# East West University

## Undergraduate Project Report
## On

# ANALYSIS OF SPECTRUM SENSING IN COGNITIVE RADIO NETWORK

By

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# Declaration

We, hereby declare that our project work solely to be our own scholarly work. To the best of our knowledge, it has not been shared from any source without due acknowledgement and permission. It is being submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Electronics and Telecommunications Engineering. It has not been submitted before for any degree or examination in any other university.

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# Abstract

Phenomenally, the using of wide spectrum of wireless-network communications is increasing day by day which introduces efficiently utilization of unused spectrum. The Cognitive Radio Network (CRN) assumed one of the best technologies which most efficiently use the unused spectrum. Reducing the unused spectrum and increasing the communication quality both are the main reasons for using CRN. This project is elaborately described two case null hypothesis ($H_0$) for no primary user and hypothesis one ($H_1$) for primary user available in the spectrum and also goal to detect the probability of detection ($P_D$) and the probability of false alarm ($P_{FA}$) and another thing is increasing $P_D$ and decreeing$P_{FA}$. In this project, we have detected $P_D$ by using the given $P_{FA}$ in Matlab. We have compared between analytical and simulation values and observed that stimulated $P_D$ is very closer to theoretical value of $P_D$.Individual spectrum sensing by CR may not accurate due to fading and shadowing effect It avoids the harmful interference with licensed or primary user need to take much number of sample and little bit more false alarm. Cooperative sensing is also an effective and attractive approach to combat multiple fading and receiver's uncertainty and hidden primary problem.

**Keywords:** Cognitive radio ,spectrum, Probability of false alarm, Probability of miss detection, Primary and secondary user, AWGN channel, Fading, Cooperative sensing ,matlab.

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# Fundamentals of Cognitive Radio

## Chapter Outlines

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- Features of Cognitive radio

## 1.1 Introduction

In recent times, the advancement of next generation radio access technologies is limited by the shortage of the available radio spectrum. These new technologies are becoming even more bandwidth demanding due to their higher data rate requirements. CR is a promising technology geared towards solving the spectrum scarcity problem by opportunistically identifying the vacant portions of the spectrum and transmitting in them. But the licensed or PUs of the spectrum are not affected by this. This necessitates adapting to the dynamically changing spectrum resource, learning about the spectrum occupancy, making decisions on the quality of the available spectrum resource including its expected duration of use, probability of disruption caused by the PUs. Thus, Cognitive radio networks (CRN) help to make efficient use of the available spectrum by using bands such as television broadcast frequencies below 700MHz which have been recently marked for CR operation. CRN and spectrum sensing techniques are natural ways to allow these new technologies to be deployed.

### 1.1.1. Cognitive Radio

CR is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also can improve radio operating behavior. CRN (from now on called secondary networks) will also need to coexist with legacy ones which have the right to their spectrum slice and thus cannot accept interference.

### 1.1.2. History and Background leading to Cognitive Radio

The concept of CR was first proposed by Joseph Mitola III in a seminar at KTH (the Royal Institute of Technology in Stockholm) in 1998 and was published in an article by Mitola and Gerald Q. Maguire, Jr. in 1999 [1]. It was a novel approach in the wireless communication field. The sophistication possibility in a 'Software Defined Radio' (SDR) has now reached the level where each radio can conceivably perform profitable tasks that help the user, help the network and help minimize spectral congestion. Radios are already demonstrating one or more of these capabilities in limited ways [1]. To support the technologies and regulatory considerations three major applications make it cognitive radio. They are as follows:

- Spectrum management and optimizations.
- Interface with a wide variety of networks and optimization of network resources.
- Interface with a human and providing electromagnetic resource to aid the human in their activities.

Many technologies have come together to result in the spectrum efficiency and CR technologies. These technologies represent a wide swath of contributions upon which cognitive technologies may be considered as an application on top of a basic SDR platform which is implemented largely from digital signal processors and general-purpose processors (GPPs) built in silicon.

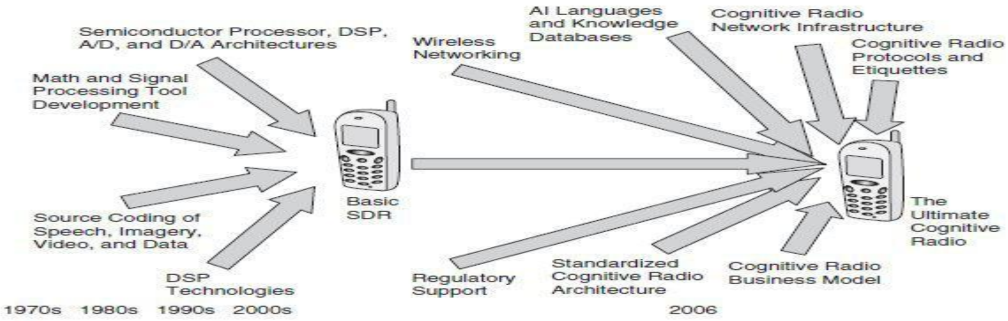

Figure 1.1: Technology Timeline: SDR becomes the platform of choice for the cognitive radio [2].

In many cases, the spectral efficiency and other intelligent support to the user arises by sophisticated networking of many radios to achieve the end behavior which provides added capability and other profits to the user.

### 1.1.3. Versatile nature of Cognitive Radio

Traditional wireless systems are typically designated to operate over a certain frequency band under a well-designed transmission format and infrastructure, including Physical (PHY) layer modulation/demodulation (MODEM), channel coder/decoder (CODEC), Medium access control (MAC) protocols, and Networking infrastructure. So legacy wireless systems are inflexible transmission format but CR is a flexible wireless communication system. The CR is capable to provide a wide variety of intelligent behavior. It can monitor the spectrum and choose frequencies that minimize interference to existing communication activity. When doing so, it will follow a set of rules that defines what frequencies may be considered, what waveforms may be used, what power levels may be used for transmission, and so forth. It may also be given rules about the access protocols by which spectrum access is negotiated with spectrum license holders (if any) and the manner by which it must check with other users of the spectrum to ensure that no user hidden from the node wishing to transmit is already communicating. In addition to the spectrum optimization level, the CR may have the ability to optimize a waveform to one or many criteria. For example, the radio may be able to optimize for data rate, for packet success rate, for service cost, for battery power minimization, or for some mixture of several criteria. The user does not see these levels of sophisticated channel analysis and optimization except as the recipient of excellent service. The CR may also exhibit behaviors that are more directly apparent to the user. These behaviors may include: (a) awareness of geographical location, (b) awareness of local networks and their available services, (c) awareness of the user and the user’s biometric authentication to validate financial transactions, and (d) awareness of the user and his/her prioritized objectives. The CR developer must use caution to avoid adding cognitive functionality that reduces the efficiency of the user at his or her primary tasks. If the user thinks of the radio as a cell phone and does not wish to access other networks, the CR developer must provide a design that is friendly, timely and responsive to the user. But it is not continually intruding with attempts to be helpful by connecting to networks that the user does not need or want. If the radio's owner is a power user, however, the radio may be asked to watch for multiple opportunities such as access to other wireless networks for data services, notification of critical turning points to aid navigation, or timely financial information. The CR must offer functionality that is timely and useful to its owner and yet not disruptive.

### 1.1.4. Need for a flexible wireless communication system

It is commonly believed that there is a spectrum scarcity of frequencies that can be economically used for wireless communications. This problem arises from the intense competition for use of spectrum at frequencies below 3 GHz. So, wireless channels are scarce resources. From figure 1.2 we can see the frequency allocation for various purposes.

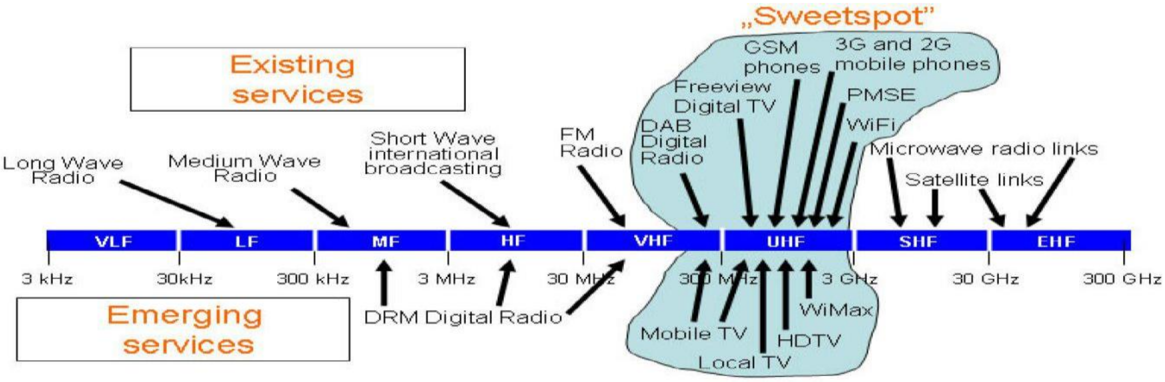

Figure 1.2: Frequency allocation for various purposes [3].

From the above figure, we can see that 3 KHz to 300 KHz are used for emergency services. Here 300 KHz to 300MHz is allocated for DRM Digital Radio. Very High frequency (VHF) which starts from 30 MHZ to 300 MHz is allocated for FM Radio. Sweet-spot for radio transmissions: 200MHz ~ 3GHz. TV, microwave ovens, mobile phones, Wi-Fi, Bluetooth, Zigbee, GPS etc are sharing these frequency ranges.

