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Performance Comparison of Energy Detection Based Spectrum Sensing for Cognitive Radio Networks

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Abstract:- With the rapid deployment of new wireless devices and applications, the last decade has witnessed a growing demand for wireless radio spectrum. However, the policy of fixed spectrum assignment produces a bottleneck for more efficient spectrum utilization, such that a great portion of the licensed spectrum is severely under-utilized. So the concept of cognitive radio was introduced to address this issue.The inefficient usage of the limited spectrum necessitates the development of dynamic spectrum access techniques, where users who have no spectrum licenses, also known as secondary users, are allowed to use the temporarily unused licensed spectrum. For this purpose we have to know the presence or absence of primary users for spectrum usage. So spectrums sensing is one of the major requirements of cognitive radio.Many spectrum sensing techniques have been developed to sense the presence or absence of a licensed user. This paper evaluates the performance of the energy detection based spectrum sensing technique in noisy and fading environments.The performance of the energy detection technique will be evaluated by use of Receiver Operating Characteristics (ROC) curves over additive white Gaussian noise (AWGN) and fading channels.

***Index Terms*:-** Cognitive Radio(CR), Spectrum Sensing, Energy Detection, Detection Probability(P_D),Probability of miss-detection(P_M) and Probability of false alarm(P_{FA})

I. INTRODUCTION

With the popularity of various wireless technologies and fixed spectrum allocation strategy, spectrum is becoming a major bottleneck, due to the fact that the most of the available spectrum has been allocated. Moreover, the increasing demand for new wireless services, especially multimedia applications, together with the growing number of wireless users and demand of high quality of services have resulted in overcrowding of the allocated spectrum bands, leading to significantly reduced levels of user satisfactionyet most of the spectrum are under-utilized This motivates a new paradigm of either through opportunistic spectrum sharing or through spectrum sharing for exploiting the spectrum

Resources in a dynamic way. Cognitive radio (CR) allows the secondary users (SUs) (lower priority) to share the licensed spectrum originally allocated to the primary users (PUs) (higher priority). In opportunistic spectrum access, the SU needs to sense the radio environment andidentify the temporally vacant spectrum. Moreover, energy detector is mainly used in ultra wideband communication to borrow an idle channel from licensed user [1] [2][3].The correctness of the spectral availability information is defined using sensing quality parameters i.e. probability of detection, (P_D), probability of false alarm, (P_{FA}) and probability of missed detection, (P_m) and illustrated by receiver operating characteristics(ROC) curves($P_D$vs. SNR) and complementary ROC curves(P_D vs. P_{FA}).

The rest of the paper is organized as follows. In Section II, channel model is described and we briefly describe the probabilities of detection and of false alarm over additive white Gaussian noise (AWGN) channel and fading channels. Our simulation results and discussions are presented in Section III. Finally we conclude in Section IV.

II. SYSTEM MODEL

Energy detection is a non-coherent detection method that is used to detect the licensed User signal. [2]. It is a simple method in which prior knowledge of primary or licensed user signal is not required, it is one of popular and easiest sensing technique of non-cooperative sensing in cognitive radio networks[4][5].For implementing the energy detector, 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 timeinterval T. Next, the output

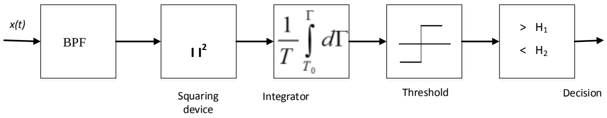

Figure 1: Block Diagram of Energy Detector

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. Figure 1 shows the block diagram of energy detector

Analytically, determining the sample signal x(t) is reduced to an identification problem, formalized as an hypothesis test; H_0 and H_1. H_0 implies an absence of the signal, whereas H_1 denotes presence of the signal.

