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Performance Comparison of Cognitive Radio Network by Spectrum Sensing Methods

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Abstract - *Cognitive radio is an emerging technology which is able to solve the problem of spectrum inefficiency. Each wireless system occupies some bandwidth but there is limited spectrum which is given to the licensed user. This allotted spectrum is sometimes underutilized. Cognitive radio senses the spectrum, find the unused space in the spectrum and allot it to the unlicensed secondary user without any interference to the primary licensed users. These unlicensed secondary users are called the cognitive radio users. Spectrum sensing is the main key task of cognitive radio. There are different types of spectrum sensing techniques which are energy detection, matched filter detection and cyclostationary detection. In this paper we are designing a cognitive radio system which can analyze the energy of the spectrum. Using energy detection technique, we analyze the performance of our system on different fading channels like Additive White Gaussian Noise (AWGN) channel, Rayleigh fading channel and Nakagami fading channel.*

***Key words:*Cognitive Radio(CR), Spectrum Sensing, Energy Detection, AWGN,Rayleigh,Nakagami.**

1.INTRODUCTION

The radio frequency spectrum is a natural source which is used by the wireless devices for the transmission. Every wireless device transmits with the radio spectrum, but the allocation of the radio spectrum is based on the licensed policy. Federal communication commission is the organization which allots the spectrum to different area of wireless system but in the age of high speed number of users is increasing day by day the spectrum has become a scarce source. The fixed spectrum allocation (FSA) policy was used in the past but currently it is going towards a bottle neck condition.

New Wireless technologies are providing services from voice-only communications to multimedia applications. It requires more bandwidth but much of the spectrum has already been allotted to the conventional radio system. Studies have shown that the allotted spectrum is underutilized by the system. These frequencies are not utilized by the wireless system all the time. Thus for many times frequency band remains idle.

The solution of this problem is Cognitive radio (CR) was suggested by the Joseph Mitola. Mitola's definition for cognitive radio is "an intelligent wireless communication system that's aware of its surrounding environment (outside world) and uses the methodology of understanding by building to learn from its environment and adopt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain parameters "

Spectrum sensing is the main task of the cognitive radio. Cognitive radio sense the spectrum allotted to the primary licensed user. A band of frequency which is not utilized by the primary user is called the spectrum hole or white space and is allotted to the secondary unlicensed user without causing any interference to the primary user. When cognitive radio sense that the primary user require the band, CR switch the secondary user to the next available space.

In this paper we will discuss the energy detection method of spectrum sensing and we will design a system model to perform the spectrum sensing. Performance of cognitive radio system is analyzed on the basis of Receiver Operating Characteristics (ROC) ROC curves are generated by plotting either probability of detection (P_d) versus probability of false alarm probability (P_{fa}) or missed detection probability (P_{md}) versus false alarm probability(P_{fa}). Further we will study the impact of different fading channel on the energy detection spectrum sensing technique.

1.1 Cognitive Radio

The related word cognition can be described by three points; 1) Mental states and processes intervene between input stimuli and output responses. 2) The mental states and processes are described by algorithms. 3) The mental states and processes lend themselves to scientific investigations. It can then be inferred that cognition is all about intelligence that is how to maximum utilize mind and ideas. It can be concluded that CR aims at maximum utilization of spectrum. Utilization of precious radio magnetic spectrum helps us to overcome major bottle neck i.e. spectrum limitation for efficient communication. Due to control regulation the problem of spectrum access also becomes significant issue, since it limits the user to obtain access.

1.2 Users

Primary or licensed user is the actual user of the frequency that is the one with the license or in other words the assigned user. Secondary user or unlicensed user, on the other hand, uses primary user's frequency for the time primary user is idle.

1.3 Spectrum Hole

Some frequency bands in radio spectrum are not occupied or incompletely occupied while some are deeply occupied; this causes underutilization of the spectrum which direct to the concept of Spectrum holes. Spectrum hole is the frequency which is in actual assigned to primary user but for limited time is not in use by that user, so for that portion of time that frequency is used by secondary user that have no licensed frequency, the occupation of frequency band is improved which is the aim of CR. In the implementation of CR detection of spectrum holes must be assured. Spectrum holes can be classified in three forms. Black spaces are occupied by high power. Grey spaces are occupied by low power and White spaces are characterized as free of RF interferer except for noise.