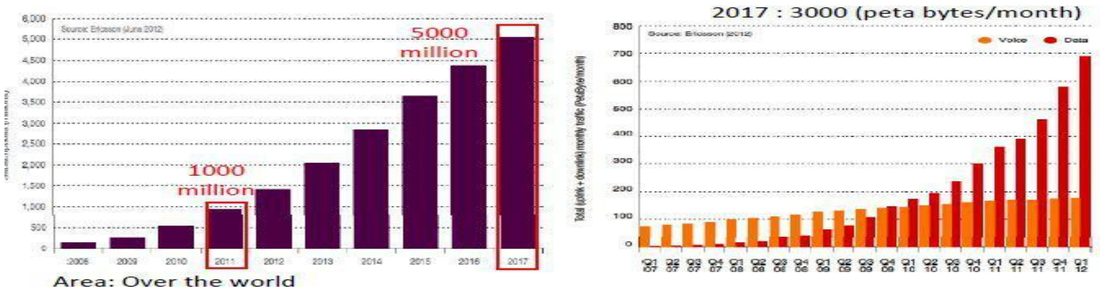

Figure 1.3: (a) Time vs. Number of mobile users, (b) Traffic Vs Voice & Data [3].

Due to the rapid growth of population, the number of mobile devices increases day by day. As a result the data traffic in mobile network also increases. We can see in figure 1.3 (a) and figure 1.3 (b) two graphs which represent the current and future picture of the number of mobile devices, and the voice traffic. The graph shows that the number of mobile device increases exponentially and the data traffic in mobile network increases exponentially as well. While the voice traffic increases linearly, where some legacy systems are spectrally or temporally inefficient which is a huge problem for wireless communication.

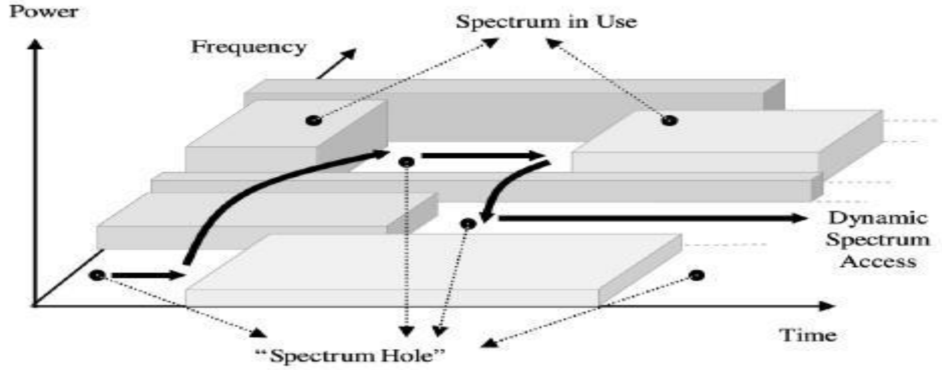

Figure 1.4: Concept of Spectrum Holes [3].

Not only that, temporal and geographical variation in spectrum utilization ranged from 15% ~ 85%. In order to utilize this spectrum (white spaces), white spaces refer to frequencies allocated to a broadcasting service but not used locally; the Federal Communication Commission (FCC) has issued a Notice of Proposed Rule Making (NPRM-FCC 03-22) advancing CR technology as a candidate to implement negotiated or opportunistic sharing. The figure 1.4, depicts how control Units(CUs) dynamically use spectrum holes or white spaces, which are temporarily not used in space, time and/or frequency. If a band is then used by a PU, the CU which is occupying this band goes to another spectrum hole or continues to use the band but changes its transmit power and modulation scheme so as to avoid interference with the PU. In this way, dynamic Spectrum Access (DSA) is achieved. In the figure 1.4, the solid arrows illustrate a possible DSA scheme.

### 1.1.5. Advantages of cognitive radio system

There are lots of advantages of CR system, which are given below:

**Utilization of idle frequencies in white spaces:**

National and international bodies assign different frequencies for specific uses. In most cases licensed users have the rights to broadcast over these frequencies. This frequency allocation process creates a band-plan. This band-plan assigns white spaces for technical reasons to avoid interference. In this case, while the frequencies are unused, they have been specifically assigned for a purpose, such as a guard band. Most commonly however, these white spaces exist naturally between using channels, since assigning nearby transmissions to immediately adjacent channels will cause destructive interference to both. In addition to white space assigned for technical reasons, there is also an unused radio spectrum which has either never been used, or is becoming free as a result of technical changes. A CR reconstructs those unused spectrums and makes them usable to the other users.

**Adaptive communications:**

Adaptive communication is a form of communication which is tailored to someone's needs and abilities. It is designed to provide people with the ability to communicate with others.

- **Robust wireless systems (network switches):** It can monitor the spectrum and choose frequencies that minimize interference to existing communication activity.

- **Dynamic spectrum access:** It has the strong ability to access free spectrum and able to modify it to use for the users who have the scarcity of spectrum.

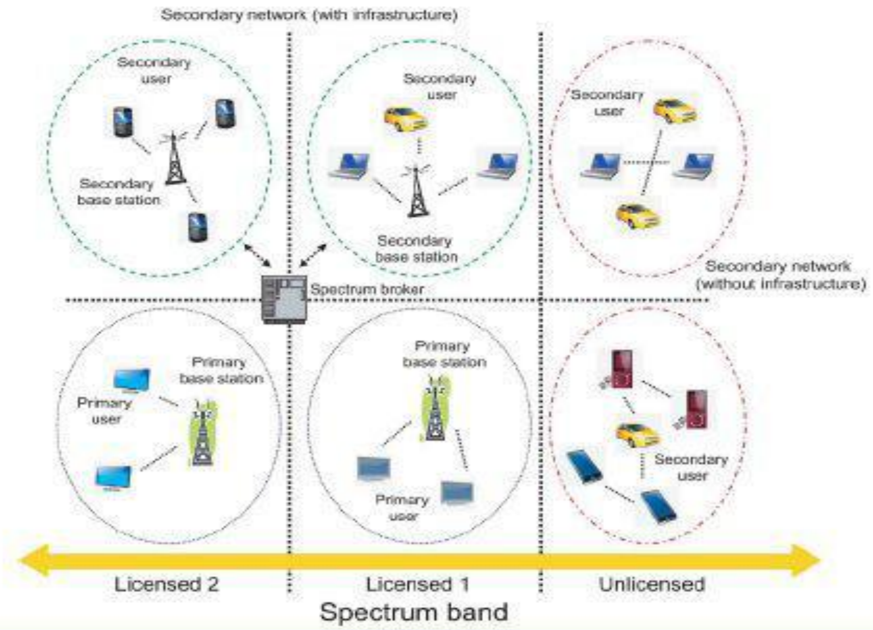

Figure 1.5: Spectrum Bands [3]

- **On-demand spectrum sharing, exchanges and merchandising:** On demand when there is any scarcity of unavailability of frequency CR can share, exchange or merchandising their frequency. The above figure 1.5 and figure 1.6 shows some of those situations, where PUs are sharing spectrum with a SU through a spectrum broker. In figure 1.6 the PUs of licensed 1 and licensed 2 are sharing their network with SUs and create a secondary network (with infrastructure). This network also exchanges the spectrum and create a secondary network (without infrastructure) which is used by secondary unlicensed users.

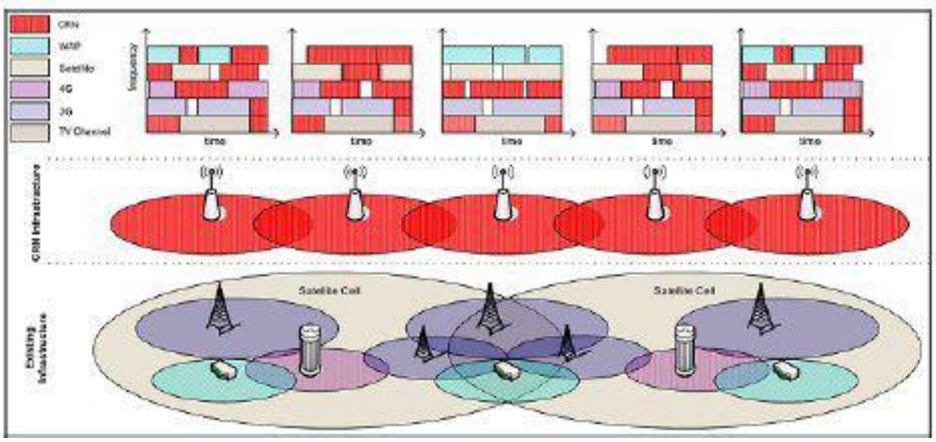

Figure 1.6: Spectrum sharing, exchanges and merchandising [3].

## 1.2. Features of Cognitive radio

The followings are the features of cognitive radio:

**Frequency Agility**: CR has this ability to change its operating frequency to optimize the usage under certain conditions.

**Dynamic Frequency Selection (DFS)**: CR has this ability to sense signals from other nearby transmitters in an effort to choose an optimum operating environment.

**Location Awareness**: CR provides the ability for a device to determine its location and the location of other transmitters. At first, it determines whether it is permissible to transmit at all, then to select the appropriate operating parameters such as the power and frequency allowed at its location.

**Negotiated Use**: A CR can incorporate a mechanism that enables the sharing of spectrum under the terms of a prearranged agreement between a licensee and a third part.

