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# Narrowband Spectrum Sensing for Different Fading Channels for Cognitive Radio Networks

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***Abstract***: *Nowadays the demand of applications of wireless communication has increased rapidly which causes the scarcity of radio spectrum. To empower future wireless communication services, the radio spectrum management is a very important factor. Cognitiveradio is a promising technology which provides an innovative way to improve utilization efficiency of available electromagnetic spectrum by sensing spectrum and shares it without harmful interference to other users. Narrowband spectrum sensing is the technique where the bandwidth of active primary transmitter in the vicinity of cognitive radio is less than the coherence bandwidth of channel. Fading is one of the greatest impairment of narrowband spectrum sensing. It is deflection of the attenuation. It influences a signal over certain propagation media.A communication channel that experiences fading isknown as fading channel. The effects of fading can be reduced by several fading models. In this paper, performanceanalysis of several realistic fading models on narrowband channel using energy detection method is employed. Finally, performance comparison of various fading models is guaranteed through simulation.*
***Keywords:***cognitive radio, narrowband spectrum sensing, fading models.

## I. INTROEDUCTION

The CR wireless network is intended as an advanced technology integration environment with a motivation on making adaptive, spectrum efficient systems with emerging programmable radios.Wireless communication phenomena are mainly due to scattering of electromagnetic waves from surfaces or diffraction over and around buildings[1]. The communication channels are required to design such a way that make the received power sufficient to overcome background noise over each link.Minimization of interference to other more distant links operating at the same frequency is also required. Each transmitted signal cross a different path to reach to receiver due to presence of reflection in the environment. The sight of reflector causes multiple path and during traveling each signal on each path will go through different delay,attenuation and phase shift which causes constructive and destructive fading. Fading channel models are frequently used to image the effects of electromagnetic transmission of information. The narrowband channels are called flat fading channel as the coherence bandwidth of the channel is greater than the bandwidth of the signal. Rayleigh, Rician and Nakagami fading models are used to reduce the fading of these channels.

In this paper, narrowband spectrum sensing for different fading models are considered. First we use BPSK modulated signal. Then observe the probability of detection($P_d$) and probability of false alarm($P_f$) over Rayleigh fading channel. Then we apply Rician fading channel. At last we observed the performance of Nakagami fading channel. We calculate their energy and compare the energy value with a threshold value. We also observe their receiver operating characteristics(ROC) curve and complementary receiver operating characteristics (CROC) curve. We observe their performance by their ROC and CROC curve. Finally we compare Rayleigh, RicianandNakagamifading channel depending on their performance.The remainder of this paper is arranged as follows. Different fading models are described in Section 2. System model is described in Section 3. In Section 4 thesimulation results. The conclusion is described in Section 5.

## II. DIFFERENT FADING MODELS

### A. Rayleigh Fading Model

For a large number of path, the impulse response can be modeled as zero mean complex-valued Gaussian process to model fading channel [2]. This channel is known as Rayleigh fading channel. It is best suited for flat fading signal and can be figured from sum of two Gaussian noise signals. It is used in urban areas where there are no line of sight (LOS) components.When the baseband components of $h(t)$ are independent the probabilitydensity function(PDF) of the amplitude $r = |h| = \alpha$ assumes Rayleigh PDF [1]:

$$f(r) = \frac{r}{\sigma^2} e^{(-\frac{r}{2\sigma^2})} \quad (1)$$

where $2\sigma^2 = E\{r^2\}$ and $r \geq 0$. The PDF is independent of amplitude. It is the most commonly used model. To construct a multipath Rayleigh fading channel four parameters should be specified and they are: a) sample time of input signal, b)maximum Doppler shift, c) path delay and d) average path gain. Path delay and average path gain should be of same length.