2.SYSTEM MODEL

Energy detection is the most popular spectrum sensing method since it is easy to implement and does not require any prior information about the primary signal. An energy detector (ED) merely treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal. Since it does not need any a prior knowledge of the primary signal, the ED is robust to the variation of the primary signal. Moreover, the ED doesn't involve complicated signal processing and has low complexity. In practice, energy detection is especially suitable for wide-band spectrum sensing.Energy detector is composed of five main blocks as shown in Figure 1

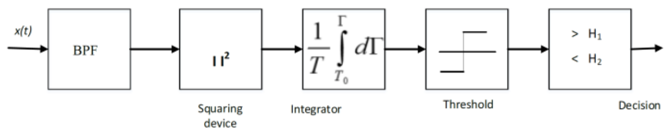

Figure 1: Block Diagram of Energy Detector

Here,the received signal x(t) is filtered by a band pass filter (BPF), followed by a square law device. The band pass filter serves to reduce the noise bandwidth. Hence, noise at the input to the squaring device has a band-limited flat spectral density. The output of the integrator is the energy of the input to the squaring device over the time interval T. Next, the output signal from the integrator (the decision statistic), Y, was compared with a threshold to decide whether a primary (licensed) user is present or not. Decision regarding the usage of the band will be made by comparing the detection statistic to a threshold. This output is considered as the test statistic to test the two hypotheses H0 and H1.

H_0: corresponds to the absence of the signal and presence of only noise.

H_1: corresponds to the presence of each signal and noise.Thus for the 2 state hypotheses number of necessary cases are:-

a) H_1 turns out to be TRUE in case of presence of primary user i.e. P (H_1 / H_1) is known as the Probability of Detection(P_d).

b) H_0 turns out to be TRUE in case of presence of primary user i.e. P (H_0 / H_1) is known as the Probability of Missed- Detection (P_{md}).

c) H_1 turns out to be TRUE in case of absence of primary user i.e. P (H_1 / H_0) is known as the Probability of False Alarm (P_{fa}).

The received signal in narrowband energy detection follows a two hypothesis can be shown as below

$$x(t)=\begin{cases} n(t) & H_0 \\ h*s(t)+n(t) & H_1 \end{cases} \quad (1)$$

where:
x(t) = Signal Received by Secondary User
n(t) = AWGN
s(t) = Transmitted Signal by Primary User
h = Gain of the Channel.

$$Y=\begin{cases} \chi^2_{2u} & H_0 \\ \chi^2_{2u}(2\gamma) & H_1 \end{cases} \quad (2)$$

where *Y* means the collected energy by a cognitive user, *u* refers to the time-bandwidth product of the energy detector.For simplicity, it is assumed to be an integer, and χ^2_{2u} represents a central chi-square distribution with $2u$ degrees of freedom while $\chi^2_{2u}(2\gamma)$ represents a non-central chi-square distribution with $2u$ degrees of freedom and a non-centrality parameter *2λ* for H_1.The probability density function (PDF) of Y can be expressed as

$$f_Y(y)=\begin{cases} \frac{1}{2^u\Gamma(u)} y^{u-1} e^{\frac{-y}{2}} & ,H_0 \\ \frac{1}{2}\left(\frac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{\frac{-2\gamma+y}{2}} I_{u-1}(\sqrt{2\gamma y}) & ,H_1 \end{cases} \quad (3)$$

Where Γ(.) is the gamma function and I_{u-1}(.) is the (u-1)th order modified Bessel function of the first kind.