This is represented by:

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

Where, *x (t)* is the sample to be analyzed at each instant *t*, *n(t)* is additive noise; assumed to be white Gaussian noise (AWGN) (with samples having zero-mean and variance σ^2), *h* is the complex channel gain between the primary signal transmitter and the detector and *s(t)* is the transmitted signal to be detected

A.Energy Detection and False alarm probabilities

A1. Over AWGN

In energy detection, the received signal is first pre-filtered by an ideal bandpass filter which has bandwidth W, and the output of this filter is then squared and integrated over a time interval $T$to produce the test statistic. The test statistic Y is compared with a predefined threshold value λ. The probabilities of false alarm (P_f) and detection (P_d)can be evaluated as $P_r(Y > \lambda|H_0)$a nd $P_r(Y > \lambda|H_1)$ respectively to yield:

$$P_f = \frac{\Gamma\left(\mu, \frac{\lambda}{2}\right)}{\Gamma(\mu)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$P_d = Q_\mu\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \dots\dots\dots\dots\dots\dots (3)$$

where u= WT, $\gamma$is SNR given as $E_s|h|^2/N_0$, E_s is the is the power budget at the primary user,$Q_\mu(.\,,\,.)$ is the μth order generalized Marcum-Qfunction, Γ(.) is the gamma function, and Γ(.,.) is the upper incomplete gamma function. Probability of false alarm P_f can easily be calculated using (3.4), because it does not depend on the statistics of the wireless channel. In the sequel, detection probability is focused. The generalized Marcum-Qfunction can be written as a circular contour integral within the contour radius r∈[0, 1). Therefore, expression can be re-written as [6]:

$$P_d = \frac{e^{\frac{-\lambda}{2}}}{j2\pi} \oint_\Omega \frac{e^{\left(\frac{1}{z}-1\right)\gamma + \frac{\lambda}{2}z}}{z^u(1-z)} dz \dots\dots\dots\dots\dots (4)$$

$M_\gamma(s) = E(e^{-s\gamma})$where Ω is a circular contour of radius r∈[0, 1). The moment generating function (MGF) of received SNR $\gamma$is, where E(.) means expectation. Thus, the average detection probability $\overline{P_d}$, is given by:

$$\overline{P_d} = \frac{e^{\frac{-\lambda}{2}}}{j2\pi} \oint_\Omega g(z)dz \dots\dots\dots\dots\dots\dots\dots (5)$$

Where

$$g(z) = M_\gamma\left(1 - \frac{1}{z}\right)\frac{e^{\frac{\lambda}{2}z}}{z^u(1-z)}$$

Since the Residue Theorem in complex analysis is a powerful tool to evaluate line integrals and or real integrals of functions over closed curves, it is applied for the integral in (5).

A2. Probability of Detection for Fading Environment

In this case, the average probability of detection $\overline{P_d}$ may be derived by averaging (3.4) over fading statistics,

$$\bar{P}_d = \int_0^\infty Q_u\left(\sqrt{2\gamma},\sqrt{\lambda}\right) f_\gamma(\gamma)\, d\gamma \ldots\ldots\ldots\ldots\ldots (6)$$

where, $f_\gamma(\gamma)$ is the PDF of SNR under fading. The expression for P_f given in (3.3) remains the same for fading case due to independency of γ. In the following subsequent sections, various statistical models of several fading channels such as Rayleigh, Nakagami-m, channels are studied.

A. Rayleigh Fading Channel

If the signal amplitude follows a Rayleigh distribution, then the SNR γ follows an exponential PDF given by [3]

$$f_\gamma(\gamma) = \frac{1}{\gamma} exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \; ; \; \gamma \geq 0 \ldots\ldots\ldots\ldots.. (7)$$

The average P_d in this case, $\bar{\mathrm{P}}_{\mathrm{d,Ray}}$ can be evaluated by substituting (7) in (6):

$$\bar{\mathrm{P}}_{\mathrm{d,Ray}} = \exp\left(-\frac{\lambda}{2}\right)\sum_{k=0}^{u-2}\frac{1}{k!}\left(\frac{\lambda}{2}\right)^{k} + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{u-1} \times \exp\left(-\frac{\lambda}{2(1+\bar{\gamma})}\right) - \exp\left(-\frac{\lambda}{2}\right) \times \sum_{k=0}^{u-2}\frac{1}{k!}\left(-\frac{\lambda\bar{\gamma}}{2(1+\bar{\gamma})}\right)^{k} \ldots\ldots\ldots\ldots (8)$$

