ISSN 2250-3153

# Spectrum Sensing in Cognitive Radio under different fading environment

**Itilekha Podder , Monami Samajdar**

Bengal College of Engineering and Technology, Durgapur
West Bengal University of Technology

***Abstract-*** In this Project emphasis has been laid on the study of cognitive radio technology and its spectrum sensing techniques. Here local spectrum sensing will be performed using energy detection procedure under two different kinds of environment namely-Additive White Gaussian Noise (non-fading) channel and Rayleigh Fading channel. The simulations will be done using MATLAB version 7.9.0(R2009b). From the results obtained, we will figure out the variations caused under fading environment when compared with that of non-fading environment. And thereafter the performance will be checked under collaborative spectrum sensing.

***Index Terms***- Cognitive radio, spectrum sensing, radio frequency, quality of service

## 1. INTRODUCTION

Current wireless networks are characterized by a static spectrum allocation policy, where governmental agencies assign wireless spectrum to license holders on a long-term basis for large geographical regions. Recently, because of the increase in spectrum demand, this policy faces spectrum scarcity in particular spectrum bands. In contrast, a large portion of the assigned spectrum is used sporadically, leading to underutilization of a significant amount of spectrum. Hence, dynamic spectrum access techniques were recently proposed to solve these spectrum inefficiency problems.

The key enabling technology of dynamic spectrum access techniques is **cognitive radio (CR) technology**. This technology allows the unlicensed users to access the spectrum opportunistically when the spectrum is free and when primary licensed users are inactive or idle. In such technique secondary user regularly check for the primary user signal in order to avoid the interference between each other, thus leaving the spectrum as soon as primary user signal is sighted. A mechanism must be there allowing the secondary users to perfectly spot both the presence of primary user signal and its arrival if the secondary user is operating in the primary user band thus reducing the chances of interferences. The secondary user initially checks if a communication channel is not in use, and if idle it moves into that liberated empty space thus using that radio frequency without interfering with the licensed users.

CR networks are envisioned to provide high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques. This goal can be realized only through dynamic and efficient spectrum management techniques. CR networks, however, impose unique challenges due to the high fluctuation in the available spectrum, as well as the diverse quality of service (QoS) requirements of various applications.

In order to address these challenges, each CR user in the CR network must:
• Determine which portions of the spectrum are available
• Select the best available channel
• Coordinate access to this channel with other users
• Vacate the channel when a licensed user is detected

Recent measurements suggest the possibility of sharing spectrum among different parties subject to interference-protection constraints. In order to enable access to unused licensed spectrum, a secondary user has to monitor licensed bands and opportunistically transmit whenever no primary signal is detected. However, detection is compromised when a user experiences shadowing or fading effects. In such cases, user cannot distinguish between an unused band and a deep fade. **Collaborative spectrum sensing** is proposed and studied as a means to combat such effects.

## 2. History Of Cognitive Radio

The idea of cognitive radio was first presented officially by Joseph Mitola III in a seminar at KTH, The Royal Institute of Technology, in 1998, published later in an article by Mitola and Gerald Q. Maguire, Jr in 1999. It was a novel approach in wireless communications that Mitola later described as:

The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs.

Regulatory bodies in various countries (including the Federal Communications Commission in the United States, and Ofcom in the United Kingdom) found that most of the radio frequency spectrum was inefficiently utilized. For example, cellular network bands are overloaded in most parts of the world, but amateur radio and paging frequencies are not. Independent studies performed in some countries confirmed that observation, and concluded that spectrum utilization depends strongly on time and place. Moreover, fixed spectrum allocation prevents rarely used frequencies (those assigned to specific services) from being used by unlicensed users, even when their transmissions would not interfere at all with the assigned service. This was the reason for allowing unlicensed users to utilize licensed bands whenever it would not cause any interference (by avoiding them whenever legitimate user presence is sensed).

The first phone call over a cognitive radio network was made on Monday 11 January 2010 in Centre for Wireless Communications at University of Oulu using CWC's cognitive radio network CRAMNET (Cognitive Radio Assisted Mobile Ad Hoc Network) that has been developed solely by CWC researchers.

Today the sophistication possible in a Software Defined Radio (SDR) has now reached the level where each radio can conceivably perform beneficial tasks that help the user, help the network, and help minimize spectral congestion.

## 3. Cognitive Radio Technology

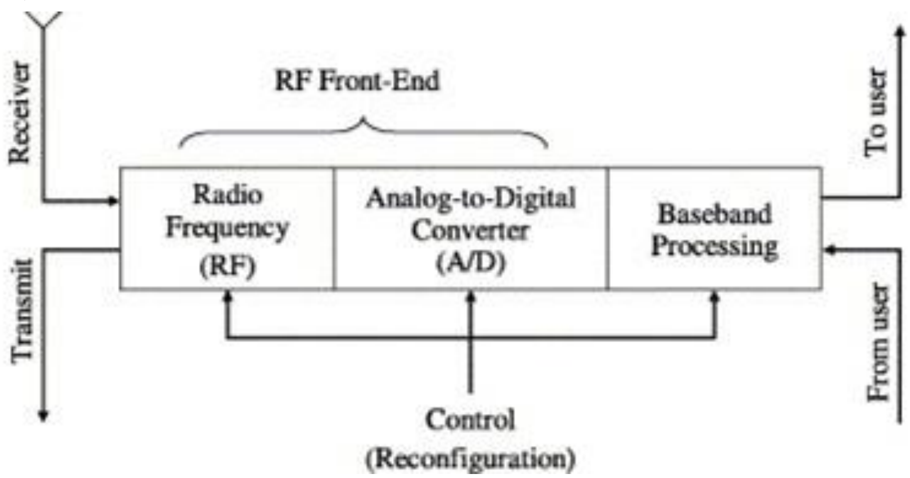
A Cognitive Radio is defined as a radio that can change its transmitter parameters based on interaction with its environment.
From this definition, two main characteristics of cognitive radio can be defined:
• Cognitive capability: Through real-time interaction with the radio environment, the portions of the spectrum that are unused at a specific time or location can be identified.
CR enables the usage of temporally unused spectrum, referred to as spectrum hole or white space. Consequently, the best spectrum can be selected, shared with other users, and exploited with- out interference with the licensed user.
• Re-configurability: A CR can be programmed to transmit and receive on a variety of frequencies, and use different access technologies supported by its hardware design.

