A Study Paper on Spectrum Sensing Techniques in Cognitive Radio Network

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Abstract- Cognitive radio permits unlicensed users to access licensed frequency bands through dynamic spectrum access so as to reduce spectrum deficiency. This requires intelligent spectrum sensing techniques like co-operative sensing which creates use of information from number of users. The main challenge in any cognitive radio system is to maximize secondary user's throughput while limiting interference imposed on licensed users. In this consideration finding the optimal sensing and transmission timing strategies and accurate sensing techniques are of great importance in a cognitive radio network. In this paper, examine different on Matched filtering, Energy detection and Cyclostationary feature detection cognitive radio spectrum sensing techniques over AWGN channel. It also contain combined analysis of Matched filtering, Energy detection and Cyclostationary feature detection technique for common scenario through decision accuracy vs SNR plots over Nakagami-m Fading Channel , Rician Fading Channel.

Keyword – Cognitive Radio (CR), Additive White Gaussian Noise (AWGN), Primary User (PU), Secondary User (SU).

1. INTRODUCTION

In wireless communication systems, the demands of greater speed more reliable and wider coverage are ever increasing and so is the need for new spectra. But there is very limited amount of unallocated spectrum available in the usable bands of < 3Hz [1] .The spectrum is generally defined by frequency, transmission power, spectrum owner (i.e., licensee), type of use, and the duration of license. Usually, a license is assigned to one licensee, and the use of spectrum by this licensee must be conformed to the specification in the license. The Federal Communications Commission (FCC) published a report prepared by Spectrum Policy Task Force (SPTF) .This report indicates that Most of the allotted channels are not in use utmost of the time; some are partially occupied while others are used the majority of the time.[2]

The most recommended solution for the problem of spectrum scarcity is cognitive radio (CR) described by Joseph Mitola in his doctoral dissertation [3]. CR technology is considered as the best solution because of its ability to rapidly and autonomously adapt operating parameters to changing requirements and conditions [4]To get better the efficiency and utilization of the radio spectrum, the above mentioned limitations should be amended by modifying the spectrum licensing scheme and adopting a dynamic spectrum management model. The basic idea is to make spectrum access more flexible by allowing the unlicensed users to access the radio spectrum under certain situation and boundaries. Because the conventional wireless systems were designed to operate on a dedicated frequency band, they are not able to utilize the improved flexibility provided by this spectrum licensing scheme.

2. COGNITIVE RADIO NETWORK

The formal definition for Cognitive Radio is given as "Cognitive Radio is a radio for wireless communication in which either a network or a wireless node changes its transmission or reception parameter based on the interaction with the environment to communicate effectively without interfacing with the licensed users."

The term "Cognitive Radio" (CR) was coined by Joe Mitola in 1999-2000, in a number of publications and in his PhD thesis. The term was intended to describe intelligent radios that can autonomously make decisions using gathered information about the RF environment through model-based reasoning, and can also learn and plan according to their past experience. Clearly, such a level of intelligence requires the radio to be self-aware, as well as content and context-aware. The functionalities of cognitive radio network is showing in the fig.1 [3][4]

The main important characteristics of Cognitive radio [5]

- *Cognitive capability:* Cognitive Capability explains the ability to capture or sense the information from its surrounding radio environment.
- *Reconfigurability*: The second key feature that distinguishes a cognitive radio from a traditional one, and completes the cognition cycle depicted in Fig. 1, is its ability to re-tune its transceiver parameters on the fly based on its assessment of the surrounding radio environment.

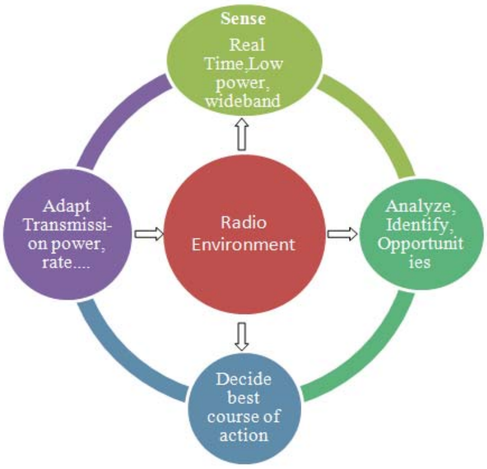

Fig 1: Functional architecture of Cognitive Radio Network

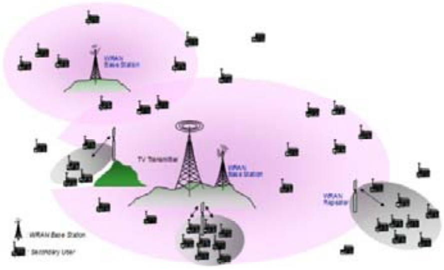

Fig 2: An 802.22 System Development Scenario

2.1 Cognitive Cycle

There are four main steps in Cognitive cycle showing in the fig.3

- *Spectrum Sensing:* It refers to detect the unused spectrum and sharing it without harmful interference with other users.

