PERFORMANCE COMPARISION OF EIGEN VALUE BASED SPECTRUM SENSING FOR DIFFERENT MODULATION SCHEMES

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Submitted by

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CERTIFICATE

This is to certify that the thesis report entitled, ***"Performance comparison of Eigen value based spectrum sensing for different modulation schemes "*** being submitted by **Rahul Kumar** to the *Department of Electronics and Communication Engineering and Applied Physics, Delhi Technological University, Delhi* in partial fulfilment of the requirement for award of Master of Technology degree in ***Microwave and Optical Communication*** is a record of bona fide work carried out by him under the supervision and guidance of **Prof. Rajiv Kapoor.** The matter embodied in this report has not been submitted for the award of any other degree.

Prof. Rajiv Kapoor

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DECLARATION

I hereby declare that all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. This report is my own, unaided work. I have fully cited and referenced all material and results that are not original to this work. It is being submitted for the degree of Master of Technology in Engineering at the Delhi Technological University. It has not been submitted before for any degree or examination in any other university.

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ABSTRACT

Recently wireless system have been growing very fast. To meet this huge growth in wireless technologies and services, researchers as well as industry have been working towards new techniques and standardizations.

The most critical consequences for this growth in wireless networks are the ones related to spectrum usage and management as the electromagnetic radio spectrum is as the most precious Natural resource when there is discussion about wireless networks. The existing policies of spectrum management are based on static spectrum allocation for a specific technology and service controlled by regulation agencies like the Federal Communications Commission (FCC) And the European Telecommunications Standards Institute (ETSI). After the appearance of wireless personal communications technologies it became unreasonable to use these policies and rely on static spectrum allocation due to economic and technical considerations.

Cognitive radio Technology was introduced to mitigate fixed spectrum allocation problem. Cognitive radio is a radio that adapts to the conditions of the environment by analysing, observing and learning. The cognitive network makes use of these adaptations for future decisions. Cognitive radio is basically used for maximum utilization of the radio bandwidth. The core of the performance

Accurate detection of available spectrum is the main problem in cognitive radio. Performance of cognitive radio mainly depends on its detection accuracy. A cognitive radio should detect any type of radio signal available to its radio environment. In this project a survey detection probability for different modulation schemes has been presented.

A cognitive radio should have fast processing speed and able to take fast decision. For that its design structure should be less complex. So for that purpose, improvement on existing Eigen value based spectrum sensing is also presented and probability of detection are calculated for TV band and mobile communication band communication.

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TABLE OF CONTENTS

LIST OF FIGURES

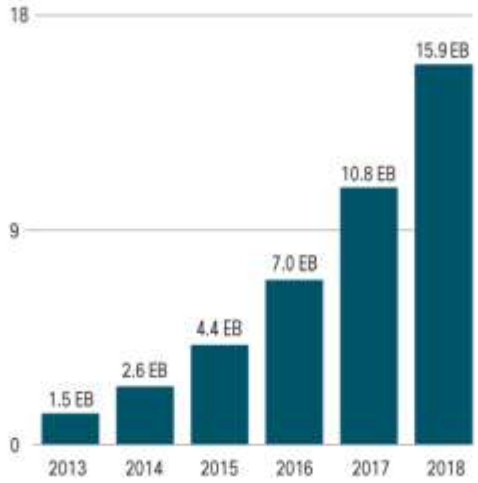
FIGURES

Chapter 1
Introduction

According to a survey taken by cisco for global mobile data traffic update, 2013-2018, Figure-1.1 Mobile data traffic will achieve the following milestones within the next 5 years.

- Monthly use of global mobile data traffic will cross 15 Exabyte's by 2018.
- The average data connection speed will increase over 2 Mbps by 2016.
- Due to increasing use on smartphones, smartphones will reach 66 % of mobile data traffic by 2018.
- Monthly use of mobile tablet traffic will increase over 2.5 Exabyte per month by 2018.
- 4G data traffic will be greater than half of the total mobile data traffic by 2018.

Data uses in Exabyte's (10^{18} bytes) per month



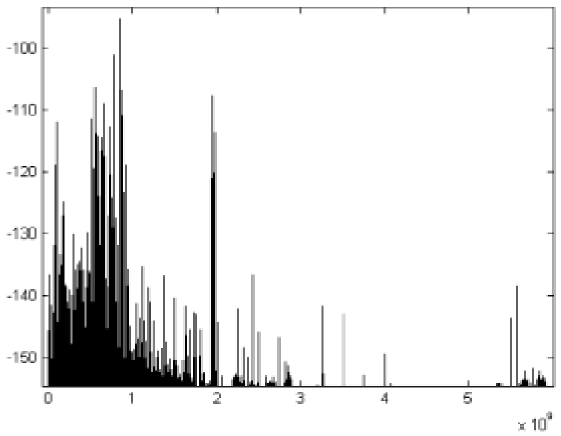


Figure 1.1 Cisco Forecasts 15.9 Exabyte's per Month of Mobile Data Traffic by 2018

Figure 1.2 Measurement of 0-6 GHz spectrum utilization at BWRC [10]

Source: CISCO VNI Mobile, 2014

From above records shown in figure-1.1, it seems that after ten years, the majority of spectrum bands, suitable for mobile communication will be entirely engaged.

On the other hand, actual measurements taken as shown in Figure-1.2 indicates, poor utilization of available spectrum, especially in the 3 to 6 MHz bands. Figure-1.2 shows the PSD of the received 6 GHz wide signal, data samples are collected for a span of 50ms and sampled at 20 GS/s [10]. Studies of these results is done by FCC's Spectrum Policy Task Force, And they reported, that there is vast temporal and geographic variations in the use of allocated spectrum with utilization ranging from 15% to 85%. In order to use these unutilized spectrum band (spectrum holes), the Federal Communication Commissions (FCC) had proposed a Notice of Making [10] advancing Cognitive Radio technology.

"Cognitive Radio" is an intelligent radio that can sense its operating environment, and can modify it operating parameters autonomously to provide best quality of service according to is operating condition. In order to efficient utilization of available spectrum, cognitive radio technology is expected as a key technology.

1.2 Motivation and Problem Statement

By comparing two reports from cisco and FCC, Development of an intelligent radio or cognitive radio is made obvious and necessary. A great research in field of developing cognitive radio has been proposed. The main function of cognitive radio is precisely detection of available frequency spectrum in given radio environment. The accuracy in spectrum sensing is our main concern. If cognitive radio device is not able to sense the spectrum properly it will cause a harmful interference to the licensed user.

Various techniques for spectrum sensing had been proposed, and eigenvalue based method is proposed in recent years is proved to better as compare to previous spectrum sensing techniques. But as the signal detection capability is increased using Eigen value based method the system complexity and processing speed is also affected. Due to use of large numbers of receiver components, the complexity and its effective cast will increase, while need of large number of data samples and complex calculation will make processing speed slow. Which will affect the performance of sensing. Here in this project work we have worked on these problem. Figure-1.3 shows summary of project work.

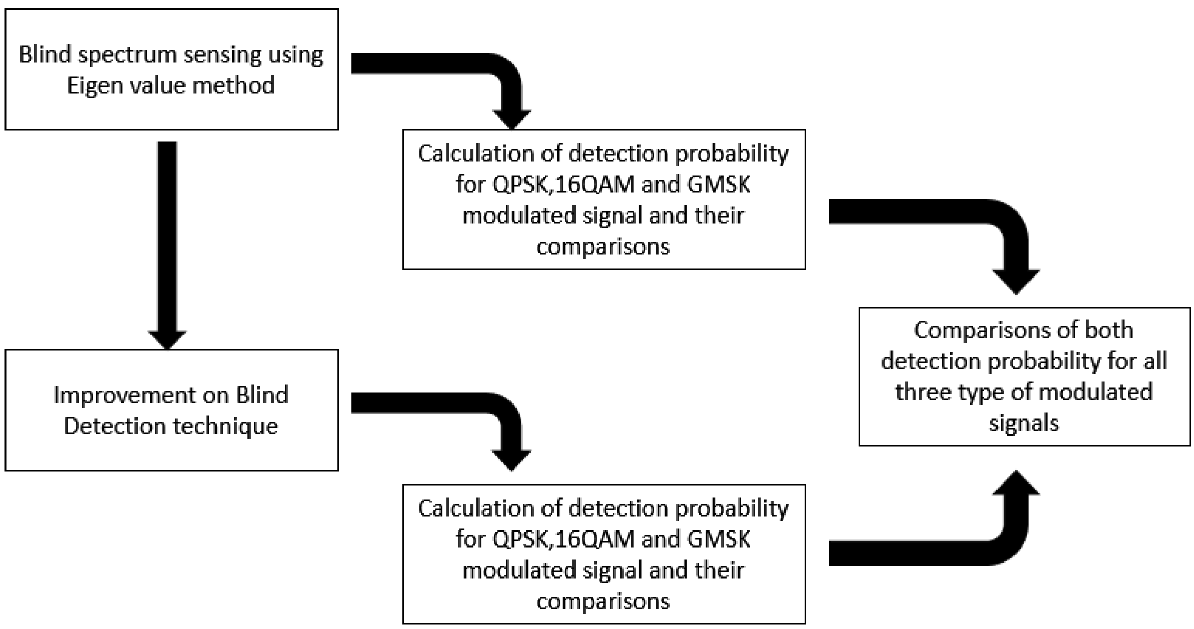


Figure-1.3 summary of project work

1.3 Goals/Scope of present work

Developing a cognitive device which have detect the presence of unknown signal then it is necessary to observe it performance for the presence of various available known signal. Signals present in wireless environment can be characterized modulation scheme used to transmit that signal. So here in this project work our goal is twofold. At first step we analysis the performance of Blind Eigen value detection technique TV band and mobile band frequency spectrum. And probability detection is calculated for these band signals. At second stage optimization of existing Eigen value technique is presented and its performance is calculated and compared with the existing technique.

The modified approach is described here and its performance is analyzed for various modulation techniques. Modified approach worked better even at low SNR condition.

1.4 Thesis Structure

The thesis report is divided into seven chapters, each having ample information for comprehending the concept of this project.

Chapter 1 introduces the need of Cognitive radio technology. And basic introduction on project work.

Chapter 2 presents the literature review on cognitive radio technology. It includes basic structure of cognitive radio network and its sub components.

Chapter 3 provides the details existing spectrum sensing techniques, their limitations and advantages.

Chapters 4 presents blind Eigen value based spectrum sensing technique and it improved structure. Probability of detection and false alarm probability are derived in this chapter.

Chapter 5 discusses about the different modulation schemes, which are currently used in wireless communication systems.

Chapter 6 summarizes detailed results of simulation analysis.

The Final chapter of the thesis (Chapter 7) presents the conclusions and future aspects of this project. The significance and contribution of this work is summarized.

Chapter 2

Literature Review

2.1 Introduction

Recently wireless system have been growing very fast. To meet this huge growth in wireless technologies and services, researchers as well as industry have been working towards new techniques and standardizations.

The most critical consequences for this growth in wireless networks are the ones related to spectrum usage and management as the electromagnetic radio spectrum is as the most precious Natural resource when there is discussion about wireless networks. The existing policies of spectrum management are based on static spectrum allocation for a specific technology and service controlled by regulation agencies like the Federal Communications Commission (FCC) And the European Telecommunications Standards Institute (ETSI). After the appearance of wireless personal communications technologies it became unreasonable to use these policies and rely on static spectrum allocation due to economic and technical considerations.

2.2 Cognitive Radio

The term cognitive radio was first introduced by Joseph Mitola [2]. The Cognitive radio is a radio that adapts to the conditions of the environment by analyzing, observing and learning. The cognitive network makes use of these adaptations for future decisions [3]. Cognitive radio is basically used for maximum utilization of the radio bandwidth. The core of the performance Optimization is the cognitive process which is shared by the cognitive radio and the cognitive Networks. The main part of this process is to learn from the past decisions and make use of it for future decisions.

2.3 The Cognitive Radio Operation

Fig. 2.1 shows the basic cognitive radio tasks, spectrum sensing, spectrum analysis and spectrum decision in the radio environment.

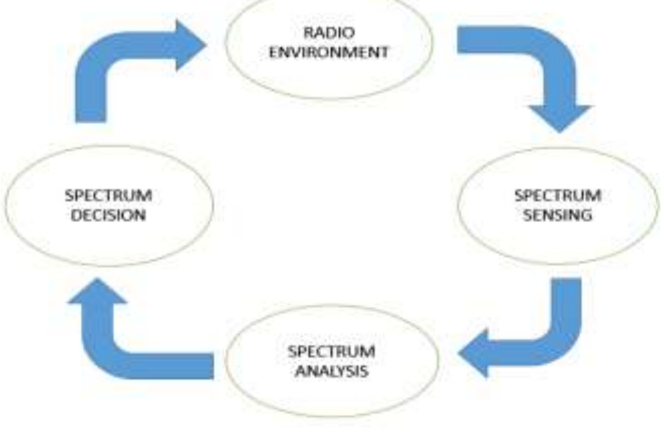


Figure 2.1 Cognitive cycle [3]

2.4 Cognitive Radio Network Architecture

Some part of the wireless spectrum is licensed for different tasks and few bands are still unlicensed. In this section, there is discussion about all the possible scenarios for a better description of the communication protocols. The components of the cognitive radio architecture are illustrated in Fig 2.2. In Fig 2.2 it is clear that there are two main groups, the primary networks and the cognitive radio networks (the next generation networks).

2.4.1 Primary network

The primary networks have special rights to specific bands. The primary network includes the Primary user and the primary base-station.

• **Primary user:** Primary users also called licensed users, operate in specific spectrum bands. This operation is entirely controlled by the only primary base-station. These primary users do not require any further enhancements for the coexistence of the primary base-stations and the primary users.

• **Primary base-station:** The primary base station has a fixed infrastructure. Primary networks do not have the ability of cognitive radio for sharing the spectrum with cognitive users but it can be requested to have both legacy and cognitive radio protocols for primary network access of cognitive radio users.

2.4.2 Cognitive radio network

Cognitive radio networks do not have the permission to operate in the required band. The CR networks can be deployed both with infrastructure and without infrastructure networks as illustrated in fig 2.2. The components of the network are as follows:

• **Cognitive Radio user:** The CR user (the unlicensed user) has no spectrum license, so extra functionalities are needed for sharing the spectrum band.

• **Cognitive Radio base-station:** The CR base-station (the unlicensed base station) has a fixed infrastructure component with CR abilities. Cognitive Radio can access the different networks by providing the single hop network connection to CR user [5]. Single hop connection is used to reduce the propagation delay; it has now become essential to have single hop network connection which connects the user terminals.

The CR network architecture in Fig. 2.2 shows different types of networks primary network access, with infrastructure based CR network, without infrastructure based CR network (adhoc network). The CR networks operate both in licensed and unlicensed bands (mixed spectrum environment). There are three access types are:

• **CR network access:** The CR users can access the CR base-station not only the licensed bands but also the unlicensed spectrum bands.

• **CR ad hoc access:** The CR users communicate with different CR users through the ad hoc connection on licensed and unlicensed bands.

• **Primary network access:** The licensed bands are means for the CR users through which they access the primary base-station.

