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Energy Detection Spectrum Sensing Technique in Cognitive Radio over Fading Channels Models

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ABSTRACT

Cognitive Radio (CR) is an embryonic technology which able to increase the spectrum utilization by allowing the CR users to carry unused radio spectrum from primary licensed users or share the spectrum with the primary users without causing the inference by spectrum sensing method. This method is used for sensing the used spectrum, and we focus on the performance of CR users based on spectrum sensing energy detection technique in non-fading (AWGN) channel and fading channel such as Rayleigh, Rician and Nakagami [6]. This paper presents a Simulation comparison of this fading channel in Cooperative and Non-Cooperative spectrum for P_f *(Probability of False Alarm) Vs* P_m *(Probability of Miss Detection). The Cooperative spectrum sensing is based on Hard decision fusion rule (OR-rule, AND –rule and MAJORITY-rule). We compare AWGN, all fading channel and observer that the detection of signal is better in Nakagami then Rayleigh and Rician in OR-rule, but it is also observed that spectrum sensing is better results in Rician when compare to other fading channel.*

KEYWORDS

Cognitive Radio, Spectrum Sensing, Hard decision rules, Fading Channels and Energy Detection.

INTRODUCTION

The rapid growth in wireless communications has devote to huge demand for Spectrum Utilization so new wireless technology are coming to overcome spectrum inefficiency problem [7]. So the new wireless technology, Cognitive Radio was proposed to solve the spectrum inefficiency problem by using unutilized spectrum of licensed users for other secondary users (CR users) by spectrum sensing technique. Spectrum sensing method is the key task component of Cognitive Radio technology in wireless communication.

Spectrum sensing can identify the unutilized spectrum from licensed users (i.e. Primary Users) and utilize that radio frequency spectrum for unlicensed users (i.e. Secondary Users) without causing any interference to Primary Users. They are two categories of Spectrum Sensing Cognitive Radio they are Cooperative Spectrum Sensing and Non-Cooperative Spectrum sensing. In order to assign CR users to the vacant bands in the radio spectrum, the CR users should sense the spectrum continuously [4]. So there are three different detection techniques in spectrum sensing to known the spectrum holes: Energy detection, Matched filter detection and Cylostationary detection. Out of this, Energy detection has widely used to detect the signal of unused spectrum, Energy Detection based on Spectrum sensing algorithm is used. Energy detector (ED) are well known for their low computational complexity, low cost for implementation, efficiently and relevancy.

NOMENCLATURE

- s(t): Signal transmitted from Primary User (PU).
- x(t): Signal received by secondary user.
- n(t): noise waveform which is modeled as a zero-mean white Gaussian random process.
- N_0 : One-sided noise power spectral density.

- E_s: Signal energy; $E_s = \int_0^T s^2(t)d$.
- $\gamma = \frac{E_s}{N_0}$: Signal-to-noise-ratio (SNR), $\bar{\gamma}$: Averagr SNR
- W:One-sided banbwidth (Hz), i.e. positive bandwidth of low-pass (LP) signal.
- $u{:}\frac{L}{2} = T$:Time-abndwidth poduct.
- f_c: Carrier frequency
- P_d: Probability of detection at CR.
- $\overline{P_d}$: Average probability of detection at CR in fading channels.
- P_f: Probability of false alarm at CR, P_m : 1-P_d: Probability of miss detection at CR.
- Q_d: Overall probability of detection at FC, Q_f: Overall probability of false alarm at FC.
- Q_m = 1-Q_d: Overall probability of miss detection at FC
- H_0: Hypothesis 0 that corresponds to presence of PU.
- H_1: Hypothesis 1 that corresponds to absence of PU.
- N: Number of CR users, $N(\mu, \sigma^2)$: A Gaussian variate with mean μ and varianceσ^2.
- X_α^2 : A central Chi-square variate with α degree of freedom.
- $X_\alpha^2(\beta)$: A non-central chi-square variate with α degree of freedom and non-centrality parameterβ [2].

SYSTEM MODEL

We consider a network of N CRS, one PU and One FC. Each CR assembled with one ED, whose details are shown in Fig. 2.