### 3.1 Cognitive Radio Transceiver Architecture

The main components of a CR transceiver are-

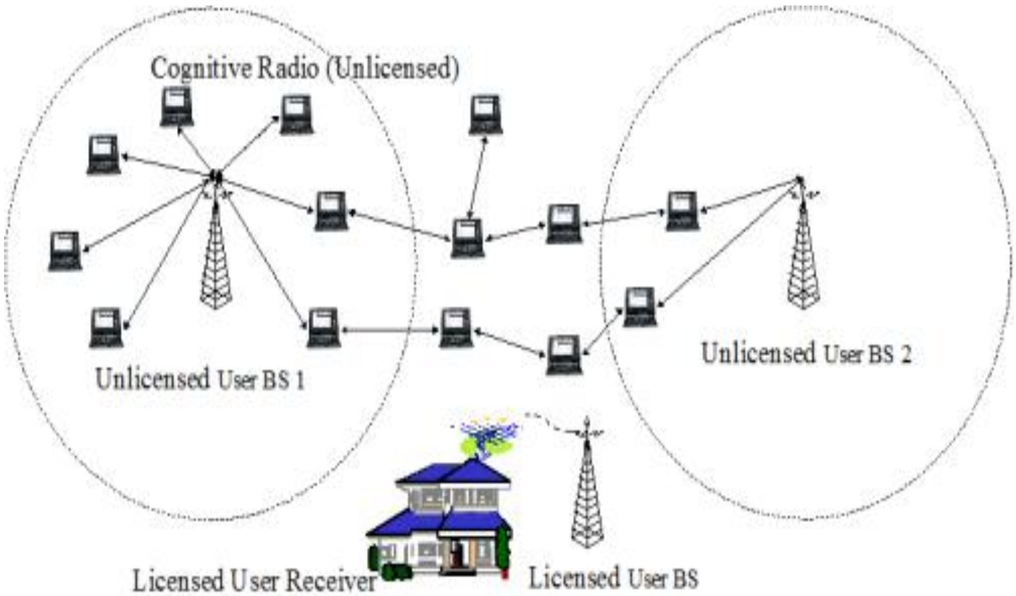
- Radio Frequency (RF) Unit- In the RF front-end unit, the received signal is amplified, mixed, and analog to-digital (A/D) converted. In the baseband processing unit, the signal is modulated/ demodulated.
- Baseband Processing Unit- In the baseband processing unit, the signal is modulated or demodulated.

Each component can be reconfigured via a control bus to adapt to the time- varying RF environment. The block diagram for CR transceiver is shown below:



### 3.2 Cognitive Radio Network Architecture

The cognitive radio network architecture is shown in the figure given below:




**<u>Network Components:</u>**

The components of the CR network architecture can be classified as two groups: The primary network (or licensed network) is referred to as an existing network, where the primary users have a license to operate in a certain spectrum band.
If primary networks have an infrastructure, primary user activities are controlled through primary base stations. The CR network (also called the dynamic spectrum access network, secondary network, or unlicensed network) does not have a license to operate in a desired band. Hence, additional functionality is required for CR users to share the licensed spectrum band. CR networks also can be equipped with CR base stations that provide single-hop connection to CR users.

The operation types for CR networks can be classified as licensed band operation and unlicensed band operation.
• Licensed band operation: CR networks are focused mainly on the detection of primary users in this case.
• Unlicensed band operation: In the absence of primary users, CR users have the same right to access the spectrum.

**<u>Network Heterogeneity:</u>**

• CR network access: CR users can access their own CR base station, on both licensed and unlicensed spectrum bands.
• CR ad hoc access: CR users can communicate with other CR users through an ad hoc connection on both licensed and unlicensed spectrum bands.
• Primary network access: CR users can also access the primary base station through the licensed band. Unlike for other access types, CR users require an adaptive medium access control (MAC) protocol.

## 4. SPECTRUM MANAGEMENT FRAMEWORK

The spectrum management process consists of four major steps:

### 4.1 Spectrum sensing

It enables CR users to adapt to the environment by detecting spectrum holes without causing interference to the primary network. Generally, spectrum sensing techniques can be classified into three groups: primary transmitter detection, Primary receiver detection, and interference temperature management.

Primary Transmitter Detection- It is based on the detection of a weak signal from a primary transmitter through the local observations of CR users.
Three schemes are generally used for transmitter detection:
• Matched filter detection: When the information of the primary user signal is known to the CR user, the optimal detector in stationary Gaussian noise is the matched filter.

• Energy detection: If the receiver cannot gather sufficient information about the primary user signal, the optimal detector is an energy detector.
• Feature detection: In general, modulated signals are characterized by built-in periodicity or cyclostationarity.

Primary Receiver Detection- The most efficient way to detect spectrum holes is to detect the primary users that are receiving data within the communication range of a CR user.

Interference Temperature Management-This model limits the interference at the receiver through an interference temperature limit, which is the amount of new interference the receiver could tolerate.

Spectrum Sensing Challenges-
• Interference temperature measurement
• Spectrum sensing in multi-user networks
• Spectrum-efficient sensing

### 4.2 Spectrum Decision

CR networks require the capability to decide which one is the best spectrum band among the available bands according to the QoS requirements of the applications. This notion is called spectrum decision.
After the available spectrum bands are characterized, the most appropriate spectrum band should be selected, considering the QoS requirements and spectrum characteristics. Accordingly, the transmission mode and bandwidth for the transmission can be reconfigured.

Spectrum Decision Challenges -
• Decision model
• Cooperation with reconfiguration
• Spectrum decision over heterogeneous spectrum bands

### 4.3 Spectrum Sharing

The first classification is based on the architecture, which can be centralized or distributed.
• Centralized spectrum sharing: The spectrum allocation and access procedures are controlled by a central entity.
• Distributed spectrum sharing: Spectrum allocation and access are based on local (or possibly global) policies that are performed by each node distributively.
The second classification is based on allocation behavior, where spectrum access can be cooperative or non cooperative.
• Cooperative spectrum sharing: Cooperative (or collaborative) solutions exploit the interference measurements of each node such that the effect of the communication of one node on other nodes is considered.
• Non-cooperative spectrum sharing: Only a single node is considered in non- cooperative (or non-collaborative, selfish) solutions. Because interference in other CR nodes is not considered, non-cooperative solutions may result in reduced spectrum utilization.
The third classification for spectrum sharing in CR networks is based on the access technology.
• Overlay spectrum sharing: Nodes access the network using a portion of the spectrum that has not been used by licensed users.
• Underlay spectrum sharing: The spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by licensed users.
Finally, spectrum sharing techniques are generally focused on two types of solutions: spectrum sharing inside a CR network (intra network spectrum sharing) and among multiple coexisting CR networks (internetwork spectrum sharing).