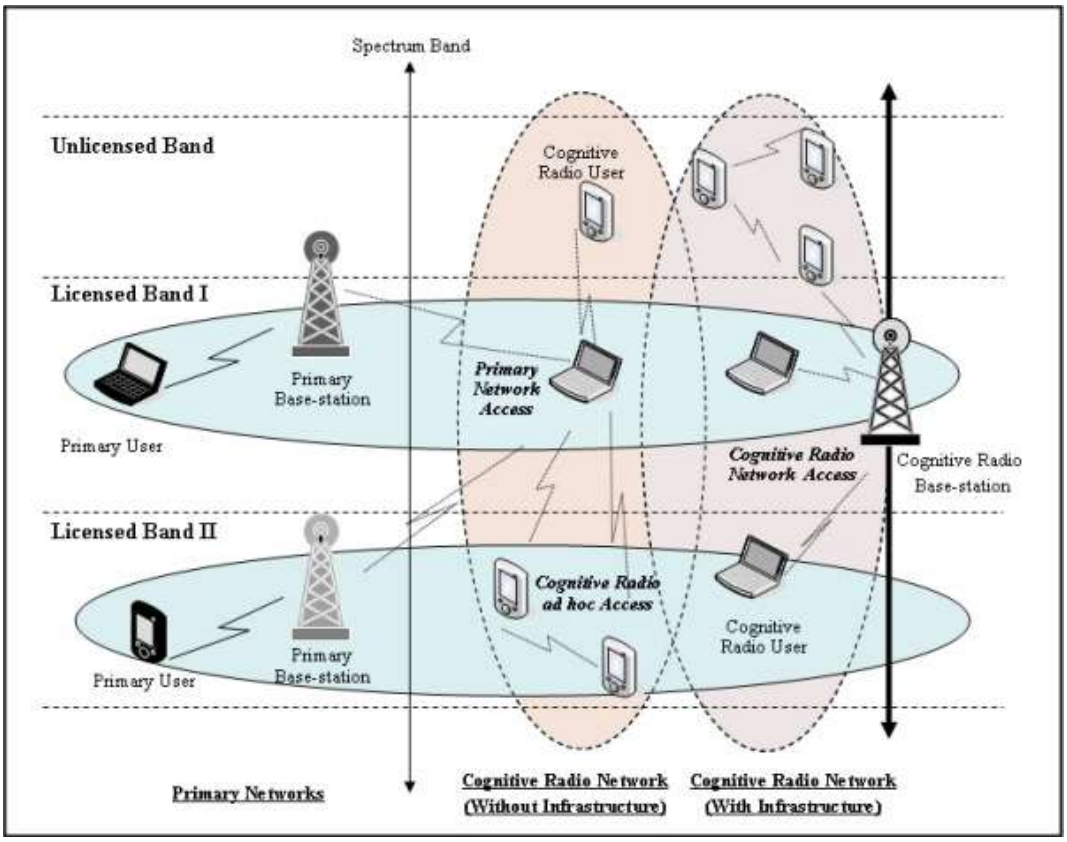


Figure-2.2 cognitive radio network architecture [5]

2.5 Spectrum Sensing

Due to an increasing demand of high data rates, static frequency cannot fulfill the demand of these high data rates. As a result of this, new methods for exploiting the spectrum are introduced. In cognitive radio, exploiting the unused spectrum is a new way to access the spectrum. Spectrum sensing is measuring the interference temperature over the spectrum to find the unused channels [5]. In this way efficient use of spectrum is utilized. Spectrum sensing is also involved in determining the type of the signal like carrier frequency, the modulation scheme, the waveform etc [5].

2.5.1 Methods

The mostly used spectrum sensing techniques are given as [5],

- Matched Filtering
- Waveform-Based Sensing
- Cyclostationary Based Sensing
- Energy Detector Based Sensing
- Radio Identification

The methods will be discussed in detail in chapter 3.

2.5.2 Challenges

There are some challenges which needs to be solved for efficient spectrum sensing which are gives as,

• Hardware Requirements
• The Hidden Primary User Problem
• Spread Spectrum Primary Users
• Sensing Time
• Other Challenges

These challenges will be discussed in detail in chapter 3.

2.6 Spectrum Management

The goal is to find the best available spectrum to fulfill the needs of the communication. The licensed, unlicensed and unused spectrum bands are spread over a large number of frequencies in the cognitive radio networks. These unused spectrum bands show different properties according to the time varying radio environment. The Cognitive radio has to decide the best available spectrum band, such that it fulfills the QoS requirements [5].

2.6.1 Spectrum analysis

Spectrum analysis discovers the different functionalities of the spectrum bands, to make productive use of the spectrum band according to the requirements. Each spectrum hole (Band of frequencies assigned to the primary user, but at a specific time and geographic location, these bands is not fully utilized by that user [2].) should be defined according to the time varying environment and the information of the band like frequency and bandwidth. To represent the quality of the spectrum band, parameters are defined such as interference, holding time, path loss, link layer delay, wireless link errors etc.

• **Interference:** The interference characteristics of the channel can be determined from the spectrum band in used. The permissible power of a CR user can be calculated, from the amount of interference which is use for the calculation of the channel capacity.
• **Holding time:** Holding time is an expected time, from which the CR user occupy the licensed band before its interruption. For better quality holding time should be as long as possible.
• **Path loss:** If the operating frequency increases, the path loss will also be increased. If the cognitive users have the constant transmission power then at higher frequencies their transmission range decreases. In order to compensate the increased path loss if we increase the transmission power this yields in higher interference to the other users.
• **Wireless link errors:** This error rate of the channel changes according to the change in modulation scheme and interference level of the spectrum band.
• **Link layer delay:** Different link layer protocols are required to address path loss, interference and wireless link errors.

2.6.2 Spectrum decision

When an analysis of all the spectrum bands is completed, a spectrum band should be selected for the transmission according to the QoS requirements. The decision rules are focused on the cost of communication and fairness [6].

2.6.3 Spectrum management challenges

Challenges for the spectrum management are listed below; a lot of research is still needed for these issues.

• How to integrate all the parameters of the spectrum, for the spectrum decision.
• Multiple spectrum bands used for simultaneous transmission.
• Spectrum decision and reconfiguration is needed in a cooperative framework.
• Spectrum decision over heterogeneous spectrum bands.

For the decision of the best spectrum band over the heterogeneous environment, the CR network supports the spectrum decision operation both for licensed and unlicensed bands under different characteristics.

2.7 Spectrum mobility

In cognitive radio networks, spectrum mobility occurs when the frequency of operation changes. For better transition of the spectrum, spectrum mobility maintains all the requirements of the communication. Spectrum mobility has a vital role while designing cognitive protocols [3]. Two main factors affect the spectrum mobility. The first one is the delay incurred during the spectrum handoff. This delay affects the communication at different layers. When the primary user appears, the cognitive radio performs a new type of handoff which we call a spectrum handoff.

2.7.1 Spectrum Handoff

The cognitive radio has the ability to adapt to the frequency operation. Due to this the network Protocol changes its mode of operation from one mode to another. The main goal of mobility Management is for these transitions to be completed without any disturbance and in a time efficient manner. The mobility management should have an awareness of the duration of the spectrum handoff, from the sensing algorithm. When the mobility management learns about the latency, its job is to confirm that the communication of the CR user should undergo on minimum performance degradation [3], [4]. In the same way, multi-layer (supports mobility management for different types of application) documents are needed for accomplishing the functionalities of spectrum mobility.

The interaction between spectrum management and spectrum mobility can be illustrated as in Fig 2.3. The spectrum sensing and spectrum sharing are keen to enhance the spectrum efficiency. The spectrum management functionalities cooperate with communication layers. The spectrum management needs QoS information, sensing, scheduling, transport and routing for the decision of the appropriate spectrum band. From Fig. 2.3, link layer information and sensing delays information are required for the estimation of spectrum handoff latency. The transport layer and application layer should know the latency, for the route recovery by using the spectrum handoff. Due to this, spectrum handoff is very important in the communication layers.

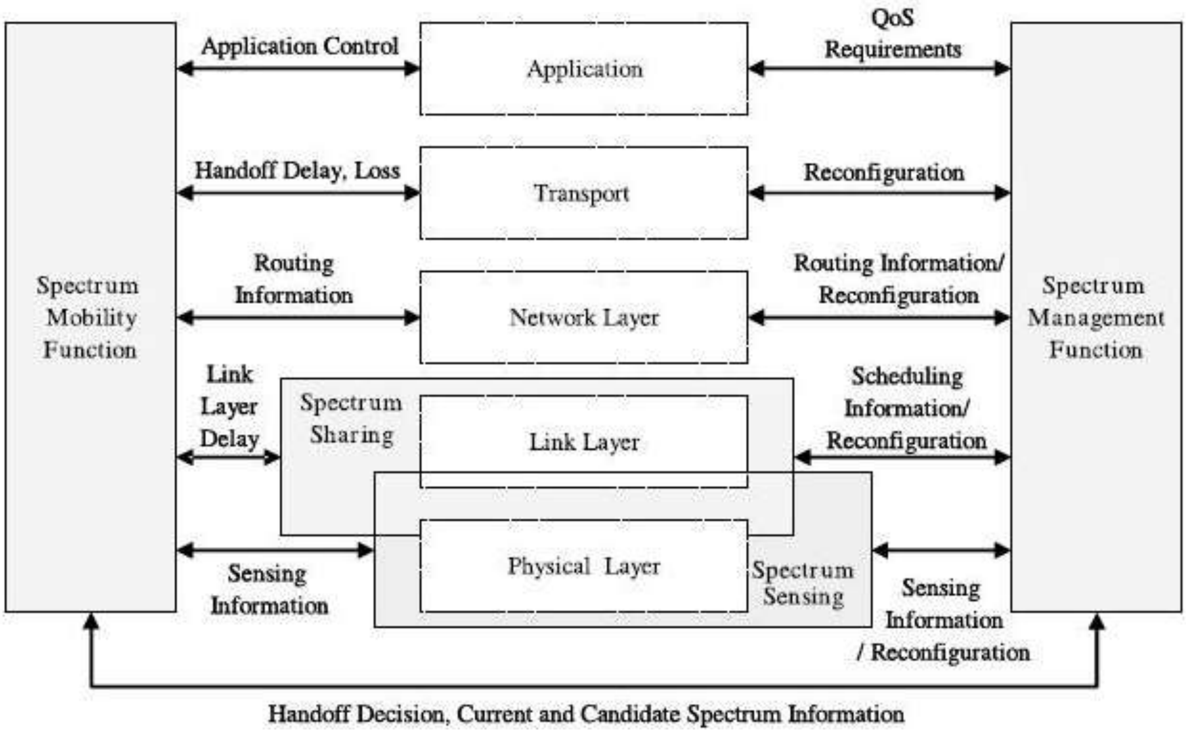


Figure-2.3 Handoff decision and network communication [3]

2.7.2 Spectrum mobility challenges

The below are some open research challenges for efficient spectrum mobility in cognitive networks [8].

• Spectrum mobility in time domain. The available channels change with respect to time, so to maintain QoS in this environment is a challenge. The physical radio goes through the spectrum to fulfil the QoS requirements.

• Spectrum mobility in space. As user changes its position from one place to another, the available bands also changes. To assign a spectrum is a major issue in the CR networks.

• If CR user moves to another place, the available spectrum bands also changes and due to this spectrum handoff takes place. So the required spectrum handoff scheme should be integrate inter cell handoff. The spectrum handoff in different networks is referred as vertical handoff which takes place in the CR networks.

• At a particular instance, many frequency bands are available for a CR user. For the selection of the best available spectrum, algorithms are required.

• When the operational frequency becomes busy in the communication by a CR user. Then the node applications have to move to other available frequency bands.

• Designing a new mobility management, to reduce the loss and the delay in a handoff.

2.8 Spectrum Sharing

Spectrum sharing is the major challenge which open spectrum usage faces. Spectrum sharing is related to medium access control (MAC) problems in the current system; however, there are Different challenges for the spectrum sharing in cognitive radio. Spectrum sharing consists of five steps which are,

• **Spectrum sensing**: The CR can allot a specific part of the spectrum if it is not used by the licensed user. When a CR wants to transmit data, it will first sense its surrounding spectrum usage.
• **Spectrum allocation:** When spectrum is available, a channel is allocated. This allocation depends on the availability of the channel and also internal/external policies.
• **Spectrum access**: When the nodes are trying to access the available spectrum, spectrum access helps to prevent colliding and overlapping of the spectrum.
• **Transmitter-receiver handshake:** The transmitter-receiver handshake is essential for effective communication in cognitive radio, after the determination of the spectrum.
• **Spectrum mobility:** The spectrum mobility is important in the communication between the nodes. If a particular part of the spectrum is required by the licensed user, communication should be continued by utilizing another free part of the spectrum.

2.8.1 Classification of spectrum sharing

Spectrum sharing can be classified into three main parts, i.e. architecture, spectrum allocation behavior and spectrum access techniques which is illustrated in Fig2.4 [5].

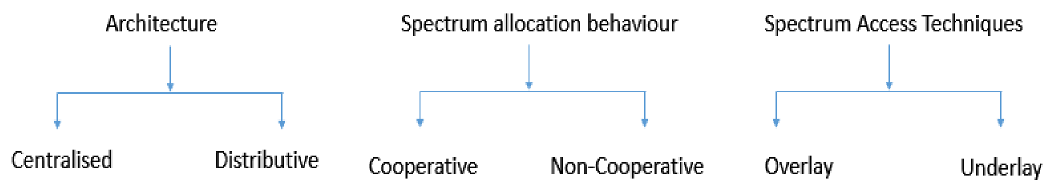


Figure 2.4 Classification of spectrum sharing in Cognitive Radio [5]

• **Centralized spectrum sharing:** In centralized spectrum sharing, spectrum allocation and access procedures are controlled by a centralized entity [7]. Each entity in the CR network forwards the measurements of spectrum allocation to the central entity.
• **Distributed spectrum sharing:** when the construction of an infrastructure is not suitable, then distributed solutions are proposed.
• **Cooperative spectrum sharing:** The interference measurements are distributed among other nodes, the centralized solution is also referred as cooperative.
• **Non-cooperative spectrum sharing:** Non-cooperative solutions only think about the nodes in hand that's why also called selfish solutions. The Non-cooperative solutions are reduced spectrum utilization and minimal communication requirements.
• **Overlay spectrum sharing:** This overlay spectrum sharing is also known as the spectrum access technique. The node accesses the network by using that portion which is not under usage of the licensed user (LU).
• **Underlay spectrum sharing:** The underlay spectrum sharing technique take advantage of the spread spectrum techniques which are specifically developed for cellular networks [8]. The underlay spectrum sharing requires such spread spectrum technique from which it can utilize high bandwidth.

2.8.2 Spectrum sharing challenges

There is a huge amount of ongoing research issues in spectrum sharing, which should be properly investigated for the efficient use of the spectrum. A few challenging issues in CR along with their possible solutions are [7]:

- **Common control channel (CCC):** In spectrum sharing solutions, when the primary user has selected a channel, this should be vacated without any interference. As a result, implementation is not feasible in fixed CCC CR networks. When we are not using CCC, the handshaking between the transmitter and the receiver becomes a challenge.
- **Dynamic radio range:** In CR networks, huge amounts of spectrum are used. Node neighbors change with respect to the variation of the operating frequency. The changing in the neighbor node affects the interference profile and the routing decisions. For minimum interference, control channels will be selected from the lower portion (high transmission range and selection of data channels in the high part of the spectrum.) and data channels will be selected from the higher portion.

