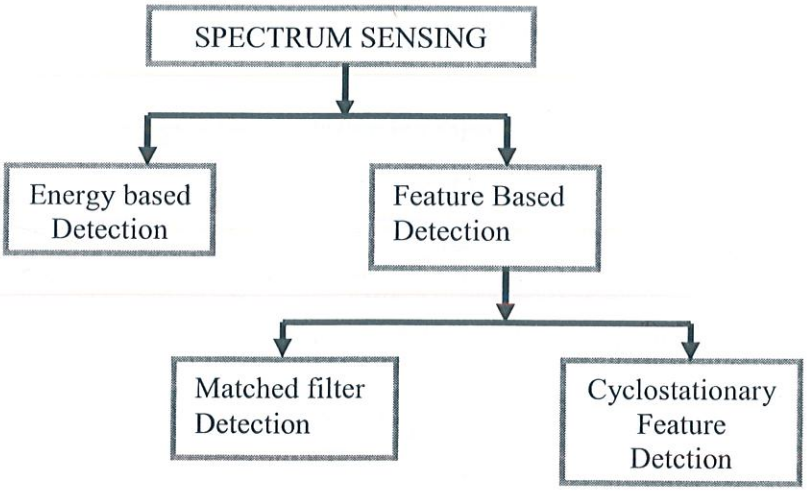

Figure2:Spectrum sensing classification

4.4.1 Energy Based Detection Technique

Energy Detector based approach, also known as the radiometry, is the most common way of spectrum sensing because of its low computational and implementational complexities. Also it does not require any prior knowledge of the primary signal.

The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor. If the energy is less than the threshold value, the spectrum is declared as idle or a spectrum hole is declared.

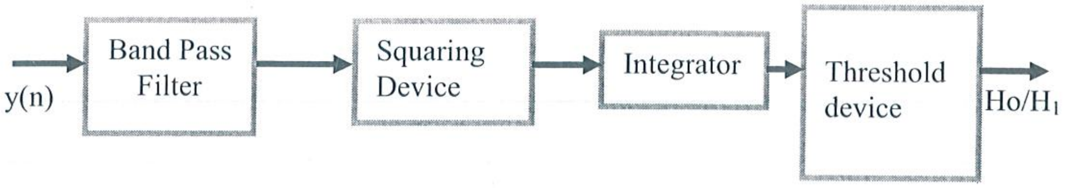

Figure 3: Block diagram of Energy Detector

The block diagram for energy detection technique is shown in figure3.

First, the input signal x(t) is filtered using a band pass filter to select the bandwidth of interest W. The filtered signal is then squared and integrated over the observation time T.Finally, the output of the integrator is compared to the threshold to decide whether the primary user is present or not. When the spectral environment is analyzed in the digital domain, energy detection can be implemented using Fast Fourier Transform (FFT) based method.

Assuming that the received signal has the following form:

$$y(n) = x(n) + w(n)$$

Where x(n) is the signal to be detected and w(n) is the additive white Gaussian noise sample and n is the sample index. The signal x(n)=0 when there is no transmission by the primary user. The decision matrix for the energy detector can be written as:

$$M = \sum_{n=0}^{N} |y(n)|^2$$

where, N is the size of the observation vector.

The decision on the occupancy of the band can be obtained by comparing the decision metric M against a fixed threshold value λ_E.

The performance of the detection algorithm can be summarized with the following two probabilities:

P_Di.e. probability of detection: It is the probability of detecting a signal when it is truly present. It can be formulated as:

$$P_D = P_r(M > (\lambda_E|H_1)$$

P_Fi.e. probability of false alarm: It is the probability that the test incorrectly decides that the considered frequency is occupied when it actually is not. It can be written as :

$$P_F = P_r(M > (\lambda_E | H_0)$$

$P_F$should be kept as small as possible in order to prevent underutilization of transmission opportunities. The decision threshold λ_E can be selected for finding an optimum balance between $P_D$andP_F .

Advantages:

1. Low computational and implementational complexity
2. No prior requirement of primary user signal

Drawbacks:

1. Performance is highly susceptible to noise level uncertainty.
2. It is difficult to set the threshold used for primary user detection since it is highly susceptible to the changing background noise and especially interference level.
3. Inability to differentiate interference from primary user and noise.
4. Poor performance under low SNR values.

4.4.2 Matched Filter Detection

A matched filter is a linear filter designed to maximize the output signal to noise ratio for a given input signal. When secondary user has a prior knowledge of primary user signal, matched filter detection is applied.

Matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and the time shifted version of a reference signal. The operation of the matched filter detection is expressed as :

$$y(n) = \sum_{k=-\infty}^{\infty} h[n-k]x[k]$$

Where ‘x’ is the unknown signal and is convolved with ‘h’, the impulse response of matched filter that is matched to the reference signal to maximize the SNR. Detection by using matched filter is useful on in cases where the information of the primary user signal is known to the cognitive users.

Matched filters are extensively used in radio communications and radar transmissions. In the cognitive radio scenario, however, use of matched filter as a spectrum sensing technique is highly limited since the information of the primary user signal is very rarely available to the cognitive radio.If however, partial information of the primary user is available, such as pilot, matched filter can be used for coherent detection.The architecture digital implementation of coherent pilot detection is shown in following figure.

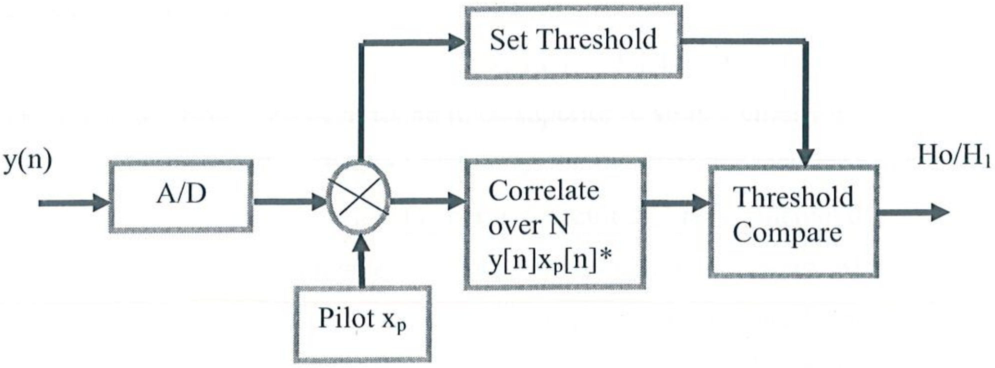

Figure 4: Digital Implementation of a coherent Pilot Detector

Advantages:

1. Matched filter detection requires short time to achieve a certain probability of false alarm or probability of misdetection as compared to other techniques.

Disadvantages:

1. Matched filter detection requires prior knowledge of every primary signal. If the information is not accurate, Mf performs poorly.
2. Since cognitive radio needs receivers for all signal types, the implementation complexity of sensing unit is large.
3. Large power consumption as various receiver algorithms need to be executed for detection.
4. In matched filter detection, a cognitive radio has to perform timing, carrier synchronization and even channel equalization. So, a cognitive radio needs a

dedicated receiver for every kind of primary system, which increases the complexity of the system.

4.4.3 Cyclostationary feature detection

We introduce the cyclostationary feature detection in the next chapter. We choose to work with this technique because of the various advantages it has over other transmitter detection techniques.

Recent research efforts exploit the cyclostationary feature of signal as method for classification, which has been found to be superior to simple energy detection and match filtering. As discussed, a matched filter as a coherent detector requires prior knowledge about primary user's wave whilean energy detector as a non-coherent detection does not require any sort of prior knowledge about primary user's waveform. Although energy detector is easy to implement, it is highly susceptible to band interference and changing noise levels and cannot differentiate between signal power and noise power. Whereas, cyclostationary based detection algorithm can differentiate noise from primary user's signals. This is because of the fact that noise is wide sense stationary with no correlation while modulated signals are cyclostationary with spectral correlation due to redundancy of signal periodicities. Furthermore, cyclostationarity can be used for distinguishing among different type of transmissions and primary users.

If the correlation factor is greater than the threshold then it means that there is a primary user in radio environment. Although it performs better than energy detector because it can differentiate between signal power and noise power, it is computationally very complex that requires long processing time, which generally degrades the performance of CR.