Spectrum Sharing Challenges
• Common control channel
• Dynamic radio range
• Spectrum unit
• Location information

### 4.4 Spectrum Mobility

After a CR captures the best available spectrum, primary user activity on the selected spectrum may necessitate that the user change its operating spectrum band(s), which is referred to as spectrum mobility. The purpose of the spectrum mobility management in CR networks is to ensure smooth and fast transition leading to minimum performance degradation during a spectrum handoff. An important requirement of mobility management protocols is information about the duration of a spectrum handoff. This information can be provided by the sensing algorithm.

Spectrum Mobility Challenges
• Spectrum mobility in the time domain
• Spectrum mobility in space

## 5. PROPAGATION ENVIRONMENT

In this project, the spectrum has been sensed under following two different kinds of environment

- Additive White Gaussian Noise (AWGN) Channel
- Rayleigh Fading Channel

### 5.1 Additive White Gaussian Noise

Additive white Gaussian noise (AWGN) is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density and a Gaussian distribution of amplitude. The model does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. However, it produces simple and tractable mathematical models which are useful for gaining insight into the underlying behaviour of a system before these other phenomena are considered.

### 5.2 Rayleigh Fading

A fading that crops up due to number of reflection in an environment is referred to as Rayleigh fading and is evaluated using various statistical methods. In urban areas plus in scenarios where diverse paths are used by a signal, to check the performance of radio wave propagation Rayleigh faded model is foremost alternative because of reflection from obstacles. A disperse signal between receiver and transmitter also demonstrate to be a good case to study Rayleigh fading as the received signal might be an arrangement of the all the signals reaching to the receiver through diverse paths and depending upon the phase they might either add or subtract from the received signal. Rayleigh fading is also referred to as non line of sight fading.
In probability theory and statistics, the Rayleigh distribution is a continuous probability distribution. A Rayleigh distribution is often observed when the overall magnitude of a vector is related to its directional components

The Rayleigh probability density function is

$$f(x;\sigma) = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2}, \quad x \geq 0,$$

For parameter $\sigma > 0$, and cumulative distribution function

$$F(x) = 1 - e^{-x^2/2\sigma^2}$$

For $x \in [0, \infty)$.

## 6. SENSING TECHNIQUES FOR SPECTRUM

The most excellent exploitation of the spectrum is to identify the white spaces in the spectrum and in Cognitive radio technology an efficient approach for it is a well-known practice called opportunistic access. The likelihood to do so is completely reliant on how the cognitive radio assembles information regarding its environment of operation for which the obvious choice is careful sensing. Depending upon the consequences certain communication parameters are used, so that the adjusted parameter then helps to perform the transmission and reception in an enhanced manner. In cognitive radio technology the most obvious concern is that of sensing, while precise sensing to the highest degree improves by and large the performance of the cognitive radio network since the operation can be continued until an accurate sensing is made continuously. Due to diverse variety of modulation types and having extensive range of power schemes, primary user have diversity of choices to utilize any of these to access the band, and in such cases to properly sense the spectrum for use by the secondary user is a tricky job. The secondary user might also possibly face several harms of fading and shadowing themselves and in such scenarios to spot the presence of primary user signal is incredibly tough thus leading to underutilization of the spectrum and performance hindrance due to erroneous sensing.
A binary hypothesis problem given as H0 and H1 can be in use as a testing scheme for sensing the spectrum precisely and this helps to spot the existence and nonexistence of primary user prior to using the spectrum.

In this method H0 imply that the primary users are not in attendance and the spectrum can be used, whereas H1 signify that the primary user is in attendance on the band, and based on these testing the secondary user can sketch the conclusions whether to employ or not exploit the spectrum.

H0: {Primary User not in Attendance}
H1: {Primary User in Attendance}

### 6.1 Different Spectrum Sensing Techniques

#### 6.1.1 Matched Filter Method for Detection

A matched filter is a scheme used for the discovery of primary user signal and the basic aim of this approach is to take benefit of the white spaces of the band. In this technique a linear match filer is obtained so that for a prearranged input signals, the SNR ratio is maximized and it is done when, a signal which is not known to the detector is allied with the device known signal. This technique helps to identify the presence of the acknowledged signal in the signal which is not familiar to the detector.
For the method to work the preliminary information concerning the primary user signal such as arrangement of the packet, order and shape of pulse with modulation type is obligatory but is extremely difficult, nevertheless the technique is exceedingly appropriate for sensing as it boosts the SNR in AWGN.

#### 6.1.2 Energy Detection Procedure

For the reason of its simplicity energy detection is regarded as one of the finest of all the primary transmitter detection schemes and is used to detect zero mean signals. In this technique energy that have been received because of the received radio frequency is measured and an already specified threshold, which is chosen depending on the surrounding radio environment where the operation is to be done, is used as a judgment parameter which is then used to conclude whether there is a primary user signal at hand or not. A significant matter in energy detection scheme is to set the threshold which is exceptionally complicated task because in must deal with the susceptibility of the radio environment being especially flexible and might change soon.
Because of its simplicity energy detection is the main preference for spectrum sensing and there are number of factors that construct it as one of the most attractive pick, because in order to become aware of the primary user signal, the energy detection does not require any preliminary knowledge of the detected signal. The energy detection scheme for the primary user signal detection is shown below:

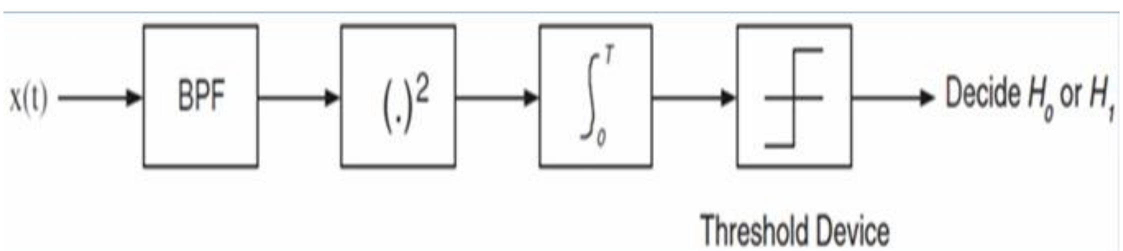



Fig. depicts block-diagram of an energy detector. The input band pass filter selects the centre frequency, fs, and bandwidth of interest, W. This filter is followed by a squaring device to measure the received energy and an integrator which determines the observation interval, T. Finally, output of the integrator, Y, is compared with a threshold, λ, to decide whether signal is present or not.
The procedure of energy detection starts when a signal is received, which is then passed through a band pass filter, so to choose only those frequencies that are preferred bypassing all other undesired frequencies. The received energy is considered by a squaring device after the filter selects the frequency and bandwidth denoted by W and then after the squaring device, there is an integrator which is used to measure the observation time over an interval T. The final output from the integrator denoted by R, is then compared with the threshold denoted by lambda which is defined on subject to the radio surroundings, and subsequent to the evaluation the results are sent to the conclusion or decision device, where based on the outcome the verdict is taken to decide whether a primary user signal is in attendance or not.