Chapter 3
Spectrum Sensing Techniques

3.1 Introduction

This describes existing Spectrum sensing techniques and their limitation and advantages. The challenges which we have to face during design of cognitive radio are describe first here.

3.2 Challenges

Before a detailed description of spectrum sensing techniques will be given, spectrum sensing challenges associated with cognitive radio are discussed in this section.

3.2.1 Hardware Requirements

Analog to digital converters (ADCs) with high speed signal processors, high resolution and with larger dynamic range are required for spectrum sensing for cognitive radio networks [14]. Noise variance estimation techniques have been widely used for optimal receiver designs like channel estimation, soft information generation *etc.*, as well as for channel allocation techniques, and improved handoff power control [14]. As receivers are tuned to receive signals which are transmitted over a desired bandwidth that's why problem of interference is also an Easy case in this scenario. Furthermore, receivers are able of processing the narrowband baseband signals with sensibly low complexity and low power processors. In cognitive radio, terminals are essential for processing transmission for any opportunity over a much wider band. Hence, in order to identify any spectrum opportunity, the CR should be in a position to capture And analyze a larger band. Radio frequency (RF) components are imposed on additional requirements by larger operating bandwidths such as antennas and power amplifiers. There are Two architectures for the sensing process: single radio and dual radio [15].

Table 3.1 has a comparison of the advantages and disadvantages for single and dual radio Architectures.

	Single Radio	Dual radio
Advantages	Simplified Low costly	Better spectrum efficiency Higher sensing accuracy
Disadvantages	Low spectrum efficiency Low spectrum precision	High cost More power consuming complex

Table-3.1 advantages and disadvantages for single and dual radio Architectures.

3.2.2 Hidden Primary User Problem

This hidden primary user problem is like the hidden node dilemma in Carrier Sense Multiple Accessing (CSMA) [16]. Many factors like shadowing or severe multipath fading which is observed by secondary user during the transmission scanning for the primary user, create this hidden primary user problem.

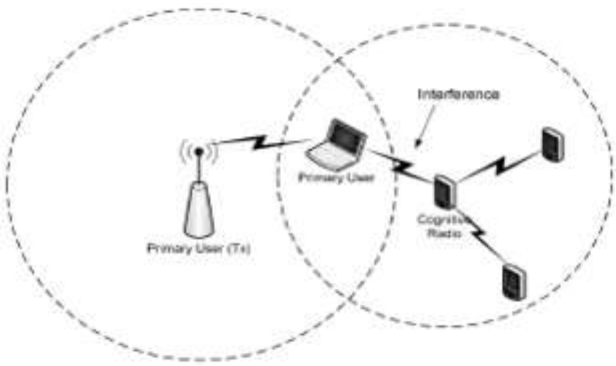


Figure-3.1 Hidden primary user problem [16]

Fig 3.1 illustrates the hidden node problem while the operating ranges for the primary user (PU) and for the cognitive radio device are shown by dashed lines. Here, unwanted interference is generated by cognitive radio devices to the primary user because due to the location of the devices, the primary transmitter's signal could not be detected. To deal with this primary user Problem co-operative sensing technique is proposed [16].

3.2.3 Detection of Spread Spectrum Primary Users

Devices which are commercially available have two types of technologies:

• Fixed Frequency
• Spread Spectrum

Spread spectrum has two further types of technologies:

• Frequency hopping spread spectrum (FHSS)
• Direct sequence spread spectrum (DSSS)

An example of fixed frequency devices is IEEE 802.11a/g based WLAN and these devices function at a single frequency or channel. FHSS devices adjust their operational frequencies vigorously to multiple narrowband channels. This is called the hopping and is performed according to a sequence which is recognized by the transmitter and the receiver also. DSSS devices resemble the FHSS devices but they utilize a single band in order to spread their energy. Primary users (PUs) which use spread spectrum signaling are hard to identify as the power of The PUs is dispersed over a broad frequency range, while the real information bandwidth is much narrower [17]. A partial solution of this problem is that if you know the hopping pattern and method of perfect synchronization, but it is possible but not easy to develop such an algorithm through which estimation in code dimension is possible.

3.2.4 Sensing Duration and Frequency

As the CR operates in the bands of primary users, these bands can be claimed by primary users at any time so in order to avoid interference to and for the PU, the CR should be so sensible that it could identify the presence of the PU and leave the band immediately. Hence within a certain duration, the CR should identify the presence of the PU. Although this condition puts some complexity and challenges for the design of CR. The sensing frequency (how often sensing should be performed by the cognitive radio) is a key parameter which should be chosen carefully. Sensing frequency requirements can be relaxed if you know that the status of the PU is going to change slowly. For example in the case of TV channel detection, in a geographic area presence of a TV channel does not change frequently unless an existing channel goes off or a new channel starts broadcasting. Sensing period for IEEE 802.22 draft standard is 30 seconds. Except sensing frequency, other timing related parameters like channel move time and channel detection time etc, are also defined in the standard [18].

Interference tolerance of the primary license holder is another factor which affects the sensing frequency. In order to avoid any interference, sensing should be done as often as possible in the case when the CR is operating in public safety bands and it should vacate the bands immediately if required by public safety units. A channel which is being used by the SU cannot be used for sensing procedure, that's why before the spectrum sensing interpretation by the SU should be done for data transmission. Due to this spectrum efficiency of the overall system is decreased. To mitigate this dilemma, a technique known as dynamic frequency hopping (DFH) is proposed in [19]. This DFH method relies on the assumption of comprising more than a sole channel. In the operation on a functioning channel, the anticipated channel is sensed in parallel and if there is an available option, switching takes place and one of the anticipated channels becomes the operating channel. The Channel-hopping pattern is decided by an access point (AP) and this information is broadcasted to connected stations.

3.2.5 Decision Fusion in Cooperative Sensing

For the case of Co-operative sensing all results due to various measurements and sharing information among CR was a difficult task. There are two types of decisions, soft decisions and hard decisions, based on shared information made by each cognitive device [20]. The results existing in [20], illustrate that soft information-combining outperforms hard information-combining technique in terms of the possibility of missed opportunity. While on the other hand when co-operative users are high, hard decisions perform as good as soft decisions. The Chair-Varshney rule [21] based on a log-likelihood ratio test for combining sensing information is the guideline for optimum fusion rule. A variety of, simpler, schemes for combining sensing results are exploited in [21]. The performances of selection combining (SC), switch and stay combining (SSC) and equal gain combining (EGC) are examined for energy detector based spectrum sensing for Rayleigh fading. SC and SSC are found to have a gain of approximately one order of magnitude while EGC having two orders of magnitude gain. In the case of hard decisions, methods which combine information from different CRs are AND, OR or M-out-of-N schemes [22]. The Dempster-Shafer's theory of evidence is used for a combination of information from different secondary users and results depicted in [23] shows improved performance than AND or OR-rules.

3.2.6 Security

The cognitive radio air interface can be modified by a malicious user to mimic a primary user. Hence primary users can be misleading during the spectrum sensing process. Such a behavior or attack is called as primary user emulation (PUE) attack. The transmitter position is used to identify an attacker in [24]. A challenging problem is to develop valuable countermeasures when an attack is identified. In order to prevent secondary users masked as primary users, public key encryption based primary user recognition is proposed in [25]. An encrypted value (signature) which is generated using a private key is required to transmit with the transmissions of legitimate primary users. This signature is used to validate the primary user but this method is only used with digital modulations. That's why the secondary user should have the capacity for synchronization and demodulation of primary user's signal.

3.3 Spectrum Sensing Techniques

In CR communication, spectrum sensing is a key element and it should be performed before an unlicensed user is allowed to access a vacant licensed channel. The essence of spectrum sensing is a binary hypothesis-testing dilemma:

H_0 **:** Primary user is absent

H_1**:** Primary user is in operation.

The probability of correct detection P_d , probability of false alarm P_f and probability of Miss P_m Pm are the key metric in spectrum sensing, given respectively as:

P_d = Prob {Decision = H_1 / H_1

P_f = Prob {Decision = H_0 / H_0

P_m = Prob {Decision = H_0 / H_1

There are many signal detection techniques, in order to enhance detection probability, which can be used in spectrum sensing [26].

3.3.1 Energy Detection

If the previous information of the PU signal is anonymous, then this energy detection method is optimal for detecting any zero-mean constellation signals [26]. In this energy detection approach, in order to determine whether the channel is occupied or not, the received signal strength indicator (RSSI) or radio frequency (RF) energy in the channel is measured. The implementation of this method for spectrum sensing is shown in fig 3.3a. Firstly, in order to select the bandwidth of interest; the input signal is filtered by a band pass filter. After getting the square of the output signal, it is integrated over the observation interval. At the end, the output from the integrator is compared to a predetermined threshold value to conclude the presence or not of the PU signal. Fast Fourier transforms (FFT) based methods shown in fig 3.3b, are used when the spectral is analyzed in the digital domain. Specifically, the received signal $\boldsymbol{X(t)}$ sampled in a time window are first passed through an FFT device, in order to get the power spectrum$\boldsymbol{X(f)}$. Then the signal energy in the frequency domain is collected and the following binary decision is made.

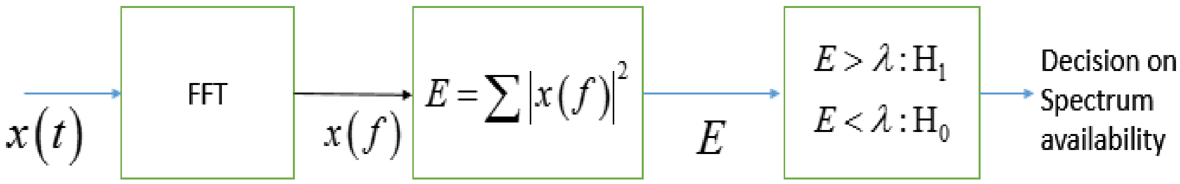


Figure-3.2 Energy detection based spectrum sensing

Rather than that this method can be implemented without prior knowledge of PU, it has still some drawbacks also. The first hitch is that it shows poor performance under low SNR conditions because at low SNR noise variance is not accurately known [26]. Another issue is about the ability to differentiate between the other secondary users which are sharing the same channel and the primary user [27]. The threshold selection is also knotty since it is highly vulnerable to the changing background noise and interference level.

3.3.2 Matched Filter

A matched filter is the finest detection technique as it maximizes the signal to noise ratio (SNR) of the received signal in the existence of additive Gaussian noise [26]. It is obtained by correlating a known signal with an unknown signal in order to detect the existence of the known signal or template in the unknown signal. It is the same as convolving the unknown signal with a time-reversed version of the template. Radar transmission has common use of a matched filter but its usage in CR is limited because of little available information of primary user signals in cognitive radio. Its usage is possible for coherent detection if partial information of PU signals is known. For example, in the case of Digital Television, to detect the presence of DTV signals, its pilot tone can be detected by passing the DTV signal through a delay-multiply circuit. Then the square of magnitude of the output signal is taken and if this square is larger than a threshold, the presence of the DTV signals can be detected.

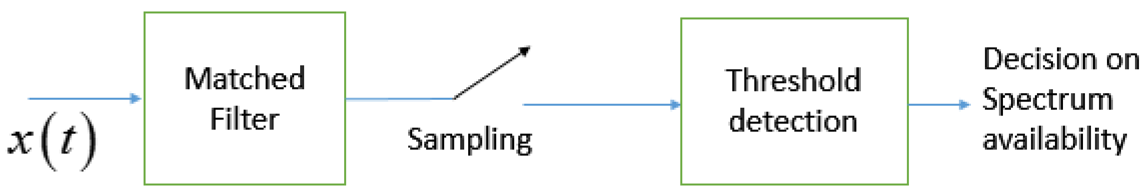


Figure-3.3 Matched Filter based spectrum sensing

3.3.3 Cyclostationary Detection

Man-made signals are normally not stationary but some of them are Cyclostationary, showing periodicity in their statistics. This periodicity can be utilized for the detection of a random signal which has a particular modulation type in a background of noise. Such detection is called Cyclostationary detection. The signal of the PU can be detected at very low SNR values if it exhibits strong Cyclostationary properties. If the autocorrelation of a signal is a periodic function of time *t* with some period then such a signal is called Cyclostationary and this Cyclostationary detection is performed as follows,

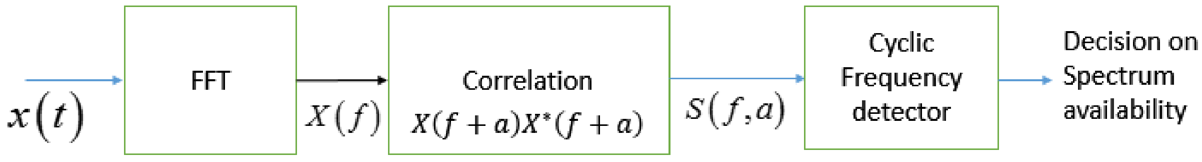


Figure-3.4 Cyclostationary detection technique

Here α is cyclic frequency and E is the statistical expectation operation. The spectral correlation function (SCF) denoted by $S(f,\propto)$, also called the cyclic spectrum is obtained by computing the discrete Fourier transformation of the cyclic auto correlation function (CAF). Detection is completed finally by searching for the unique cyclic frequency corresponding to the peak in the SCF plane. This approach is vigorous to interference and random noise from other modulated signals, because different modulated signals have different unique cyclic frequencies while noise has only a peak of SCF at zero cyclic frequency.

3.3.4 Wavelet Detection

The wavelet approach offers advantages in terms of both implementation cost and flexibility for signal detection over wideband channels, in adapting to the dynamic spectrum in contrast to the conventional implementation of multiple narrowband band pass filters (BPF) [28]. By employing a wavelet transform of the power spectral density (PSD) of the observed signal $x(t)$, the singularities of the PSD $S(f)$ can be sighted and thus the vacant frequency bands can be found. One major issue in the implementation of this approach is the high sampling rates characterizing larger bandwidths.

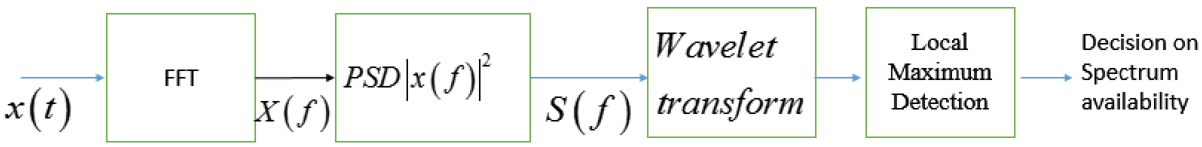


Figure-3.5 Wavelet transform based spectrum sensing

Spectrum sensing techniques	Advantages	Disadvantages
Energy detection	1. Low computation **2.** Does not need any prior information	1. Cannot work in low SNR 2. Cannot distinguish Users 3. Sharing the same channel
Matched Filter	1. Optimal detection performance 2. Low computational cost	1. Requires prior knowledge of primary Users
Cyclostationary Detection	1. Robust in low SNR 2. Robust to interference	1. Requires partial information of primary users **2.** High computational cost
Wavelet Detection	1. Effective for wideband signal	1. High computational cost **2.** Does not work for Spread spectrum signals

Table 3.2: Advantages and Disadvantages of Spectrum Sensing Techniques [26]

Table 3.2 has the overall summary of advantages and disadvantages of all the spectrum sensing techniques for non-cooperative case. By means of time-frequency analysis, maximum interval of a signal and standard variation of the instant frequency are extracted and for recognition of dynamic transmissions by means of these features, neural networks are used. For detection and signal organization, cycle frequencies of the received signal are used. A Hidden Markov model (HMM) is used for processing the (Cyclostationary) signal features for signal identification.