CHAPTER 5

CYCLOSTATIONARY FEATURE DETECTION

5.1 Introduction

Signal processing techniques motivate the need to study other feature detection techniques that can improve sensing detection and recognize modulation, number and type of signals in low SNR regimes, and this is what our project work pertains to. We have chosen Cyclostationary Feature Detection over the other types of transmission detection techniques because it gives better results than Matched Filter Detection or Energy Based Detection under low SNR values, i.e. values below -30dBs. Furthermore, the cyclostationary feature detection out performs the other two techniquesas 100% "probability of primary detection" and zero "probability of false detection" is achieved at -8 dBs.

A detailed overview of the cyclostationary feature detection is given as under.

5.2 Background

Modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hopping sequence, or cyclic prefixes which results in built in periodicity. Even though the data is stationary random process, these modulated signals are characterized as cyclostationary. This is because their statistics- mean and autocorrelation- exhibit periodicity. These features are detected by analyzing a spectral correlation function.The periodicity is provided for signal format so that receiver can use it for parameter estimation like pulse timing, carrier phase etc. This periodicity can be used in the detection of random signals with a particular type of modulation with the noise and other modulated signals.

A process x(t) is said to be cyclostationary in wide sense stationary if its mean and autocorrelation are periodic with a period T_0 i.e.

$$Mx(t + T_0) = Mx(t)$$

And

$$Rx(t_1, t_2) = Rx(t_1 + T_0, t_2 + T_0)$$

Where the autocorrelation function is given by:

Taking $t_1 = t + \tau/2$ and $t_1 = t - \tau/2$

$$Rx(t + \tau/2, t - \tau/2) = E\{x(t + \tau/2)x(t - \tau/2)\}$$

Since the autocorrelation is periodic in t with period T_0, it can be expressed as a Fourier Series:

$$Rx(t + \tau/2, t - \tau/2) = \sum_{\alpha} R_x^{\alpha}(\tau)e^{j2\pi\alpha t}$$

Where the sum is over the integer multiples of fundamental/cyclic frequency, α which is reciprocal of the period T_0.

The Fourier co-efficient $R_x^{\alpha}(t)$, which depend on the lag parameter τ, are given by:

$$R_x^{\alpha}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_T x(t + \frac{\tau}{2})x(t - \frac{\tau}{2})^* e^{-j2\pi\alpha t} dt$$

The function $R_x^{\alpha}(t)$ is called the cyclic autocorrelation function.For α=0, it reduces to the conventional autocorrelation function $R_x^0(t)$.

According to the cyclic Wiener relation, the spectral correlation function (SCF)/Cyclic spectral Density (CSD) can be obtained from the Fourier transform of the cyclic autocorrelation function:

$$S_x^{\alpha}(f) = F\{R_x^{\alpha}(\tau)\} = \int_{-\infty}^{\infty} R_x^{\alpha}(\tau)e^{-j2\pi f\tau} d\tau$$

For α=0 it reduces to the conventional power spectral density (PSD), that is the spectral density of the time-averaged power. However for α≠0, it can be shown that $S_x^{\alpha}(f)$ is the density of spectral correlation between spectral components at the frequencies $f + \alpha/2$ and$f - \alpha/2$.

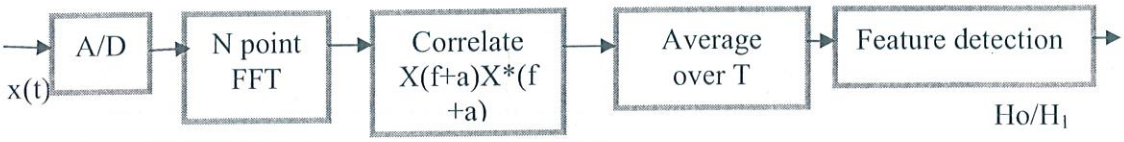

Figure 5: Block diagram for implementation on cyclostationary feature detection.

Implementation of spectrum correlation function for cyclostationary feature detection is depicted in figure 4. Detected features are number of signals, their modulation type, symbol rates and presence of interferers.

The SCF function outputs peak values when the cyclic frequency is equal to the fundamental frequencies of transmitted signal $x(n)$.

5.3 Advantages and Limitations

Advantages:

1. The main advantage of cyclostationary detection is that it can distinguish between noise and the signal. This is due to the fact that noise has no spectral correlation function whereas the modulated signals which are cyclostationary in nature have spectral correlation due to the embedded redundancy of signal periodicities.
2. Cyclostationary detector is more robust to noise uncertaininty than an energy detector
3. It can work in low SNR regions since it exploits the information embedded in the received signal.

Limitations:

1. The implementation of cyclostationary feature detection is more complex.
2. These detectors also require longer observation time than energy detectors. Hence, the spectrum holes with short time duration may not be exploited efficiently.

5.4 Cyclostationary Feature Detection Offshoots

Cyclostationary based detector is heavily under research and until date has been categorized under the following heads on the basis of the various properties:

1. Single Cycle(SC) detector in Gaussian noise
2. Single Cycle detector in Non-Gaussian noise
3. Optimum MultiCycle(MC) detector in Gaussian noise
4. Optimum MultiCycle detector in Non Gaussian noise
5. Suboptimum MC detector
6. GLRT for cyclostationarity
7. GLRT MultiCycle detector
8. Spatial sign detector
9. DVB-T detector
10. Spread-spectrum signal detector
11. Synchronized averaging based test

5.4.1 Single Cycle Detectors

Single cycle detector is the most basic least complex Cyclostationary detector. This detector works on the correlation function but for only one single cyclic frequency. I.e. for the same lag in the Fourier expansion of any signal embedded noise. This is one reason why single cycle detector is not very pragmatic in nature.

Generally, the signal which is transmitted belongs to different primary users in the same spectrum band. Single cycle detector can operate for the attributes of a single primary user. It is generally used in the initial session to test a detector however, with more complex situation, we switch to the other off shoots which have been mentioned in the report.

The complexity of single cycle detector is greater than energy detector.

5.4.2 Multi Cycle Detectors:

Typical communication signals exhibit cyclostationarity at multiple cyclic frequencies instead of just a single cyclic frequency.That is, for example a signal that is cyclostationary at the symbol frequency is typically cyclostationary at all integer multiples of the symbol frequency as well. If one is testing for the presence of many different signals at a given frequency band, or in case the cyclic frequencies are unknown, it would be desired to test over the entire set of cyclic frequencies. This is especially desirable in a cognitive radio application where aim is to find the unoccupied frequency bands i.e. in case of spectrum sensing. Otherwise the frequency band may unnecessarily be classified as occupied for most of the time.

CHAPTER 6

IMPLEMENTATION AND SIMULATION RESULTS

For a better comparison between the three fundamental detection techniques, we simulated graphs for all three detection techniques.

6.1 Energy Detection:

The simplest detection technique for spectrum sensing is Energy Detection. As discussed in Chapter 2 energy detector measures the energy received from primary user during the observation interval. If energy is less then certain threshold value then it declares it as spectrum hole.

6.1.1 Algorithm

The algorithm for energy detection in a simple AWGN environment that we have simulated is as follows:

Step 1: First estimate Power Spectral Density (PSD) by using periodogram function in MATLAB.

$$Pxx = Periodogram(r)$$

Step 2: The power spectral density (PSD) is intended for continuous spectra. The integral of the PSD over a given frequency band computes the average power in the signal over that frequency band.

$$Hpsd = Dspdata.psd(P_{xx}))$$

Step 3: Now one frequency component takes almost 20 points in MATLAB. So for each frequency there points are summed and the result is computed.

Step 4: On experimental basis when results at low and high SNR are compared then threshold λ is set to be 5000.

Step 5: Finally the output of the integrator, Y is compared with a threshold value λ to decide whether primary user is present or not.

The MATLAB script '*energydet.m*' is present in the end, in the appendix.

6.1.2 Output and Analysis

The output of energy detector when there is primary detector user present at 100 Hz using a very good SNR(30 dB). At a poor SNR (-30 dB) there are clearly many peaks, and the detector compares every point with the threshold, hence, energy detector said that primary users are present at all along the spectrum.

The figure 5 shows the output in an SNR of 30 dB and the figure 6 shows the output in the SNR of -30 dB.

