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Performance Analysis of Energy Detection Technique for Cognitive Radio Over Different Fading Channels

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Abstract: The rapid growth in wireless communication systems has made the problem of under utilization of spectrum. To solve this problem the concept of cognitive radio (CR) emerged, the main goal of which is to provide adaptability to wireless transmission through dynamic spectrum access (DSA) so that the utilization of the frequency spectrum can be enhanced without losing the benefits associated with spectrum allocation. To sense existence of licensed user, Energy Detection based spectrum sensing technique is used over different wireless fading channels. In the energy detection approach, the radio-frequency (RF) energy in the channel or the received signal strength indicator is measured to determine whether the channel is idle or not. This paper gives the primitive study and performance analysis of energy detection based spectrum sensing technique. Performance is done under three different fading channels i.e. Rayleigh, Nakagami and Rician. Probability of detection and Probability of missed detection vs. probability of false alarm for all different channels has been calculated and also simulation comparison among different wireless fading channels is presented.

Keywords: Cognitive Radio , Energy Detection, Fading Channels, Spectrum Sensing, Pd, Pfa, Pmd, nakagami,rayleigh, rician.

I. INTRODUCTION

The available radio spectrum is limited and it is getting crowded day by day as there is increase in the number of wireless devices and applications. In the studies it has been found that the allocated radio spectrum is underutilized and the approach of radio spectrum management is not flexible, . In the present scenario, it has been found out that these allocated radio spectrums are free most of the time i.e. they are inefficiently used depending upon the geographical area. The average utilization of the spectrum is low as illustrated in Figure 1 [3], [4]. And this underutilization is due to the fact that a licensed user may not fully utilize the spectrum at all times in all locations.

The issue of spectrum underutilization in wireless communication can be solved in a better way using Cognitive Radio. After Mitola coined the word "Cognitive radio" its definition is also growing as research interest in CR is increasing. According to Mitola [5], CR is defined 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: (a) detect user communications needs as a function of use context, and (b) to provide radio resources and wireless services most appropriate to those needs.

However the concept of CR is not limited strictly to wireless devices such as PDAs. Simon Haykin defines Cognitive Radio, it as follows [6]: "Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- highly reliable communications whenever and wherever needed;
- efficient utilization of the radio spectrum

Cognitive Radio (CR) is a promising technique to mitigate the scarcity of spectrum by sensing the spectrum, detecting the unused licensed bands, and efficiently utilizing these under-utilized bands. Energy detection is the most popular spectrum sensing method since it is simple to implement and does not require any prior information about the primary signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor.

The performance of energy detector is analyzed using ROC (Receiver operating characteristics) curves Energy detector performance can be expressed with two parameters: detection probability and false alarm probability [7 –11]. First parameter affects the radio system's interference level and the second the cognitive network spectral efficiency.

This paper gives the expressions for probability of detection for various channel and simulation comparison among different wireless fading channels like Rayleigh, Nakagami and Rician channel. The results show that probability of detection is improved in all fading channels and Nakagami-m fading channels gives more improved performance than other fading channels by using Energy Detection Spectrum Sensing Technique.

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This paper is further organized as: Section II energy detection based spectrum sensing concept. Section III shows performance metrics under different fading channel. Section IV represents simulation results and tables for comparison and conclusion is given in section V.

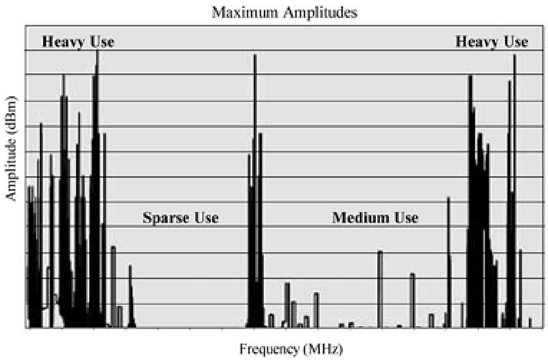

Fig. 1 Spectrum Under Utilization

II. ENERGY DETECTION BASED SPECTRUM SENSING

This section provides a survey of the energy detection scheme to analyze how the probability of detection and probability of false alarm.

A. *System model*

Energy detector is the most popular way of spectrum sensing because of its low computational and implementation complexities. The receivers do not need any knowledge about the primary users. An energy detector (ED) simply 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.

The received signal contains two binary hypothesis-testing dilemmas [12]:

H0: Primary user is absent.

H1: Primary user in operation.