.

# 7. MATHEMATICAL APPROACH

## 7.1 ROC Performance Metric Curve

Receiver Operating Characteristics (ROC) is used as an analytical curve in different fields of technology and medicine for gauging the performance in terms of sensitivity.

ROC curve can as well be used for investigating the performance of the spectrum sensing by making an assessment between two probabilities i.e. the probability of false alarm signified by (Pf) and probability of detection (Pd) or probability of miss detection denoted by (Pm). This curve gives an improved understanding of how the expand in one probability have impact on other plus what are the conducts of the system under the effects of shadowing and fading and how it affects the spectrum sensing by simulating various curves.

### 7.1.1 Probability of Detection and Miss Detection:

Probability of Detection (Pd) is the probability to spot in the area of operation of a secondary user, whether there is a primary user signal in attendance or not. Larger the probability of detection the odds are that more exact will be the sensing and thus extremely little chances of intervention as secondary user will classify the existence of primary user signal and will not use the band consequently avoiding the interference.

However if the probability of detection declines then the probability of miss detection (Pm) which is in reality the inverse of probability of detection (Pd), increases indicating that there are added likelihood of missing the primary user signal which is at hand, in the area of operation and it increases the chances of interferences between the primary user and secondary user. In a non –fading environment were h(amplitude gain of the channel) is deterministic, probabilities of detection and false alarm are given by the formulae:

$$\mathrm{Pd} = \mathrm{P}\{\mathrm{Y} > \lambda \mid H1\} = \mathrm{Qm}\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \qquad (1)$$

$$\mathrm{Pf} = \mathrm{P}\{\mathrm{Y} > \lambda \mid H0\} = \frac{\Gamma(\mathrm{m}, \frac{\lambda}{2})}{\Gamma(\mathrm{m})} \qquad (2)$$

Where Γ (.) and Γ (.,.) are complete and incomplete gamma functions respectively and Qm(.,.) is the generalized Marcum Q-function defined as follows

$$\mathrm{Qm}(\mathrm{a}, \mathrm{b}) = \int_{\mathrm{b}}^{\infty} \frac{\mathrm{x}^{\mathrm{m}}}{\mathrm{a}^{\mathrm{m}-1}} e^{\frac{-(\mathrm{x}^2+\mathrm{a}^2)}{2}} \mathrm{I}_{\mathrm{m}-1}(\mathrm{ax})\, \mathrm{dx}$$

Where $\mathrm{I}_{\mathrm{m}-1}(.)$ is the modified Bessel function of $\mathrm{m}-1$th order.

So for better performance of Cognitive Radio Network the probability of detection must be evaluated.

### 7.1.2 Probability of False Alarm:

Sometimes there is a white space in the spectrum which can be utilized by the secondary users but the secondary users formulates a wrong ruling by identifying it as, already packed space of spectrum by another signal which escorts to an erroneous verdict and such a probability is known as probability of false alarm (Pf).

If the probability of false alarm (Pf) enlarges then it results in a very low utilization of spectrum as the white spaces of the band which can be use by the secondary users, are identified as all ready filled space due to erroneous sensing resulting in the performance degradation.

For an ideal system the probability of miss detection (Pm) and probability of false alarm (Pf) must be extremely low and the probability of detection (Pd) must have a higher value.

### 7.2 Spectrum Sensing In Fading Environment

The goal of spectrum sensing is to decide between the following two hypotheses,

$$X(t)= \begin{cases} w(t) & :H0, \\ Hs(t)+w(t) & :H1, \end{cases}$$

where x(t) is the signal received by secondary user and s(t) is primary user's transmitted signal, w(t) is the additive white Gaussian noise (AWGN) and h is the amplitude gain of the channel. We also denote by γ the signal-to-noise ratio (SNR).

The output of the integrator Y serves as the decision statistic and may be shown to have the following distribution:

$$Y \sim \begin{cases} (\chi 2TW)\,2 & :H0, \\ (\chi 2TW)\,2(2\gamma) & :H1, \end{cases}$$

Where (χ2TW)2 and (χ2TW)2(2γ) denote central and non-central chi-square distributions respectively, each with 2TW degrees of freedom and a non-centrality parameter of 2γ for the latter distribution. For simplicity we assume that time-bandwidth product, TW, is an integer number which we denote by m.

As expected, Pf is independent of γ since under H0 there is no primary signal present. On the other hand, when h is varying due to shadowing/fading, (1) gives probability of detection conditioned on the instantaneous SNR, γ. In this case, average probability of detection (which with an abuse of notation is denoted by Pd) may be derived by averaging (1) over fading statistics,

$$Pd = \int x\, Qm\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) f_{\gamma}(x)\, dx$$

Where f□(x) is the probability distribution function (PDF) of SNR under fading.
The fundamental trade off between Pm and Pf has different implications in the context of dynamic spectrum-sharing. A high Pm would result in missing the presence of primary user with high probability which in turn increases interference to primary licensee. On the other hand, a high Pf would result in low spectrum utilization since false alarms increase number of missed opportunities (white spaces).

The probability of miss detection can be written as given in the equation below:

Pm=1-Pd

## 8. SIMULATION AND EXPLANATION

The simulation was done using MATLAB version 7.9.0 (R2009b). In the initial part emphasis was to show, how the energy detection works by sensing the primary user signal so to make use of the spectrum, a graphical observation of the probability of miss detection (Pm) verses probability of false alarm (Pf) was shown, plotting in the MATLAB in receiver operating curve (ROC) with all the required parameters.
A complementary ROC curve is obtained by simulating energy detection technique in occurrence of AWGN and after that on the foundation of the resulted curves conclusion regarding the performance of the energy detection is made.

### 8.1 Rayleigh Fading Effects on Energy Detection

When a secondary user is under effect of fading then the channel gain denoted by "h" might diverge to some level depending upon what sort of phenomena it is exaggerated by, and the detection procedure in addition is also affected by this expand thus the detection probability (Pd) then depends upon that instantaneous SNR. If instantaneous SNR is the consequential of fading then the received

SNR pursue a particular probability distribution function which is used to obtain average detection probability (Pd) given by the equation.

$$\mathrm{Pd} = \int x\, \mathrm{Qm}\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) f_{\gamma}(x)\, dx$$

With fading being the factor for that instantaneous SNR, the probability distribution function (PDF) for that received SNR by secondary user is signified by the function f□(x).