### B. Rician Fading Model

Rician fading is comparable to Rayleigh except for the phenomenon that there will present strong dominant component. It can be figured using two Gaussian components of one with zero mean and other with non-zero mean. It is best suited in sub-urban areas. The baseband signal for Rician channel

$$h = \alpha e^{j\emptyset} + v e^{j\theta} \quad (2)$$

where$\alpha$follows the Rayleigh distribution and$v^2$ depicts the power of line of sight component.$\emptyset$and$\theta$are mutually independent and uniform and their limit is in [-π,π]. The PDF of Rician fading [1],

$$f(r) = \frac{r^2}{\alpha^2} e^{\left(-\frac{r^2+v^2}{2\alpha^2}\right)} I_0\left(\frac{rv}{\alpha^2}\right) and r \geq 0 \quad (3)$$

where $E\{\alpha^2\} = 2\alpha^2$ and $I_0$ is the Bessel function of order zero. The relation between the power of Rician component and Rayleigh component can be explained by rice factor which is denoted by,

$$K = \frac{v^2}{2\sigma^2} \quad (4)$$

Rician distribution acquit like Rayleigh component if $v = 0$

### C. Nakagami Fading Model

The Nakagami-*m* distribution is considered as one of themost important models among all the statistical ones that have been proposed to characterize the fading envelopedue to multipath fading in wireless communications [3]. It is applicable for empirical fading data. It is used to model signal for excessive to temperate fading case by properly setting the value of Nakagami parameter m. If the signal amplitude follows a Nakagamidistribution,then the PDF of r follows a gamma distribution [4]. The Nakagami PDF from [1],

$$f(r) = \frac{2}{\Gamma(\mathrm{m})} \left(\frac{m}{2\sigma^2}\right)^m r^{2m-1} e^{(-\frac{mr^2}{2\sigma^2})} and r \geq 0 \quad (5)$$

where $2\sigma^2 = E\{r^2\}$and$\Gamma(\cdot)$denotes the gamma function.

## III. SYSTEM MODEL

In this paper, we proposed a method for narrowband spectrum sensing technique for a BPSK modulated signal over different fading models using energy detection scheme. We observe the performance by analyzing their ROC and CROC curve. In this section we will describe the proposed method and some important terms of the proposed method.

**The proposed method is described following:**

This thesis work is based on the method that a signal is added with noise and model with fading models for energy detection method and observation of the performance of these fading models for energy detection method is performed. For the evaluation of the proposed method first a narrowband signal is modulated by BPSK modulation method then it is model with the fading models and added with noise. Then it is applied to energy detector and at last the performance is measured by their ROC curves for energy detection method. The evaluation process is described by following block diagram.

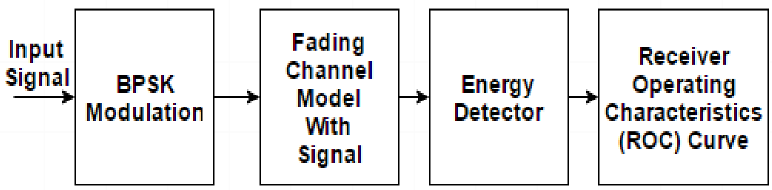


**Fig. 1.**Block diagram of proposed method evaluation

### A. Energy Detection Method

The fundamental scheme for spectrum sensing is based on energy detection where specific time or frequency interval is used to measure the received signal energy. Thistechnique is also a prime choice due to its low computational and implementation complexities. In addition, in this detection scheme receivers do not require any knowledgeabout the primary users(PUs) signal.Energy detector is non-coherent detector[4]. The signal is detected by analogizing the output of the energydetector with a threshold which depends on the noise. For the evaluation of the energy of a signal first the signal should be passed through a band pass filter. For evaluating power the signal should be squared by a squaring device and the integrator integrates all the signal power and evaluates the energy. At last the energy is compared with a predefined threshold value to detect the presence or absence of the primary user. The whole process is described the block diagram in Fig. 2.