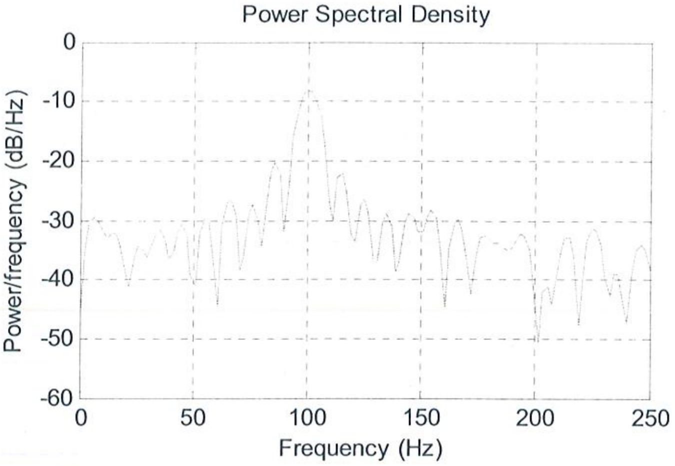

Figure 6(a): Energy Detector output at SNR 30dB

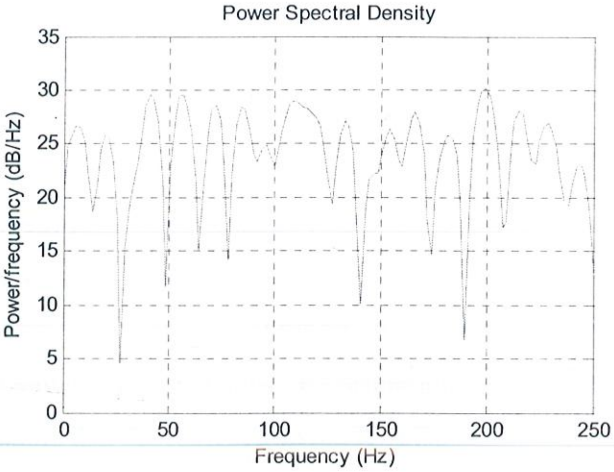

Figure 6(b): Energy Detector output at SNR -30dB

Clearly, for a BPSK signal, energy detector does not show satisfactory results in poor SNR. When there is no primary user, even then energy detector detects primary user in low SNR conditions. This is the main drawback of energy detector. In these conditions, it is not able to distinguish between noise and signal. Hence, if it is white noise (we have used the AWGN channel), it shows primary user present all around the spectrum.

6.2 Matched Filter

Matched filter requires prior knowledge about the primary user's waveform. Hence, it requires less sensing time for detection.

6.2.1 Algorithm

The algorithm used to implement matched filter on a laboratory level is as under:

Step 1: For the matched filter prior knowledge of primary user waveform is required. Therefore a local carrier is generated using local oscillator.

Step 2: $xcorr$ estimates the cross-correlation sequence of a random process. Autocorrelation is handled as a special case.

Step 3: On experimental basis when results at low and high SNR are compared then threshold λ is set to be ± 35.

Step 4: Finally the output of the integrator, Y is compared with a threshold value λ to decide whether primary user is present or not.

The MATLAB implementation of the above algorithm is given as *matchdfilt.m* in the appendix.

6.2.2 Output and Analysis

In our case (BPSK signal), two pulses p(t) and –p(t) are considered. The correlation coefficient of these pulses is -1. Under good SNR conditions the receiver computes the correlation between p(t) and the received pulse. If correlation is 1, we receive a neat bell curve, otherwise, we assume that the received signal is –p(t).

When SNR conditions are not good the correlation coefficient is smaller in magnitude which means the distinguishability is reduced.

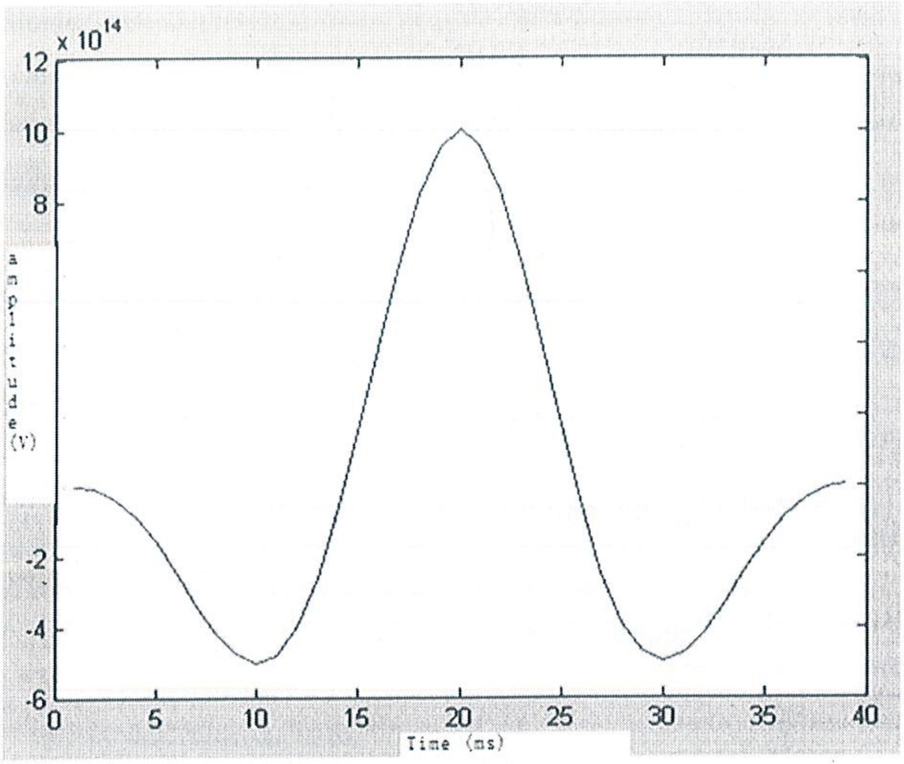

Figure 7: Matched Filter output at SNR 30 dB

6.3 Cyclostationary Detectors

6.3.1 Basic Modeling

To implement the detector, SCF of the given signal is taken at the kth cyclic frequency, where the value of k can vary from 0 to ∞.

Whenever a signal is converted into the frequency domain, the Fourier expansion gives us the Fourier coefficients which are the periodic auto correlation function. The lag between two consecutive coefficients is known as the cyclic frequencies.

Whenever we use only one cyclic frequency, the detection is called single cycle detection and when more than one cyclic frequency is used, the detection is called multi cycle detection.

Single Cycle Detector:

This kind of detector is the simplest and has the least delay. It measures signal power for only one cyclic frequency. If x(t) is the received signal, its auto correlation is given by the following expression:

$$R_x^\alpha(\tau)=\lim_{t\to\infty} 1/T \int_{t-T/2}^{t+T/2} x\left(t+\frac{\tau}{2}\right) x(t-\frac{\tau}{2})^* \, e^{-j2\pi t\alpha} dt$$

For $t = mT$ (where Ts is the sampling period)

Hence, the sufficient statistics in different hypotheses can be represented as follows:

$$H_0: Y_{sc} = \frac{1}{N_s} \sum n\text{^}[m]\, e\text{^}(-j2\alpha\pi m)$$

$$H_1: Y_{sc} = \frac{1}{N_s} \sum \quad (s[m] + n[m])^2 e^{-j2\alpha\pi m}$$

Where $n[m]$ is an AWGN Gaussian noise sample.

Further two subsets of this detector have been considered.

1. in Gaussian noise
2. in Non-Gaussian noise

6.3.2 Single Cycle Detection in Gaussian Noise

6.3.2.1 Algorithm

Algorithm to plot power v/s frequency graph and find out if the signal exists or not:

Step 1: First take Fourier of the received signal by using 'fft' function.

$$X(f) = fft(x)$$

Step 2:take the absolute value of the Fourier transform of the given signal. After which its square is taken. This gives us the power spectrum density.

$$X_{PSD} = |X(f)|^2$$

Step 3: compute the autocorrelation function by taking out the inverse fourier transform of the value obtained in step 3.

$$Y = ifft(X_{PSD})$$

This value is periodic in time. It is this periodicity we exploit to check whether or not the signal is present.

Step 4: On experimental basis when results at low and high SNR are compared then threshold is set.

Step 5: Finally the output is compared with a threshold value λ to decide whether primary user is present or not.

6.3.2.2 Output and Analysis

The output of the above mentioned simulations were formulated in the form of graphs and are given as under.