- *Spectrum Management:* It is the task of capturing the best available spectrum to meet user communication requirements. [5]

-Spectrum Mobility: It is defined as the process where the cognitive user exchanges its frequency of operation.

-Spectrum Sharing: To distribute the spectrum among the secondary users according to the usage cost. [5]

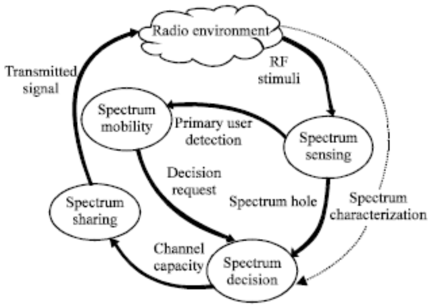

Fig 3: Cognitive Cycle [7]

3. SPECTRUM SENSING

Spectrum sensing is the major task in cognitive cycle and the major threat to the CRs. In spectrum sensing studying the spectrum and find the unused bands and sharing it while avoiding the spectrum that is occupied by PU. It can be defined as [6] “action of a radio measuring signal feature”. To enhance the detection probability many spectrum detection techniques can be used, as shown in Figure 4. [7]

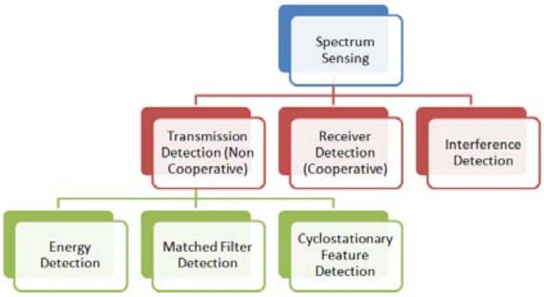

Fig 4: Spectrum Sensing Techniques [5]

3.1 Concept of two hypotheses (Analytical Model)

Spectrum sensing can be simply reduced to an identification problem, modelled as a hypothesis test . The sensing equipment has to just decide between for one of the two hypotheses:-

$$H1: y\ (n) = r(n) + x(n), n=1,2,3....N \qquad (1)$$

$$H0: x\ (n) = x(n),\ n=1,2,3....N \qquad (2)$$

where ‘y(n)’ is the signal transmitted by the primary users.

‘r(n)’ being the signal received by the secondary users.

‘x (n)’ is the additive white Gaussian noise with \ Variances σ^{2n} x.

Hypothesis ‘H0’ indicates absence of primary user

Hypothesis ‘H1’ points towards presence of primary user

Thus for the three state hypotheses numbers of important cases are:-

- H1 turns out to be TRUE in case of presence of primary user i.e. P(H1 / H1) is known as Probability of Detection (Pd).

- H0 turns out to be TRUE in case of presence of primary user i.e. P(H0 / H1) is known as Probability of Miss-Detection (Pm).

- H1 turns out to be TRUE in case of absence of primary user i.e. P(H1 / H0) is known as Probability of False Alarm (Pf).

The probability of detection is of main concern as it gives the probability of correctly sensing for the presence of primary users in the frequency band. Probability of miss-detection is just the complement of detection probability. The goal of the sensing schemes is to maximize the detection probability for a low probability of false alarm. But there is always a trade-off between these two probabilities. Receiver Operating Characteristics (ROC) presents very valuable information as regards the behaviour of detection probability with changing false alarm probability (Pd v/s Pf) or miss-detection probability (Pd v/s Pm).

Probability of acquisition

$$\int P_a = \int_{Z_0}^{0} p_{r|H_0}(R|H_0)dR \qquad (3)$$

Probability of false alarm

$$\int P_f = \int_{Z_1}^{0} p_{r|H_0}(R|H_0)dR \qquad (4)$$

Probability of acquisition

$$\int P_d = \int_{Z_1}^{0} p_{r|H_1}(R|H_1)dR \qquad (5)$$

Probability of acquisition

$$\int P_A = \int_{Z_0}^{0} p_{r|H_1}(R|H_1)dR \qquad (6)$$

3.2 Transmission Detection (Non-Cooperative)

A. Matched-Filtering Technique:

Matched-filtering is known as the optimum method for detection of primary users when the transmitted signal is known. The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of miss detection as compared to other methods. Matched-filtering requires cognitive radio to demodulate received signals. Hence, it requires perfect knowledge of the primary users signalling features such as bandwidth, operating frequency, modulation type and order, pulse shaping, and frame format.