**Adaptive Modulation**: CR features with the ability to modify transmission characteristics and waveforms to exploit opportunities to use spectrum.

**Transmit Power Control (TPC)**: CR allows full power limits when it needs to transmit. But it can construct the transmitter power to a lower level to allow greater sharing of spectrum when higher power operation is not necessary.

### 1.2.1. Interference Management and Spectrum Sensing

In order to share the spectrum with legacy systems, CRN need to follow some policies. This is defined by regulatory agencies. These policies are based on the central idea where there are primary systems which have the right to the spectrum and secondary systems. They allow using the spectrum as long as they do not disturb the communications of the primary systems. So, these policies deal with controlling the amount of interference that the secondary systems can incur to the primary ones. Thus, this kind of problem is considered as interference management.

### 1.2.2. Receiver Centric Interference Management

In the receiver centric approach, an interference limit at the receiver is calculated and used to determine the restriction on the power of the transmitters around it. This interference limit, called the interference temperature is chosen to be the worst interference level. It can be accepted without disturbing the receiver operation beyond its operating point. This approach requires knowledge of the interference limits of all receivers in a primary system. Such knowledge depends on many variables, including individual locations, fading situations, modulations, coding schemes and services. Receiver centric interference management techniques will not be addressed in this chapter as they have been recently ruled out by the IEEE SCC41 CRN standard.

### 1.2.3. Transmitter Centric Interference Management

In the transmitter centric approach, the focus is shifted to the source of interference .The transmitter does not know the interference temperature, but by means of sensing, it tries to detect free bandwidth. The sensing procedure allows the transmitter to classify the channel status to decide whether it can transmit and if yes, with how much power. In an actual system, since the transmitter does not know the location of the receivers or their channel conditions, it is not able to gather how much interference these receivers can tolerate. Thus, spectrum sensing solves the problem for the worst case scenario. Assuming strong interference channel, the secondary system transmits only when it senses an empty medium [4].

# CHAPTER 2

## Literature Survey

### Chapter Outline

- Cognitive Cycle
- Main Functions of Cognitive Radio
- Sensing Capability
- Cognitive Radio Front-end
- Signal processing techniques for spectrum sensing
- Pros and Cons of the signal processing techniques for spectrum sensing

## 2.1 Introduction

In this chapter we mainly focus on cognitive cycle, different types of cognitive radio like primary user, secondary user of cognitive radio network and we try to show how sensing spectrum works and modeling and simulation also. During the literature survey lots of different research papers, books and journals were covered related to this thesis. Some of the topics that we have gone through during this period are in the following subsections.

## 2.2 Cognitive Cycle

A basic cognitive cycle begins with radio scene analysis and identifying the spectrum holes, which is shown in figure (2.1). In addition, it also performs channel estimation for the channel capacity, channel state, transmitted power, transmitted frequency, issued signal to transmit power control and manage the spectrum management. Finally, the cycle establishes connection with a proper initial handshake with the receiver.

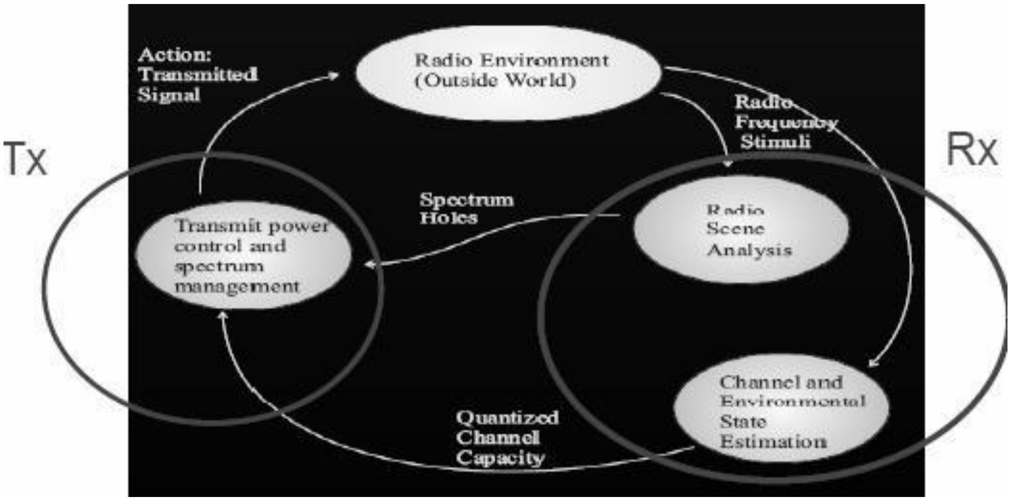

Figure 2.1: Cognitive Cycle [5].

Raut and Kulat conducted a study to improve spectrum utilization in the paper “Cognitive radio technology” [5]. In this paper, they have verified the efficiency of the algorithm. It configures the convolution encoder to produce a lower Bit Error Rate (BER) for increased bandwidth available. For this reason they have tested Field-Programmable Gate Array (FPGA) implementation of the convolution encoder by using a Matlab Hardware Description Language( HDL) coder [5].At the present time, CR is becoming a promising technology for improving spectrum application. The research work which is discussed here is mailing the tracks for rate adoptive coder compliant with minimum BER for emergency services over CR. The results verify the efficiency of the algorithm. It configures the convolution encoder to produce a lower BER for increased available bandwidth. This can be eagerly implemented in the Software Defined Radio(SDR) library functions. This has been tested by FPGA implementation of the convolution encoder by using a Mat lab HDL coder.

The coder has presented the output of the FPGA implemented VHDL code [5].In this article, the concept of CR and the problem as a coder adaption for available bandwidth is defied. So, the proposed algorithm at the Smart Codec is the solution for the problem. It justifies its applicability by presenting the simulation and hardware implementation results [5].

### 2.2.1 Types of Cognitive Radio

There are various kinds of CR. In this article "Spectrum Sensing Smart Codec Design for CR" [5], the authors have discussed about some of them. CR is classified depending on the set of parameters. These parameters are chosen from transmission and reception changes and for historical reasons. One of them is known as Full CR ("Mitola radio") [5] in which every possible parameter is observable by a wireless node. Another one is Spectrum Sensing CR. In this type of CR, only the radio frequency spectrum is considered. On the component of the spectrum availability, CR can be classified into two classes. First one is Licensed Band CR, where CR is capable of using bands assigned to licensed users, apart from unlicensed bands. Another one is Unlicensed Band CR, which can only utilize only unlicensed parts of radio frequency spectrum.

### 2.2.2 Main Functions of Cognitive Radio

The followings are the major functions of CR:

**a) Spectrum Sensing:** An essential capability of the CR is spectrum sensing, i.e., The capability of timely sensing spectrum holes. This is also the basis and precondition for CR application. In order not to interfere with the Licensed User (LU), when a Control Unit (CU) uses a spectrum hole to communicate, it has to quickly detect the presence of the LU and timely exit from a related band or continues to use the band for communication if the interference threshold is not exceeded. As a result, CUs should be equipped with highly reliable spectrum sensing function and be able to detect spectrums in a continuous and real-time way.

**b) Spectrum Management:** Spectrum analysis and spectrum decision are the most important tasks to be carried out during Spectrum Management.

**c) Spectrum Mobility:** This should ensure seamless operation and most exchange operating frequencies accordingly.

**d) Spectrum Sharing:** Spectrum scheduling method takes care of sharing the available spectrum.

But present work lies in for the spectrum sensing CR. Once a bandwidth is available and wide enough, we have two options:

- Transmit bulk data at higher data rate e.g. real time applications like mobile services.
- Transmit small packets of data with high accuracy, required in Emergency Services (time bound emergency information should take care of data reduction by minimizing the possible size so as to utilize low data rates where BER is low).

But present work focuses on the second option for improving the BER performance of the system.

## 2.3 Cognitive Radio Front-end

Spectrum sensing is best addressed as a cross-layer design problem. CR sensitivity can be improved by enhancing radio RF front-end sensitivity, exploiting digital signal processing gain for specific primary user signal and measurements [7].There are two frequency bands where the cognitive radios might operate in a near future: 400-800 MHz (UHF TV bands) and 3-10 GHz. The Federal Communication Commission (FCC) has noted that in the lower Ultra High Frequency (UHF) bands almost every geographical area has several unused 6 MHz wide TV channels. This frequency band is particularly appealing due to good propagation properties for long-range communications. The static TV channel allocations and the timing requirements for spectrum sensing are very relaxed. The FCC approval of Ultra Wideband (UWB) underlay networks in 3-10 GHz indicates that this frequency range might be opened for opportunistic use**.** Regardless of the operating frequency range, a wideband front-end for a CR could have architecture as depicted in figure (2.7). The wideband RF figure (2.7) signal presented at the antenna of a CR includes signals from close and widely separated transmitters and from transmitters operating at widely different power levels and channel bandwidths. As a result, detection of weak signals must the frequently performed in the presence of very strong signals. Thus, there will be extremely stringent requirements placed on the linearity of the Radio Frequency (RF) analog circuits as well as their ability to operate over wide bandwidths. In order to keep the requirements on the final analog to digital (A/D) converter at a reasonable level in a mostly digital architecture, front-end design needs a tunable notch analog processing block that would provide a dynamic range control [7].