Under Rayleigh fading, □ would have an exponential distribution given by

$$f(\gamma) = \left(\frac{1}{\bar{\gamma}}\right) \exp\left(-\frac{\gamma}{\bar{\gamma}}\right), \gamma \geq 0$$

And Pd can be specified by the following equation.

$$\mathrm{Pd} = e^{-\frac{\lambda}{2}} \sum_{j=0}^{m-2} \left(\frac{1}{j!}\right) \left(\frac{\lambda}{2}\right)^{j} + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{m-1} \times \left(e^{-\lambda/2(1+\bar{\gamma})} - e^{-\frac{\lambda}{2}} \sum_{j=0}^{m-2} \left(\frac{1}{j!}\right) \left(\frac{\lambda\bar{\gamma}}{2(1+\bar{\gamma})}\right)^{j}\right)$$

In the simulation done in this case, energy detection practice for two secondary users with average received SNR of 10 dB and time and bandwidth product of m=5 is exposed in which one of the secondary user is affected by Rayleigh fading and the other has no fading associated to it.

### 8.2 Collaborative Spectrum Sensing In Fading Environment

In case of fading and shadow of an obstacle, which causes the intensity of SNR to be extremely low, the performance of energy detector degrades and to deal with this hindrance a procedure called collaboration of secondary users is suggested. Such a sensing involving the collaboration of secondary users with each other sharing their individual information is defined as Collaborative Spectrum Sensing. In order to minimize the communication overhead, users only share their final 1-bit decisions (H0 or H1) rather than their decision statistics.

Let n denote the number of users collaborating. For simplicity we assume that all n users experience independent and identically distributed fading/shadowing with same average SNR. We assume that all users employ energy-detection and use the same decision rule (i.e. same threshold λ).

A secondary user receives decisions from n−1 other users and decides H1 if any of the total n individual decisions is H1. This fusion rule is known as the OR-rule or 1-out-of-n rule. Probabilities of detection and false-alarm for the collaborative scheme denoted by Qd and Qf respectively may be written as follows

$$\mathrm{Qd} = 1 - (1 - \mathrm{Pd})^{n}$$
$$\mathrm{Qf} = 1 - (1 - \mathrm{Pf})^{n}$$

where Pd and Pf are the individual probabilities of detection and false-alarm respectively.

## 9. RESULTS AND DISCUSSION

**i**

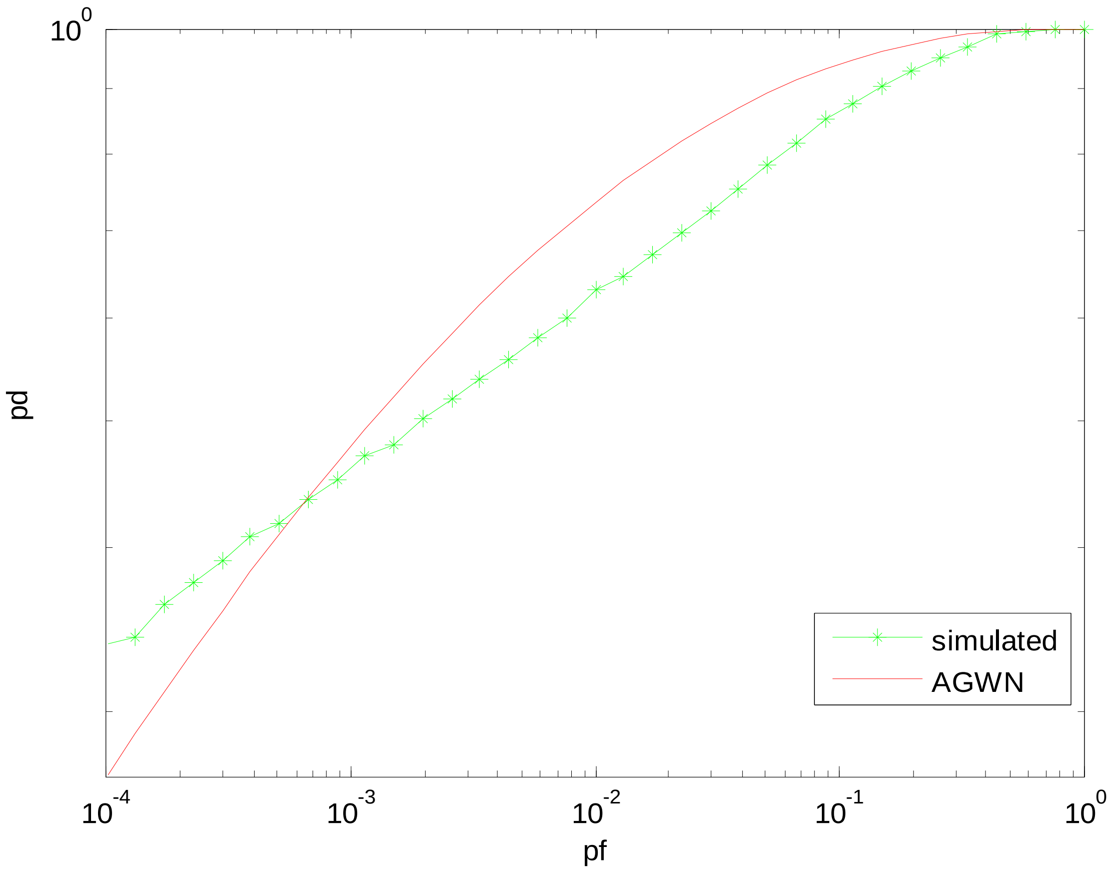



Fig1: Complementary ROC (Pd v/s Pf) under gaussian channel, AWGN is provided for comparison.

**Inference**

This above figure provides plots of complimentary ROC curve under AWGN and Gaussian channel. When Pf > 6.67x 10-4 performance of energy detector degrades.