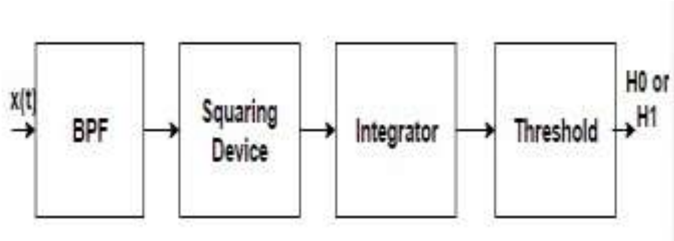


**Fig. 2**. Block diagram of energy detector

Herex(t)= received signal, $H_0$= absence of primary user, $H_1$= presence of primary user. This technique is the optimal solution when PUs transmission is unknown. A major drawback is that it has poor detection performanceunder low signal to noiseratio (SNR)scenarios [5]-[6].

**B. BPSK Modulation Technique**

The data stream is encoded using non return to zero NRZ encoding. In NRZ encoding the first thing is to keep the binary signal's amplitude of 1, where it has value on and replace value of 0 with -1. Secondly, the number of elements of binary signal is up sampled by repeating the number of 1s and number of -1s to make the size of matrix equal to the size of carrier wave over the specific time. Afterwards, the NRZ encoded data is multiplied by a carrier wave.

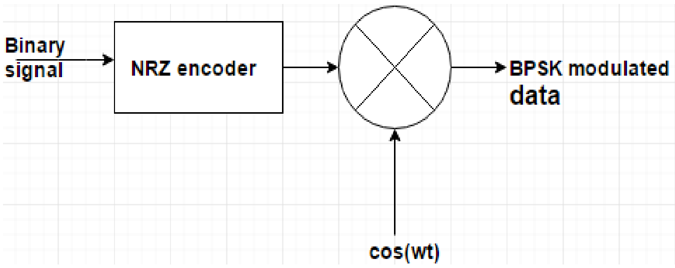


**Fig. 3**. Block diagram of BPSK modulation

In BPSK, a carrier sinusoidal wave with center frequency$f_c$is generated and multiplied by the NRZ encoded binary signal. This part of model can be implemented physically by using simple multiplier circuitry.

**C. Receiver Operating Characteristics (ROC)Curve**

The receiver-operating characteristic (ROC) curve is a basic plot in signal detection theory. They are advantageous in that sense that all phase of signal detection theory can be represented in one graph. The curve results in plotting the true positive rate against the false positive rate at various thresholds. For this process, we have used Monte-Carlo simulation. The process is described by the following figure.

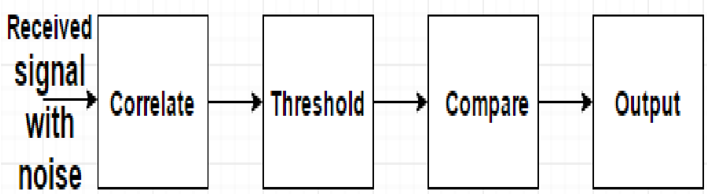


**Fig. 4.** ROC curve simulation process

## IV. SIMULATIONS

In this section we evaluate the performance of the proposed scheme. The characteristics of three fading models Rayleigh, Rician and Nakagami are observed. First their individual performance is observed. Finally their performance is compared.

Fig. 5 depicts the probability of detection and the probability of false alarm under Rayleigh channel for 60000 Monte Carlo simulation. The value of sample frequency of input signal was set 100000 and maximum Doppler shift was set 130. The value of path delay and average path gain was of same vector length. From the transmitter modulated signals BPSK with different SNR values are passed through the AWGN and Rayleigh noise. The Rayleigh noise was zero mean signal. Noise is added with the signalthrough the transmission path. When the signal reached at the detector the energy of received signal has been calculated. Then the calculated value has been compared with a threshold value. In this case Inverse Gamma function has been used. The estimated signal power is compared with the threshold values. The values of the signalpower that are large enough to exceedthe threshold are considered as actual signal. This means the detector successfully detects the signal. A ROC curve is plottedwith the value of $P_f$ and $P_d$. Different ROC curve is obtained for different SNR values.From the figure it can be noticed that at first when the threshold value is high both the value of $P_d$and $P_f$ is small, $P_f$ ismuch small compared to $P_d$. The threshold value decreases gradually at the same timethe value of $P_f$ and $P_d$ is increasing. It happens because at high threshold signal withhigh amplitude values exceed the threshold and can be detected. Signals with lowamplitudes cannot be detected due to high threshold. As a result only a few signalswith high amplitudes are detected. Again Due to high threshold weak signals or signals with low amplitudes cannot exceedthe threshold levels and they are considered as noise. As a result probability of considering the noise as signal also decreased. So $P_f$ and $P_d$ both are low at high threshold. But with decreasing value of threshold both of them are increasing. From the figure it can also be seen that with low value of SNR the probability of detection lower but the performance increases with increasing value of SNR.