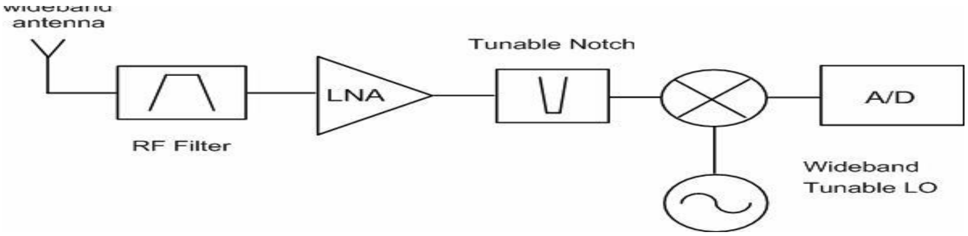

Figure 2.2: Wideband RF/analog front-end architecture for cognitive radio [7].

## 2.4 Signal processing techniques for spectrum sensing

Here, we discuss about of four techniques that are used in traditional systems.

**Matched Filter:** The optimal way for detecting a signal is matched filter. It maximizes received signal-to-noise ratio (SNR). However, a matched filter effectively requires demodulation of a primary user signal.

**Energy Detector:** To simplify matched filtering approach, one has to perform non-coherent detection through energy detection. This sub-optimal technique has been extensively used in radiometry. An energy detector can be implemented similarly to a spectrum analyzer by averaging frequency holder of a Fast Fourier Transform (FFT). Samples are required to meet a probability of detection constraint due to non-coherent processing.

**Cycle stationary Feature Detection:** This can be used for detection of a random signal with a particular modulation type in a background of noise and other modulated signals. Common analysis of stationary random signals is based on auto correlation function and power spectral density. On the other hand, cycle stationary signals exhibit correlation between widely separated spectral components due to spectral redundancy caused by the periodicity spectral correlation function is also termed as cyclic spectrum.

**Cooperative Spectrum Sensing:** The performances of these techniques are limited by received signal strength which may be severely degraded due to multipath fading and shadowing. In such a scenario cooperative sensing may alleviate the problem of detecting the primary user by reducing the probability of interference to a primary user. In cooperative sensing we rely on the variability of signal strength at various locations. It is expected that a large network of cognitive radios with sensing information exchanged between neighbors would have a better chance of detecting the primary user compared to individual sensing.

### 2.4.1 Pros and Cons of the signal processing techniques for spectrum sensing

The pros and cons of the four techniques of signal processing are described below by a table, which helps us to find out which signal processing technique is better for spectrum sensing.

Table 1.1: Overview of available techniques for spectrum sensing [7].

| **Spectrum Sensing Technique** | **Advantage** | **Disadvantage** |
|---|---|---|
| Matched Filter | 1.Best in Gaussian knowledge<br>2. Need shorter sensing duration.<br>3. Less power consumption. | 1. Requires a prior info on PU transmissions, and extra hardware on nodes for synchronization with Primary User (PU). |
| Energy Detection | 1. Requires the least amount of computational power of nodes. | 1. Requires longer sensing duration.<br>2. Higher power consumption.<br>3. Accuracy highly dependent on noise level variations. |
| Cyclo-stationary Feature Detection | 1. Most flexible to variation in noise levels. | 1. Requires a prior knowledge about PU transmissions.<br>2. Requires high computation capability on nodes. |
| Cooperative Sensing | 1. Recommended by the FCC.<br>2. Guarantees a predetermined interference to PU is not exceeded. | 1. Requires knowledge of location PU and imposes polynomial calculations based on these locations. |

## CHAPTER 3

# Methodology Adopted and Justification of the Project

## Chapter Outline

## 3.1 Introduction

This chapter mainly focuses on the justification of this thesis based on cooperative sensing according to three rules which are AND, Majority, OR rules. Here, we have analyzed the Cooperative Spectrum Sensing under the AWGN channel and the relation of cognitive radio with Software defined radio and Adaptive Radio. From this chapter, we can understand the methodology adopted for the simulation and also find out the better rule for the simulation.

## 3.2 Relation between Adaptive Radio and Cognitive Radio

The adaptive radio system has a feature of demonstrating an awareness of its environment and an ability to automatically react. CR and adaptive wireless in essence mean the same thing. CR can include additional features beyond adaptation.

## 3.3 Local Spectrum sensing

To achieve accuracy and improve reliability, cooperative spectrum sensing is usually used. But the cost of cooperation is overhead among CR users. This overhead can be reduced by improving local spectrum sensing accuracy as we know that an accurate spectrum sensing technique can reduce the probability of false alarms and miss detection.

## 3.4 Probability of false alarm and probability of miss detection

In CRN there are two types of users ,Primary users (licensed user)  and Secondary users (unlicensed user).The PU can access any channel in case of its availability, but SU users have lower priority and can access a channel only when it is unused by PUs. A SU searches for free channels and communicates using free channels when available.  PU want to use that channel, SU instantly release the channel. Now let us consider a observed simple signal is x(0).

$$H_0\text{: x(0)=w(0)}$$
$$H_1\text{: x(0)=w=s(0)+w(0)} \quad (3.1)$$

where $H_0$ is the null hypothesis, to there are no observes signal w(o) exists.

And $H_1$ is the alternative hypothesis , so s(0) signal lives with noise w(0).

### 3.4.1 Spatial False alarm in cognitive network

In CR, secondary user (SU) performs spectrum sensing with a certain sensing range. This sensing range has a similar definition as the carrier sensing range of IEEE 802.11 MAC. It is widely considered that a SU is permitted to utilize the primary channel if no PU transmits data inside its sensing range. However, it is observed that a busy PU outside the sensing range still can be detected by SU. As a result, the SU misinterprets that this busy PU is inside its sensing range, and hereby loses opportunity to utilize the primary channel. This new sensing issue is termed as spatial false alarm (SFA) problem.

## 3.4.2 Misdetection

Misdetection is occur when the interference of PU with SU , that means SU detect that the primary user are not available in the channel but channel are occupied by PU .so the miss interfacing between them

The false alarm and detection for the *i*-th SU are, respectively

$$\gamma(t)=\begin{cases}\{r(t)\geq\tau; & false\ alarm\\ \{r(t)\geq\tau; & detection\end{cases} \tag{3.2}$$

Theoretically, Let us consider x is a function of signal and Hypothetically we can consider $H_0$ and $H_1$ where$H_0$is represent to a null hypothesis and another $H_1$ is represent to an alternative hypothesis.

X→ x~ p(x;$H_0$);That is probability of null hypothesis

X→ x~ p(x;$H_1$) ;That is probability of alternative hypothesis (3.3)

To maximize the probability of detection, $P_D$for a given $P_{FA}$ (Probability of false alarm) where, $P_{FA}$= ∝; and here ∝ is content term. So the likelihood function,

$$L(x)=\frac{P(x;H_1)}{P(x;H_0)}>\gamma. \tag{3.4}$$

Here γ is a constant value and it is also threshold. And the likelihood function L(x) be grater then this threshold value (γ).So we can write the probability of false alarm,

$$P_{FA}=P_r\{L(x)>\gamma\ ;H_0\}=\propto. \tag{3.5}$$

Assume that x(n) observe a realization of a random variable whose PDF is either N(0,1) or N(1,1) Where the notation N($\mu,\sigma^2$) denotes a Gaussian PDF with mean η and variance $\sigma^2$

Where

$$H_0: \mu = 0,$$
$$H_1: \mu=1, \tag{3.6}$$

So we can say, x~N($\mu,\sigma^2$)

$$w(0)\sim N(0,\sigma^2)$$

$$H_0: P(x(0);H_0)=N(0,\sigma^2) \tag{3.7}$$

$$H_1: P(x(0);H_1)=N(1,\sigma^2) \tag{3.8}$$

The likelihood function for the observe sample signal,

$$L(x)=\frac{P(x(0);H_1)}{P(x(0);H_0)}>\gamma. \tag{3.9}$$

From normalized function, Gaussian have

$$f(x)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}. \tag{3.10}$$

So, from this theory we can write

$$=>\frac{\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{1}{2}\left(\frac{x(0)-1}{\sigma}\right)^2}}{\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{1}{2}\left(\frac{x(0)}{\sigma}\right)^2}}>\gamma$$

$$=> e^{-\frac{1}{2\sigma^2}\left(x^2(0)-2x(0)+1-x^2(0)\right)}>\gamma$$

$$=> e^{-\frac{1}{2\sigma^2}\left(1-2x(0)\right)}>\gamma$$

$$=> -\frac{1}{2\sigma^2}\left(1-2x(0)\right) > ln\gamma$$

$$=> -\left(1-2x(0)\right) > 2\sigma^2 ln\gamma$$

$$=>x(0)>\frac{2\sigma^2 ln\gamma+1}{2}. \tag{3.11}$$

$T(x) > \gamma'$, where $\gamma` = \sigma^2 ln\gamma+\frac{1}{2}$ and T(x)=x(0).