The probability of correct detection P_d, probability of false alarm P_{fa} and probability of missed detection P_{md} are the key metric in spectrum sensing, given respectively as:

P_d = Prob.{Decision = H1/H1} …..(1)

P_{fa} = Prob.{Decision = H0/H0} …..(2)

P_{md} = Prob.{Decision = H0/H1} ….(3)

B. *Energy Detection*

Energy detection represent the most popular spectrum sensing schemes, its objective is to determine whether H0 or H1 is true; this is achieved by sensing the energy of signal [13][14].

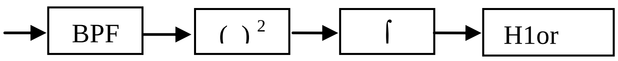

Fig. 2 Energy Detector block diagram

The process flow of the energy detector is given in fig. 2, the received signal is passed through the filter followed by ADC then squared those values and average over the observation interval. Then the output of the detector is compared to a pre defined threshold value to decide whether the primary user is present or not. Output is considered as the test statistic to test the two hypotheses H0 and H1.

Hypothesis test can be performed as [14]

$$\begin{cases} y(k) = n(k) \ldots\ldots\ldots\ldots H0 \\ y(k) = h*s(k) + n(k) \ldots\ldots H1 \end{cases} \quad \text{-------- (4)}$$

Final output is obtained as

$$Z = \frac{1}{N}\sum_{j=1}^{N} |y_j(t)|^2 \quad \text{-------------- (5)}$$

Thus, based on the central limit theorem, when N is large enough, the value of Z approximates Gaussian distribution

III. DECISION STATISTICS

In this section average detection probability for AWGN, Rayleigh, Rician and nakagami fading channels are given.

A. *AWGN Channel*

Additive white Gaussian noise (AWGN) is a basic noise model in communication channels, which defines linear addition of wide-band or white noise and Gaussian distribution of amplitude. How-ever multipath propagation, signal fading, scattering, nonlinearity or dispersion does not account for this channel. In this the probability of detection and may be given by,

$$P_{dj} = P(Z_i > \mu_{i|H_1}) = \int Q_m(\sqrt{2\delta_i}, \sqrt{\mu_i}) f_\gamma(x) d(x) \quad \text{------ (6)}$$

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

B. *Rayleigh Channel*

Rayleigh fading is the specialized model for random fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalized concept of rician fading. In Rayleigh fading, the amplitude gain is characterized by a Rayleigh distribution. An assumption made in Rayleigh fading channel is that the propagating signals vary its amplitude randomly over the channel. There is no line of sight component in faded signal. Under Rayleigh fading γ have an exponential distribution given by,

$$f(\gamma) = \frac{1}{\gamma}\exp\left(-\frac{\gamma}{\gamma}\right), \gamma \geq 0 \quad \text{------- (7)}$$

Probability of detection is obtained in this case as,

$$P_{dj} = P(Z_i > \mu_{i|H_1}) = \int Q_m(\sqrt{2\delta_i}, \sqrt{\mu_i}) f_\gamma(x) d(x) \quad \text{------ (8)}$$

C. *Nakagami Channel*

Nakagami has introduced the Nakagami distribution to characterize fast fading in long distance HF channels in the early 1940's [9][15]. It is also known as *Gamma Distribution Function*. To fit empirical data the Nakagami distribution was selected, and it provide some close match

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to some experimental data than the Rayleigh distributions. If Nakagami distribution is followed by the signal amplitude, then the PDF of gamma given by,

$$f(\gamma) = \frac{1}{\tau(m)} \left(\frac{m}{\bar{\gamma}}\right)^m \gamma^{m-1} \,\mathrm{EXP}\left(-\frac{m}{\bar{\gamma}}\gamma\right), \gamma \geq 0 \quad \text{----(9)}$$

Here, m is the Nakagami parameter. The probability of detection for Nakagami channel is given by,

$$P_{dNak} = \alpha\left[G_1 + \beta \sum_{n=0}^{N-1} \frac{\lambda/2}{2(n!)} F_1\left(m; n+1; \frac{\lambda}{2}\frac{\bar{\gamma}}{m+\bar{\gamma}}\right)\right] \quad \text{------- (10)}$$

Where F1 (.;.;.) is the confluent hyper geometric function and

$$\alpha = \frac{1}{\tau(m)2^{m-1}} \left(\frac{m}{\bar{\gamma}}\right)^m \quad \text{---------- (11)}$$

$$\beta = \tau(m)\left(\frac{2\bar{\gamma}}{m+\bar{\gamma}}\right) e^{-\lambda/2} \quad \text{----------- (12)}$$