3.4 Cooperative Spectrum Sensing

Cooperation sensing is a proposed solution to the problems that arise during spectrum sensing like fading, shadowing and noise uncertainty [29]. Cooperative sensing has decreased the miss detection and false alarm problem up to a satisfactory level. In addition cooperative sensing can solve one of the most critical issues of spectrum sensing, hidden terminal problem. This problem occurs when the CR is shadowed or in severe multipath fading [29].

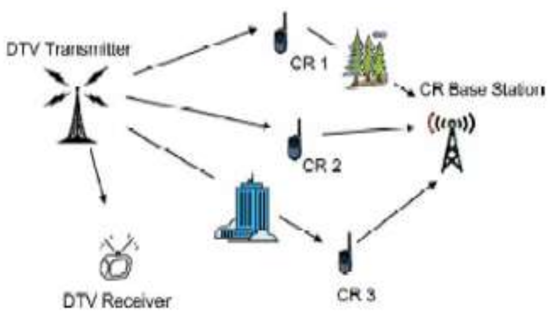


Figure-3.6 cooperative spectrum sensing in CR networks; CR 1 shadowed over the sensing channel and CR 3 is shadowed over reporting channel [29]

Fig 3.6 shows that CR3 is shadowed by a high building over the sensing channel. In such a case, the presence of the primary user is not sensed by the CR and as a consequence channel access is allowed while on the other hand the PU is still in operation. To deal with this problem, multiple CRs can be organized in order to perform spectrum sensing cooperatively. Due to recent research, cooperative sensing is able to greatly increase the probability of detection in fading channels [29]. In general cooperative spectrum sensing consists of the following steps.

• Every CR independently performs measurements for its local spectrum sensing and then makes a binary decision to check on whether the PU is present or not.

• These binary decisions by all CR are forwarded to a common receiver which is a base station (BS) in a cellular network or an access point (AP) in a wireless LAN.

• Those binary decisions are combined by a common receiver and a final decision is made in order to infer the absence or presence of the PU in the observed band. To build a cooperative sensing network, cooperation among CRs and external sensors can be made. Cooperation in the former case is implemented in two fashions: centralized or distributed [29]. These methods are external sensing and are discussed as follows.

3.4.1 Centralized Sensing

In centralized sensing, sensing information from the cognitive devices is collected by a central Unit. The available spectrum is identified and this information is broadcasted to other CRs or directly controls the CR traffic. At AP, all hard sensing results are gathered. The goal is to increase detection performance by alleviating the fading effects of the channel. Local observations of CRs are quantized to one bit in order to decrease the sharing bandwidth. Furthermore, only the CRs with trustworthy information are approved to account their decisions to the central unit and some sensors are censored. This censoring is performed by applying two threshold values instead of only one. Analytic presentation of this scheme is considered for both perfect and imperfect coverage channels.

3.4.2 Distributed Sensing

In distributed sensing although cognitive nodes share information between each other they formulate their personal decisions as to which component of the spectrum they are able to utilize. Distributed sensing is more useful than centralized sensing in cases where there is no requirement for backbone transportation and it has less cost. Collaboration is performed between two SUs, then the user which are nearer to a primary transmitter, and who has a better possibility of detecting the PU transmission, cooperate with far-off users. An algorithm used for pairing SU without a centralized mode is projected. In order to reduce the network overhead because of collaboration, only ultimate decisions are pooled and in order to advance detection capability of the system features gained at different radios are shared along with cognitive users.

Chapter 4
Eigen value based spectrum sensing

4.1 Introduction

To overcome the shortage of previous spectrum sensing techniques, Eigenvalue of covariance metrics based spectrum sensing method has been developed in recent years. , Eigenvalue based method can further divided in two sub categories: 1) method that assume knowledge of noise level (semi blind), 2) and method they do assume knowledge of knowledge of noise (blind spectrum sensing). In present chapter study of blind method is studies and then modified blind spectrum sensing method has been discussed.

In Eigenvalue based method, Eigen value of covariance metrics is considered as test statistics. This method outperforms the conventional energy detection based method for correlated signals, and for iid signal this method approaches to energy based detection

4.2 Detection principle

In signal detection there can be two possibility 1) signal present 2) signal not present. Case when signal will not be present their will be only noise and at receiver side we will receive only noise power. Noise samples are purely uncorrelated to each other while in transmitted signal some correlation will be always present. In Eigen value based method while detecting received power we take consideration of correlation among the signal ,since covariance metrics catches the correlation between the samples the Eigen value of covariance metrics is used here as test statics. The signal covariance shown below shows the covariance between the signal samples at different noise environment.

Figure 4.1 shows the covariance between the same signal components when noise effect is not considered. A strong correlation can be found, in a pure transmitted signal. Which is positive increasing straight line.

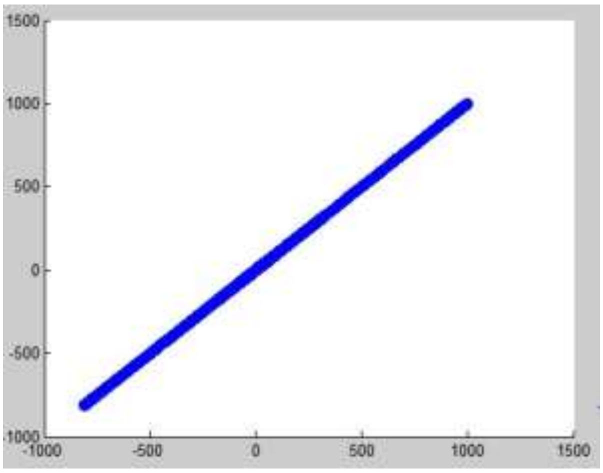


Figure-4.1 Covariance when no noise effect

Figure 4.2 shows the covarience when small amount of noise is added to the transmitted signal .as from the figure we can observe that as noise effect will increase linearity will be affected and signal detection will become more difficult.

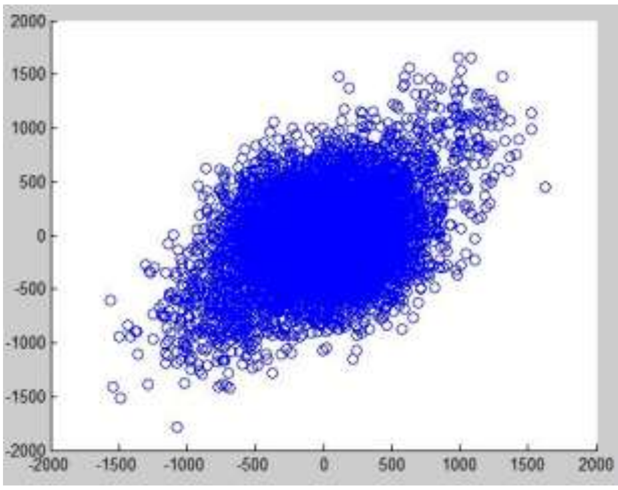


Figure-4.2 Covarience for low noise effected signal

Figure 4.3 shows the condition when transmitted signal is corrupted by noise up to the extent that signal detection is not possible.

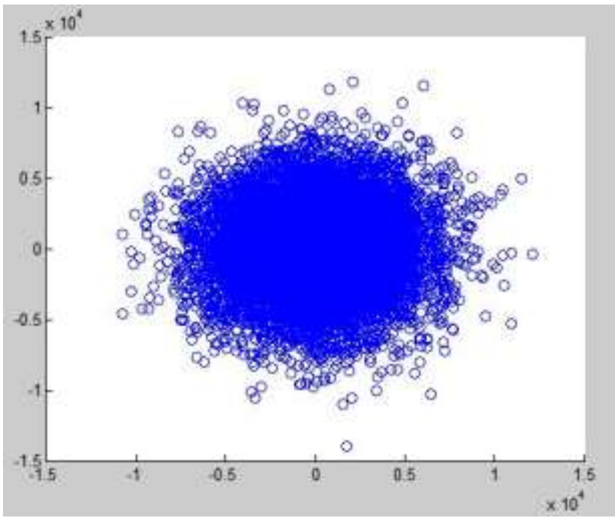


Figure-4.3 Covarience for highly noise effected signal

4.3 Blind Eigen value based detection

Block diagram for Eigen value based detection technique [30]is given in figure 4.4. Covariance of received signal vector R from K number of receivers is calculated. Test statics is defined as the ratio of largest Eigen value of covariance metrics to the trace of sample covariance metrics. If test statics have greater value than the threshold then signal will be present in given channel and channel is not vacant for the use of secondary users. If the previous condition is not satisfied then cannel will considered and available for the secondary user transmission.

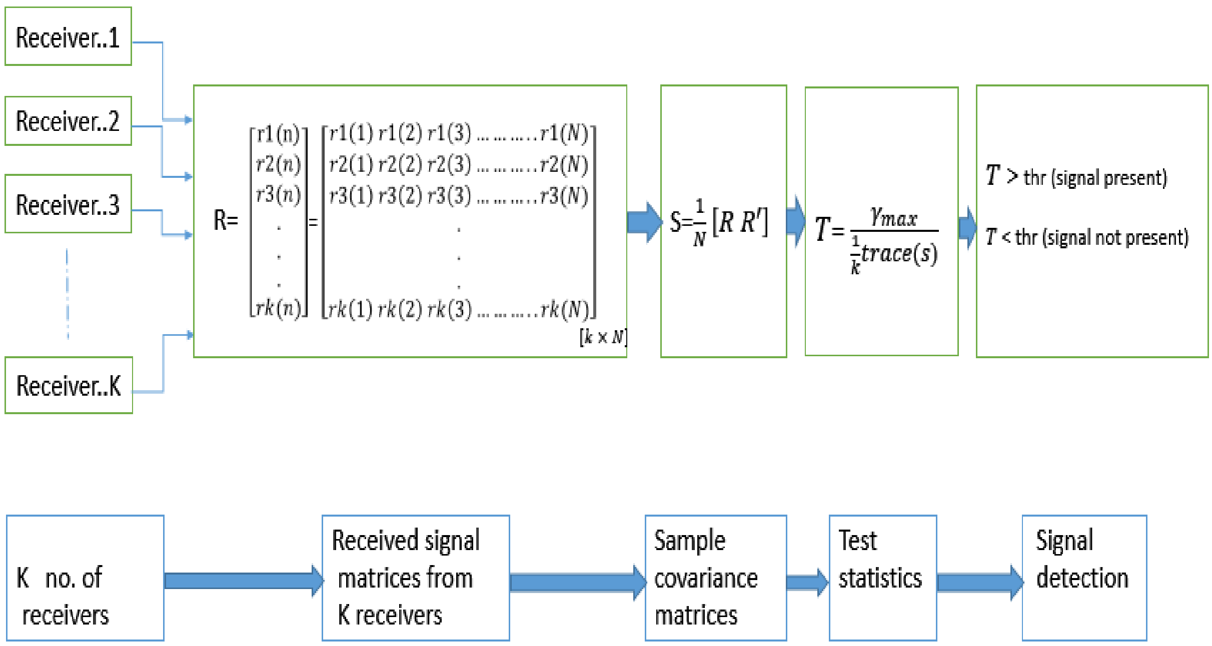


Figure-4.4 Block diagram for blind Eigen value detection

4.3.1 Advantages

1. Better performance at low signal noise ratio situations.

2. Don’t require prior knowledge of signal level or noise level

4.3.2 Limitation

1. To many number of receivers are requires to take decision

2. Complex implementation

Comment: Due to use of to many receivers in Eigen value based method system complexity will increased along with that use of many receivers will increase the cost of system.In Eigen value based method explained above requires too many numbers of samples to make proper decision of channel availability. As the required number of samples will increased their processing will be more and more time taking which should be avoided in designing of cognitive radio .a cognitive radio should take its decision very frequent to avoid interference to the primary user.

These limitation are improved in method discussed in next section

4.4 Improved Eigen value based detection

Block diagram of improved Eigen value method is shown below in figure-4.5. The covariance from the k number of receivers will give the same result as the covariance between the K numbers of samples from a single received signal vector. This fact is utilized here to reduce the system complexity. And use of multiple numbers of antenna will make signal detection even at increased noise power.

In our analysis we have taken two antenna at the receiver, which will make signal detection even at 3 dB increased noise power.

Detection principle will be same as discussed in previous section.

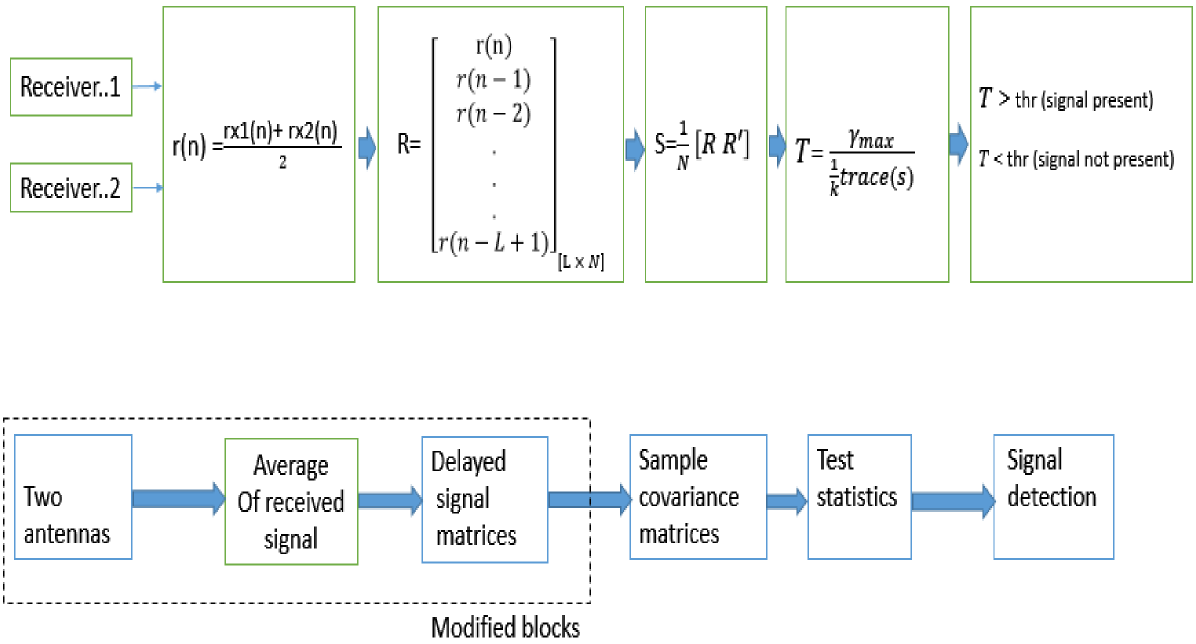


Figure-4.5 Block diagram for improved blind Eigen value detection technique

4.5 Probability calculation

In this section mathematical derivation of probability of false alarm, threshold, and probability of detection is given [30].