In order to make the comparison a little easier, we have first shown how a pure signal (cosine wave in this case) behaves while undergoing Cyclostationary Feature Detection.

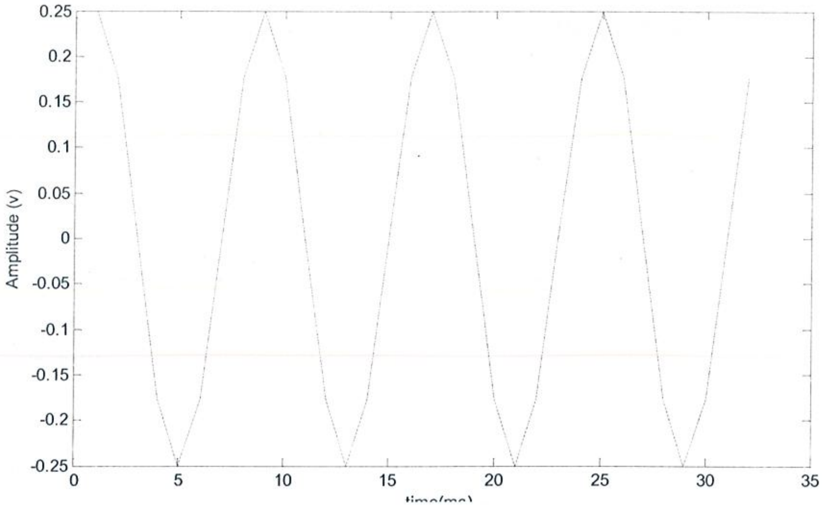

Figure 8(a): Cosine Waveform for Cyclostationary feature

The above graph shows a cosine waveform, the PSD of the same has been shown in the next graph.

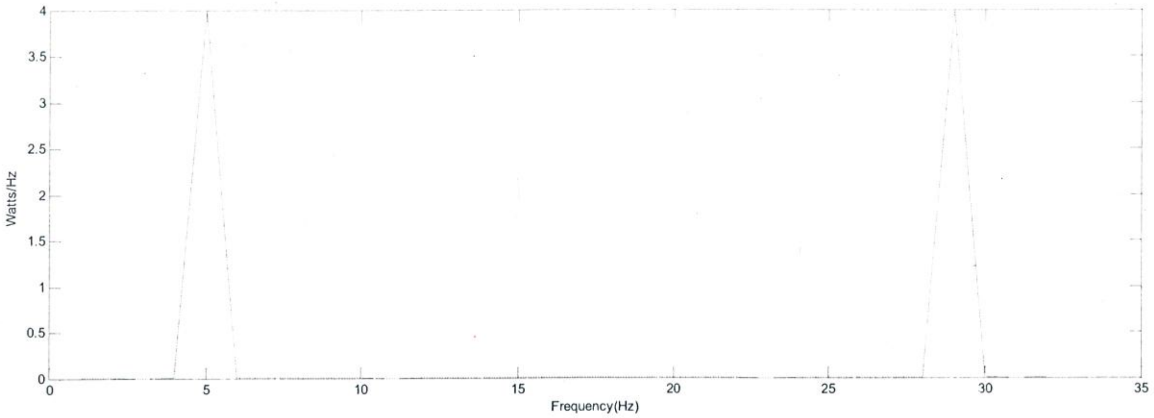

Figure 8(b): Power Spectral Density of the cosine wave

The autocorrelation function of the above graph is shown as under. It is periodic in time as it can be clearly seen.

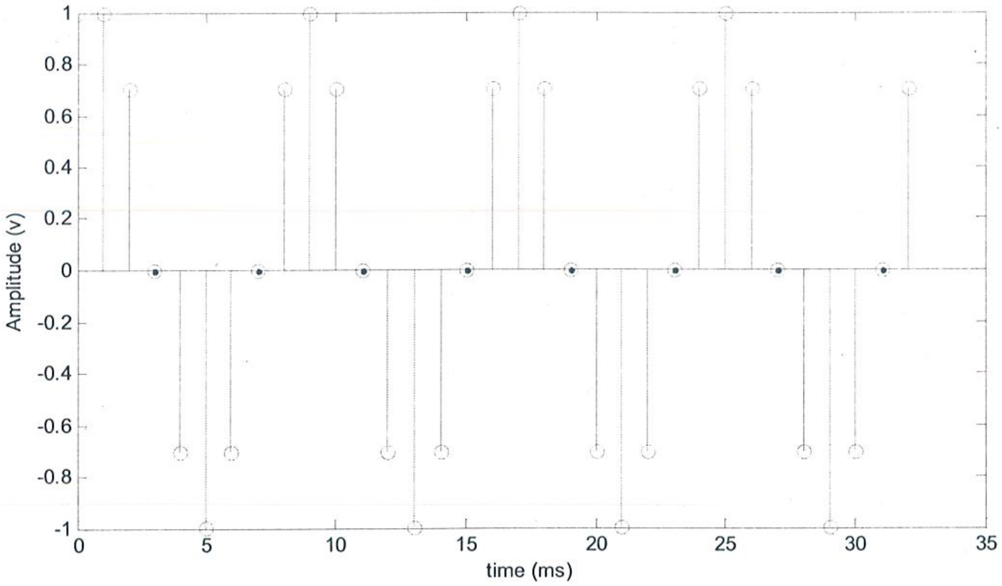

Figure 8(c): Autocorrelation function of the cosine wave

Now, we will show pure noise and how it behaves (stationary) in case Cyclostationary detection.

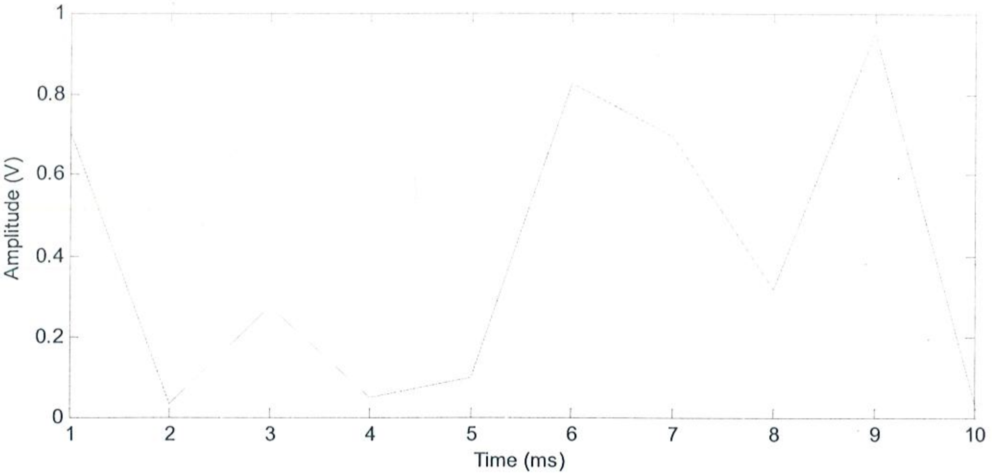

Figure 9(a): Pure random function which has been taken as noise.

The PSD of this function is taken and has the following graph.

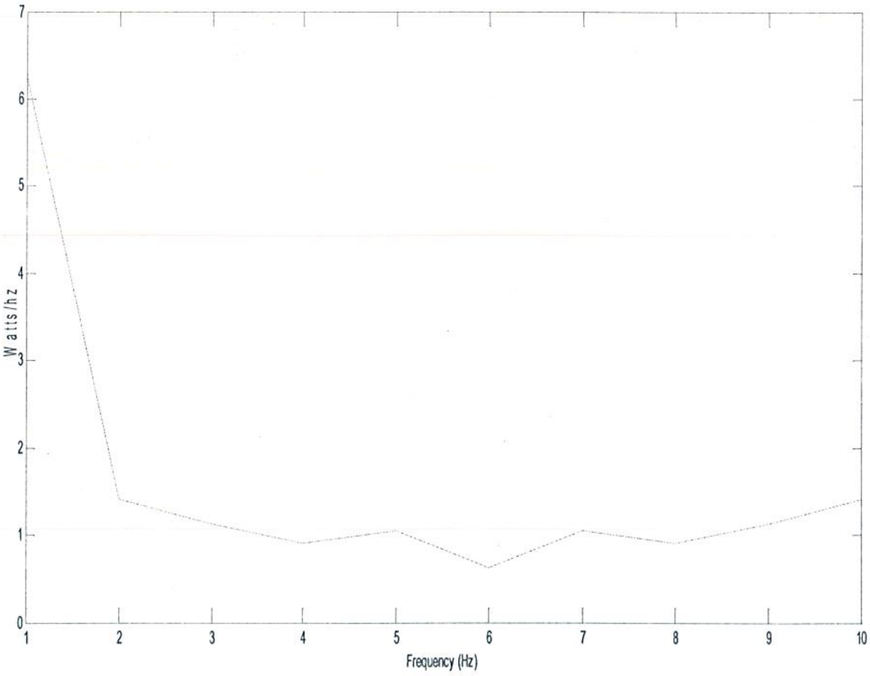

Figure 9(b): Power Spectral Density of the Noise function

The auto correlation of this signal is given as under.