D. *Rician Channel*

Rician fading of propagated signal is a random model for radio propagation caused by partial cancellation of a radio signal. In rician fading channel a strong dominant component is present. This dominant component can be the line-of-sight wave. In Rician fading, the amplitude gain is characterized by a Rician distribution. In Rician fading channels, chi-square distribution with two degree of freedom given by

$$f(\gamma_n) = \frac{k_{n+1}}{\bar{\gamma}_n} exp\left\{-k_n - \frac{(k_n+1)\gamma_n}{\bar{\gamma}_n}\right\} \times I_0\left(2\sqrt{\frac{k_{n(k_n+1)\gamma_n}}{\bar{\gamma}_n}}\right), \ \gamma_n > 0 \quad ---(13)$$

Where, k_n is the Rician factor for the n-th channel. With distinct$\bar{\gamma}_n$, SNRis given as

$$\gamma = \sum_{n=1}^{N} \gamma_n \quad \text{------- (14)}$$

We get the average detection probability as

$$\bar{P}_{d\_Ric} = Q\left(\sqrt{\frac{2k\bar{\gamma}}{k+1+\bar{\gamma}}}, \sqrt{\frac{\lambda(k+1)}{k+1+\bar{\gamma}}}\right) \quad \text{-------- (15)}$$

IV. SIMULATION RESULTS

MATLAB simulation is done under different fading channel. The receiver operating characteristic (ROC) curves P_{md} Vs P_{fa} of the energy detection for fading channels are plotted in fig. 3-6 for different SNR values. The key measurement metrics that are used to analyze the performance of spectrum sensing techniques are detection probability (P_d), False alarm probability (P_{fa}) and missed detection probability (P_{md} = 1 - P_d) .