4.5.1 System model

Let $$r(t) = x(t) + w(t) \qquad \text{……………………4.1}$$

$r(t)$ is the received signal, where $x(t)$ is the received primary user signal and $w(t)$ is the AWGN noise signal with zero mean and varianceσ^2, there are two Hypothesis: 1) H_0 when signal is not present and 2) H_1 when signal is present. The received signal under two hypothesis can be given as

$$r(t) = \begin{cases} w(n), & : H_0 \\ x(n) + w(n), & : H_1 \end{cases} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

Where, n is the number of received samples.

Here two probability 1) probability of detection and 2) probability of false alarm can be defined as,

$$P_d\,[H_1 : r(n) = \; x(n) + w(n)] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

$$P_{FA}\,[H_0 : r(n) = w(n)\;] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.4$$

And,

$$\text{SNR} = \frac{\sigma_n^2}{\sigma_s^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.5$$

Let received signal be $r(n)$

$$r(n) = [r_1(n)\,,\; r_2(n)\,.\ldots\ldots..\,r_K(n)]^T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.6$$

From $K \times 1$ receivers at time instant n.

Where, $r_K(n)$ is the discrete sample at receiver$K$,

The received signal samples, are stored in $K \times N$ metrics form as

$$R \cong [\,r(1), r(2)\ldots\ldots\ldots\ldots..\,r(N)] = x + w \qquad \ldots\ldots\ldots\ldots\ldots\ldots 4.7$$

Where,

$$x \cong [\,r(1), r(2)\ldots\ldots\ldots\ldots..\,r(N)] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.8$$

is a $K \times N$ transmitted signal matrices , and

$$w \cong [\,w(1), w(2)\ldots\ldots\ldots..\,w(N)] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.9$$

Is a $K \times N$ noise metrics. The received metrics R can be given as

$$R = \begin{bmatrix} r_{11}\; r_{12}\ldots\ldots\ldots\ldots\ldots..\,r_{1N} \\ r_{21}\; r_{22}\ldots\ldots\ldots\ldots\ldots\ldots r_{2N} \\ . \\ . \\ r_{K1}\; r_{K2}\ldots\ldots\ldots\ldots\ldots\ldots r_{KN} \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.10$$

The sample covariance metrics $\hat{S}$ is given by

$$\hat{S} = \frac{1}{N}\,RR' \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.11$$

Where R' is transpose of the received signal metrics$R$.Let $\lambda_1 > \lambda_2 > \lambda_3 > ....\lambda_K$ be the Eigen values of $\hat{S}$ .And T be the test statistics to decide H_0 and H_1 .To make decision for signal present, test statistics compares T with γ , If $T > \gamma$ then it decides H_1 : signal will be present, otherwise signal will not be present. So the probability of false alarm can be given as

4.5.2 Probability of False Alarm

There will be false alarm, when a cognitive radio will decide presence of primary user when primary user is not present. False alarm will degrade the system performance and should be kept minimum as much possible.

$$P_{fa} = \Pr(T > \gamma : H_0) \qquad \text{.......................4.12}$$

And probability of detection can be given by

$$P_d = \Pr(T > \gamma : H_1) \qquad \text{......................... 4.13}$$

Expression for thresholdγ , detection probability P_d , and false alarm P_{fa} is given by expression below. Here the distribution of λ_1 can be approximated as in 4.15, and from 4.14, distribution of summation of other Eigen values under hypothesis H_0 can be approximated to as

$$H_0 : \frac{1}{K-1}\sum_{i=2}^{K}\lambda_i \simeq \sigma_n^2 \qquad \text{...........................4.14}$$

$$\sum_{i=2}^{K}\lambda_i \simeq (K-1)\sigma_n^2 \qquad \text{...........................4.15}$$

$$H_0 : \frac{\lambda_1}{\sum_{i=2}^{K}\lambda_i} = \frac{1}{(K-1)}\frac{\lambda_1}{\sigma_n^2} \qquad \text{.........................4.16}$$

$$P_{fa} = \Pr\left(\frac{1}{(K-1)}\frac{\lambda_1}{\sigma_n^2} > \gamma \middle| H_0\right) \qquad \text{..........................4.17}$$

$$P_{fa} = \Pr\left(\frac{\left(\lambda_1/\left((K-1)\sigma_n^2\right)\right) - \left(\mu_{nK}/(\mathrm{K}-1)\right)}{\sigma_{nK}/(K-1)} > \frac{\gamma - \left(\mu_{nK}/(\mathrm{K}-1)\right)}{\sigma_{nK}/(K-1)}\right) \text{.....4.18}$$

$$P_{fa} = 1 - F_1\left(\frac{\gamma - \left(\mu_{nK}/(K-1)\right)}{\left(\sigma_{nK}/(K-1)\right)}\right) \qquad \text{........................4.19}$$

4.5.3 Threshold calculation

Threshold can be calculated for given value of false alarm. To calculate threshold we fix false alarm probability and calculate threshold by using inverse relationship. Expression given in equation 4.20 gives the threshold value.

$$\gamma = \frac{1}{N\left(K-1\right)}\left[\left(\sqrt{N-\frac{1}{2}}+\sqrt{K-\frac{1}{2}}\right)^{2}+\frac{\left(\sqrt{N-\frac{1}{2}}+\sqrt{K-\frac{1}{2}}\right)^{4/3}}{\left(\left(N-\frac{1}{2}\right)\left(K-\frac{1}{2}\right)\right)^{1/6}}F^{-1}\left(1-P_{fa}\right)\right] \quad ....4.20$$

4.5.4 Probability of detection

Probability of detection should be kept as high as possible. High detection probability will give high accuracy for spectrum sensing. Probability of detection can be calculated under hypothesis H_1.

$$H_1 : \frac{1}{K-1}\sum_{i=2}^{K}\lambda_i \simeq \sigma_n^2 - \frac{\sigma_n^2\lambda_1}{N\left(\lambda_1-\sigma_n^2\right)} \quad ....4.21$$

$$\sum_{i=2}^{K}\lambda_i \simeq \left(K-1\right)\sigma_n^2\left(1-\frac{\sigma_n^2+\sigma_s^2}{N\sigma_s^2}\right) \quad ....4.22$$

$$\sum_{i=2}^{K}\lambda_i \simeq \left(K-1\right)\sigma_n^2\left(1-\frac{1+SNR}{1-SNR}\right) \quad ....4.23$$

$$H_1 : \sum_{i=2}^{K}\lambda_i \sim N\left(\frac{(1+SNR)(1+((\mathrm{K}-1)/\mathrm{N}\,SNR))}{(\mathrm{K}-1)(1-((1+SNR)/\mathrm{N}\,SNR))}, \frac{(1+SNR)^2}{N(\mathrm{K}-1)^2(1-((1+SNR)/\mathrm{N}\,SNR))^2}\right)$$

.............................4.24

$$P_d = \Pr\left(\frac{\left(\lambda_1/\sum_{i=2}^{K}\lambda_i\right)-mean\left(\lambda_1/\sum_{i=2}^{K}\lambda_i\right)}{\sqrt{\mathrm{var}\left(\lambda_1/\sum_{i=2}^{K}\lambda_i\right)}} > \frac{\gamma-mean\left(\lambda_1/\sum_{i=2}^{K}\lambda_i\right)}{\sqrt{\mathrm{var}\left(\lambda_1/\sum_{i=2}^{K}\lambda_i\right)}}\right) \quad ....4.25$$

$$P_d = Q\left(\frac{\gamma - mean\left(\lambda_1 / \sum_{i=2}^{K}\lambda_i\right)}{\sqrt{\mathrm{var}\left(\lambda_1 / \sum_{i=2}^{K}\lambda_i\right)}}\right) \qquad \text{.............................4.26}$$

$$mean\left(\lambda_1 / \sum_{i=2}^{K}\lambda_i\right) = \frac{(1+SNR)\left(1+(K-1)/N.SNR\right)}{(K-1)\left(1-(1+SNR)/N.SNR\right)} \qquad \text{............................4.27}$$

$$Var\left(\lambda_1 / \sum_{i=2}^{K}\lambda_i\right) = \frac{(1+SNR)^2}{N\,(K-1)^2\left(1-(1+SNR)/N.SNR\right)^2} \qquad \text{............................4.28}$$

$$P_d = Q\left(\frac{\gamma\sqrt{N}\,(\mathrm{K}-1)\left(1-\left((1+\mathrm{SNR})\big/ N.SNR\right)\right)}{1+SNR} - \sqrt{N} - \left(\frac{K-1}{\sqrt{N}SNR}\right)\right) \text{................4.29}$$

Probability of false alarm, threshold, and probability of detection are calculated in expression given by 4.19, 4.20 and 4.29.based on these values different probabilities are calculated for different modulation schemes.

Chapter 5
Modulation Techniques

5.1 Introduction

Developing a cognitive device which have detect the presence of unknown signal then it is necessary to observe it performance for the presence of various available known signal. Signals present in wireless environment can be characterized modulation scheme used to transmit that signal. Taking these points in consideration this section covers the main digital modulation techniques.

5.2 Application

Table given below covers the applications of different modulation schemes in communications system.

S.No	**Modulation Schemes**	**Application**
1.	MSK ,GMSK	CDPD ,GSM
2.	BPSK	Deep space telemetry
3.	QPSK, $\pi/4$ DQPSK	Satellite, CDMA, TETRA etc.
4.	OQPSK	Satellite, CDMA
5.	8 PSK	Satellite ,aircraft
6.	16 QAM	Microwave digital radio, DVB-C,DVB-T
7.	32 QAM	Terrestrial microwave ,DVB-T
8.	64 QAM	DVB-C, broadband set top box, MMDS
9.	256 QAM	DVB-C(Europe),Digital video (US)

Table-5.1 Application of different modulation Techniques

5.3 Digital modulation schemes

Now a day's maximum of work is focuses on digital modulation schemes. Due to their advantages over conventional analog modulation schemes. In this section a brief description of practical modulation techniques is given.

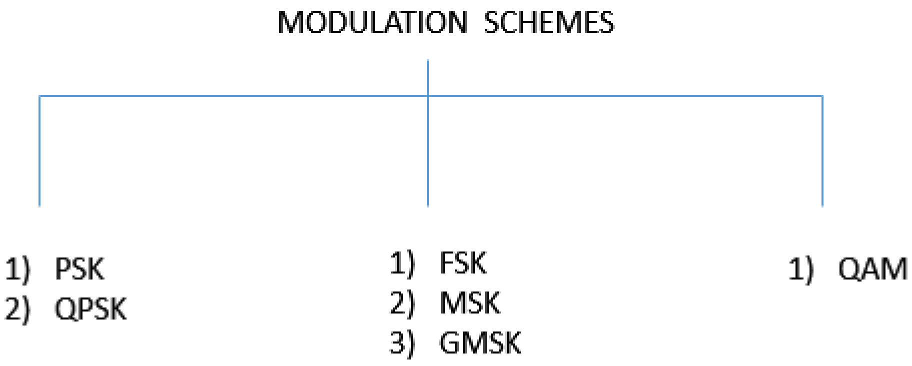


Figure-5.1 Digital modulation schemes

5.3.1 Phase Shift Keying (PSK)

One of the simple type of digital modulation scheme is binary or Bi-Phase Shift Keying (BPSK). One application where it is used is for deep space communication. The phase angle of a constant amplitude carrier signal changes between 0 and 180 degrees.
Phase shift Keying have two possible locations in the state diagram as shown below, so a binary 1 or 0 can be sent. The symbol rate for PSK is one bit per symbol.

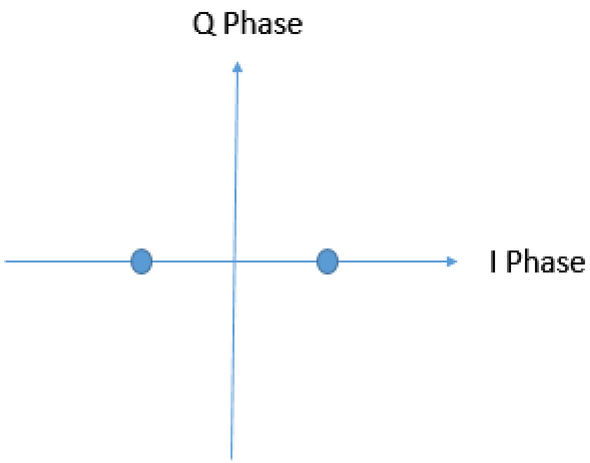


Figure-5.2 Constellation diagram for phase shift keying

One bit per symbol is transmitted

5.3.2 Quadrature Phase Shift Keying (QPSK)

The more common application of phase modulation is Quadrature Phase Shift Keying (QPSK). QPSK modulation is used in applications including CDMA (Code Division Multiple Access) cellular service, wireless local loop system, Iridium (a voice/data satellite system) and DVB-S (Digital Video Broadcasting - Satellite).
Quadrature means that the signal varies between phase states which are separated by 90 degrees angels. The carrier phase shifts in increments of 90 degrees, from 45 to 135, –45, or –135 degrees. These points are selected as they can be easily implemented using an *I/Q* modulator. We need only two *I* values and two *Q* values are needed for signal representation and this will

gives two bits per symbol. QPSK is more bandwidth-efficient modulation compare to BPSK, potentially twice as efficient. Two bits per symbol are transmitted in QPSK modulation technique.

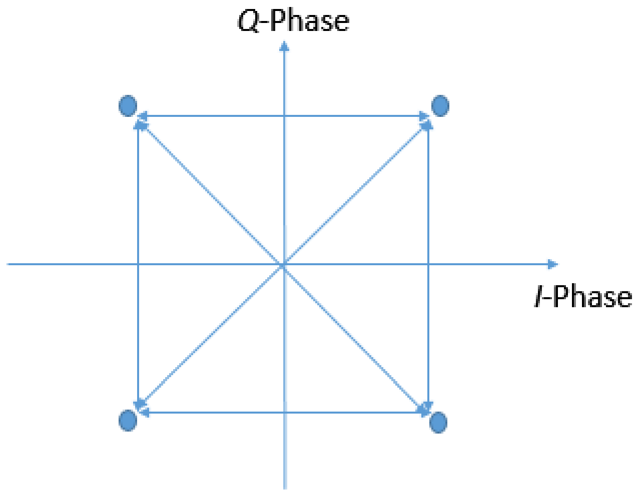


Figure-5.3 Constellation diagram for Quadrature phase shift keying

5.3.3 Frequency Shift Keying

Phase modulation and Frequency modulation are closely related to each other. A static frequency increment of +1 Hertz means that the phase angle is constantly advancing at the rate of 360 degrees per second (2 ¹ rad/sec), relative to the phase angle of the not shifted (unshifted) signal.