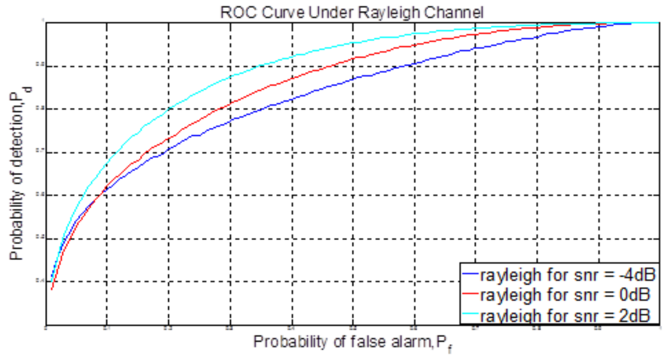


**Fig. 5**. ROC curve for BPSK signal for Probability of false alarm vs probability of detection under Rayleigh channel

The probabaility of detection and false alarm under Rician channel is illustrated in Fig. 6 for 60000 Monte-Carlo simulation. The Rician noise was a summation of zero mean and a non zero mean signal and the value of sample frequency and maximum doppler shift was set 100000 and 130 and the value of rice factor K=2 was set. With the incresing value of $P_f$ the value of $P_d$ also increases which means if the high probability of false alarm is tolerable the the probability of detection would be high. Again the probability of detection for for higher value of SNR outperforms the result for low SNR as expected.

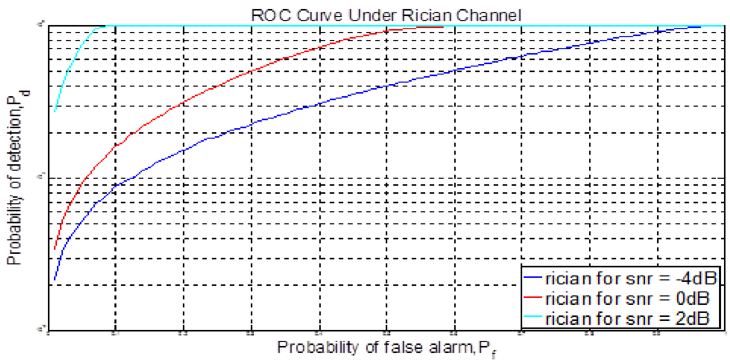


**Fig. 6.** Probability of false alarm vs probability of detection under Rician channel for different value of SNR

Fig. 7 illustrates the probability of false alarm vs probility of detection under Nakagami channel for different value of SNR. The Nakagami parameter m was set 2. From the figure it can be noticed that with low value of $P_f$, $P_d$ reach the highest value and with increasing more $P_f$, $P_d$ becomes saturated for SNR 2dB. As per earlier discussion the higher value of SNR outperforms the lower value of SNR.

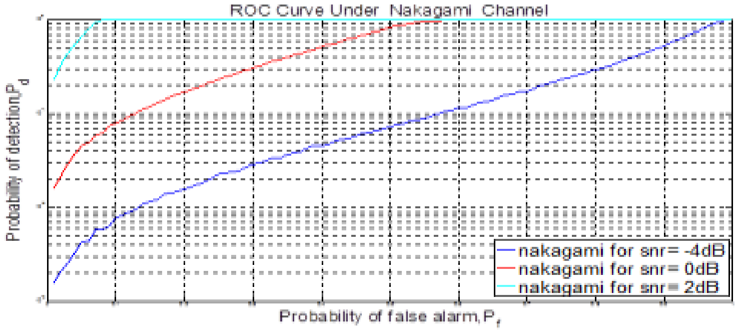


**Fig. 7**. Probability of false alarm vs probability of detection under Nakagami channel.

Fig. 8 depicts the comparison of Rayleigh, Rician and Nakagami channel for the probability of detection and the probability of false alarm for different SNR value. From the figure it can be noticed that the performance of Rayleigh channel is better than Rician and Nakagami channel for lower value of SNR For higher SNR (2dB) the performance of Rician and Nakagami outperforms Rayleigh.