Table -1: Parameters for Spectrum Sensing

P_{fa}	Probability of false alarm probability.
P_d	Probability of detection.
P_{md}	Probability of Missed-Detection.
λ	Threshold
γ	SNR
u	Time Bandwidth Product

2.1 DETECTION AND FALSE ALARM PROBABILITIES OVER AWGN CHANNELS.

Additive White Gaussian Noise (AWGN) is the simplest radio environment, in which a wireless communication system operates. The parameter *h* define the type of fading channel, when the signal is free from fading effect or, consider the fading parameter (*h*) is equal to one. In non-fading environment the average probability of false alarm, the average probability of detection, and the average probability of missed detection are given, respectively, by

$$P_d = P\{Y>\lambda \mid H_1\} = Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right) \quad (4)$$

$$P_{fa} = P\{Y>\lambda \mid H_0\} = \frac{\Gamma(u,\lambda/2)}{\Gamma(u)} \quad (5)$$

and

$$P_{md} = 1-P_d \quad (6)$$

where λ denotes the energy threshold. Γ(.) and Γ(.,.) are complete and incomplete gamma functions respectively and $Q_u(.,.)$ is the generalized Marcum Q-function defined as follows,

$$Q_u(a,b)=\frac{1}{a^{u-1}}\int_b^\infty x^u e^{-\frac{x^2+a^2}{2}} I_{u-1}(ax)dx$$

where $I_{u-1}(.)$ is the modified Bessel function of (*u*−*1*)th order. If the signal power is unknown, we can first set the false alarm probability P_{fa} to a specific constant. By equation (5), the detection threshold *λ* can be determined. Then, for the fixed time-bandwidth product *u* the detection probability P_d can be evaluated by substituting the λ in (4). As expected, P_{fa} is independent of γ since under H_0 there is no primary signal present. When *h* is varying due to fading, equation (4) gives the probability of detection as a function of the instantaneous SNR, γ. In this case, the average probability of detection P_d may be derived by averaging (4) over fading statistics ,

$$P_d = \int_x Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right) f_\gamma(x)dx \quad (7)$$

where $f\gamma(x)$ is the probability distribution function (PDF) of SNR under fading.

2.2 DETECTION PROBABILITY UNDER RAYLEIGH FADING CHANNELS.

When the composite received signal consists of a large number of plane waves, for some types of scattering environments, the received signal has a Rayleigh distribution . If the signal amplitude follows a Rayleigh distribution, then the SNR γ follows an exponential PDF given by

$$f(\gamma)=\frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right),\ \gamma\geq 0 \quad (8)$$

In this case, a closed-form formula for P_d may be obtained (after some manipulation) by substituting $f_\gamma(x)$ in (7),

$$\bar{P}_{dRay}=e^{-\frac{\lambda}{2}}\sum_{k=0}^{u-2}\frac{1}{k!}\left(\frac{\lambda}{2}\right)^k+\left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{u-1}$$
$$\times\left(e^{-\frac{\lambda}{2(1+\bar{\gamma})}}-e^{-\frac{\lambda}{2}}*\sum_{k=0}^{u-2}\frac{1}{k!}\left(\frac{\lambda\bar{\gamma}}{2(1+\bar{\gamma})}\right)\right) \quad (9)$$

2.2 DETECTION PROBABILITY UNDER NAKAGAMI FADING CHANNELS.

The probability of detection over Nakagami channel is determined by averaging the detection probability for a given SNR over the Nakagami distribution. If the signal amplitude follows a Nakagami distribution, then PDF of SNR , follows a gamma PDF given by ;

$$f(\gamma)=\frac{1}{\Gamma(m)}\left(\frac{m}{\bar{\gamma}}\right)^m\gamma^{m-1}\exp\left(\frac{-m\gamma}{\bar{\gamma}}\right),\gamma\geq 0 \quad (10)$$

The average PD in the case of Nakagami channels is obtained by averaging (3.35) over (4)

$$P_{DNak}=\int_0^\infty P_D f(\gamma)d\gamma \quad (11)$$

where f(γ) is the probability density function of the instantaneous SNR at the receiver node,
m is the Nakagami-m fading parameter, which describes the severity of fading; m < 1 suggests severe fading, while m > 1 indicates less severe fading . Solving the integral in (11) as identified in & after simple mathematical manipulation , the probability of detection over Nakagami fading channels can be approximated as a closed form expression of the Probability of detection in Nakagami channels as:

$$P_{DNak}=1-\beta\left(\frac{\gamma^*\left(\frac{\lambda}{2},u\right)}{\Gamma(u)}\right)$$

Where $\beta=\left[\frac{2m}{2m+\bar{\gamma}}\right]$

$\gamma^*(.,.)$ to represent the lower incomplete gamma function.