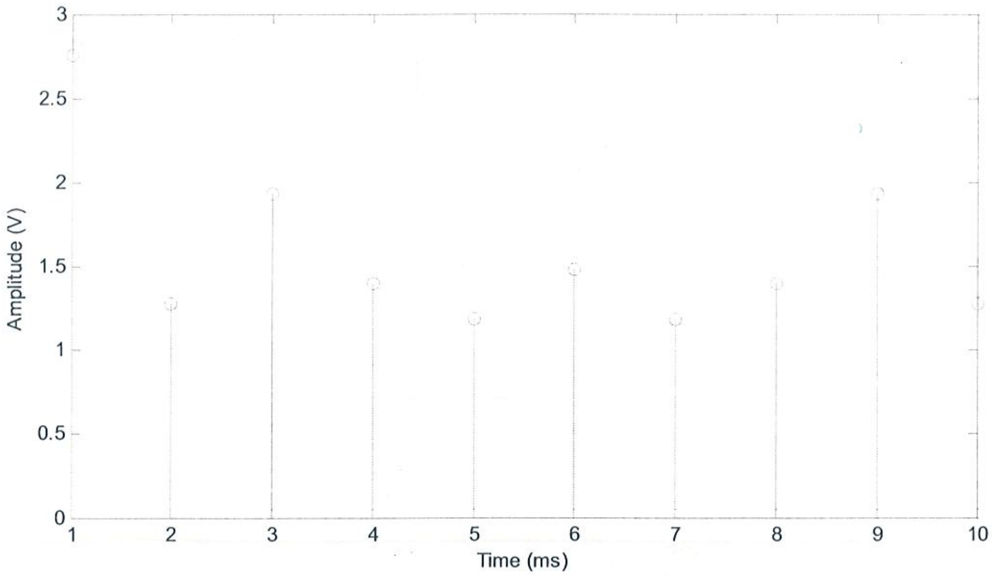

Figure 9(c): Autocorrelation function of the Gaussian noise.

Clearly, this graph is non-periodic, which is how we differentiate between noise and pure signal. The autocorrelation of noise is always non-periodic as we can see in this graph.

Now we will check the same simulations in signals which have been fed to Additive White Gaussian Noise channels. The autocorrelation function of that particular signal is also nearly periodic, with some margin taken experimentally.

The graph of the noise fed signal is given below.

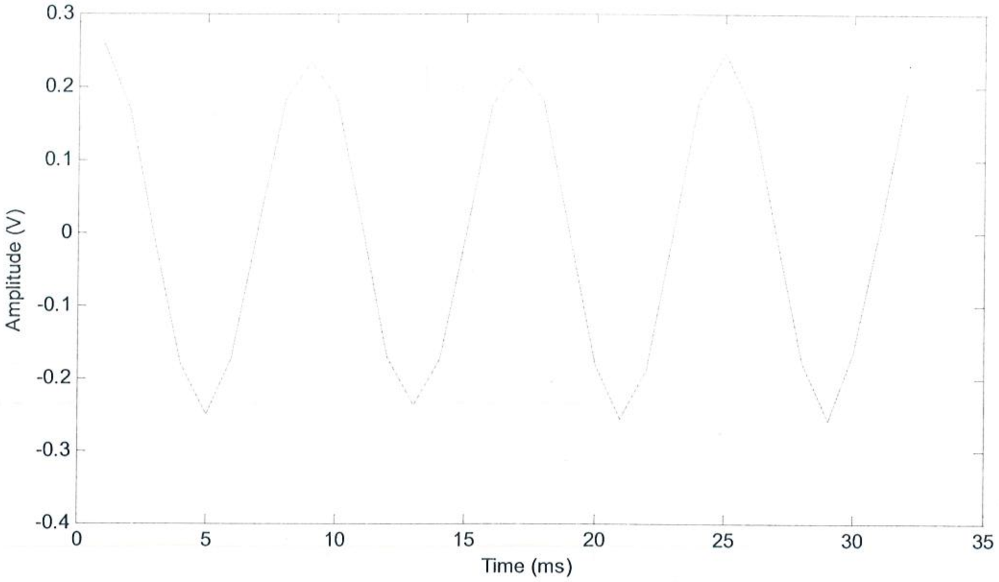

Figure 10(a): Noise fed signal for single cycle detection

The PSD of the signal is given as under

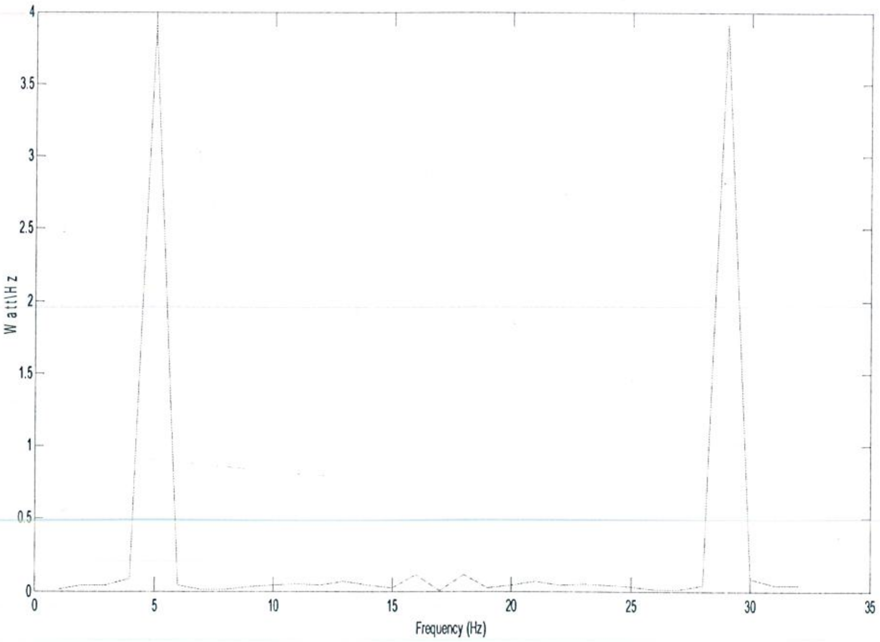

Figure 10(b): Power Spectral Density of Noise fed signal

The autocorrelation of the given signal is as under.

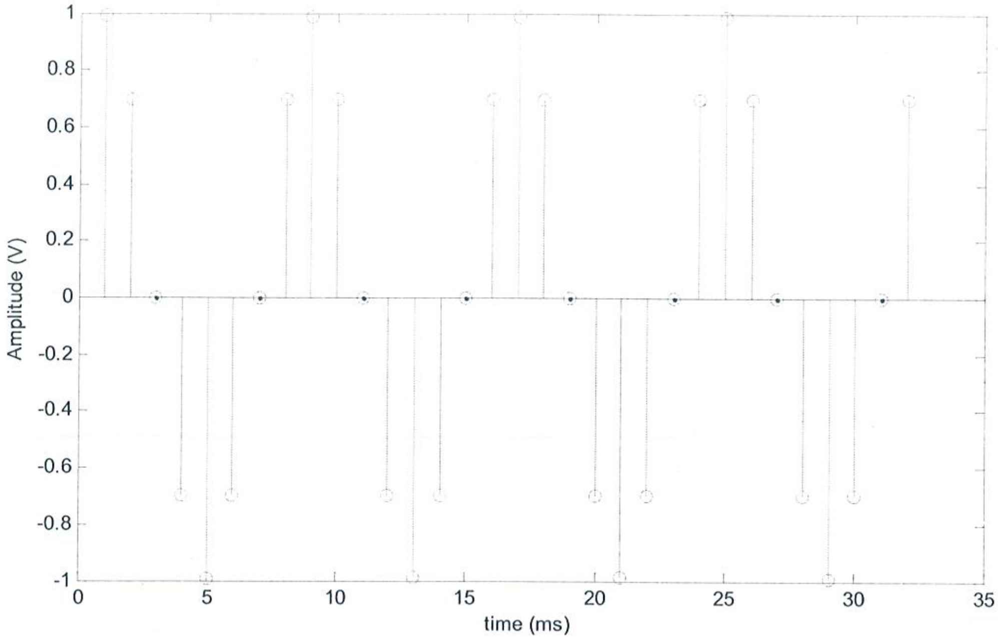

Figure 10(c): Autocorrelation of Noise fed Signal, SNR= 40dB

As we can see that it is still periodic in time. Hence, it can be detected in severe conditions. SNR=40dB.