Let us consider $\frac{1}{2}$ the value that being called the threshold. We can make two type of errors with the scheme. If we decide $H_1$but $H_0$is true, We make type II error on the other hand if we decide $H_0$but$H_1$ is true. We make type II error. And denoted as probability P($H_1$; $H_0$), where

$$P_{FA}=P(H_1;H_0)$$

$$=P_r\{x(0)>\gamma\ ;H_0\}$$

$$=\int_{\gamma}^{\propto} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2} \mathrm{dt}$$

$$=Q(\gamma). \qquad (3.12)$$

And probability of detection,

$$P_D = P(H_1; H_1)$$

$$=P_r\{x(0) > \gamma ; H_1\}$$

$$=\int_{\gamma}^{\propto} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(t^2-1)} \mathrm{dt}$$

$$=Q(\gamma\text{-}1) . \qquad (3.13)$$

So x(0)=T(x) and $\gamma$ is replaced with $\gamma'$
Now consider more signal use N number of signals, then we can write the hypothesis

$$H_0: x(n)=w(n) \ ; \ n=0,1,\ldots\ldots\ldots\ldots N-1$$
$$H_1: x(n)=A+w(n) \ ; \ n=0,1,\ldots\ldots\ldots\ldots N-1 \qquad (3.14)$$

where the signal is s(n)=A for A>0 and w(n) is WGN (White Gaussian noise) with variance $\sigma^2$, where

$$H_0: \mu = 0 \ ,$$
$$H_1: \mu = A \ , \qquad (3.15)$$

Then likelihood function can be written as

$$L(x)=\frac{\frac{1}{(2\pi\sigma^2)^{\frac{N}{2}}}\exp\left[-\frac{1}{2\sigma^2}\sum_{n=0}^{N-1}(x[n]-A)^2\right]}{\frac{1}{(2\pi\sigma^2)^{\frac{N}{2}}}\exp\left[-\frac{1}{2\sigma^2}\sum_{n=0}^{N-1}x^2[n]\right]}>\gamma. \qquad (3.16)$$

Taking the logarithm of both sides ,we have

$$-\frac{1}{2\sigma^2}\left(-2A\sum_{n=0}^{N-1}x[n]-NA^2\right)>\ln\gamma, \qquad (3.17)$$

which simplifies to

$$\frac{A}{\sigma^2}\sum_{n=0}^{N-1} x[n] > ln\ \gamma + \frac{NA^2}{2\sigma^2} \qquad (3.18)$$

Since  A>0, we have finally

$$\frac{1}{N}\sum_{n=0}^{N-1} x[n] > \frac{\sigma^2}{NA} ln\ \gamma + \frac{A}{2} = \gamma'. \qquad (3.19)$$

To avoid this possibility, we adjust $\gamma'$ to control $P_{FA}$ with larger threshold values reducing $P_{FA}$ as well as $P_D$. So the means and variance are,

$$\begin{aligned} \mathrm{E}(\mathrm{T}(\mathrm{x});H_0) &= \mathrm{E}\left(\frac{1}{N}\sum_{n=0}^{N-1} w[n]\right) \\ &= \frac{1}{N}\sum_{n=0}^{N-1} E(w[n]) \qquad (3.20) \\ &= 0 \end{aligned}$$

Similarly,

$$\mathrm{E}(\mathrm{T}(\mathrm{x});H_1) = \mathrm{A}$$

and

$$\begin{aligned} \mathrm{var}(\mathrm{T}(\mathrm{x});H_0) &= \mathrm{var}\left(\frac{1}{N}\sum_{n=0}^{N-1} w[n]\right) \\ &= \frac{1}{N^2}\sum_{n=0}^{N-1} E(w[n]) \\ &= \frac{\sigma^2}{N}. \qquad (3.21) \end{aligned}$$

Similarly ,

$$\mathrm{var}(\mathrm{T}(\mathrm{x});\mathrm{H1}) = \sigma^2/N \qquad (\ 3.22)$$

where we have noted that the noise samples are uncorrelated . Thus,

$$\mathrm{T}(\mathrm{x}) \sim \begin{cases} N(0,\sigma\hat{}2\ ) under\ H0, \\ N(A,\sigma^2) under\ H1. \end{cases} \qquad (\ 3.23)$$

We have then

$$\begin{aligned} P_{FA} &= P_r\{T(x) > \gamma' ; H_0\} \\ &= Q\left(\frac{\gamma'}{\sqrt{\frac{\sigma^2}{N}}}\right), \qquad (3.24) \end{aligned}$$

and

$$P_D = P_r\{T(x) > \gamma' ; H_1\}$$

$$= Q\left(\frac{\gamma' - A}{\sqrt{\frac{\sigma^2}{N}}}\right). \qquad (3.25)$$

Now we can relate $P_D$ and $P_{FA}$ by usage

$$\gamma' = \sqrt{\frac{\sigma^2}{N}}\, Q^{-1}(P_{FA}), \qquad (3.26)$$

and

$$P_D = Q\left(\frac{\sqrt{\frac{\sigma^2}{N}}\, Q^{-1}(P_{FA}) - A}{\sqrt{\frac{\sigma^2}{N}}}\right)$$

$$= Q\left(Q^{-1}(P_{FA}) - \sqrt{\frac{NA^2}{\sigma^2}}\right). \qquad (3.27)$$

## 3.5 Energy Efficiency

We know that as the number of cooperating users grows, the energy consumption of the CRN increases but its performance generally saturates. For this reason to improve the energy efficiency in CRNs, some techniques have been developed. One simple technique to save energy is on-off sensing or sleeping, where every CR will randomly turn off its sensing device with a probability of the sleeping rate. Another technique is censoring. In such a system, a CR will only send a sensing result if it is deemed informative and it will eliminate those sensing results that are uninformative [8].

# CHAPTER 4

## Data Algorithm

### Chapter Outline

- Thesis Framework
- Proposed Framework for Cooperative Sensing

- Work flow

- Data algorithm and analysis
- Simulation setup process

## 4.1 Thesis Framework

the proper framework for implementing the centralized cooperative sensing. After that we have discussed about the workflow for our simulation. Here we have also discussed the simulation process probability of miss detection curve against the probability of false alarm after varying numbers of users.

### 4.1.1 Proposed Framework for Cooperative Sensing

The framework of cooperative sensing consists of the PU. In this case, CR users include a fusion centre (FC), all the elements of cooperative sensing, the RF environment including licensed channels and control channels with an optional remote database.

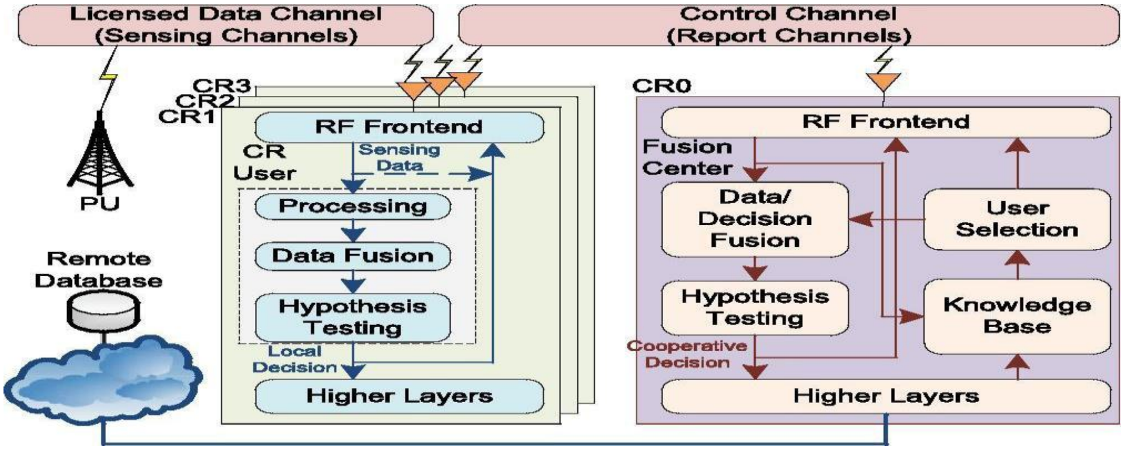

Figure 4.1: Framework of centralized cooperative sensing [12].

The above figure (4.1) illustrates the framework of centralized cooperative sensing from the perspective of the physical layer. In this proposed framework, a group of cooperating CR users performs local sensing with an RF front end and a local processing unit. The RF front end can be configured for data transmission for spectrum sensing. In addition, the RF front end includes the down-conversion of the RF signals and the sampling at Nyquist rate by an analog-to-digital converter (ADC). The raw sensing data from the RF front end can be directly sent to the FC or be locally processed for local decision. To minimize the bandwidth requirement of the control channel, certain local processing is usually required [12].

### 4.1.2 Work flow

The Cognitive Cycle begins with radio scene analysis with the scanning for spectrum holes. Once the bandwidth is available, the transmitted frequency is decided. So a Mat-lab code written for bandwidth selection was written. So now the input signal is a digital data obtained from an analogue source. After that we sense the local spectrum sensing. Then we simulate the probability of false alarm and probability of miss detection for CR user. We have been able to find out the way to reduce the miss detection. The total work flow is given through a flow chart in figure (4.2) below.

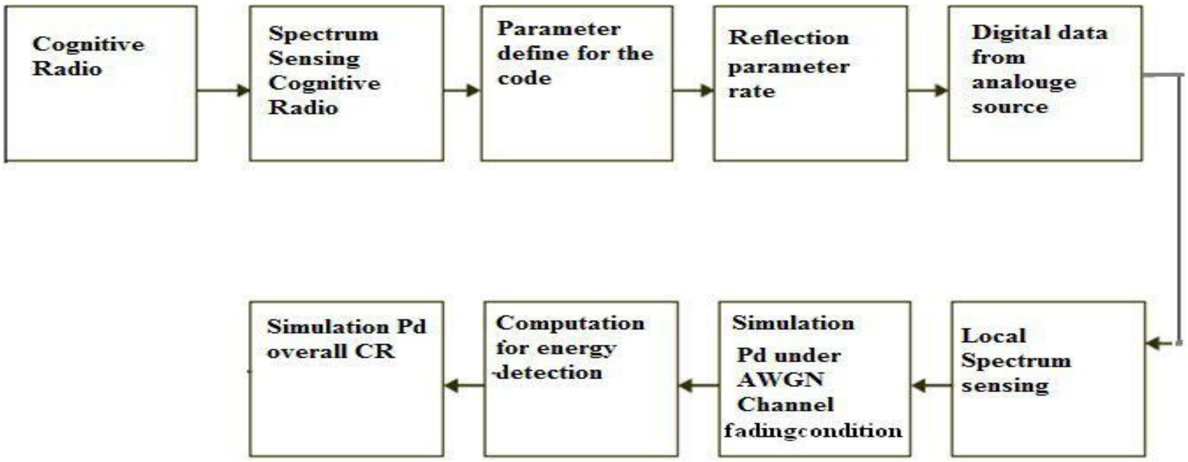

Figure 4.2: Proposed system process.