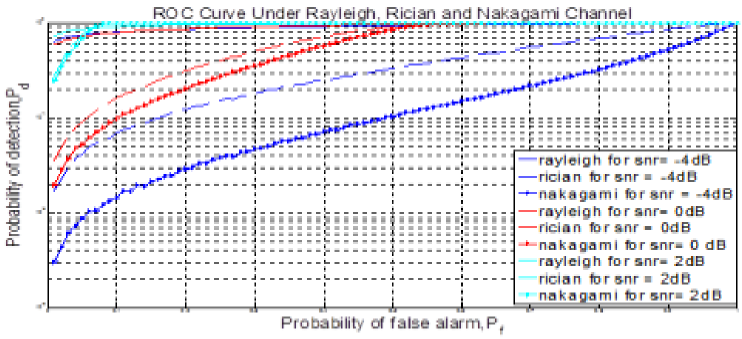


**Fig. 8.** Comparison of ROC curves of Rayleigh , Rician and Nakagami channel for different value of SNR.

Fig. 9 illustrates the probability of false alarm versus probability of misdetection for energydetection method under Rayleigh channel. We can observe that at high threshold $P_m$ is high but $P_f$ is low. At high threshold only signals with high amplitudes can exceed the threshold and considered as signal, those cannot exceed the threshold are considered as noise. Due to high SNR, Signal with low amplitudes can be easily misdirected. So $P_m$ remains high for high threshold. For the same reason the probability of mistakenly considering the noise as signal also reduces. So $P_f$ is low. As the threshold decreases more signal pass through the threshold and so the probability of unable to detect the presence of a signal though the signal is present is reduced. In the meantime as more signalscross the threshold, noise might exceed the threshold and considered as signal, so $P_f$ increases. Therefore, Pf and $P_m$ are inverse to each other. When $P_m$ increases $P_f$ decreases.From the figure it can also be observed that for lower value of SNR the performance ofRayleigh model is better with increasing value of $P_f$ . As the value of SNR increases the performance increases.

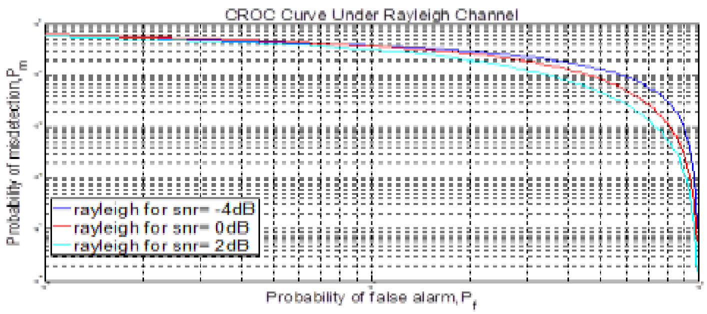


**Fig. 9**Probability of false alarm vs probability of misdetection under Rayleigh channel

With low value of SNR the Rician model shows low performance. For SNR 0dB the performanceincreases than for -4dB. But when the value of SNR increases more say 2dB the performance changes rapidly with increasing value of probability of false alarm. The performance of Ricianfading channel considering the probability of misdetection and false alarm is shown in Fig. 10.