As we start reducing the SNR, the results become less prominent.

Below are shown two conditions where detection is easy and where it is not as easy.

The next figure shows results for SNR = 15dB

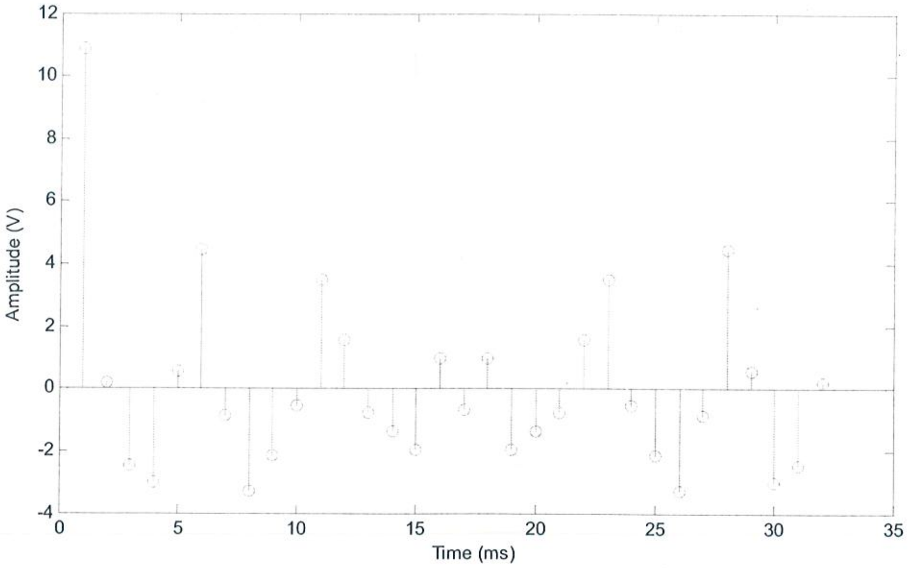

Figure 10(d):Autocorrelation of Noise fed Signal, SNR= 15dB

Now, for SNR=5dB.

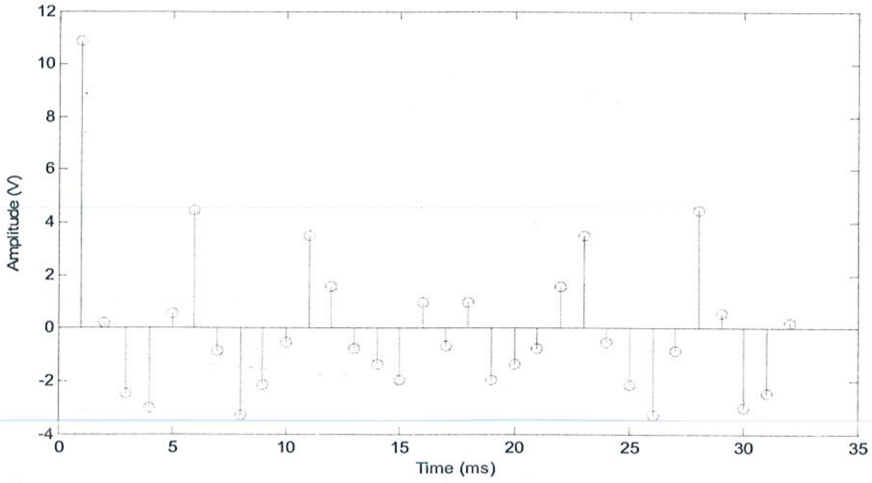

Figure 10(e): Autocorrelation of Noise fed Signal, SNR= 5dB

We see that with SNR=15dB, we have better periodicity than at SNR=5dB.

Now, we repeat the same exercise with non-Gaussian noise added to the signal. For this case, we simply add random noise to the signal.

The signal looks like as under

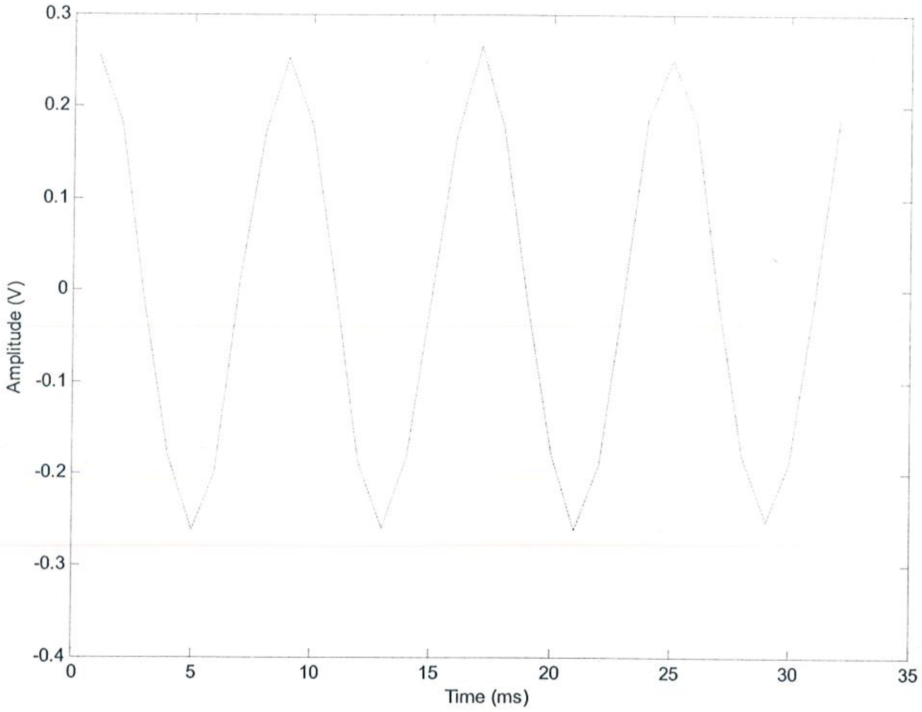

Figure 11(a): Non-Gaussian noise fed signal

The above figure is a non-Gaussian noise fed signal.

The PSD of the above signal is given next.

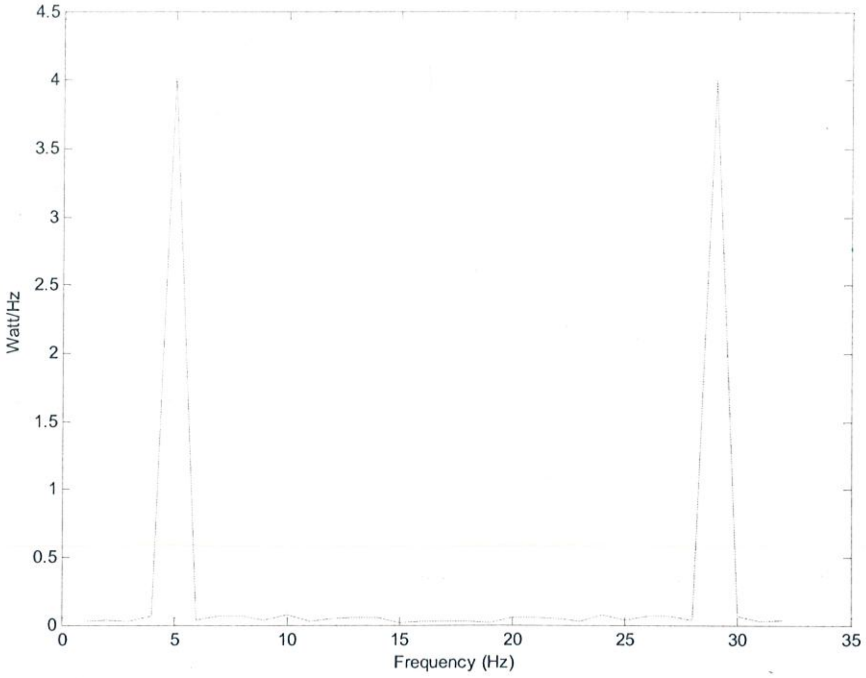

Figure 11(b): Power Spectral Density of the non-Gaussian noise fed signal

The auto correlation function of the signal in question gives the periodicity of the signal. It shows that a signal is present.