**ii**

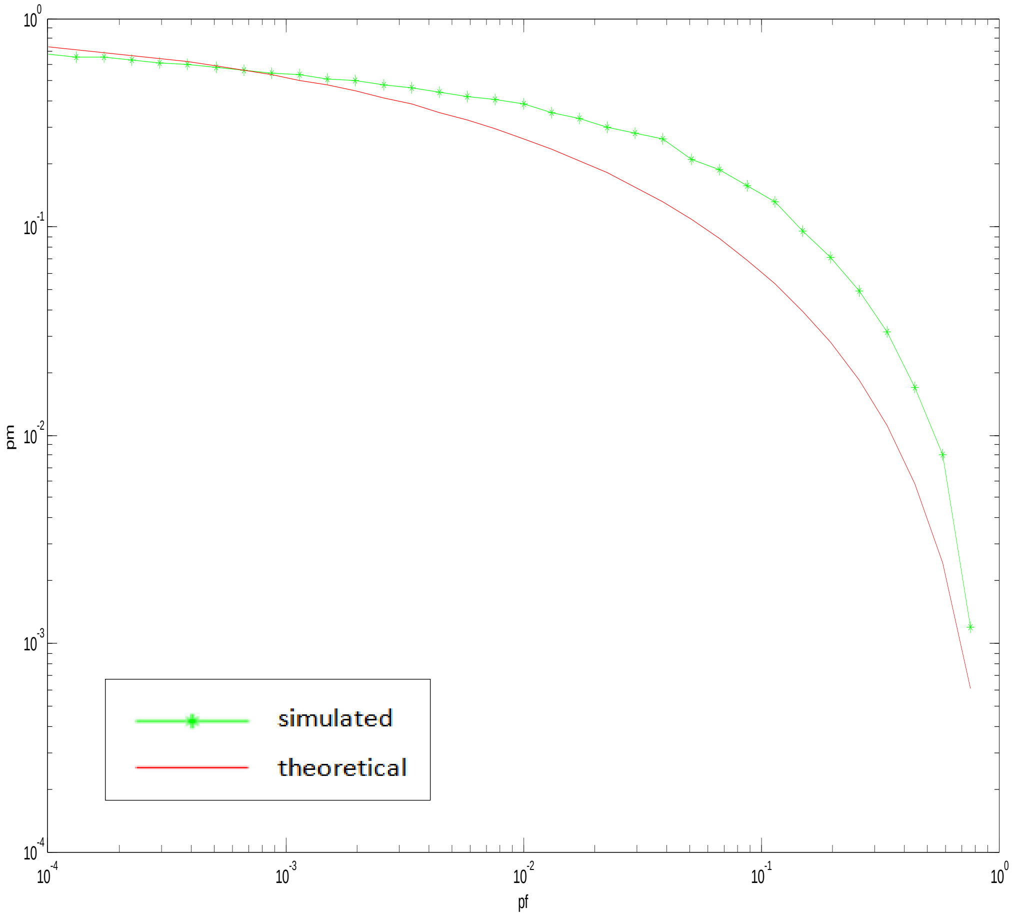



Fig2: Complementary ROC (Pm v/s Pf) under Rayleigh Fading

**Inference**

We observe that Rayleigh fading degrades performance of energy-detector significantly.
Particularly, achieving Pm < 10-2 entails a probability of false-alarm greater than 0.9 which in turn results in poor spectrum utilization.

**iii.**

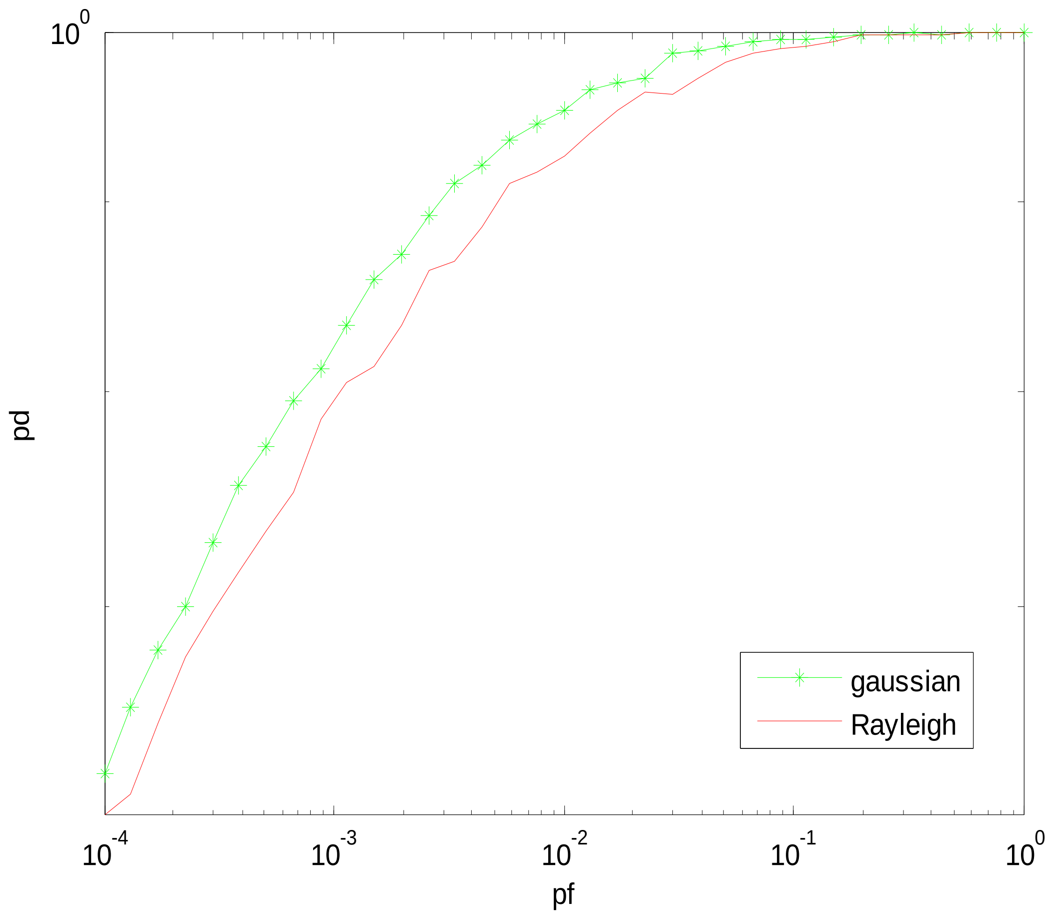



Fig 3: Pf v/s Pd under Rayleigh fading channel and Gaussian channel

**Inference**

The above figure shows the comparison between Rayleigh fading and Gaussian channel. Here, in both the channel the detection probability increases with that of the false alarm probability.