B. Nakagami-m fading Channel

If the signal amplitude follows a Nakagami-m distribution, then PDF of γ follows a gamma PDF given by [6]

$$f_\gamma(\gamma) = \left(\frac{m}{\bar{\gamma}}\right)^{m}\frac{\gamma^{m-1}}{\Gamma(m)}\, exp\left(-\frac{m\gamma}{\bar{\gamma}}\right) \; ; \; \gamma \geq 0 \ldots\ldots\ldots\ldots\ldots (9)$$

where, m is the Nakagami parameter. The average P_d in the case of Nakagami-m fading channel $\bar{\mathrm{P}}_{\mathrm{d,Nak}}$ can be evaluated by substituting (9) in (6):

$$\bar{P}_{d,Nak} = \alpha\left[G_1 + \beta\sum_{n=1}^{u-1}\frac{\left(\frac{\lambda}{2}\right)^{n}}{2n!}F_1\left(m; n+1; \frac{\lambda\bar{\gamma}}{2(m+\bar{\gamma})}\right)\right] \ldots\ldots .10)$$

Where,

$$\alpha = \frac{1}{\Gamma(m)2^{m-1}}\left(\frac{m}{\bar{\gamma}}\right)^{m} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (11)$$

$$\beta = \Gamma(m)\left(\frac{2\bar{\gamma}}{m+\bar{\gamma}}\right)^{m}\exp\left(-\frac{\lambda}{2}\right) \ldots\ldots\ldots\ldots\ldots. (12)$$

$$G_1 = \frac{2^{m-1}(m-1)!\,\bar{\gamma}}{(m/\bar{\gamma})^{m}(m+\bar{\gamma})}\exp\left(-\frac{m\lambda}{2(m+\bar{\gamma})}\right) \times\left[\left(1+\frac{m}{\bar{\gamma}}\right)\left(\frac{m}{m+\bar{\gamma}}\right)^{m-1}L_{m-1}\left(-\frac{\lambda\bar{\gamma}}{2(m+\bar{\gamma})}\right) + \sum_{n=0}^{m-2}\left(\frac{m}{m+\bar{\gamma}}\right)^{n}L_n\left(-\frac{\lambda\bar{\gamma}}{2(m+\bar{\gamma})}\right)\right] \ldots\ldots\ldots\ldots\ldots (13)$$

where$L_n(.)$ is the Laguerre polynomial of degree n. We can obtain an alternative expression for $\bar{\mathrm{P}}_{\mathrm{d,Ray}}$ when setting m=1 in (13) and this expression is numerically equivalent to the one obtained in (8) [7].

III. SIMULATION AND RESULTS

In this section, through simulations, the capability of an energy detector applied to a secondary user for spectrum sensing is evaluated. All simulations in this work is executed using MATLAB version R2013b.The emphasis is to analyze the performance of energy based spectrum sensing techniques in different fading channel. The result is conducted on the basis of probability of false alarm and probability of detection under different SNR in different channels.

Effect of SNR on probability of detection P_D, in AWGN is observed over different values of P_{FA} is as shown in figure 2. It is observed that increase in false alarm increases the detection probability.

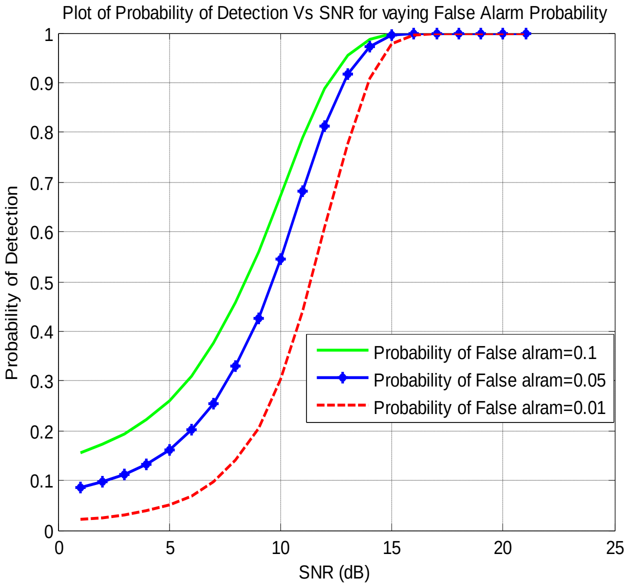

Figure 2: Probability of detection Vs SNR with varying Values of False Alarm Probability in AWGN