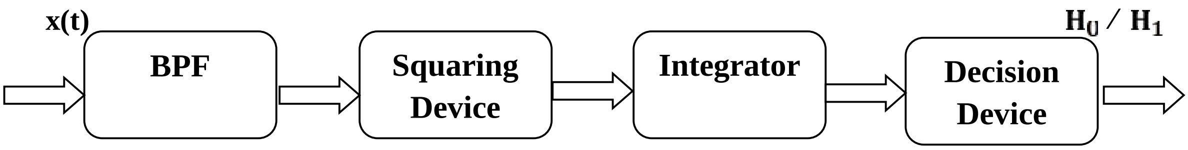

Figure 1: Block diagram of Energy Detection

The received signal x(t) from Fig.1 is first pre-filtered by an ideal band pass filter to limit the average noise power and normalized noise variance. The output of filter is passed through squaring device. The output of integrator act as test static signal to test the two hypotheses H_0 and H_1. Test static signal energy is compared with the threshold which determines the presence of primary user [5].

An energy detector receives a signal x(t) as defined below at input and gives a binary decision regarding the presences of the PU.

$$x(t) = \begin{cases} n(t) H_0 \\ h \square s(t) + n(t)\ H_1 \end{cases} \qquad 1$$

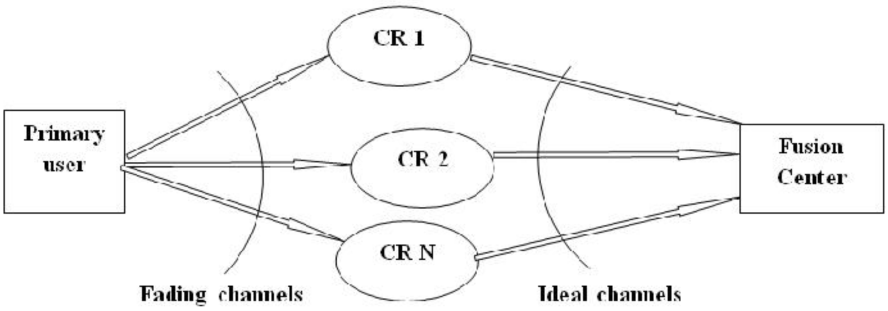

Figure 2: Cooperative spectrum sensing scenario.

CRs make hard binary decision (either binary bit ‘1’or binary bit ‘0’) and transmit their decision to FC for data fusion (shown in Fig.2).It is assumed that the distance between a CRs is less than the distance between the PU and a CR or the distance between a CR and the FC in Fig.2. Further, the channels between CRs and FC have been considered as ideal channels ((noiseless) in this paper [2].

The output of the integrator denoted by Y acts as a test statistic to test the two hypotheses H_0 and H_1.

$$Y \equiv \frac{2}{N_0} \int_0^T r^2(t)d(t) \qquad 2$$

The H_0 and H_1 are the output of the threshold detector

$$y \,\square \begin{cases} x_L^2\, H_0 \,\square\, P \qquad u \qquad i\text{:}\ a \\ x_L^2(2\gamma)\, H_1 \,\square\, P \qquad u \qquad i\text{:}\ p \end{cases} \qquad 3$$

DETECTION AND FALSE ALARM PROBABILITIES

In this section, we give the average detection probability over non fading (AWGN) channel and over fading channels such as Rayleigh, Rician and Nakagami. In wireless communication system, Rayleigh distributions, Rician distributions and Nakagami distributions are used to model scattered signal that reach a receiver by multiple paths. Depending on the density of the reflection, diffraction and scatter, the signal will shows different types of fading characteristics [1]. Rayleigh and Nakagami distribution are used to model dense scatters, while Ricican distributions model fading with a strong line-of-sight. Nakagami distribution can be reduced to Rayleigh distributions, but give better performance than the other fading channel [6].

Non-fading channel (AWGN channel)

When the signal is free from fading effects or shadowing effect, considers the fading parameters (h) is equal to one. For AWGN the detection probability and false alarm probability are given by the following formulae

$$P_d = P_r(Y > \lambda | H_1) = Q_{\frac{L}{2}}\left(\sqrt{\frac{a}{\sigma^2}}, \sqrt{\frac{\lambda}{\sigma^2}}\right) \qquad 4$$

$$P_f = P_r(Y > \lambda | H_0) == \frac{\Gamma\left(\frac{L}{2}, \frac{\lambda}{2\sigma^2}\right)}{\Gamma\left(\frac{L}{2}\right)} \qquad 5$$

$$P_m = 1 - P_d \qquad 6$$

Where $Q_{\frac{L}{2}}(.\,,.)$ is the generalized Marcum-function[1].