**9.1 Collaborative Spectrum Sensing**

**i**

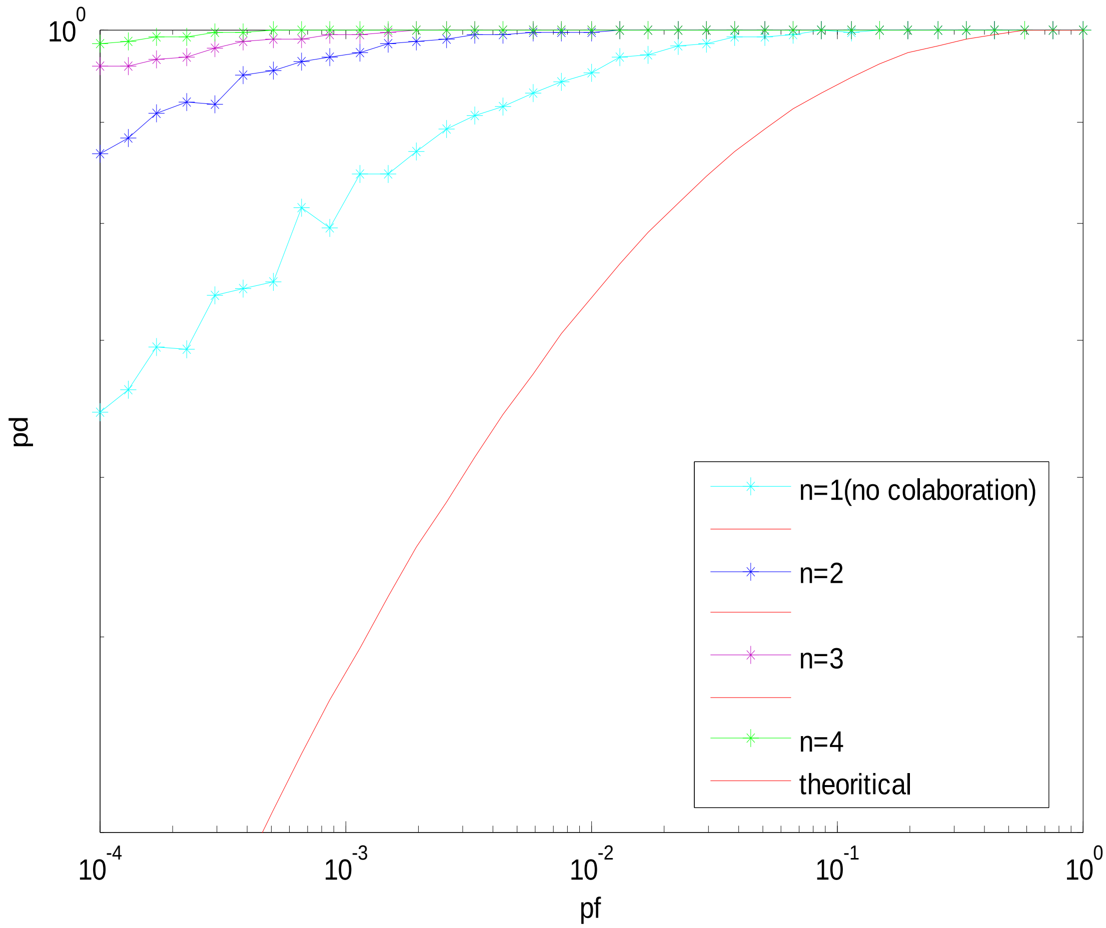



Fig4: Complementary ROC (Pf v/s Pd) under Log Normal Shadowing for collaborative spectrum sensors

**<u>Inference</u>**

From the curve, we can conclude that by increasing the number of collaborative users, the performance for spectrum sensing is improved.

**ii.**

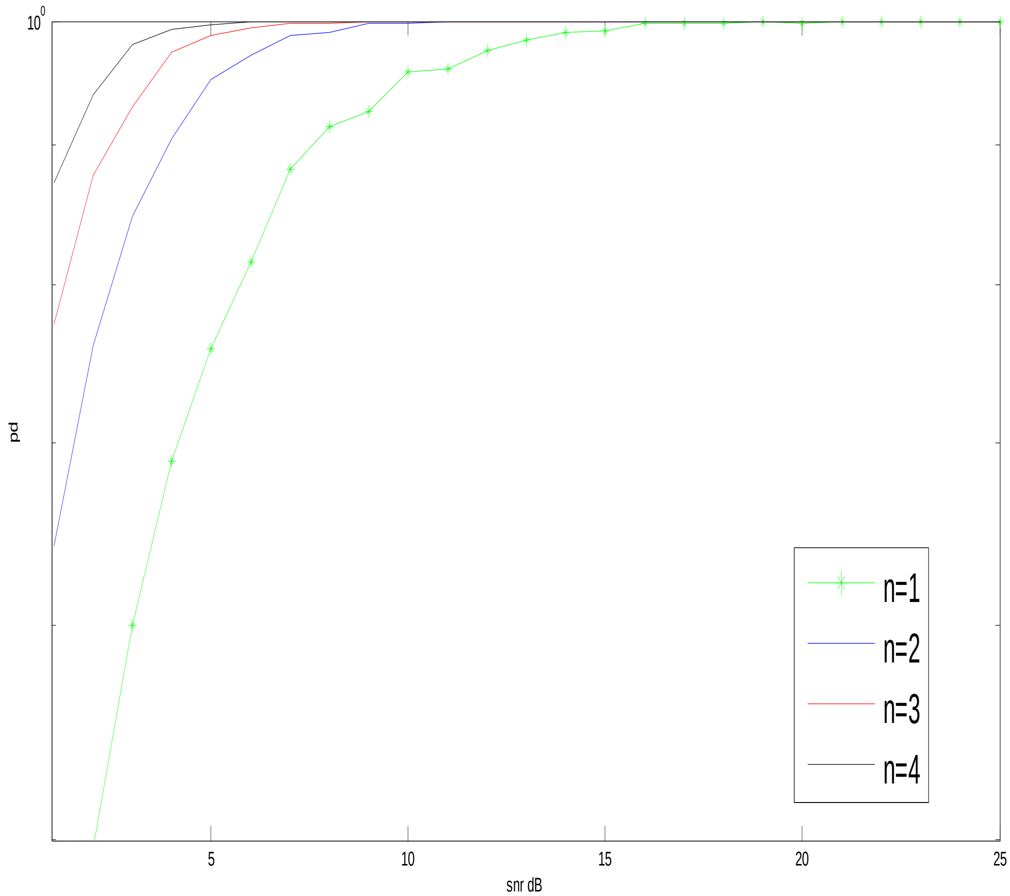



Fig 5: Complementary ROC (Pf v/s Pd) under Log Normal Shadowing collaborative spectrum sensors

## Inference

From the curve, we can conclude that by increasing the number of collaborative users, the performance of the secondary user for sensing the spectrum improves.