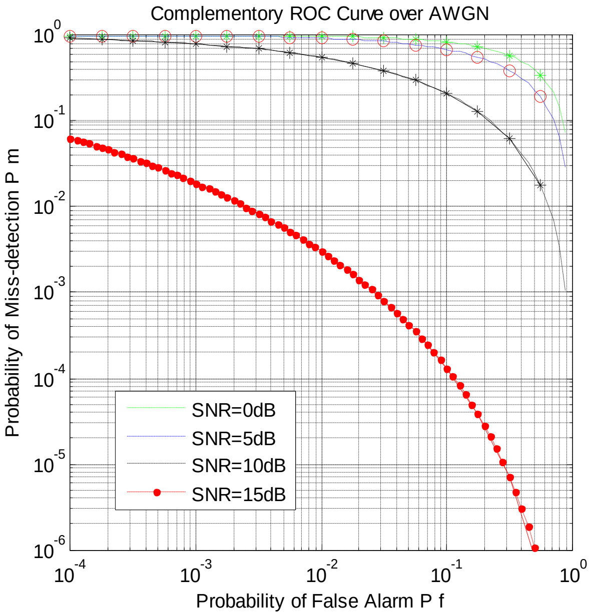

Figure 3: Complementary ROC Curve for Detection over AWGN

Figure 3 shows the complementary ROC curve for energy detection over a non-fading(AWGN) channel. Thisshows the relationship between the probability of missed detection P_M, andfalse alarm probability P_{FA}, for different values of SNR ranging from 0 to 15.

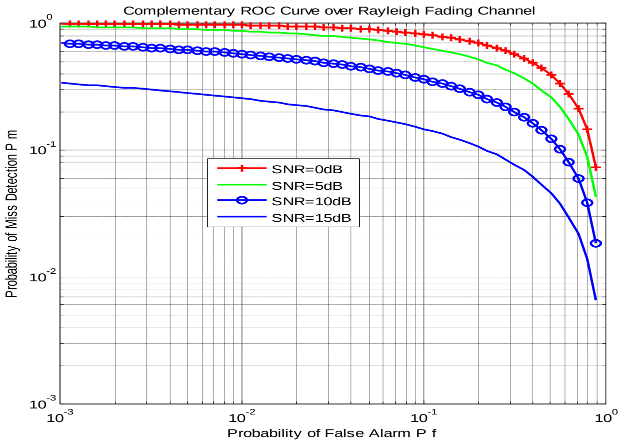

Figure 4: Complementary ROC curves for Energy Detection over Rayleigh fading Channel

Figure 4 is the complementary ROC curves over Reyleigh channel for different values of SNR (0-15 dB). From the plot of P_{FA} –P_M, it is seen that for a 5dB rise in SNR values, there is decrease in probability of miss detection i.e. increased probability of detection.It is apparent that energy detection executed over a Rayleigh channel exhibitsa tough detection performance, compared to that of AWGN. This is because, the fading severity is more in a Rayleigh channel compared to that AWGN.

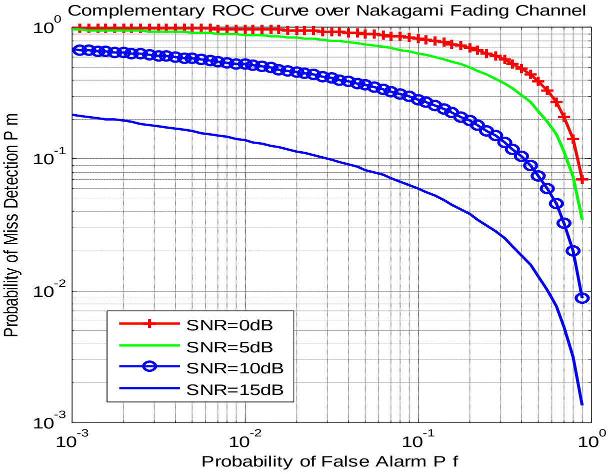

Figure 5: Complementary ROC curve for Nakagami fading channelfor different values of SNR