3.SIMULATION RESULTS & DISCUSSION

Numerical computation of Probability of detection (P_d), probability of false alarm (P_{fa}) and probability of missed detection ($P_{md} = 1- P_d$) are the significant measurement parameters that are used to examine the performance of spectrum sensing techniques. The performance of a spectrum sensing technique is illustrated by the receiver operating characteristics (ROC) curve which is a plot of P_d versus P_{fa} or P_{md} versus P_{fa}. Simulation of the system was done on MATLAB version (R2018a) over three different channels *viz.* AWGN, Rayleigh and Nakagami Channels.

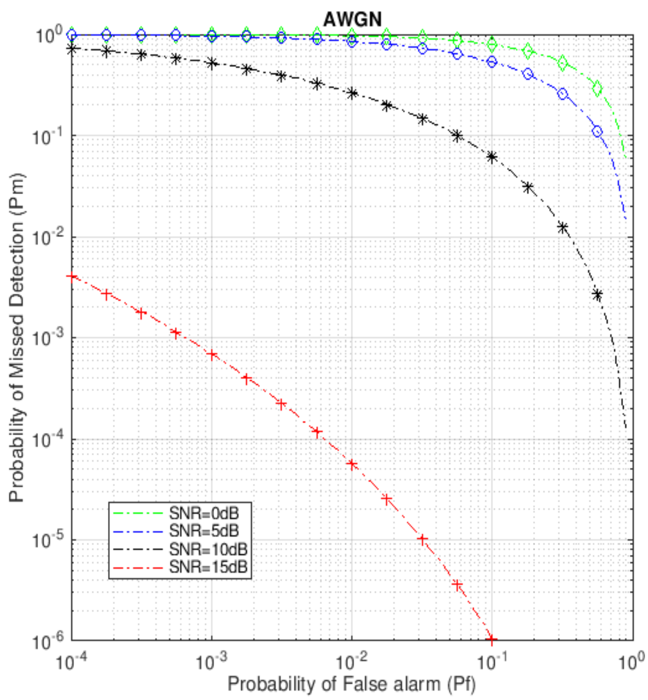

Figure 2:ROC curve for AWGN

Figure 2 shows the complementary ROC curve for energy detection over a non-fading (AWGN) channel (a case where the form of interference is only noise).This shows the relationship between the probability of missed detection P_m, and false alarm probability P_{fa}, for 0 -15 dB average SNR, time bandwidth product d = 5, sample size N = 10 respectively.The probability of missed detection is a complement of detection probability. Related by the expression P_m = 1- P_d), and is used in this case for clarity.Numerical results shown in the plot are based on equation (5 & 6) and are represented by curves. While the simulation are represented by discrete $\bar{\gamma}$ marks. From this plot, the probability of miss improves rapidly with increasing $\bar{\gamma}$; roughly a gain of one order of magnitude is achieved when increases from 10 dB to 15dB, when a node experiences no channel fading effects. This protects the point made earlier that an increase in SNR produces greater detection performance for a non-fading channel.