Average Detection Probability over fading channels

The performance of energy detection is varied due to different type of fadings. In this section probability of detection over Rayleigh, Rician and Nakagami channel are expressed [2]. Probability of false alarm P_f will remain same under any fading channel since P_f is doesn’t depend any transmission signal and SNR varies. The H amplitude is varied sue to average probability under fading statistic which is derived by averaging equation 4.

$$P_d = \int_\alpha^\alpha Q_{\frac{N}{2}}\left(\sqrt{\frac{a}{\sigma^2}}, \sqrt{\frac{\lambda}{\sigma^2}}\right) f_\gamma(y) d \qquad 7$$

Where$f_\gamma(y)$ is the probability density function (PDF) of SNR under fading [1].

Rayleigh Channels

If the signal amplitude follows a Rayleigh distribution [8], then the SNR γ follows an exponential PDF given by

$$f(\gamma) = \frac{1}{\bar{\gamma}} e.\ \left(-\frac{\gamma}{\bar{\gamma}}\right) \qquad 8$$

The average $P_d$in this case, $\overline{P}_{dR}$, can obtained by substituting 8 in 7

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$$\overline{P}_d = e^{-\frac{\lambda}{2\sigma^2}} \sum_{i=0}^{\frac{N}{2}-1} \frac{\left(\frac{\lambda}{2\sigma^2}\right)^i}{i!} + \left(\frac{2\sigma^2+a\overline{\gamma}}{a\overline{\gamma}}\right)^{\frac{N}{2}-1} \square \left[e^{-\frac{\lambda}{2\sigma^2+a\overline{\gamma}}} - e^{-\frac{\lambda}{2\sigma^2}} \sum_{i=0}^{\frac{N}{2}-1} \frac{\left(\frac{\lambda\,\overline{\gamma}}{2\sigma^2(2\sigma^2+a\overline{\gamma})}\right)^i}{i!} \right] \qquad 9$$

Rician Fading Channel

Rician fading or Ricean fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself the signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician [8] distribution

$$f(\gamma) = \frac{K+1}{\overline{\gamma}}\, e.\ \left(-K - \frac{(K+1)\gamma}{\overline{\gamma}}\right) I_0\left(2\sqrt{\frac{K(K+1)\gamma}{\overline{\gamma}}}\right) \qquad \gamma \geq 0, \qquad 10$$

Where K is Rician Factory and $I_0(\cdot)$ is the modified Bessel function. If Rician factor equal to zero, then Rician expression reduce to the Rayleigh expression.

The average P_d in the case of Rician Fading factor, the $\overline{P}_d$ is obtained by substituting equation 10 in 7

$$\overline{P}_d = Q\left(\sqrt{\frac{2K\overline{\gamma}}{K+1+\overline{\gamma}}}\ ,\sqrt{\frac{\lambda(K+1)}{K+1+\overline{\gamma}}}\right) \qquad 11$$

Nakagami Fading channel

Nakagami fading channel describes the amplitude of received signal after maximum ratio diversity combining. After *k*-branch maximum ratio combining (MRC) with Rayleigh-fading signals [2], the resulting signal is Nakagami with *m* = *k*. MRC combining of *m*-Nakagami fading signals in *k* branches gives a Nakagami signal with shape factor *mk*. If the envelope is Nakagami distributed, the corresponding instantaneous power is gamma distributed.

In Nakagami Fading, if the signal amplitude follows Nakagami distribution [8], then the PDF of γ follows a gamma PDF given by

$$f(\gamma) = \frac{1}{\Gamma(m)}\left(\frac{m^m}{\overline{\gamma}^m}\right)\gamma^{m-1} e.\ \left(\frac{-m}{\overline{\gamma}}\right) \qquad 12$$

The parameter *m* is called the 'shape factor' of the Nakagami (Nakagami-m Parameter) or the gamma distribution. In the special case *m* = 1, Rayleigh fading is recovered, with an exponentially distributed instantaneous power.