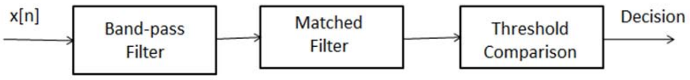

Fig 5: Matched-Filtering Technique [5]

The output of the matched filter, given that ‘x[n]’ is the received signal and ‘s[n]’ is the filter response, is given as

$$\mathrm{x(n)} = \sum_{k=\infty}^{\infty} \mathrm{x(k)s(n-k)} \qquad (7)$$

B. Energy Detector Based Sensing:

Energy detector based approach which is also known as radiometry or periodogram, is the most common way of spectrum sensing because of its low computational and implementation complexities. It is more generic method as receivers do not need any knowledge on the primary users signal.

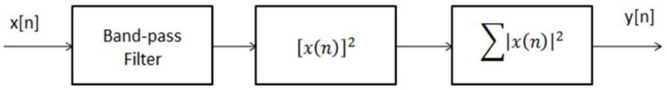

Fig 6: Energy Detector Based Sensing [5]

It has the following components:-

- *Band-pass filter* - Limits the bandwidth of the received Signal to the frequency band of interest.
- *Square Law Device* - Squares each term of the received Signal.
- *Summation Device* -Add all the squared values to Compute the energy.

A threshold value is required for comparison of the energy found by the detector. Energy greater than the threshold values indicates the presence of the primary user. The principle of energy detection is shown in figure 6. The energy is calculated as

$$\mathrm{E} = \sum_{n=0}^{N} |\mathrm{y(n)}|^2 \qquad (8)$$

the Energy is now compared to a threshold for checking which hypothesis turns out to be true.

$$E > \lambda \Rightarrow H1 \qquad (9)$$

$$E < \lambda \Rightarrow H0 \qquad (10)$$

C. Cyclostationary-Based Sensing:

Nature has its way in such a manner that many of its processes arise due to periodic phenomenon. Examples include fields like radio astronomy wherein the periodicity is due to the rotation and revolution of the planets, weather of the earth due to periodic variation of seasons [15]. In telecommunication, radar and sonar fields it arises due to modulation, coding etc. It might be that all the processes are not periodic function of time but their statistical features indicate periodicities and such processes are called cyclo-stationary process. For a process that is wide sense stationary and exhibits cyclostationary has an auto-correlation function which is periodic in time domain. Now when the auto-correlation function is expanded in term of the Fourier series co-efficient it comes out that the function is only dependent on the lag parameter which is nothing but frequency. The spectral components of a wide sense cyclostationary process are completely uncorrelated from each other. The Fourier series expansion is known as cyclic auto-correlation function (CAF) and the lag parameter i.e. the frequencies is given the name of cyclic frequencies. The cyclic frequencies are multiples of the reciprocal of period of cyclostationary. The cyclic spectrum density (CSD) which is obtained by taking the Fourier transform of the cyclic auto-correlation function (CAF) represents the density of the correlation between two spectral components that are separated by a quantity equal to the cyclic frequency. The following conditions are essential to be filled by a process for it to be wide sense cyclostationary:-

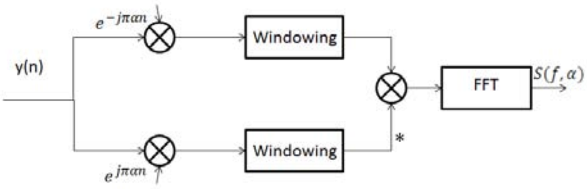

Fig 7: Cyclostationary Sensing Technique [5]

$$E\{x(t+T_0) = E\{x(t)\} \tag{11}$$

$$R_x\,(t+T_0,\tau) = R_x(t,\tau) \tag{12}$$

$$\text{Where } R_x = E\,\{\,x(t+\tau)\,x(t)\} \tag{13}$$

Thus both the mean and auto-correlation function for such a process needs to be periodic with some period say T The cyclic auto-correlation function (CAF) is represented in terms of Fourier co-efficient as:-

$$R_x^{n/T_0} = \frac{1}{T_0}\int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} R_x\,(t,\tau)e^{-j2\pi\left(\frac{n}{T_0}\right)t}\,dt \tag{14}$$