The auto correlation is as under:

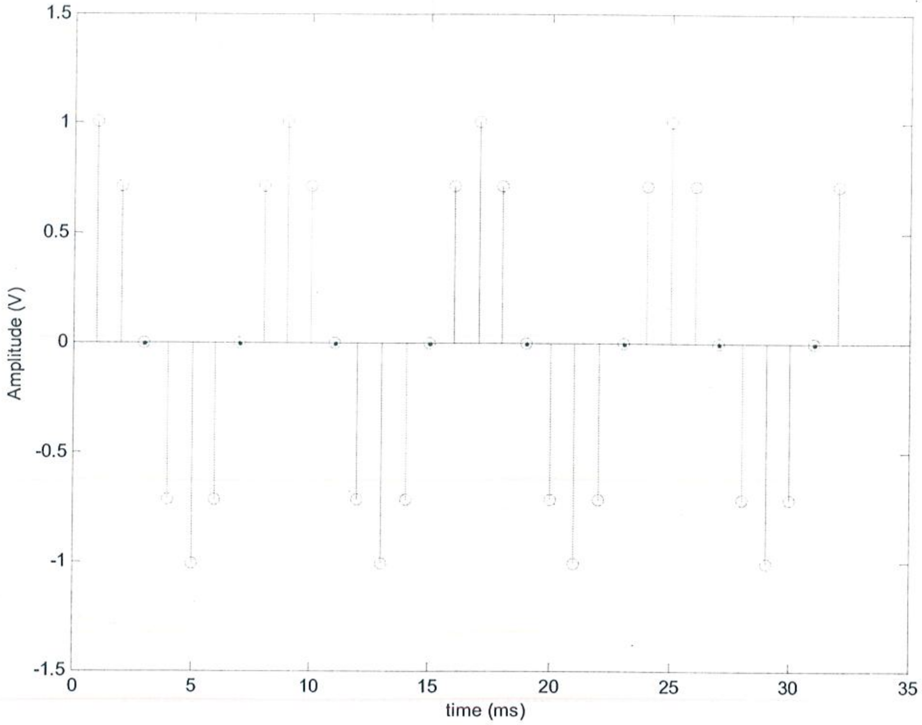

Figure 11(c): Autocorrelation of the non-Gaussian noise fed signal

The figure shows the presence of signal.

6.3.3 Multi Cycle Detector for Gaussian Noise/Non-Gaussian Noise

6.3.3.1 Algorithm

We follow the same algorithm; however, we add spectral components to the signal. As in practical use, multi-component signal is used.

$$x = \sqrt{(2/N)}\left[cos\left(2\pi\frac{F_c}{F_s}n\right) + cos\left(4\pi\frac{F_c}{F_s}n\right) + cos(6\pi\frac{F_c}{F_s}n)\right]$$

Noise behaves exactly in the same manner. However, the signal shows different periodicity in different SNR conditions.

At SNR=40dB, the signal is:

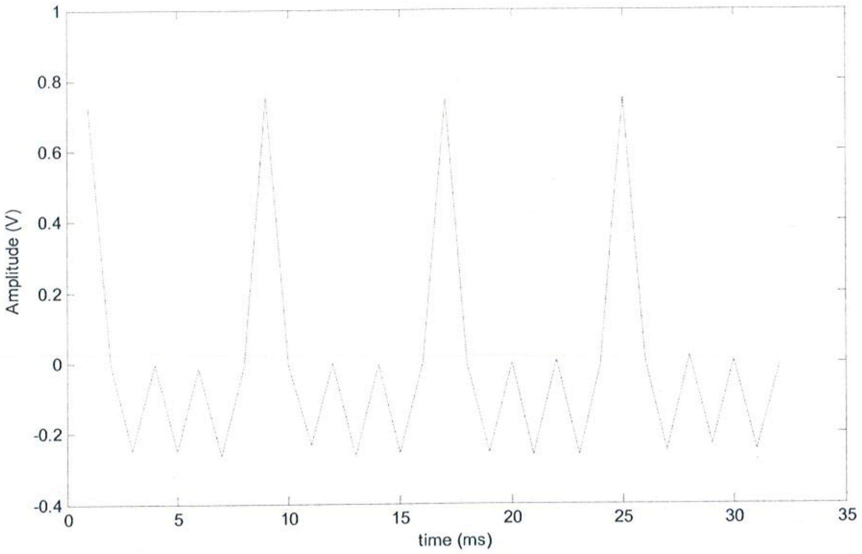

Figure 12(a): Multi-cycle Detection signal at SNR= 40dB

The PSD spectrum is as under:

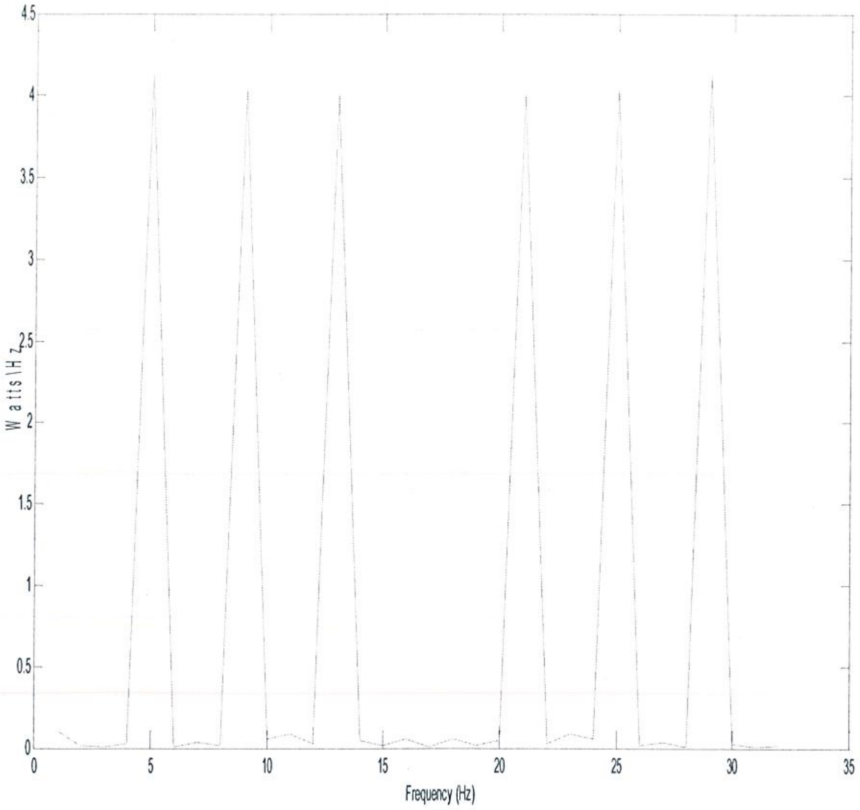

Figure 12(b): Power spectral density of the noise fed signal at SNR 40dB

The autocorrelation function looks like that under:

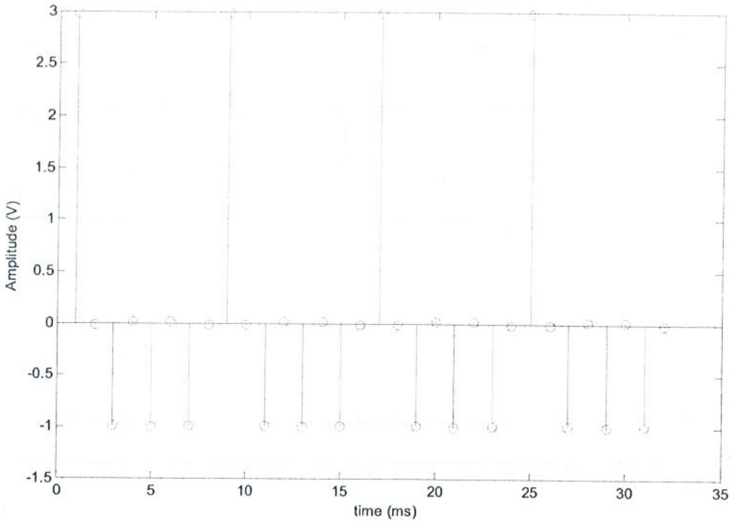

Figure 12(c): Autocorrelation of the noise fed signal at SNR 40dB

As we can see, it is clearly periodic in nature. Hence, in case of multi cycle detectors, we get periodicity.