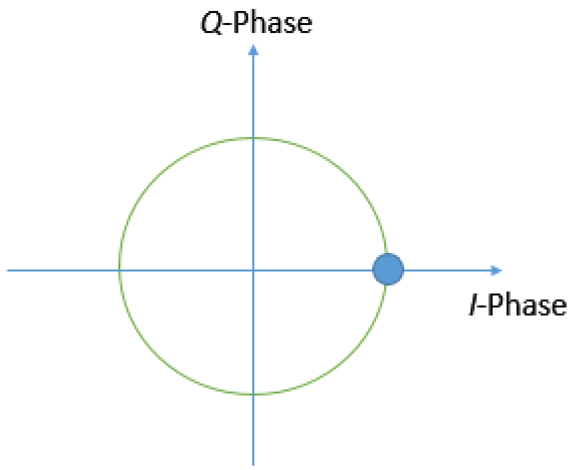


Figure-5.4 Constellation diagram for Frequency shift keying

Applications of FSK (Frequency Shift Keying) include cordless and paging systems. Some of the cordless systems include CT2 (Cordless Telephone 2) and DECT (Digital Enhanced Cordless Telephone) systems.

In Frequency shift keying, frequency of the carrier signal is varied as a function of the modulating signal (data stream) to be transmitted. Amplitude of carrier signal remains constant.

In binary frequency shift keying (BFSK), a “1” is represented by one given frequency and a “0” is represented by some another frequency.

5.3.4 Minimum Shift Keying

In FSK, frequency shift produces an advancing or retarding of phase angle, frequency shifts can be detected by sampling of phase angle at each symbol period. Phase shifts of (2N + 1)^{1}/2 radians can be easily detected with the help of *I/Q* demodulator. At even numbered symbols, the polarity of the *I* channel conveys the transmitted data, while at odd numbered symbols the polarity of the *Q* channel conveys the data. This orthogonally between *I* and *Q* simplifies detection algorithms and hence reduces power consumption in a mobile receiver. The minimum frequency shift which yields orthogonally of *I* and *Q* is that which results in a phase shift of ± ^{1}/2 radians per symbol (90 degrees per symbol). FSK with this deviation is called MSK (Minimum Shift Keying). The deviation must be accurate in order to generate repeatable 90 degree phase shifts.
MSK is used in the GSM (Global System for Mobile Communications) cellular standard. A phase shift of +90 degrees represents a data bit equal to “1”, while –90 degrees represents a “0”. The peak-to-peak frequency shift of an MSK signal is equal to one-half of the bit rate.

FSK and MSK produce constant envelope carrier signals, which have no amplitude variations. This is a desirable characteristic for improving the power efficiency of transmitters. Amplitude Variations can exercise nonlinearities in an amplifier’s amplitude-transfer function, generating Spectral regrowth, a component of adjacent channel power. Therefore, more efficient amplifiers (which tend to be less linear) can be used with constant-envelope signals, reducing power consumption. MSK has a narrower spectrum than wider deviation forms of FSK. The width of the spectrum is also influenced by the waveforms causing the frequency shift. If those waveforms have fast transitions or a high slew rate, then the spectrum of the transmitter will be broad. In practice, the waveforms are filtered with a Gaussian filter, resulting in a narrow spectrum. In addition, the Gaussian filter has no time-domain overshoot, which would broaden the spectrum by increasing the peak deviation. MSK with a Gaussian filter is termed GMSK (Gaussian MSK). One bit per symbol is transmitted in MSK technique. QI diagram is shown in figure-5.5

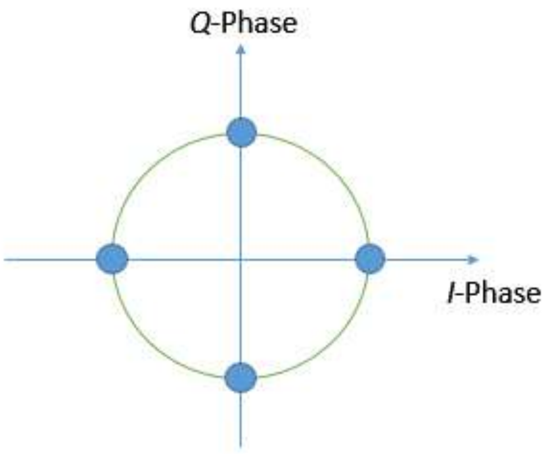


Figure-5.5 Constellation diagram for Minimum shift keying

5.3.5 Quadrature Amplitude Modulation (QAM)

Another member of the digital modulation family is Quadrature Amplitude Modulation (QAM). QAM is used in DVB-C (Digital Video Broadcasting - Cable) and microwave digital radio etc.

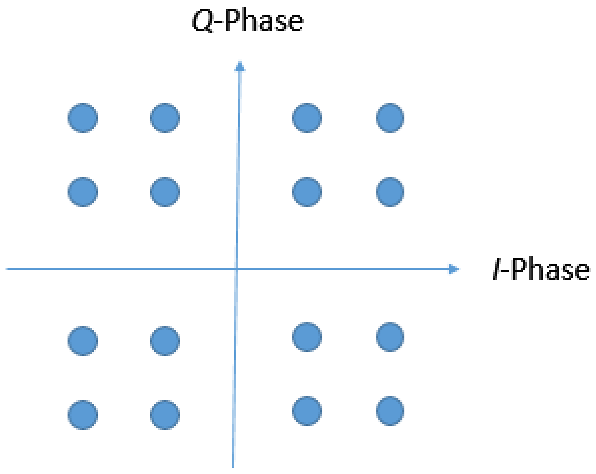


Figure-5.6 Constellation diagram for 16-Quadrature amplitude modulation

Their are16-state in Quadrature Amplitude Modulation (16 QAM), which have four *I* values and four *Q* values. This will results in a total of 16 possible states of signal. It can take transition from any state to any other state at every symbol time. Since $16 = 2^4$, so four bits per symbol can be transmitted. This consists of two bits for *I* and two bits for *Q*. The symbol rate is one fourth of the bit rate. So this modulation format produces a more spectrally efficient transmission. It is more efficient than BPSK, QPSK or 8PSK. QPSK is the same as 4QAM.
And other variation is 32QAM. In this case there are six *I* values and six *Q* values resulting in a total of 36 possible states (6x6=36). This is too many states for a power of two (the closest power of two is 32). So the four corner symbol states, which take the most power to transmit, are omitted. This reduces the amount of peak power of the transmitter has to generate. Since $2^5 = 32$, there are five bits per symbol and the symbol rate is one fifth of the bit rate.

The current practical limits are approximately 256 QAM, though work is underway to extend the limits to 512 or 1024 QAM. A 256QAM system uses 16 *I*-values and 16 *Q*-values giving 256 possible states. Since $2^8 = 256$, each symbol can represent eight bits. A 256QAM signal that can send eight bits per symbol is very spectrally efficient. However, the symbols are very close together and are thus more subject to errors due to noise and distortion. Such a signal may have to be transmitted with extra power (to effectively spread the symbols out more) and this reduces power efficiency as compared to simpler schemes.

Chapter 6
Simulation and results

6.1 Introduction

This chapter describes whole simulation process to obtain results. Flow chart given in figure-6.1 shows the steps involved.

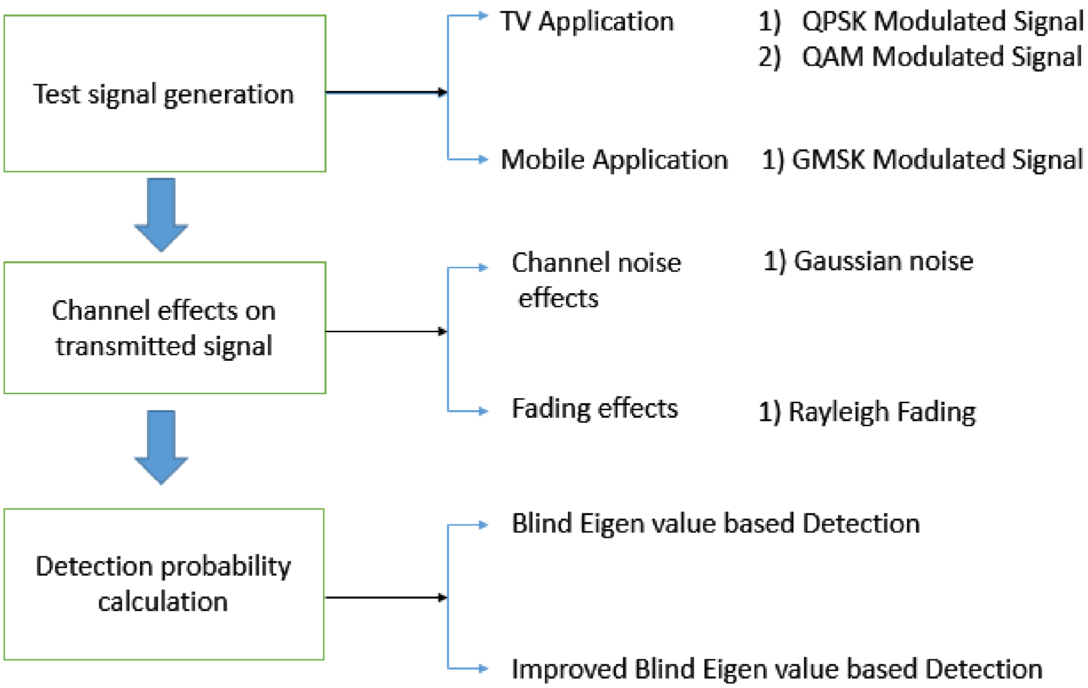


Figure-6.1 Simulation process Flow diagram

6.2 Test signal generation

Test signal is generated in TV band and mobile radio communication band (GSM Band). For TV application QPSK and 16-QAM modulated signal is generated. Power spectral density of generated signal are given figure-6.2 and figure-6.3.

In generation of QAM and 16-QAM signals, modulation parameters assumed are given below.

Carrier frequency =400MHz,

Symbol rate=5 MHz,

Sampling frequency =1500MHz,

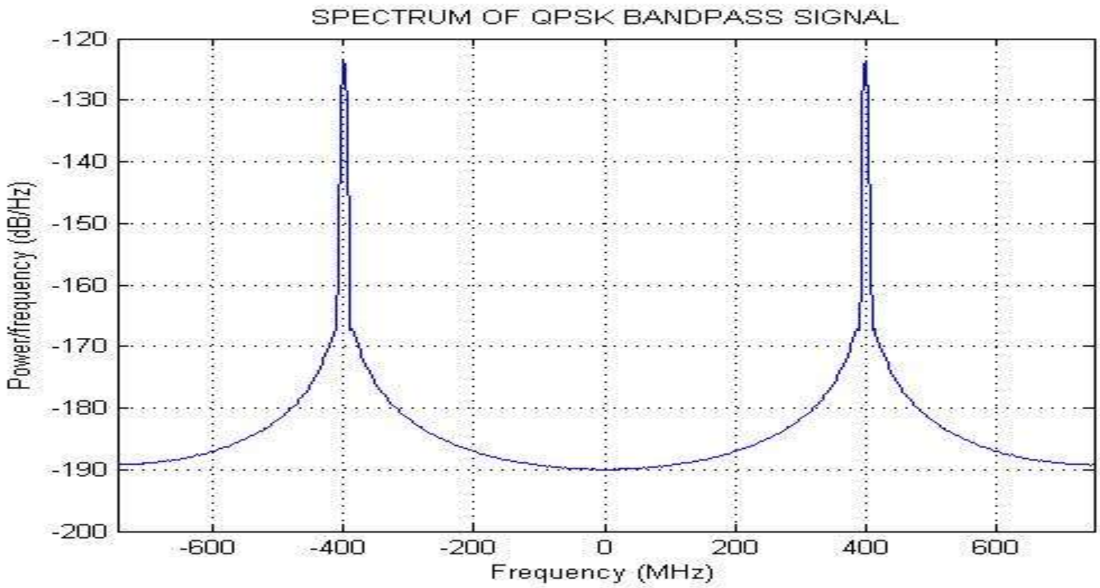


Figure-6.2 Spectrum of QPSK modulated band pass signal in TV band

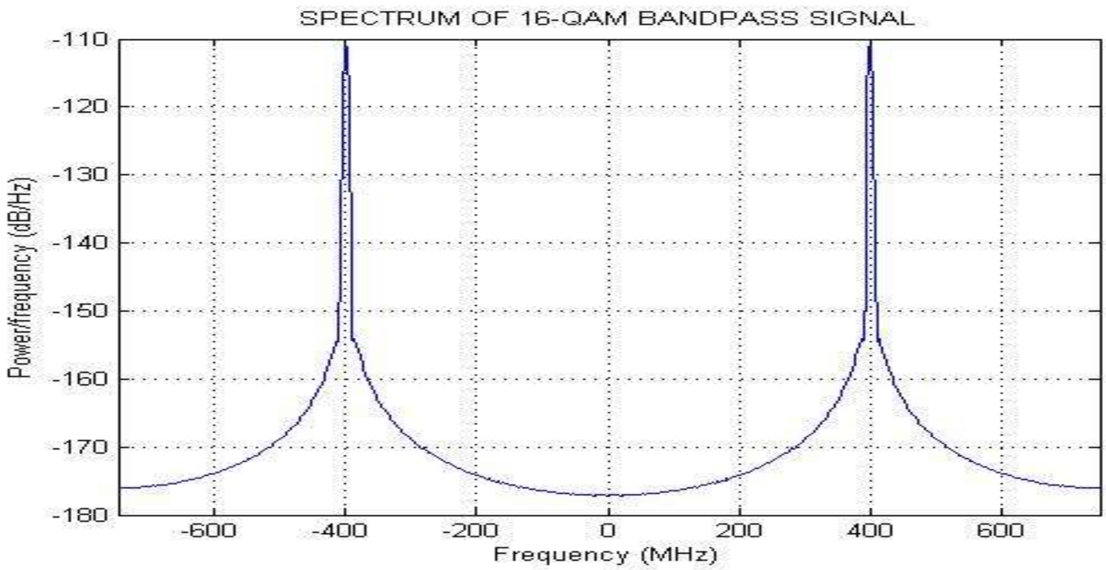


Figure-6.3 Spectrum of 16-QAM modulated band pass signal in TV band

For mobile communication Gaussian minimum shift keying modulation is used. Here we have generated a 200 KHz base band signal with GMSK modulation. Base band signal is up-converted to 1800MHz carrier frequency for transmission purpose. Power spectral density of up converted signal is shown in figure-6.4.

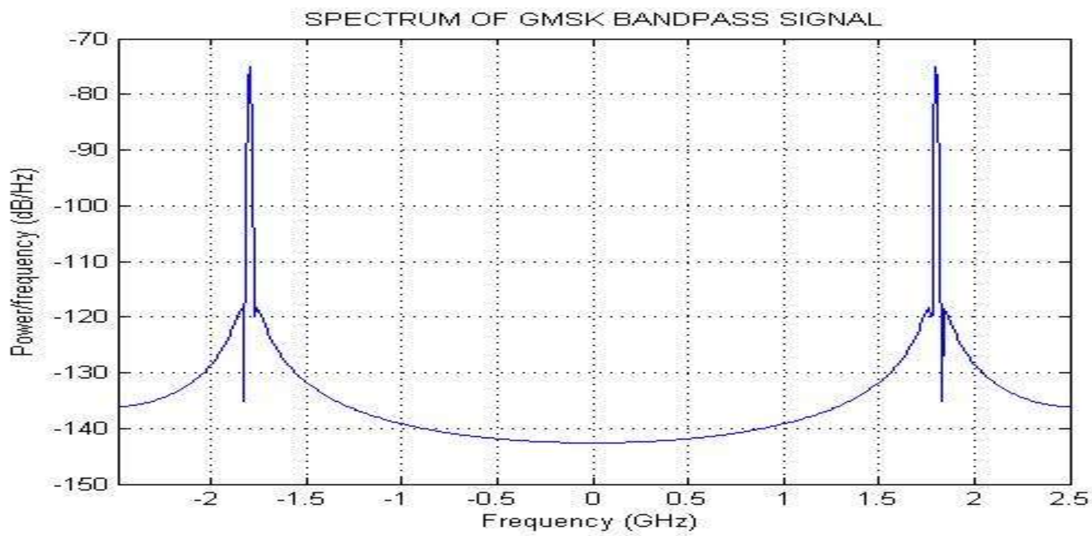


Figure-6.4 Spectrum of GMSK modulated band pass signal in GSM band

6.3 Channel Impairment on Transmitted signal

Generated signal will be transmitted through the fading channel. Transmitted signal will be affected by the noise and fading effects. Here we have considered the Rayleigh fading effect and processed our signal through AWGN channel, taking signal to noise ratio of -15dB in to simulation consideration. Signal received at received at cognitive radio receiver is given by figure given below.