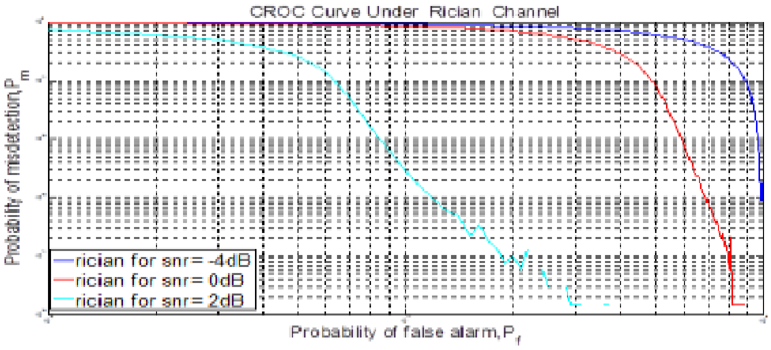


**Fig.10.**Probability of false alarm vs probability of misdetection under Rician channel.

The probability of false alarm vs probability of misdetection under Nakagami fading model for energy detection method is shown in Fig. 11. From the figure it can be observed that whenthe value of false alarm is lower the value of misdetection is higher. As the probability of false alarm increases, the probability mistakenly detection of presence of primary user decreases. It is also noticed that for higher value of SNR the performance of Nakagami channel is higher than that of lower value of SNR.

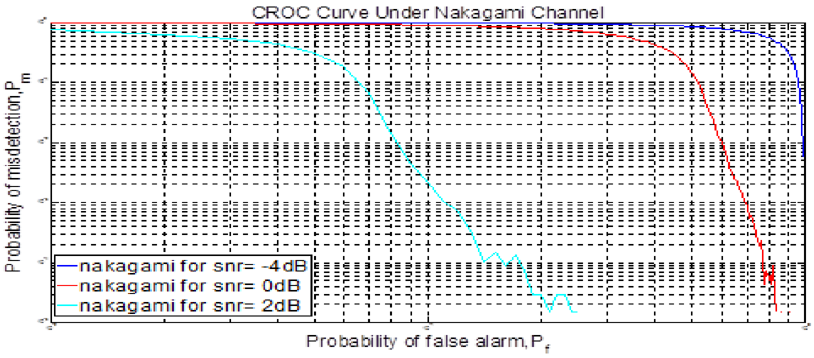


**Fig. 11**. Probability of false alarm vs probability of misdetection under Nakagami channel

The comparison of Rayleigh, Rician and Nakagami channel considering the probability of misdetectionagainst probability of false alarm is shown in Fig. 12. Comparing these channelmodels it can be noticed that Rayleigh model shows lower possibility of misdetection for -4dB than Rician and Nakagami channel. But for higher value of SNR the performance of Rayleigh model degrades.Again comparing the Rician and Nakagami channel it is noticed that the Rician channel model works better in lower SNR but in higher value of SNR Nakagami channel shows slightly better result than Rician model.So it can be concluded that Rician and Nakagami channel models are better than Rayleigh model and Nakagami model is better than both the models in higher value of SNR for energy detection method.

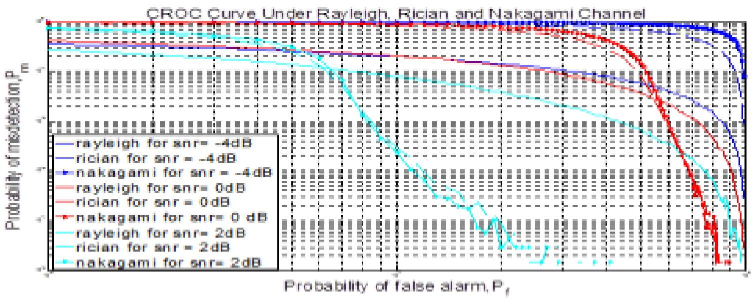


**Fig. 12.** Comparison of Rayleigh,Rician and Nakagami channel for different value of SNR for energy detection method

## V. *C*ONCLUSION

In this paper, we have depicted different fading models. Particularly we have discussed about the cognitive radio ROC curves under Rayleigh, Rician and Nakagami channel model. We have observed individual performance of each model for energy detection method for different value of SNR. It is evident that for higher value of SNR each model has shown better result for energy detection method. Rician and Nakagami fading models provide impressive result than Rayleigh model. However, the performance of Nakagami model is slightly better than Rician for higher value of SNR.

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