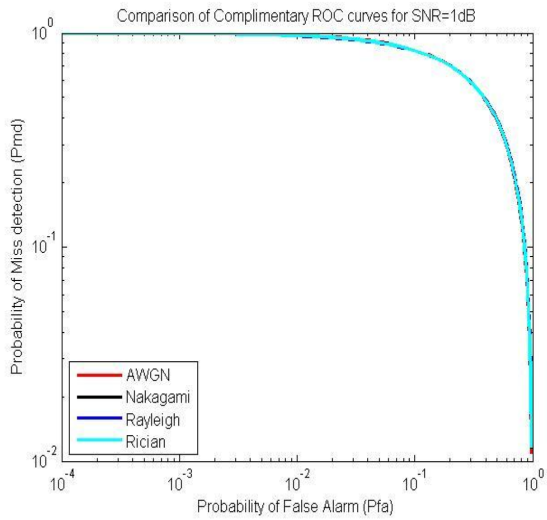

Fig. 3 Comparison of Complimentary ROC curves for SNR=1 dB

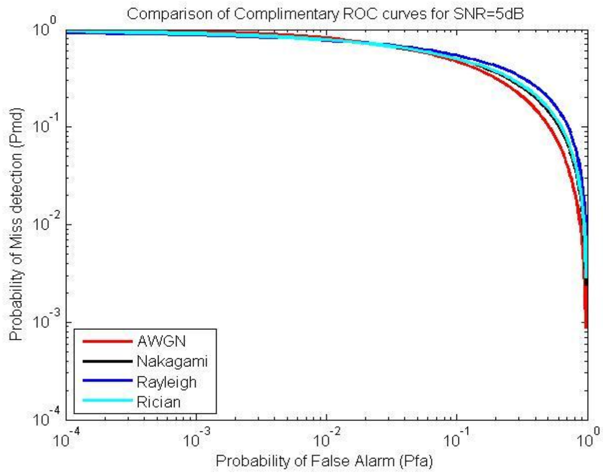

Fig. 4 Comparison of Complimentary ROC curves for SNR=5 dB

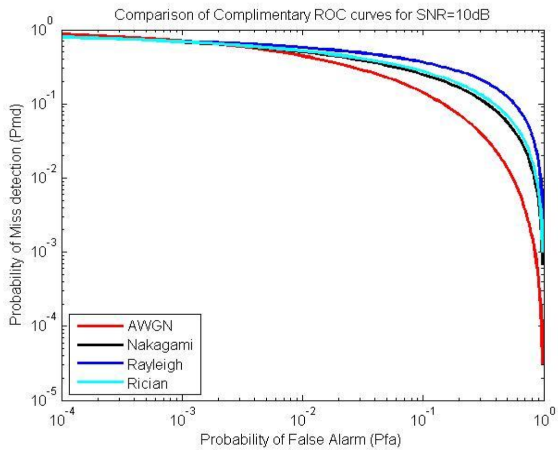

Fig. 5 Comparison of Complimentary ROC curves for SNR=10 dB

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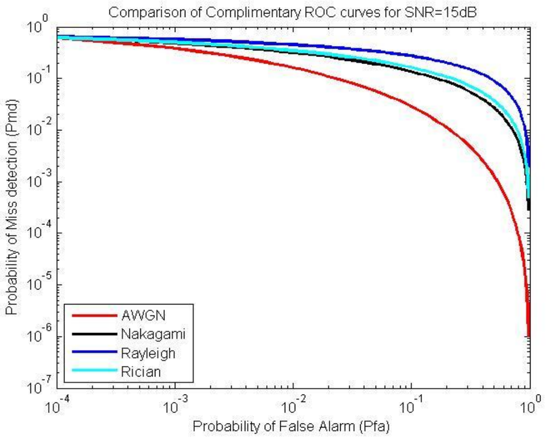

Fig.6 Comparison of Complimentary ROC curves for SNR=15 dB

Table I-IV below gives the Comparison of probability of missed detection verses probability of false alarm when signal to noise ratio is varying over different wireless fading channels like Rayleigh, Nakagami and Rician. It can be seen that as values of P_{fa} increases; there is drastic decrease in P_{md}. Similarly, as values of SNR are varying there is still decrease in values of P_{md}.

TABLE I COMPARISON OF P_{md} VS P_{fa} WHEN SNR IS VARYING OVER AWGN CHANNEL

Value of Pfa	Probability of missed detection(AWGN)			
	SNR=1 dB	**SNR=10 dB**	**SNR=15dB**	**SNR=20 dB**
1.0e-4	0.9995	0.9850	0.8684	0.6018
0.0625	0.8842	0.5581	0.1963	0.0445
0.2500	0.6408	0.2599	0.0526	0.0074
0.5625	0.0800	0.0093	0.0080	0.0033

TABLE II COMPARISON OF P_{md} VS P_{fa} WHEN SNR IS VARYING OVER RAYLEIGH CHANNEL

Value of Pfa	Probability of missed detection(Rayleigh)			
	SNR=1 dB	**SNR=10d B**	**SNR=15 dB**	**SNR=20dB**
1.0e-4	0.999	0.9344	0.7819	0.6521
0.0625	0.8778	0.6064	0.4161	0.3144
0.2500	0.6426	0.3723	0.2384	0.1747
0.5625	0.3371	0.1676	0.1019	0.0731

TABLE III COMPARISON OF P_{md} VS P_{fa} WHEN SNR IS VARYING OVER NAKAGAMI CHANNEL

Value of Pfa	Probability of missed detection(Nakagami)			
	SNR=1d B	**SNR=10 dB**	**SNR=15dB**	**SNR=20 dB**
1.0e-4	0.999	0.9655	0.8060	0.6127
0.0625	0.8818	0.5729	0.3046	0.172
0.2500	0.6410	0.3082	0.1349	0.0687
0.5625	0.3305	0.1178	0.0438	0.0205

TABLE IV COMPARISON OF P_{md} VS P_{fa} WHEN SNR IS VARYING OVER RICIAN CHANNEL

Value of Pfa	Probability of missed detection(Rician)			
	SNR=1 dB	**SNR=1 0dB**	**SNR=1 5dB**	**SNR=20 dB**
1.0e-4	0.9993	0.9595	0.7978	0.6193
0.062 5	0.8810	0.5783	0.3276	0.2011
0.250 0	0.6412	0.3204	0.1551	0.0879
0.562 5	0.3316	0.1273	0.05418	0.0289

V. CONCLUSION

Energy detector based approach is the most common way of spectrum sensing because of its low computational and implementation complexities. It is observed that Energy detection performs best in AWGN channel as compared to other channels. But when the noise power is greater than signal-to-noise ratio (SNR) then the Energy Detection cannot work accurately. The performance of energy detection over different fading channels is investigated. Among all these fading channels (Rayleigh, Rician, Nakagami) it is observed that the detection probability performance of Nakagami fading channel is better under fading conditions.

The probability of detection varies based on SNR, false alarm probability and various time bandwidth factors. When SNR increases, the detection probability increases. The false alarm probability also effects on detection probability. If false alarm increases, the detection probability increases. Thus, it improves performance of energy detector at low SNR values. 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.

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