'n/T_0' represent the cyclic frequencies and can be written as 'α'. A wide sense stationary process is a special case of a wide sense cyclostationary process for 'n/T_0 = α=0'. The cyclic spectral density (CSD) representing the time averaged correlation between two spectral components of a process which are separated in frequencies by 'α' is given as

$$s(f,\alpha) = \int_{t=-\infty}^{\infty} R_x^{\alpha}\,(\tau)e^{-j2\pi f t}\,d\tau \tag{15}$$

The power spectral density (PSD) is a special case of cyclic spectral density (CSD) for 'α=0'. It is equivalent to taking the Fourier transform of special case of wide sense cyclostationary for 'n/T_0 = α=0'.

3.2 Cooperative Techniques for Cognitive radio

Cooperative spectrum sensing can not only decrease the probabilities of false alarm and missed detection, but can also mitigate the hidden terminal problem. Thus, multiple cognitive radios are often required to collaborate for spectrum sensing. In a centralized and decentralized sensing setup as shown fig.8

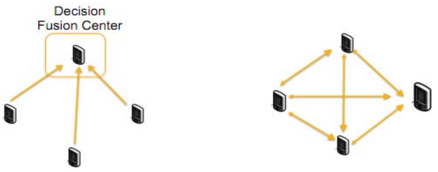

Figure 8: Cooperative sensing techniques: a-Centralised Coordinated, b Decentralised Coordinated, and [10].

A. *Centralized Techniques:*

In such networks, an infrastructure deployment is assumed for the CR users. One CR that detects the presence of a primary transmitter or receiver, informs a CR controller which can be a wired immobile device or another CR user. The CR controller notifies all the CR users in its range by means of a broadcast control message. Centralized schemes can be further classified according to their level of cooperation as: Partially cooperative where network nodes cooperate only in sensing the channel. CR users independently detect the channel and inform the CR controller which then notifies all the CR users; and totally cooperative Schemes where nodes cooperate in relaying each others information in addition to cooperatively sensing the channel [12].

B. *Decentralized Techniques:*

The cognitive users in the network don't have any kind of cooperation which means that each CR user will independently detect the channel, and if a CR user detects the primary user it would vacate the channel without informing the other users. Uncoordinated techniques are fallible in comparison with coordinated techniques. Therefore, CR users that experience bad channel realizations detect the channel incorrectly thereby causing interference at the primary receiver.

4. SPECTRUM SENSING OVER A SINGLE FADING CHANNEL

In a fading channel, the average probability of false alarm$\overline{P_f}$ will not change. In contrast, when the channel gain, h (t), varies, the average probability of detection, $\overline{P_d}$, can be calculated by averaging Pd in over all SNR values as,

$$\overline{P_d} = \int_0^\infty P_d\,(\gamma,\lambda) f(\gamma) d\gamma = \int_0^\infty Q_u\,(\sqrt{2\gamma},\sqrt{\lambda}) f(\gamma) d\gamma \tag{16}$$

where f(γ) denotes the PDF of the SNR in a fading channel.

A. *Nakagami-m Fading Channel*

In a Nakagami-m fading channel, the SNR of the signal is distributed according to a Gamma distribution as:

$$F(\gamma) = \frac{m^{\ m}(\gamma)^{m-1}}{(\bar{\gamma})^m \Gamma(\mathrm{m})} e^{-\frac{m^\gamma}{\bar{\gamma}}}, \quad \gamma = 0 \tag{17}$$

where γ denote the local-mean SNR (SNR averaged over a few tens of wavelengths), and m is

the Nakagami-m fading factor (m ∈ [1/2, ∞)).

The average probability of detection over Nakagami-m Fading Channel, $\overline{P_d Na}$, can be calculated as,

$$\overline{P_d Na} \;=\; e^{-\frac{\pi}{2}} \sum_{\mathrm{i}=0}^{\mathrm{u}-1} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} + e^{-\frac{\pi}{2}} \sum_{\mathrm{n}=\mathrm{u}}^{\infty} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} (1 - \qquad \frac{m^{\ m}}{(\bar{\gamma})^m \Gamma(\mathrm{m})} \sum_{\mathrm{k}=0}^{\mathrm{n}-\mathrm{u}} \frac{\int_0^\infty (\gamma)^{\mathrm{k}+\mathrm{m}-1} \mathrm{e}^{-\frac{\mathrm{m}+\bar{\gamma}}{\mathrm{y}}} \gamma \mathrm{d}\gamma}{\mathrm{k}!} \tag{18}$$