Now, checking for different SNR scenarios:

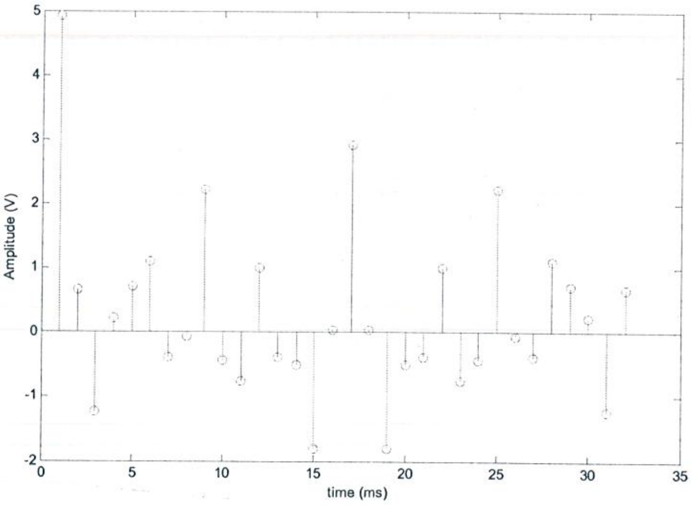

Figure 12(d): Autocorrelation of the noise fed signal at SNR 10dB

At SNR=10dB, as we can see, detecting periodicity is a little tough.

We continue with the non-Gaussian noise in a similar manner and we get similar results.

CONCLUSION

As the demand of radio spectrum increased in past few years and licensed bands are used inefficiently, improvement in the existing spectrum access policy is expected. Dynamic spectrum access is imagined to resolve the spectrum shortage by allowing unlicensed users to dynamically utilize spectrum holes across the licensed spectrum on non-interfering basis.

Our work has successfully evaluated all three detection techniques on the basis of robustness to noise. Also, we have accomplished proving why Cyclostationary based detection is a more efficient choice as compared to matched filter detection and energy detection.We have also evaluated robustness to noise for four off shoots in the Cyclostationary based detection.

In this report, main working associated with spectrum sensing techniques are highlighted. Performance of these techniques is compared on the basis ofdifferent SNR environments. As per the simulation results we have formulated the following table comparing the robustness to noise parameter for different spectrum sensing techniques.

SPECTRUM SENSING TECHNIQUE ROBUSTNESS TO NOISE					
ENERGY BASED	**MATCHED FILTER**	**CYCLOSTATIONARY BASED DETECTION**			
Very Low	Medium	**SCG**	**SCNG**	**MCG**	**MCNG**
		High	Medium	Medium	Medium

Table 1: Comparison of robustness to noise parameter for different spectrum sensing techniques

SCG: Single Cycle with Gaussian Noise

SCNG: Single Cycle with non-Gaussian Noise

MCG: Multi Cycle with Gaussian Noise

MNCG: Multi Cycle with non-Gaussian Noise

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APPENDIX

The codes used in our work are as follows:-

Energydet.m

```
clc;
Fs=500;
T=1/Fs;
L=1000;
resol=1;
t=0:.0002:.01;
y=0.2*sin(2*pi*1000*t);
z=awgn(y,30);
Pxx = periodogram(z);
Hpsd = dspdata.psd(Pxx,'Fs',Fs);
figure
plot(Hpsd)
fre=[]; o=1;
len=65537*0.5;
n_len= floor(len/2000);
for p=1:n_len:1980*n_len
fre(o)=sum(Pxx(p:p+n_len));
o=o+1;
end
sa=[];
count=0;
sa=zeros(1,100);
for w=1:1:length(fre)
if(fre(1,w)>5000)
count=count+1;
sa= [sa w];
end
end
count_m=0;
if(count>=1)
   p=0
%E(1,1)=1;
elseif(count==0)
   p=1
%E(1,2)=1;
end
end
```

Matchedfil.m

```
clc;
f=1000;
Fs=1000;
T=1/Fs;
car1=zeros(1,100);
car2=zeros(1,100);
car3=zeros(1,100);
car4=zeros(1,100);
for ii = 1:1:length(T)
car1(ii) = sin((2*pi*f*T(ii))+360); %CA RRIER TO BE TRANSMITTED
car2(ii) = sin((2*pi*f*T(ii))+90); %CARRIER TO BE TRANSMITTED
car3(ii) = sin((2*pi*f*T(ii))+180); %CARRIER TO BE TRANSMITTED
car4(ii) = sin((2*pi*f*T(ii))+270); %CARRIER TO BE TRANSMITTED
end
%matlab error
res1= xcorr(xR(1:20),car1)* 10^14;
res2= xcorr(xR(1:20),car2)* 10^14;
res3= xcorr(xR(1:20),car3)* 10^14;
res4= xcorr(xR(1:20),car4)* 10^14;
r1=sum(res1);
r2=sum(res2);
r3=sum(res3);
r4=sum(res4);
if((r1>-35 && r1<35)&& (r2>-35 && r2<35) && (r3>-35 && r3<35) && (r4>-35 &&
r4<35))
M(1,1)=1;%Primary user is not present
else
M(1,2)=1;%Primary user is present
end
```

Single cycle Cyclostationary detection (Gaussian noise)

```
clc
 Fs = 512;
Fc = 64;
N = 4*ceil(Fs/Fc);
p=Fs/Fc;

n = 0:(N-1);
x = sqrt(2/N)*cos(2*pi*Fc/Fs*n);

% figure
% plot(x)
```

```
% signal=awgn(x,40);
% figure
% plot(signal)
signal=sqrt(2/N)*cos(2*pi*Fc/Fs*n)+rand(1,10,1);
X_f=fft(signal);
figure
plot(X_f)
X_abs=abs(X_f);
figure
plot(X_abs)
X_psd=X_abs.^2;
figure
plot(X_psd)
y=ifft(X_psd);
stem(y)
for i=1:1:size(y)
if y(i)==y(i+p)
    disp('periodic');

else
    disp('non periodic');
end

end
```

Single cycle Cyclostationary detection (Non Gaussian noise)

```
clc

Fs = 512;
Fc = 64;
N = 4*ceil(Fs/Fc);
p=Fs/Fc;

n = 0:(N-1);
x = sqrt(2/N)*cos(2*pi*Fc/Fs*n);
Noise = 0.01*randn(size(x));
max(max(Noise))

signal=sqrt(2/N)*cos(2*pi*Fc/Fs*n)+Noise;
figure
plot(signal)
X_f=fft(signal);
figure
plot(X_f)
X_abs=abs(X_f);
```

```
figure
plot(X_abs)
X_psd=X_abs.^2;
figure
plot(X_psd)
y=ifft(X_psd);
stem(y)
for i=1:1:size(y)
   if y(i)==y(i+p)
      disp('periodic');

      else
      disp('non periodic');
   end

end
```

Multi cycle detector (Gaussian noise)

```
clc
% e=rand(1,10,1);
% plot(e)
Fs = 512;
Fc = 64;
N = 4*ceil(Fs/Fc);
p=Fs/Fc;

n = 0:(N-1);
x = sqrt(2/N)*(cos(2*pi*Fc/Fs*n)+cos(4*pi*Fc/Fs*n)+cos(6*pi*Fc/Fs*n));
figure
plot(x)
 signal=awgn(x,10);
 figure
 plot(signal)
X_f=fft(signal);
figure
plot(X_f)
X_abs=abs(X_f);
figure
plot(X_abs)
X_psd=X_abs.^2;
figure
plot(X_psd)
y=ifft(X_psd);
stem(y)
for i=1:1:size(y)
if y(i)==y(i+p)
```

```
        disp('periodic');

else
        disp('non periodic');
end

end
```