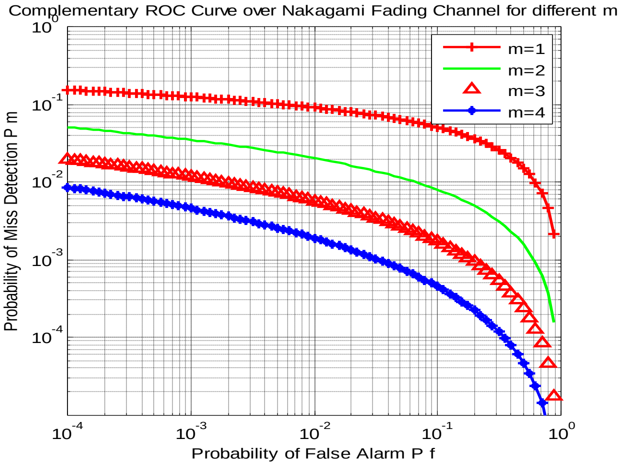

Figure 6: Complementary ROC curve for Nakagami fading channel for Different value of fading index(m).

Figure 6 shows the plot for different values of fading parameter index (m). As the value of fading parameter index increases, the fading severity decreases and vice-versa. So as the fading parameter index increases, better performance is achieved. So we can say greater performance is achieved in Nakagami with compared to Rayleigh fading channel.

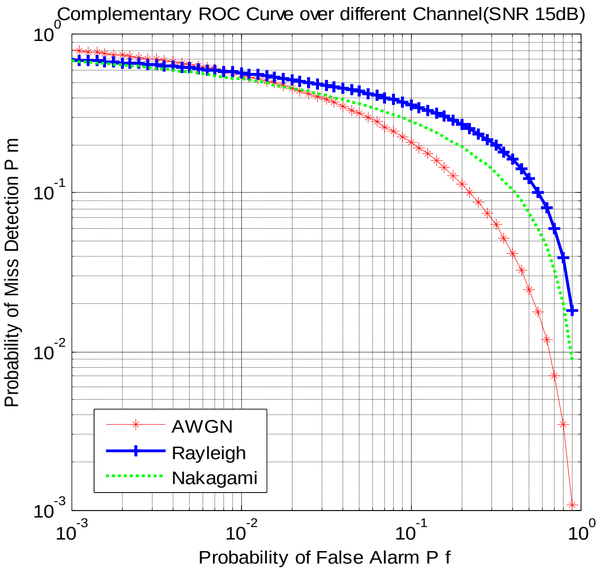

Figure 7: CROC curves for performance Comparism over different Channels

Figure 7 and 8 are the plots of Complementary ROC curves for different channels for different values of SNR (10dB and 20dB).As it is obious that AWGN performs the best as it is an ideal channel. Beside this, the performance of Nakagami fading channel is found to be better than the Rayleigh fading channel. As already discussed, Rayleigh fading channel is thought to be a type of a Nakagami fading channel for the value of the fading index equal to one and the fading severity decreases with the increase in fading index. From this plot, there is approximately an increase of roughly one order of magnitude from the P_M perspective compared with the Rayleigh case (SNR=10dB) and an increase of more than one order for the case with SNR equal to 15dB

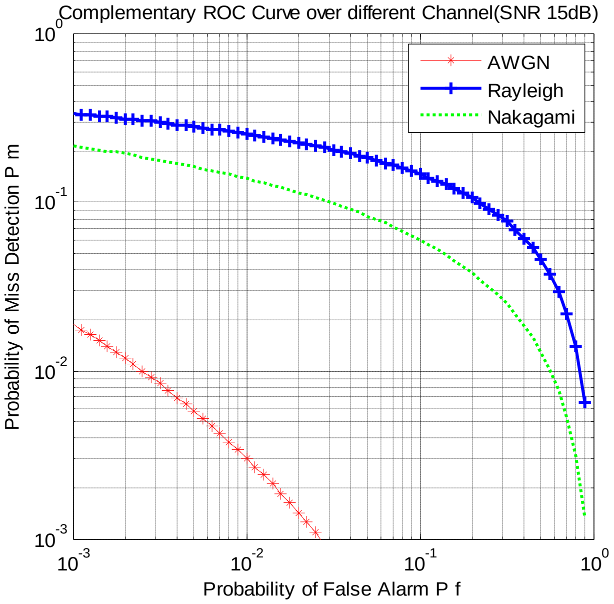

Figure 8: CROC curves for performance comparison over different channels (15dB)

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