for calculating the integral in (18), the result is obtained as,

$$\overline{P_d Na} \;=\; e^{-\frac{\pi}{2}} \sum_{\mathrm{i}=0}^{\mathrm{u}-1} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} + e^{-\frac{\pi}{2}} \sum_{\mathrm{n}=\mathrm{u}}^{\infty} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} (1 - \qquad (\frac{m}{\overline{(m+\gamma)}})^{\mathrm{m}} \sum_{\mathrm{k}=0}^{\mathrm{n}-\mathrm{u}} \left(\frac{(\mathrm{k}+\mathrm{m}-1)!}{\Gamma(\mathrm{m})\mathrm{k}!}\right) (\frac{\bar{\gamma}}{\mathrm{m}+\bar{\gamma}})^{\mathrm{k}} \tag{19}$$

It can be shown that the above representation converges to 1 when the parameter γ goes to infinity for a constant m and any positive λ. As the detection threshold λ approaches to infinity, the average probability of detection converges to zero when γ is a constant.

B. *Rician Fading Channel*

The Rician model is often used to describe propagation paths which contain a strong dominant line of sight (LOS) component and several weaker scattered components. It includes both the non fading AWGN channel and the Rayleigh fading channel as two special cases. The PDF of the SNR in a Rician fading channel is given by,

$$F(\gamma) = \frac{(K+1)e^{-K}}{\bar{\gamma}} e^{-\frac{(K+1)\gamma}{\bar{\gamma}}} I_0\left(2\sqrt{\frac{K(K+1)\gamma}{\bar{\gamma}}}\right), \gamma > 0 \tag{20}$$

where K is the shape parameter. The average probability of detection over Rician fading channel can be given by,

$$\overline{P_d R\imath} \;=\; e^{-\frac{\pi}{2}} \sum_{\mathrm{i}=0}^{\mathrm{u}-1} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} + e^{-\frac{\pi}{2}} \sum_{\mathrm{n}=\mathrm{u}}^{\infty} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} (1 - \qquad \frac{(K+1)e^{-K}}{\bar{\gamma}} \sum_{\mathrm{k}=0}^{\mathrm{n}-\mathrm{u}} \frac{\int_0^\infty (\gamma)^{\mathrm{k}} \mathrm{e}^{-\frac{1+K+\bar{\gamma}}{\bar{\gamma}}} \gamma\, I_0\left(2\sqrt{\frac{K(K+1)\gamma}{\bar{\gamma}}}\right) \mathrm{d}\gamma}{\mathrm{k}!} \tag{21}$$

for calculating the integral, with the aid of the identity for the Whittaker function, the result of $\overline{\mathrm{Pd}, \mathrm{R}\imath}$ is obtained as,

$$\overline{P_d R\imath} = e^{-\frac{\pi}{2}} \sum_{\mathrm{i}=0}^{\mathrm{u}-1} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} + e^{-\frac{\pi}{2}} \sum_{\mathrm{n}=\mathrm{u}}^{\infty} \frac{\left(\frac{\lambda}{2}\right)^{\mathrm{i}}}{\mathrm{i}!} (1 - \quad \frac{(K+1)e^{-K}}{1+K+\bar{\gamma}} \sum_{\mathrm{k}=0}^{\mathrm{n}-\mathrm{u}} \left(\frac{\bar{\gamma}}{1+K+\bar{\gamma}}\right)^{\mathrm{K}} \Phi\ (\mathrm{K}+1), 1\!: \frac{\mathrm{K}(\mathrm{K}+1)}{1+K+\bar{\gamma}} \tag{22}$$

where Φ(α, γ; z) denotes the Confluent Hypergeometric function, given by

$$\Phi(\alpha,\gamma;z) = 1 + \frac{\alpha}{\gamma}\frac{z}{1!} + \frac{\alpha(\alpha+1)}{\gamma(\gamma+1)}\frac{z^2}{2!} + \cdots \qquad (23)$$

In contrast to the result in, equation. (22) is applicable for any value of the time bandwidth product. Since the time bandwidth product, u, describes the number of independent samples of the signal in the observation time T, the result in (22) is more flexible, and can be used to analyse the performance of energy detection, when the data is sampled at any sampling rate over any observation time of T. The comparison of these expressions are shown in Figure