**iii.**

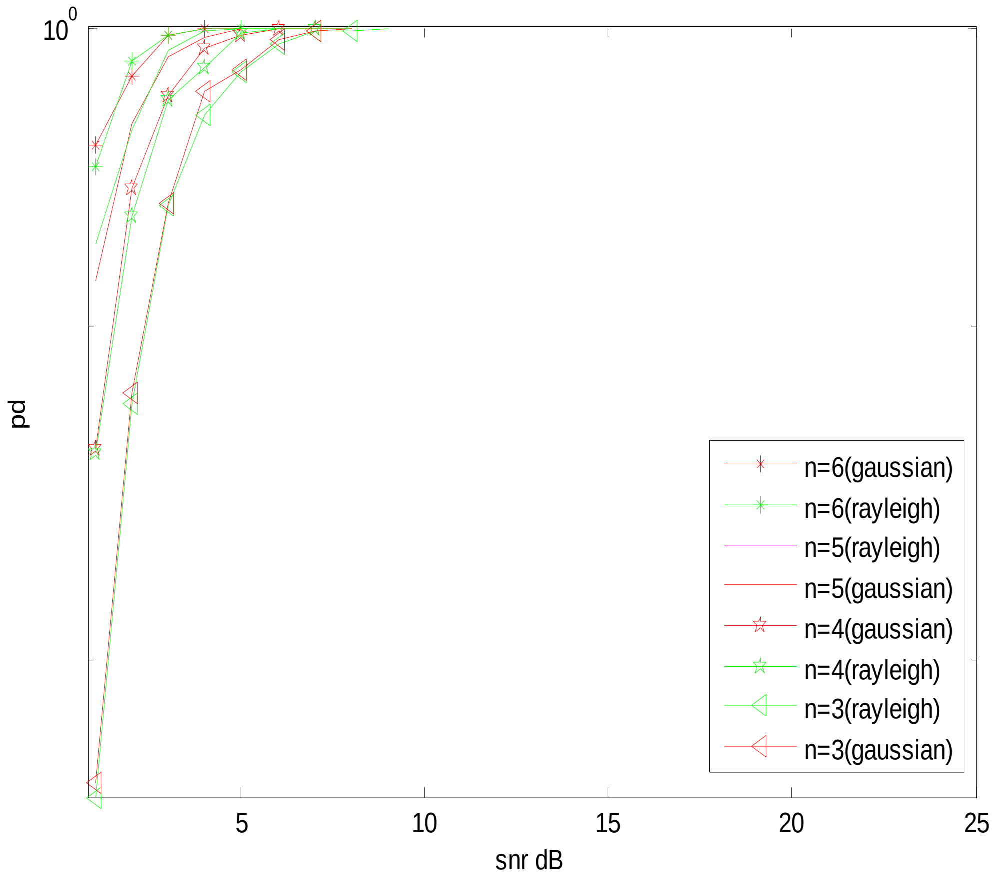



Fig6: Complementary ROC (snr v/s Pd) under Rayleigh and Gaussian channel for Collaborative spectrum sensors

**Inference**

This above figure provides plots of complementary ROC curve under Rayleigh and Gaussian channel scenarios. Here , we observe that as we increase the number of sensors, the detection probability increases which improves the performance of the energy detector.

## 10. CONCLUSION

Cognitive radio can solve the spectrum under utilization problem, using opportunistic approach to use the unused licensed bands using an efficient spectrum sensing technique. A sensing approach which provides sensing information having high probability of detection and low probability of false alarm would then not cause any intervention with the primary user signal. The technique that would be used for sensing must not be too complex and it can be incorporated in the secondary user hardware easily being cost effective.

Sensing technique such as energy detection, for detecting the primary user signal is a less complex technique and it does not require any initial know ledge about the primary users' signal, which makes it the first choice. It can also be easily incorporated into the cognitive radio hardware. Shadowing and fading are some phenomena's that causes the performance of energy detection to be degraded.

To handle problems such as fading and shadowing, collaboration between secondary users was considered to be the best option that can deal with these factors and the energy detection performance degradation was also reduce to some extent. The energy detection performance was enhanced when the number of secondary users collaborating to sense the primary user signal was increased.

All the cognitive users that are together in group effort for collaboration, sends their outcomes to the base station or band manager because it is a central entity in the network, also all the secondary user uses the similar familiar channel for sending their outcomes. However with large number of secondary users participating in the collaboration, and with limited bandwidth it is very difficult to collect the results of the entire secondary users through the common channel and also the band manager require more power for processing to make a final decision.

## 11. FUTURE WORK

- Collaborative spectrum sensing under Log Normal Shadowing.
- Collaborative spectrum sensing under Spatially-Correlated Shadowing in-
    - Suburban Environment
    - Urban Environment

## REFERENCES

[1] S. Haykin, "Cognitive radio: Brain empowered wireless communications," IEEE Journal on Selected Areas in Communications, Vol. 23, No. 2, pp.201-220, Feb. 2005.

[2] C. Cordeiro, K. Birru and S. Shanker, "IEEE 802.22: The first worldwide wireless standard based on cognitive radios ," In proc. of DySPAN'05, November 2005

[3] "IEEE 802.22 Working Group on Wireless Regional Area Network," http://www.ieee802.org/22/

[4] K. Po and J. Takada, "Signal detection for analog and digital TV signals for cognitive radio," IEICE Technical Report, SR2006-54(2006-11).

[5] K. Po and J. Takada, "Performance analysis of signal detection for cognitive radio," IEICE Technical Report, SR2007-4(2007-5).

[6] S. Kay, "Statistical decision theory I (Ch. 3)" and "Deterministic signals (Ch. 4)," in Fundamentals of Statistical Signal Processing, Detection Theory, pp.60-140, Prentice Hall, 1998.

[7] H. Tang, "Some physical layer issues of wide-band cognitive radio systems," 2005 First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), pp.151-159, Nov. 2005.

[8] "Measurement techniques of ultra-wideband transmissions," Rec. ITU-R, SM. 1754, 2006.

[9] J. Takada, S. Ishigami, J. Nakada, E. Nakagawa, M. Uchino and T. Yasui, Members, "Measurement techniques of emissions from ultra wideband devices," IEICE Trans. Fundamentals, Vol.E88-A, pp.2252-2263, No.9 September 2005.

[10] "Transmission System for Digital Terrestrial Television Broadcasting," ARIB Standard, ARIB STD-B31 Version 1.5, Association of Radio Industries and Businesses, 2003.

[11] "DA753G compact discone aerial antenna from AOR Ltd.," http://www.aoruk.com/direct/da753g.htm.

[12] "Anritsu MS2665C spectrum analyzer," http://www.us.anritsu.com/products/ARO/North

## AUTHORS

**First Author -** Itilekha Podder, Department of Electronics and Telecommunications Engineering. E-mail: itilekha19@gmail.com
**Second Author** – Monami Samajar, Department of Electrical and Electronics Engineering. E-mail:monamirc@gmail.com