### 4.1.3 Data algorithm and analysis

The following data algorithms are described below

**The probability of detection for number of sample data:**

1. Select the size of sample of received signal N and A for A>0 where primary user (PU), $H_1$ does exit and random number …sequence of SNR X and False alarm FA.

2. For different value of K= 0.1, 0.01, 0.001 probability of detection PD1 PD2 PD3 with equation of PD= $Q(a^{-1}(P_{FA})-\sqrt{\frac{NA^2}{\sigma 2}})$.

**Variation of probability of detection with respect to SNR :**

1. Select the size of sample of received signal N and A for A>0 where primary user (PU), $H_1$ does exit and random number $\sigma^2$ sequence of SNR X and False alarm FA.
2. For different value of K= 0.1, 0.01, 0.001 probability of detection PD1 PD2 PD3 with equation of PD= $Q(a^{-1}(P_{FA})-\sqrt{\frac{NA^2}{\sigma 2}})$.

**Variation of Pd with number of sample:**

1. Select the size of sample of received signal N, Variance of random number $\sigma^2$ and the number of realization of sample M.
2. Initialize an array [T(0) T(1) T(2)….. T(M-1)] to get the random noise.

3. For i=0;1-M generate random of normal pdf with mean 0 and variance $\sigma^2$ as x(i)
   T(i)=x(i)
   end
4. Generate received SNR and as an array, [r(0)] where R= $\frac{Max(T)-Min(T)}{\gamma}$ and $\gamma$ is the interval of SNR.
5. For j=0; Length ($\gamma$)-1, Determine the number of T(i) greater then $\gamma$(i) as h.
   Probability of false alarm $P_{FA}$(i)=$\frac{h}{M}$
   End.
6. Compare [$P_{FA}$(0) $P_{FA}$(1)…..$P_{FA}$(N-1)] with theoretically value, $P_{FA\text{-}Th}$(i)=$\frac{1}{2}$erfc($\gamma(i)/\sqrt{2\sigma 2/N}$).

### Variation of Pd with number of sample:

1. Select the size of sample of received signal N, Variance of random number $\sigma^2$ and the number of realization of sample M.
2. Initialize an array [T(0) T(1) T(2)….. T(M-1)] to get the random noise.
3. For i=0; 1-M generate random of normal pdf with mean 0 and variance $\sigma^2$ as x(i)
   T(i)=x(i)
   end
4. Generate received SNR and as an array, [r(0)] where R= $\frac{Max(T)-Min(T)}{\gamma}$ and $\gamma$ is the interval of SNR.
5. For j=0; Length ($\gamma$)-1, Determine the number of T(i) greater then $\gamma$(i) as h.
   Probability of false alarm $P_{FA}$(i)=$\frac{h}{M}$
   End.
6. Compare [$P_{FA}$(0) $P_{FA}$(1)…..$P_{FA}$(N-1)] with theoretically value, $P_{FA\text{-}Th}$(i)=$\frac{1}{2}$erfc($\gamma(i)/\sqrt{2\sigma 2/N}$).

### Comparison of simulation and analytical result:

1. Select the size of sample of received signal N, Variance of random number $\sigma^2$ and the number of realization of sample M.
2. Initialize an array [T(0) T(1) T(2)….. T(M-1)] to get the random noise.
3. For j=1:12 and for i=0; 1-M generate random of normal pdf with mean 0 and variance $\sigma^2$ as x(i)
   T(i)=x(i)
   end.
4. Determine the number of T(i) greater than 1.5 as h.
   Probability of false alarm $P_{FA}$(j)=$\frac{h}{M}$
5. Compare [$P_{FA}$(0) $P_{FA}$(1)…..$P_{FA}$(N-1)] with theoretically value, $P_{FA\text{-}Th}$(i)=$\frac{1}{2}$erfc($\gamma(i)/\sqrt{2\sigma 2/N}$).

## 4.1.4 Simulation setup process

We have followed the following simulation steps to achieve our desired result. These are:

**a)** At first, we created an M-file in our simulation by MATLAB.

**b)** Then we declared the time bandwidth factor, the number of cognitive users, the path loss and the samples.

**c)** Next we calculated the probability of false alarm and the SNR. Here for calculating the linear SNR, we considered the value of SNR to be 15dB.

**d)** As we know that an accurate spectrum sensing technique can help to detect the more accurate probability of false alarms and miss detection, so we calculated the local spectrum sensing for detecting the path loss and miss detection.

**e)** Then we detected the number of users under AWGN channels and fading condition. As we know under AWGN channels and fading condition, the sensing user scheme is equivalent to selecting the optimal number of SU due to all the SUs having the same instantaneous detection signal-to-noise ratio (SNR).

**f)** To justify the effect of the cognitive user in the define bandwidth we increase the number of users.

**g)** After that we also change the time bandwidth factor for finding out the effect in our simulation.

**h)** Finally, we have been able to find out the effect of probability of false alarm and probability of detection.

# CHAPTER 5

## Result Analysis

### Chapter Outline

- Introduction
- Result Analysis

## 5.1 Introduction

In this chapter we describe our simulation results in details. Here we have analyzed the graph and discussed about our resort. Finally, we have shown comparisons our result with other relevant research works, which we have previously discussed in chapter 2.

## 5.2 Result Analysis

In Figure.1 the variation of probability of detection ($P_D$) is shown against the number of samples (N) taking probability of false alarm ($P_{FA}$) as a parameters.

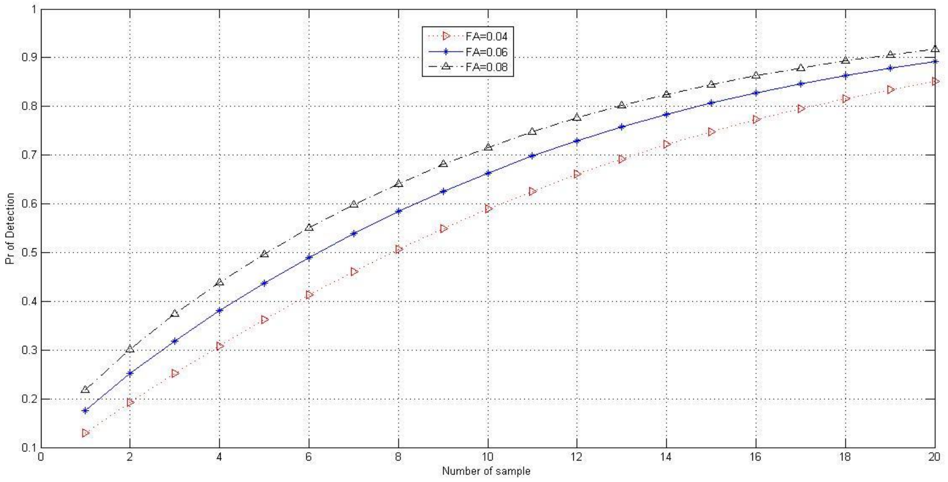

Figure 5.1: Number of sample Vs $P_D$.

It is visualized that $P_D$ increases exponentially with increasing in the number of samples .Here we have shown three curves for =0.04, $P_{FA}$=0.06, $P_{FA}$=0.08.The $P_D$ increases with increasing in $P_{FA}$ but we have to keep $P_D \geq 0.8$ and $P_{FA}$<0.08 as the convention of CRN. We have to take N ≤ 13 for $P_{FA}$=0.08, N ≥ 15 for $P_{FA}$=0.06, N ≥ 117 for $P_{FA}$=0.04.

In Figure.2 the $P_D$ is shown against SNR (signal to Noise Ratio) in dB where $P_{FA}$ is taken as a parameter.

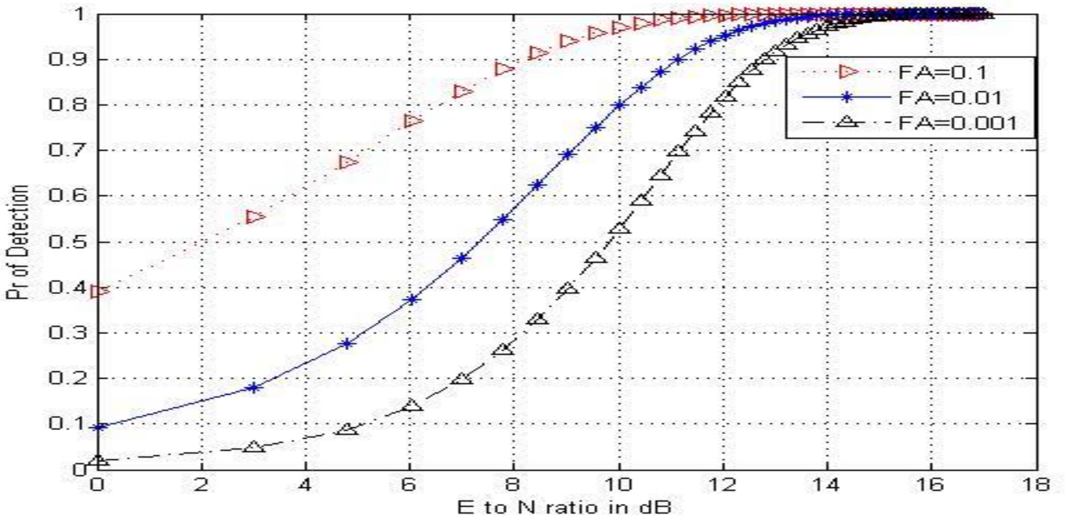

Figure 5.2: Variation of $P_D$ with respect to SNR .