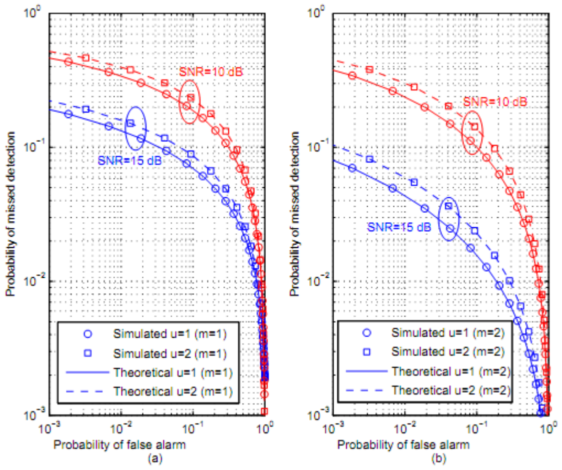

Fig 9: Complementary ROC curves of energy detection over a Nakagami-m fading channel, with (a) m = 1, and (b) m = 2. This figure is produced by changing the detection threshold λ from 0.1 to 1000. [12]

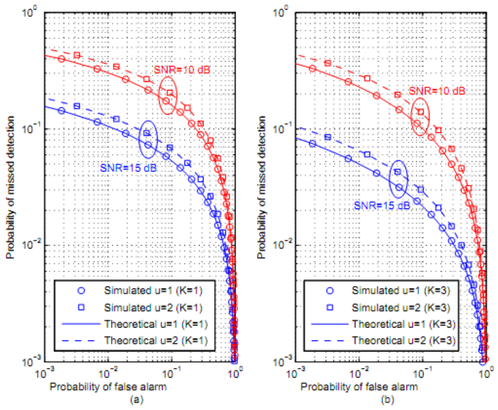

Fig 10: Complementary ROC curves of energy detection over a Rician fading channel, with (a) K = 1, and (b) K = 3. This figure is produced by changing the detection threshold λ from 0.1 to 1000.[12]

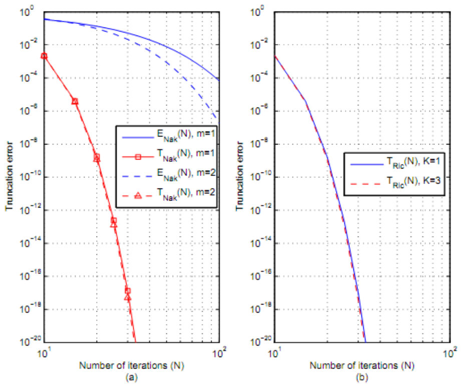

Fig 11 :The error after N iterations on index n, when the time bandwidth product u = 1, the local-mean SNR γ = 10 dB, and the average probability of false alarm Pf = 0.01, with (a) Nakagami-m fading, and (b) Rician fading.[12]

5. CONCLUSION

Cognitive radio is the promising technique for utilizing the available spectrum optimally. The important aspect of cognitive radio is spectrum sensing from that identifying the opportunistic spectrum for secondary user communication.

In this paper, we have projected a survey paper based on cognitive radio network associated to spectrum sensing techniques. It explains the four primary role of a cognitive radio: spectrum sensing, spectrum management, spectrum sharing, and spectrum mobility. After that in this paper we are focus over spectrum sensing techniques as well as different approach used for accessing licensed spectrum by secondary user. And also computed expressions for the average probabilities of detection and false alarm over a single Nakagami-m, or Rician fading channel have been derived.

Table1: Summary of advantages and disadvantages of Transmission detection (non cooperative) spectrum sensing techniques [5]

Spectrum sensing techniques	**Advantages**	**Disadvantages**
Centralized Sensing	Bandwidth efficient for same number of cooperating CRs as compared to distributed cooperation	One CR i.e. FC becomes very critical as well as complex to carry the burden of all cooperating CRs
Distributed Sensing	No need of backbone infrastructure resulting in low implementation cost	Large control bandwidth required for information exchange among all cooperating CRs Finding neighbors in itself is a challenging task for CRs Large sensing duration resulting from iterative nature of distribute techniques

Table2: Summary of advantages and disadvantages of Transmission detection (non cooperative) spectrum sensing techniques [5]

Spectrum sensing Techniques	**Advantages**	**Disadvantages**
Matched filtering	Optimal performance Low computational cost	Requires prior information of the primary user
Energy detection	Does not require prior information Low computational cost	Poor performance for low SNR Cannot differentiate users
Cyclostationary Feature	Valid in low SNR region Robust against interference	Requires partial prior information High computational cost

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