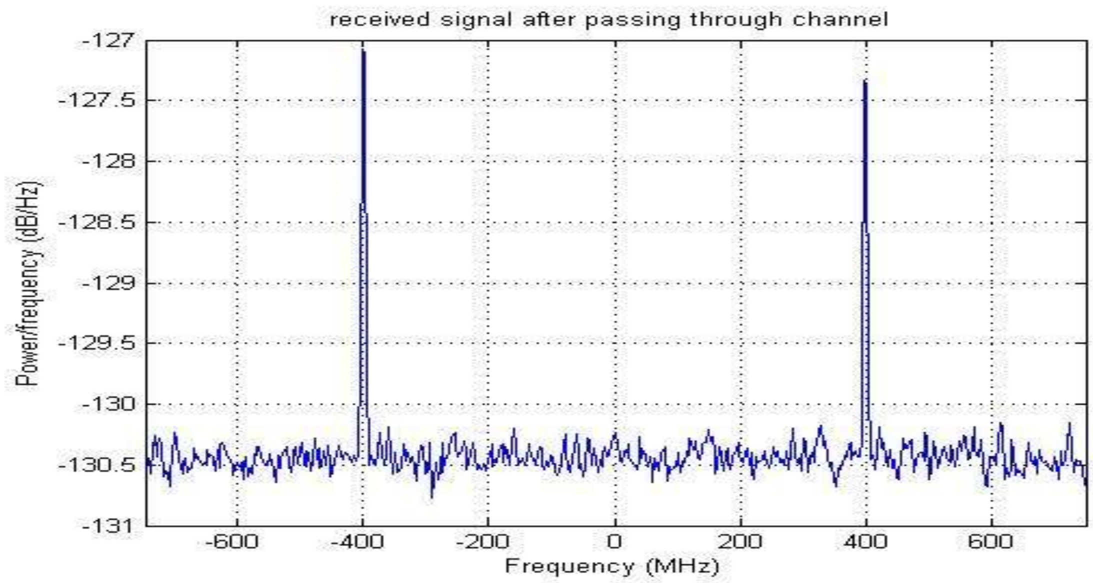


Figure-6.5 QPSK modulated signal propagation over channel

We have considered three different types of signal for our simulation purpose .channel noise effect on these signal are given in figures-6.5, 6.6 and figure 6.7

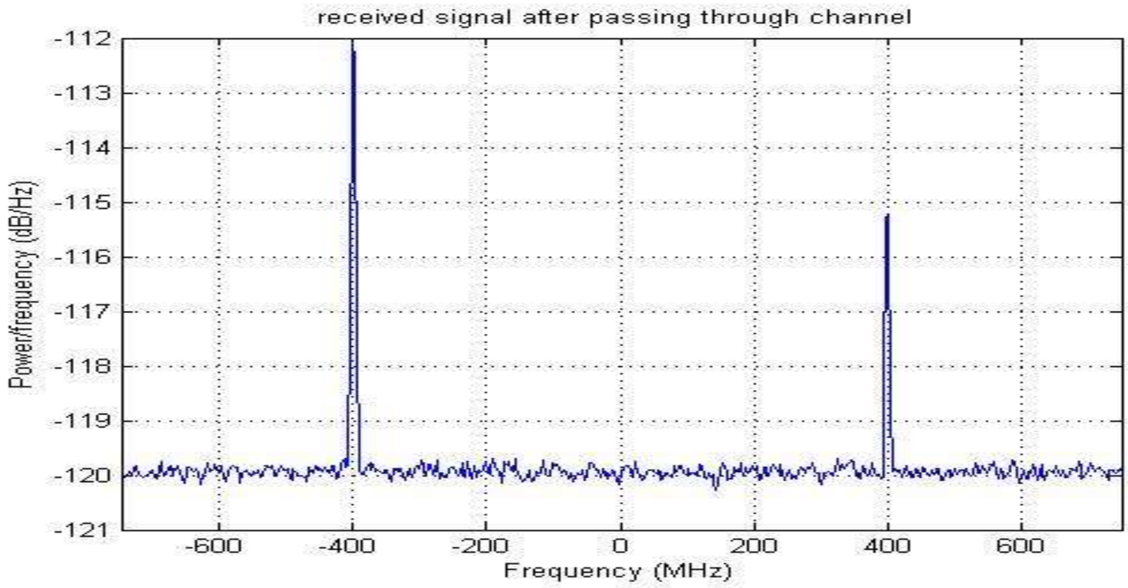


Figure-6.6 16-QAM modulated signal propagation over channel

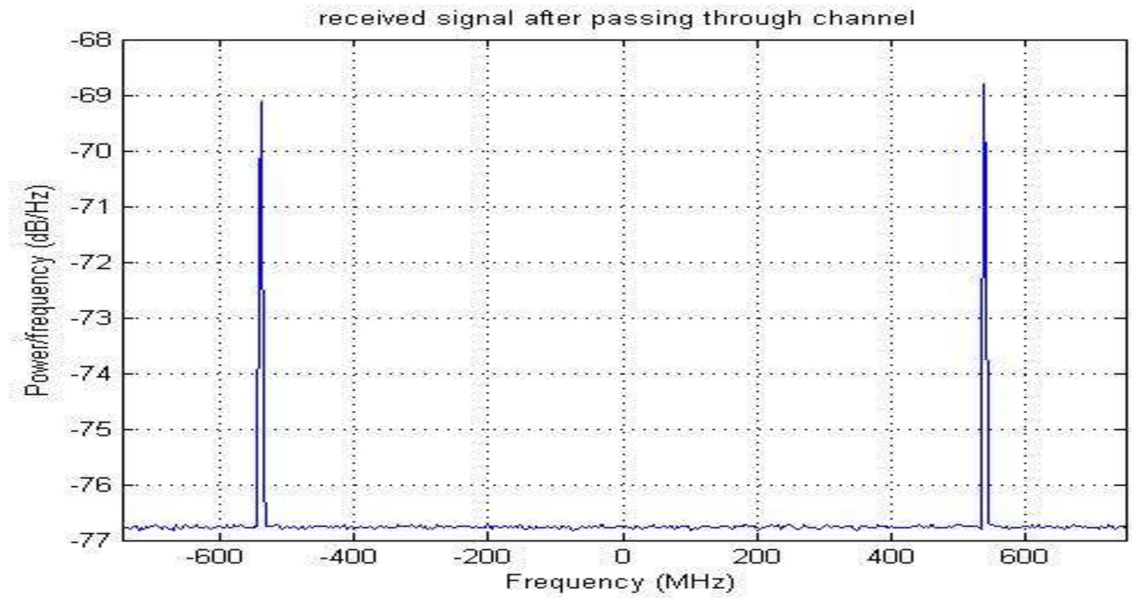


Figure-6.7 GMSK modulated signal propagation over channel

From figures we observe that snr level before transmission (-50dB) decreases to -8dB, during signal propagation through channel. Which causes difficulties to distinguish between signal and noise. And not able to differentiate noise and signal is the basic detection problem in all sensing techniques.

6.4 Probability of Detection using blind Eigen value sensing

For detection of signal, blind Eigen value based method is used and detection probability is calculated and plotted in figure-6.8, figure-6.9 and figure-6.10. From the plots we observe that detection probability is nearly same for all type of modulation schemes .From observation we conclude that we can work with same sensing technique for all modulation scheme and all band of communication .probability detection curve shows that detection probability decreases very sharply as snr level decrease below -14dB.

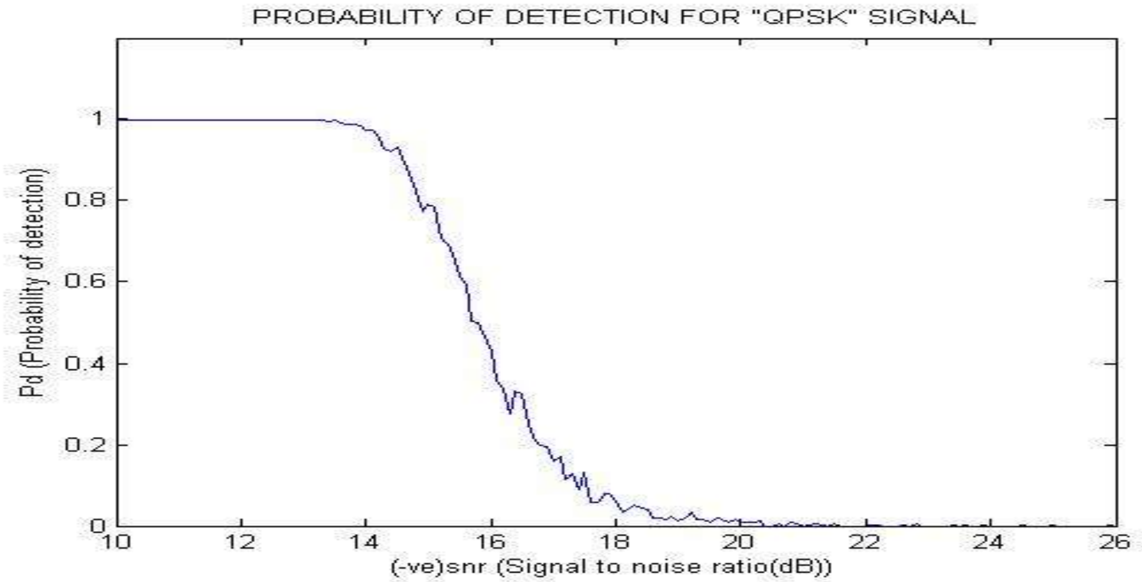


Figure-6.8 Detection probability for QPSK modulated signal

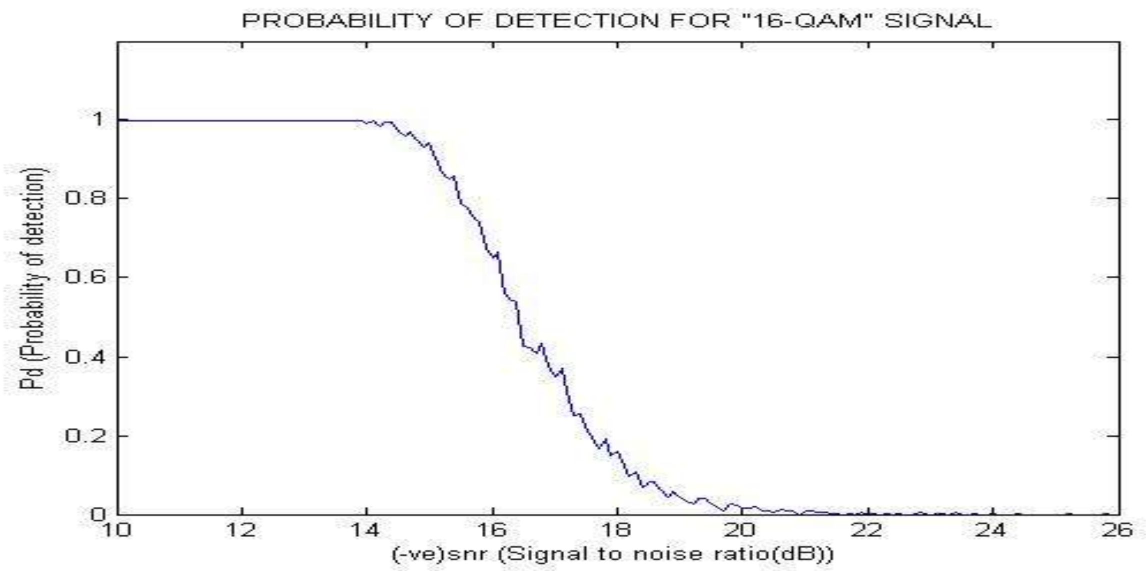


Figure-6.9 Detection probability for 16-QAM modulated signal

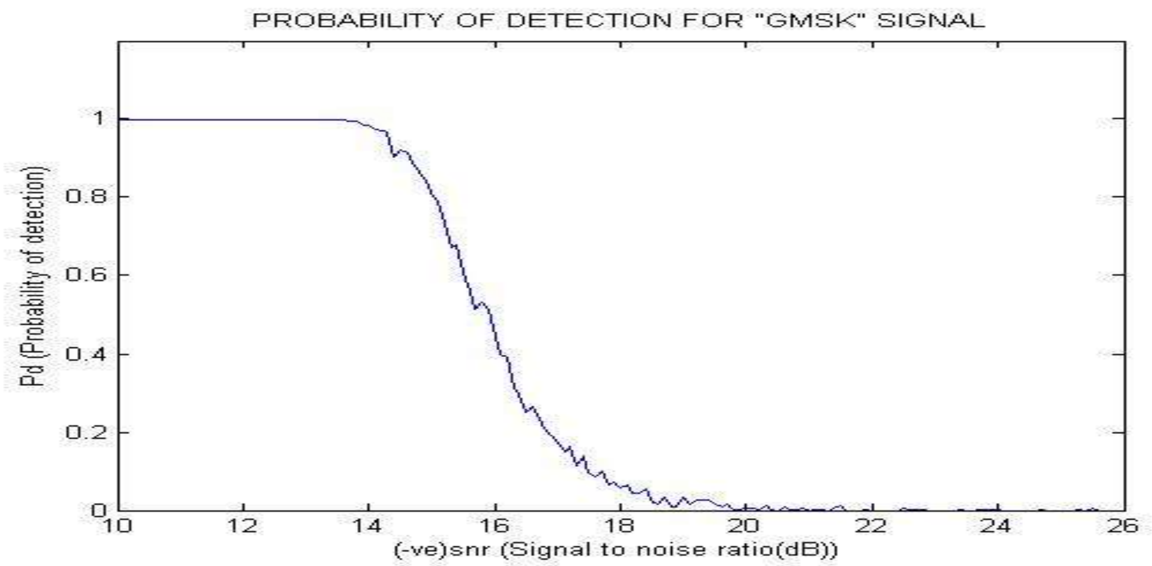


Figure-6.10 Detection probability for GMSK modulated signal

Comparisons of probability of detection for QPSK, 16-QAM and GMSK signals

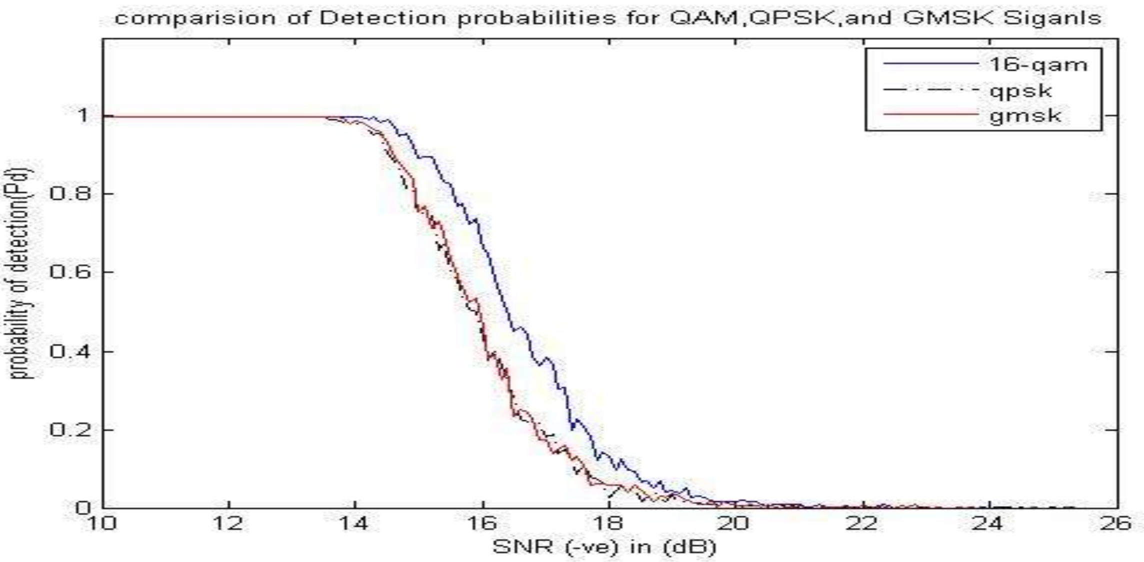


Figure-6.11 Comparisons of Detection probability using Eigen value detection technique

Figure-6.11 shows comparisons of detection probability for all three modulation schemes. We observe nearly same detection probability for all communication band included here. While 16-QAM modulated signals are detected more easily as compare to other.