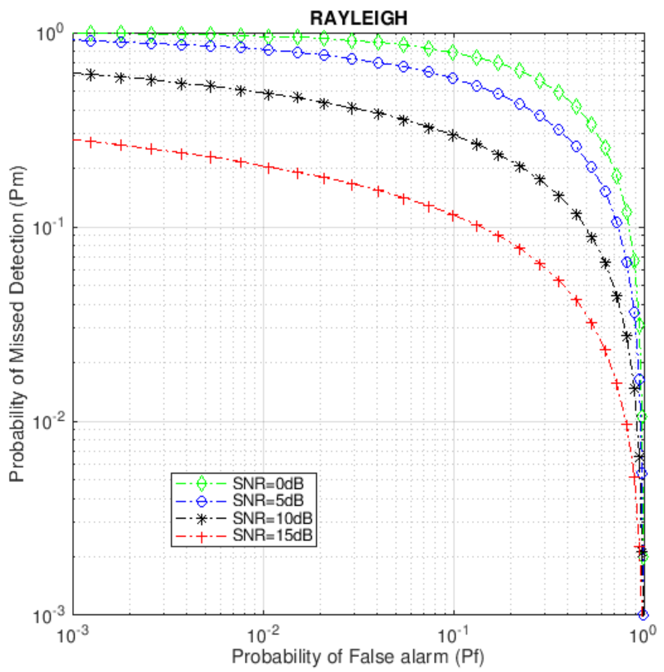

Figure 3:ROC curve for Rayleigh

The above fig. 3 shows the receiver operating characteristics of the energy detector in Rayleigh fading channel. Graph is plotted between P_{fa} and P_m at different value of SNR .We can find that as we are increasing the SNR, performance of the detector increases. For SNR=0db, 5db the probability of miss detection is almost 1.But as we come to SNR= 10 db,15db, the probability of misdetection goes on reducing & hence the probability of detection increases.

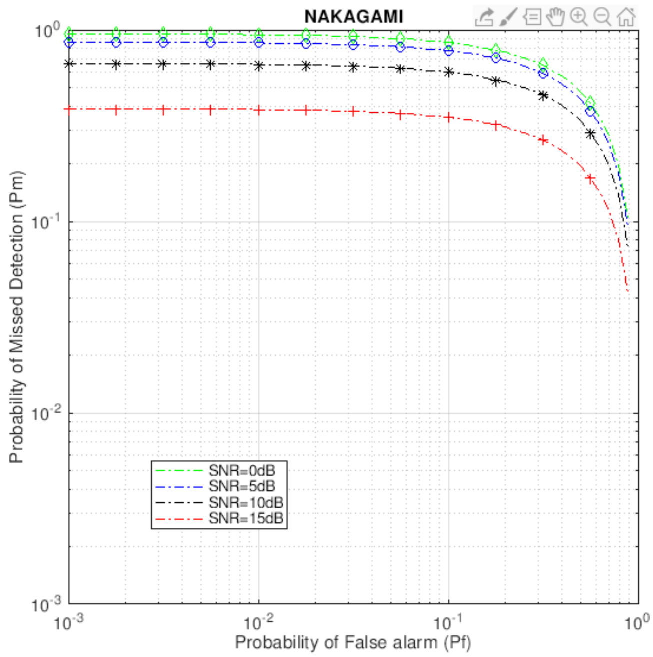

Figure 4:ROC curve for Nakagami

Next, the performance of an energy detector in a Nakagami channel is explored. This is as depicted in Figure 4..From this figure, we observe that the probability of miss detection (decreased detection performance) is very high over average SNR ($\bar{\gamma}$). Here Nakagami fading parameter m=10.We observe that spectrum sensing is harder in presence of Rayleigh and Nakagami fading and performance of energy detection degrades more in Nakagami channels than Rayleigh channels.

3. CONCLUSIONS

In this paper, we have discussed spectrum sensing ability based on energy detection in Cognitive Radio networks. ROC curves are used to plot the probability of detection versus the probability of false alarm. The probability of detection varies with different value of SNR, false alarm probability and various time bandwidth factors. SNR influences the detection probability, When SNR increases, the detection probability increases and at SNR=15dB detection probability is 1. Our analysis shows that the performance of the system is better for AWGN fading at SNR=15 db in comparison to the Rayleigh and Nakagami fading channel.Thus in Cognitive Radio Network, it is observed that with low computational complexities, detection of presence of primary user signal is easiest job by using Energy detection based Spectrum sensing technique. From comparative plot, it is clearly observed that, among various fading channels AWGN non fading channels gives more improvement in probability of detection than Rayleigh and Nakagami fading channels. In future, performance analysis can be done over other wireless fading channels like Rician, etc. Also, cooperative spectrum sensing method can be used to achieve still better sensing performance in detection of spectrum of Cognitive Radio.

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