Figure.2 is visualized that $P_D$ increases exponentially with increasing in the SNR. Here we have shown three curves for $P_{FA}$=0.1, $P_{FA}$=0.01, $P_{FA}$=0.001.The $P_D$ increases with increasing in $P_{FA}$ but we have to keep $P_D \geq$ 0.8 and $P_{FA} \geq$ 0.08 as the conversion of CRN. Here we have to take SNR $\geq$ 7 for $P_{FA}$=0.1, SNR $\geq$ 10 for $P_{FA}$=0.01 and SNR $\geq$ 12 for $P_{FA}$=0.001.

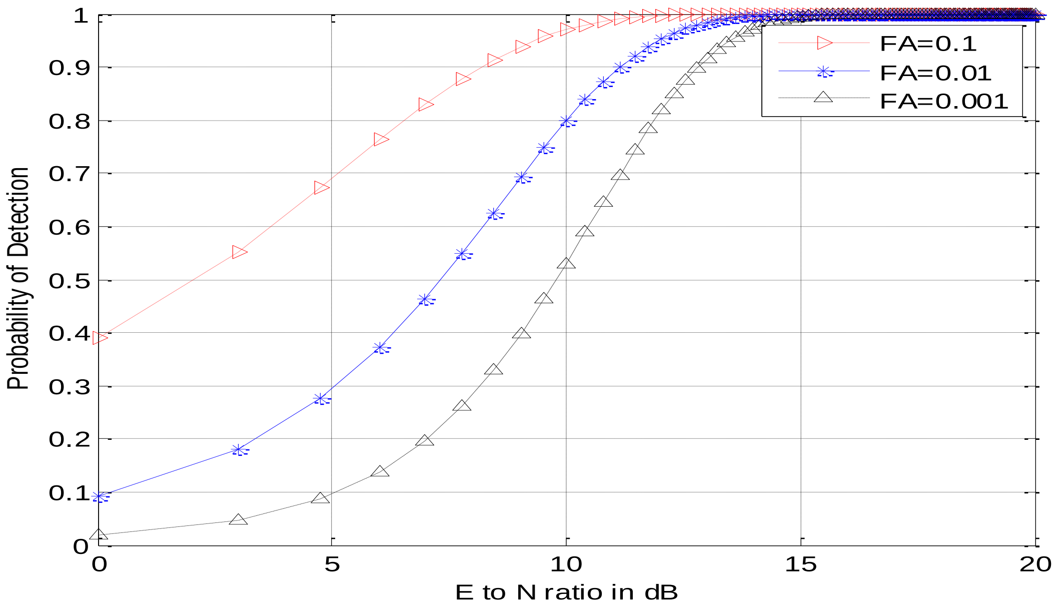

Figure 5.3: Variation of $P_D$ with number of sample.

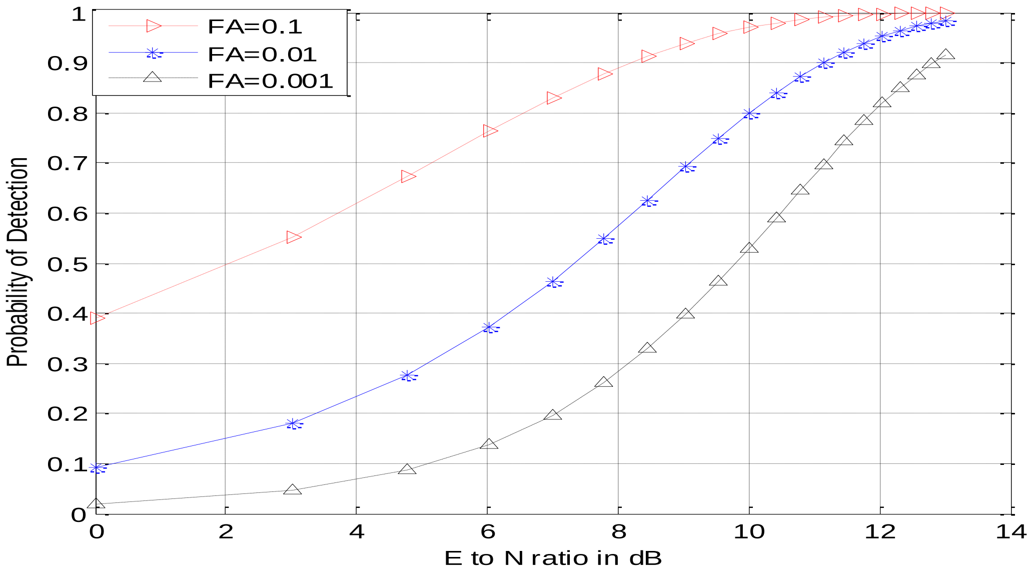

Figure 5.4: Variation of $P_D$ with number of sample.

Similarly Figure.3 and Figure.4 be described but difference among of these three Figures are the random numbers of sample. Figure.2, Figure.3 and Figure.4 are all for respectively 50, 100, and 20 samples.

In Figure 5.5 we have shown the $P_{FA}$ is plotted with respect to gamma (constant value of SNR).We can see that the $P_{FA}$ are decreasing with decreasing the vales of gamma. From this Figure5.5 we can see another thing ,when the $P_{FA}$ is almost 8% or 0.08 then gamma is around 1.5. Both simulation and analytical representation are shown here in Figure 5.5 and Figure 5.6

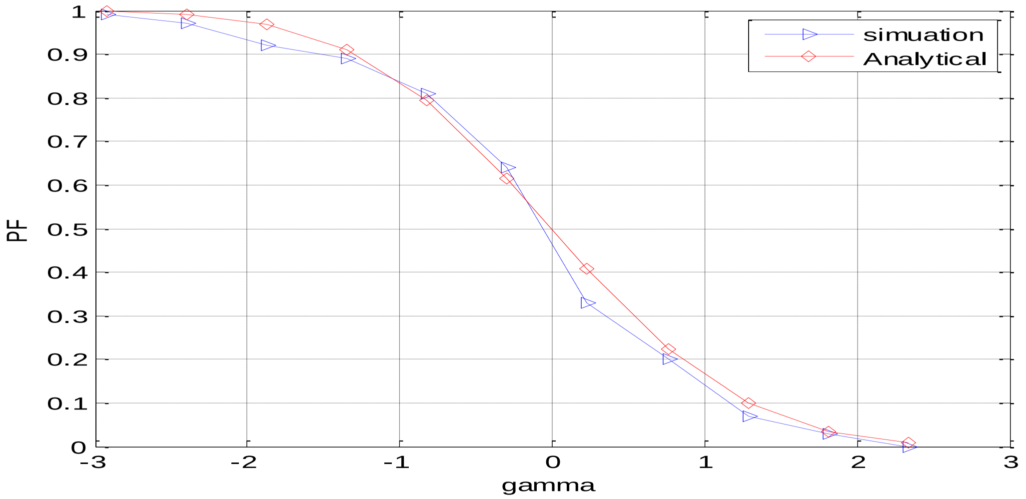

Figure 5.5: Variation of $P_D$ with number of sample.

But the main difference between Figure 5.5 and Figure 5.6 are sample numbers.Numbers of sample of Figure 5.6 are more than numbers of sample Figure 5.5. Because of that the simulation and the analytical values aloms closer to each other.

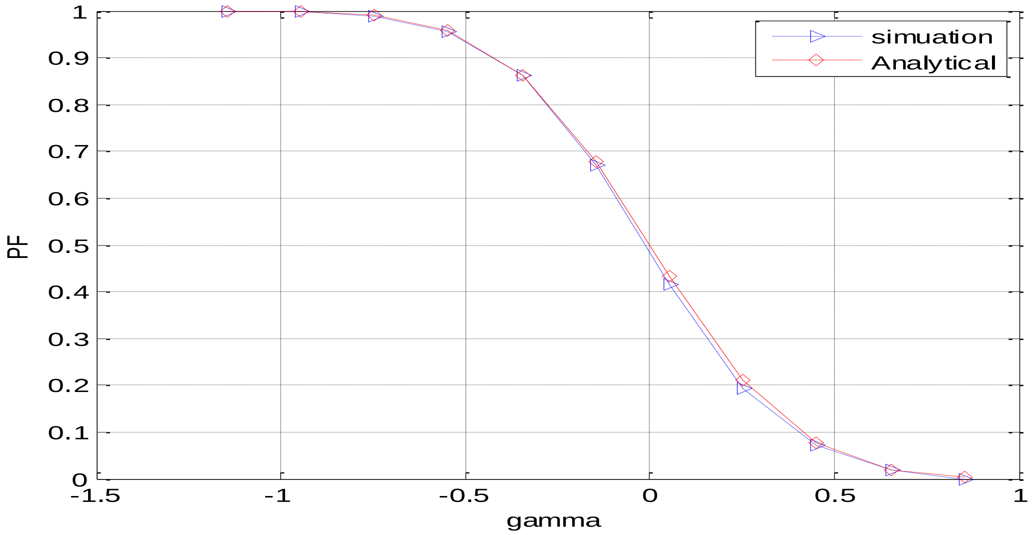

Figure 5.6: Variation of $P_D$ with number sample**.**

When we consider Figure 5.6, we can see the $P_{FA}$ is almost 20% or 0.2 when gamma is more than 0.5.If we consider more sample number , we will get proper Analytical value like as simulations.