6.5 Probability of detection for improved blind Eigen value Sensing

Figure-6.12, Figure-6.13 and Figure-6.14 shows detection probability for QPSK, 16-QAM and GMSK modulated signal. Using improved detection method we can detect signals up to 3dB noisy as compare to the previous detection technique. We are able to detect signal up to -18 dB noisy.as compare to QPSK and GMSK modulated signal QAM modulated signal detection gives better performances.

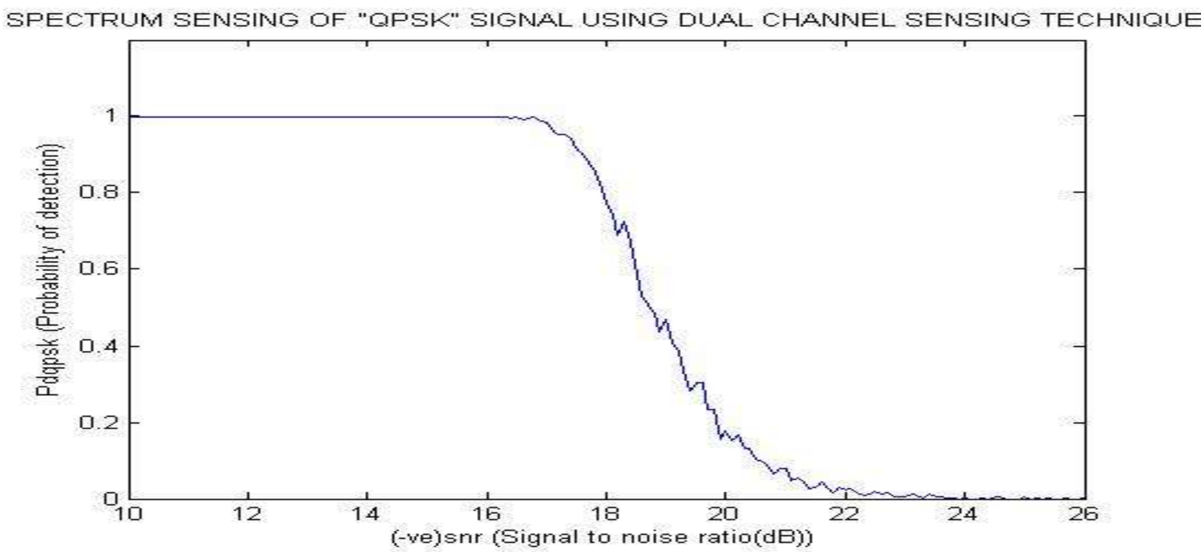


Figure-6.12 Detection probability for QPSK modulated signal

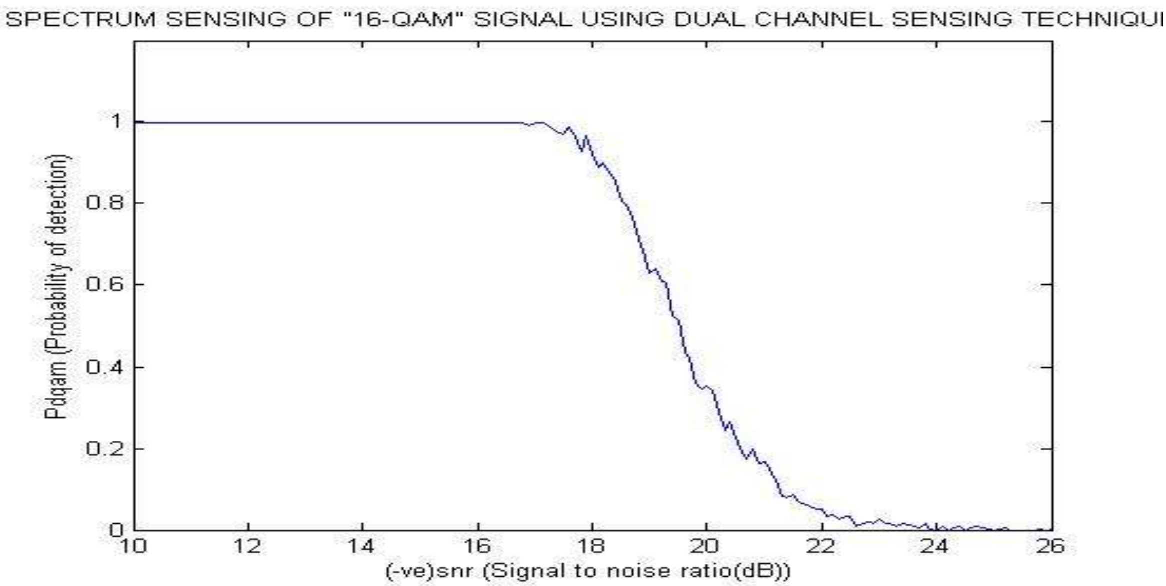


Figure-6.13 Detection probability for 16-QAM modulated signal

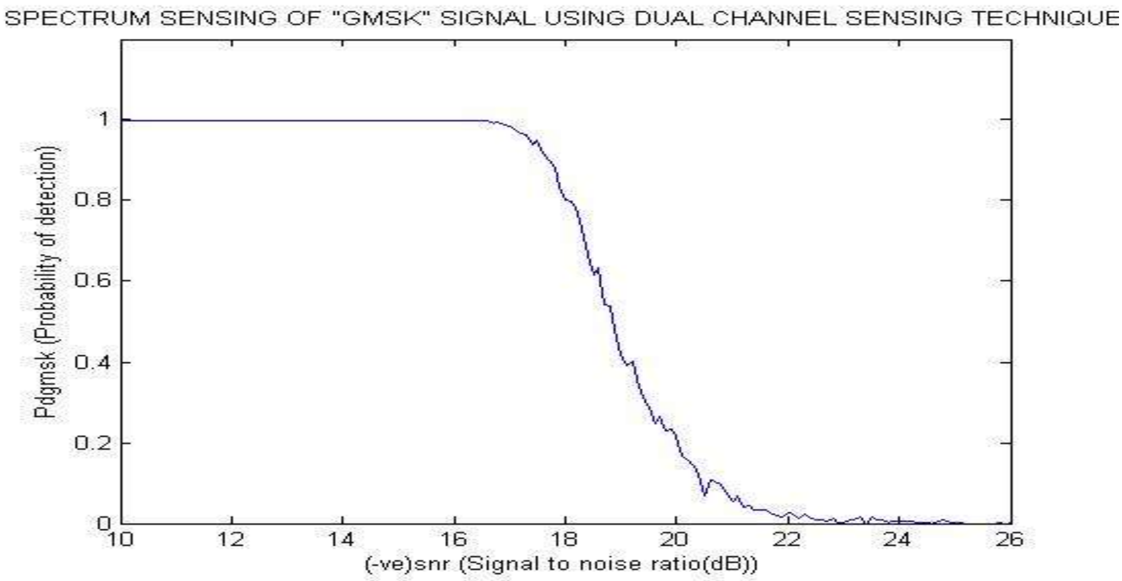


Figure-6.14 Detection probability for GMSK modulated signal

Figure-6.15 shows detection probability comparison for all three types of modulated signal. We can observe that Eigen value based sensing better performs in case of Quadrature amplitude modulated signal compare to others modulation schemes.

Comparisons of probability of detection for QPSK, 16-QAM and GMSK signals

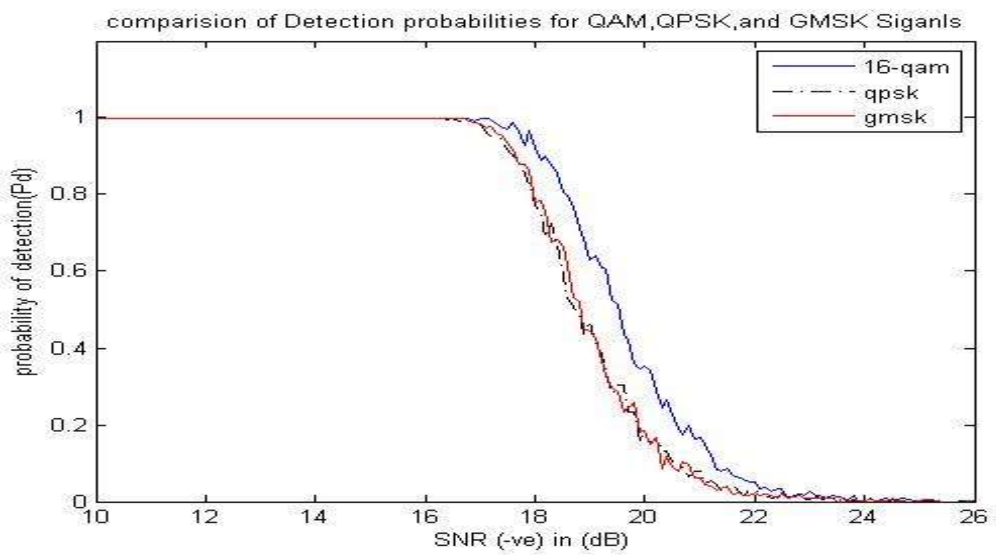


Figure-6.15 Detection probability comparison using Improved Eigen value detection

6.6 Detection Probability Comparison for Existing and Modified sensing Technique

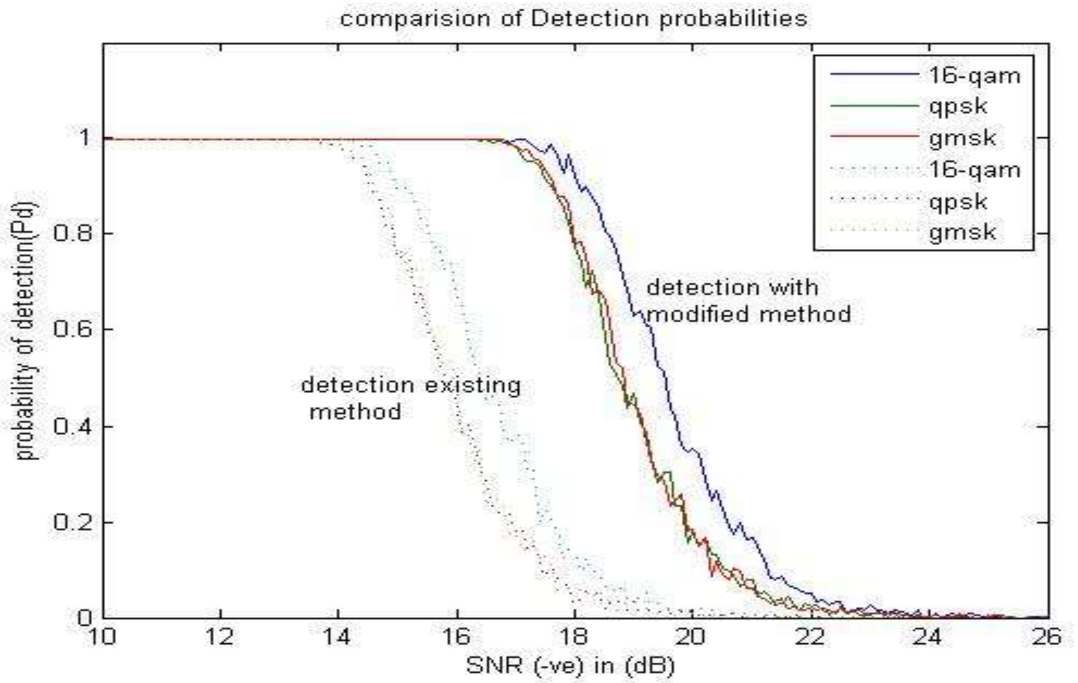


Figure-6.16 Detection probability comparison using existing and modified method

Figure-6.16 shows a comparison of detection probability for all types of modulated signals using two different modulation schemes. Dotted lines shows detection probability for existing Eigen value detection technique while solid line shows detection probability using improved Eigen value sensing technique. We find that we can detect signal up to three decibel increased noise level compare to previous detection technique.

Chapter 7
CONCLUSIONS

7.1 Conclusion

For better performance of cognitive radio, it is necessary to sense available spectrum accurately. Along with spectrum sensing accuracy cognitive radio should be able to take fast decision. Inaccuracy in spectrum sensing and delay in providing decision will cause harmful interference to primary user.

Analysis of detection performance among QPSK, 16-QAM and GMSK signal shows that probability of detection is near about same for QPSK and GMSK signals. While 16-QAM signal gives better detection performance.

Other work of project shows that improved Eigen value based detection technique gives better performance as compare to existing detection technique. Using improved method we are able to detect signal which noisier as compare to previous signals. Around 3 decibels of extra noisy signal can be detected with the help of improved detection technique. In improved method we have shown a reduced receiver structure with enhanced detection performance.

7.2 Future work

For investigating design of cognitive radio for spectrum sensing following work may be extended:

- There is a need of devices (cognitive radio), which can detect primary signal even at -20dB snr condition.
- We need fast processing of such devices so that decision making is rapid. Slow decision making will cause interference to the primary users which is undesirable.
- We need high detection probability and low probability of false alarm for proper use of cognitive radio at all channel condition.
- Requirement of wideband spectrum sensing is desired.

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