In the Figure.7 , we find the $P_D$ curve against the average SNR for both simulation and analytical values.

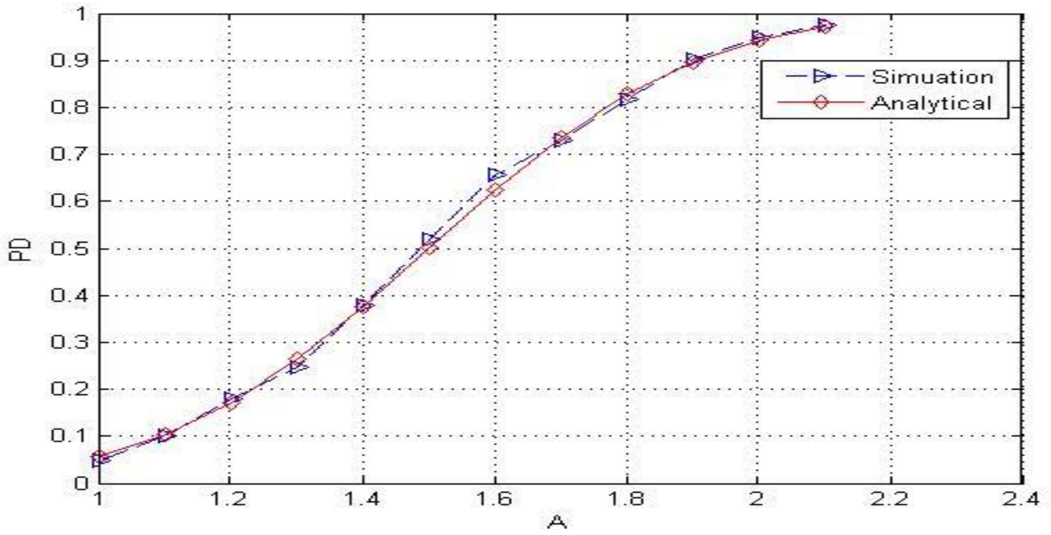

Figure 5.7: Comparison of simulation and analytical result.

In this Figure.7 , we have found the analytical and simulated curve closed to each other. Here also clearly noticed that for 80% detection both simulated and analytic need average SNR 1.78 and 1.8 which is close to each others. So we can say simulation process about right.

# CHAPTER 6

## Conclusion

### Chapter Outline

- Conclusion
- Drawbacks
- Future work on cognitive radio

## 6.1 Conclusion

Through our thesis we found out the effect on the probability of miss detection and the probability of false alarm after varying the cognitive user by using Matlab simulation. Majority rules under the AWGN channel and Fading condition. Here we have shown that the cooperative sensing gives better performance for probability detection. In cooperative technique, AND rule is employed and it evaluates the system performance by using probability of detection (Pd) and SNR as metric. We know that cooperative sensing is an effective and attractive approach to combat multiple fading and receiver's uncertainty and hidden primary problem. For energy efficiency in CRNs, some techniques have been already developed. To minimize the bandwidth requirement of the control channel, certain local processing is usually required. So the research work on CR has been concentrated on the secondary users and none of the effect was caused by these devices for the primary users. The cost of cooperation is overhead among CR users. This overhead can be reduced by improving local spectrum sensing accuracy. As we know that an accurate spectrum sensing technique can reduce the probability of false alarm and miss detection.

## 6.2 Drawbacks

During the simulation, we faced various types of problems for the detection of path loss. One of the major problems we faced is when the CR user increases much then the probability of detection becomes saturated in a certain value of probability of false alarm. This is one of our limitations of our research. We would like to work at this point in near future.

## 6.3 Future work on cognitive radio

In our paper, it has been shown that as the cognitive user is increased, the probability of miss detection can also be significantly increased. For the better detection of probability of missdetection AND rule is much better. It may also be seen that using only a few users to help us to obtain a better detection probability compared to using all the users in the network. We would like to investigate this matter. We also designed algorithms according to which the users must be taken into consideration for the cooperative spectrum sensing. It will be permitted that CR technology which is almost wireless networking will use to establish and to connect to any nearby accessible unused radio spectrum that facilitates the customer [13].

The combination of software defined radio and artificial intelligence will create new capabilities for the commercial and military marketplace.

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# Appendix

## Matlab Simulation:

This is the following codes thats we have used to simulate for getting our desired result.

---

```
clc;
closeall;
clearall;
sig=0.8;
x=1:1:100;
N=5;
A=0.5;
FA=0.1;
PD1=qfunc(qfuncinv(FA)-sqrt(x));
FA=0.01;
PD2=qfunc(qfuncinv(FA)-sqrt(x));
FA=0.001;
PD3=qfunc(qfuncinv(FA)-sqrt(x));
plot(10*log10(x),PD1,'r>:',10*log10(x),PD2,'b*-',10*log10(x),PD3,'k^-.')
legend('FA=0.1','FA=0.01','FA=0.001')
xlabel('E to N ratio in dB')
ylabel('Probability of Detection')
gridon
```

---

```
clc;
closeall;
clearall;
sig=0.8;
x=1:1:20;
N=5;
A=0.5;
FA=0.1;
PD1=qfunc(qfuncinv(FA)-sqrt(x));
FA=0.01;
PD2=qfunc(qfuncinv(FA)-sqrt(x));
FA=0.001;
PD3=qfunc(qfuncinv(FA)-sqrt(x));
plot(10*log10(x),PD1,'r>:',10*log10(x),PD2,'b*-',10*log10(x),PD3,'k^-.')
legend('FA=0.1','FA=0.01','FA=0.001')
xlabel('E to N ratio in dB')
ylabel('Probability of Detection')
gridon
```

---

```
clc;
closeall;
clearall;
var =10;
N = 10;
M =100;
% Dimension array of realizations.
T = zeros(M,1);
% Compute realizations of the sample mean.
for i = 1:M
x = sqrt (var)*randn (N,1);
```

```
T (i) = mean (x);
end
%  Set number of values of gamma.
ngam = 10;
% Set up gamma array.
gammamin = min(T);
gammamax = max (T);
gamdel = (gammamax-gammamin) /ngam;
gamma = [gammamin : gamdel : gammamax]';
%  Dimension P (the Monte Carlo estimate) and Ptrue
% (the theoretical or true probability).
P = zeros (length (gamma), 1);  Ptrue = P;
% Determine for each gamma how many realizations exceeded
% gamma (Mgam) and use this to estimate the probability.
for i =1: length (gamma)
clearMgain;
Mgam = find (T>gamma (i));
P(i) = length (Mgam)/M;
end
% Compute the true probability.
Ptrue = 0.5*erfc(gamma/ (sqrt (2*var/N)));
plot(gamma,P,'>--',gamma,Ptrue,'dr-')
legend('simuation','Analytical')
xlabel('gamma')
ylabel('PF')
grid
```

---

```
clc;
closeall;
clearall;
var =10;
N = 100;
M =1000;
% Dimension array of realizations.
T = zeros(M,1);
% Compute realizations of the sample mean.
for i = 1:M
x = sqrt (var)*randn (N,1);
T (i) = mean (x);
end
%  Set number of values of gamma.
ngam = 10;
% Set up gamma array.
gammamin = min(T);
gammamax = max (T);
gamdel = (gammamax-gammamin) /ngam;
gamma = [gammamin : gamdel : gammamax]';
%  Dimension P (the Monte Carlo estimate) and Ptrue
% (the theoretical or true probability).
P = zeros (length (gamma), 1);  Ptrue = P;
% Determine for each gamma how many realizations exceeded
% gamma (Mgam) and use this to estimate the probability.
for i =1: length (gamma)
clearMgain;
Mgam = find (T>gamma (i));
P(i) = length (Mgam)/M;
end
```

```
% Compute the true probability.
Ptrue = 0.5*erfc(gamma/ (sqrt (2*var/N)));
plot(gamma,P,'>--',gamma,Ptrue,'dr-')
legend('simuation','Analytical')
xlabel('gamma')
ylabel('PF')
grid
```

---

```
var =10;
N = 100;
M =1000;
A=1;
% Dimension array of realizations
% Compute realizations of the sample mean.
for j=1:12,
for i = 1:M
x = A+sqrt (var)* randn (N,1);
T (i) = mean (x);
end
% (the theoretical or true probability).
clearMgain;
Mgam = find (T > 1.5);
P(j) = length (Mgam)/M;
Ptrue(j) = 0.5*erfc((1.5-A)/ (sqrt (2*var/N)));
Y(j)=A;
A=A+0.1;
end
% Compute the true probability.
plot(Y,P,'>--',Y,Ptrue,'dr-')
legend('Simuation','Analytical')
xlabel('A')
ylabel('PD')
grid
```