For *m* > 1, the fluctuations of the signal strength reduce compared to Rayleigh fading. The average P_d in the case of Nakagami Fading factor, the $\overline{P}_d$ is obtained by substituting equation 12 in 7,

$$\overline{P}_d = A_1 + \beta^m e^{\frac{-\lambda}{2\sigma^2}} * \sum_{i=1}^{\frac{N}{2}-1} \frac{\left(\frac{\lambda}{2\sigma^2}\right)^i}{1!} F_i\left(m; i+1; \frac{\lambda(1-\beta)}{2\sigma^2}\right) \qquad 13$$

Where $\beta = \frac{(2m\sigma^2\ )}{(2m\sigma^2+a\overline{\gamma})}$ $F_1(.\,;.)$ is the confluent hyper geometric function and for integer m and

$$A_1 = e^{\frac{-\lambda}{2m\sigma^2}}\left[\beta^{m-1} L_{m-1}\left(\frac{\lambda(1-\beta)}{2\sigma^2}\right) + (1-\beta)\sum_{i=0}^{m-2} L_i\left(\frac{\lambda(1-\beta)}{2\sigma^2}\right)\right] \qquad 14$$

Where $L_i = (.)$ is the lagurre polynomial of degree *i* [1].

Hard Decision Fusion Rules

OR-Rule (1-out-of-N):

According to this rule the final decision of the fusion center depends upon the inputs of the local decisions [3] i.e., if any input is one the final decision would be one i.e. k=1.

$$Q_{d,O} = \sum_{l=1}^{N} \binom{N}{l} P_d^l\ (1-\mathrm{P_d})^{\mathrm{N-l}} = 1 - \binom{N}{l} P_d^l\,(1-\mathrm{P_d})^{\mathrm{N-l}}\Big|_{\mathrm{l=0}} = 1-(1-\mathrm{P_d})^{\mathrm{N}} \qquad 15$$

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AND- Rule (N-out-of-N):

According to this rule the final decision of the fusion center depends upon the all the inputs of the local decisions i.e., if all the input are one then final decision would be one [6], i.e. k=N.

$$Q_{d,A} \quad = \sum_{l=k}^{N} \binom{N}{l} \mathrm{P}_{\mathrm{d}}^{l} (1-\mathrm{P}_{\mathrm{d}})^{\mathrm{N}-l} = \mathrm{P}_{\mathrm{d}}{}^{\mathrm{N}} \qquad 16$$

Majority – Rule(N/2-out-of-N):

According to this rule the final decision of the fusion center depends upon the half or more inputs of the local decisions i.e. if half of the input are one then final decision would be one i.e. K=N/2 [3].

$$Q_{d.M} \quad = \sum_{l-\left[\frac{N}{2}\right]=k}^{N} \binom{N}{l} \mathrm{P}_{\mathrm{d,i}}^{l} \left(1-\mathrm{P}_{\mathrm{d,i}}\right)^{\mathrm{N}-l} \qquad 17$$

SIMULATION RESULTS

All simulation results are obtained from MATLAB version R2012b over three different fading under Nakagami, Rayleigh and Rician channel and a non-fading channel AWGW. The performance analysis is done based on Receiver Operating Characteristics (ROC) and complementary Receiver Operating Characteristics (CROC). ROC and CROC curves are generated by plotting the graph between Probability of Miss detection (P_m) (which is P_m=1-P_d versus Probability of false alarm (P_f) [6].

Figures 3,4,5 and 6 shows ROC for hard decision fusion rule (OR-rule, And-rule and MAJORITY-rule) and Non-cooperative spectrum sensing with parameter as CR users(N) =10, Signal to noise Ratio (SNR) =10dB, Probability of false alarm (P_f) = 0.05 and Time Bandwidth parameter(μ)= 5 by energy detection method. Spectrum sensing in Non-fading and fading channels shows that OR-rule has better performance than AND and MAJORITY rule. By observing the figures, that the probability of sensing the unused spectrum is better in hard decision fusion rule while compare to Non-cooperative spectrum sensing all fading and non-fading channel[6].

Figure 7, shows ROC curve for hard decision fusion rule (OR-rule, AND-rule and MAJORITY-rule) for three different fading channel and AWGN non-fading channel and also in Non-cooperative spectrum sensing techniques considering parameters as N=8,SNR=10dB,P_f=0.05 and μ = L/2=5. And Rician factor K=3 and Nakagami factor m=3 respectively. By observing the figure.7 we can see that performance of sensing in Nakagami has better than other Rayleigh, Rician and AWGN, But in Rician the energy detection performance is better than the other fading channels because of LOS signal. We observer that spectrum sensing performance in OR rule in better than AND-rule, MAJORITY-rule [6] and Non-cooperation spectrum sensing technique in various fading channel models and AWGN channel.

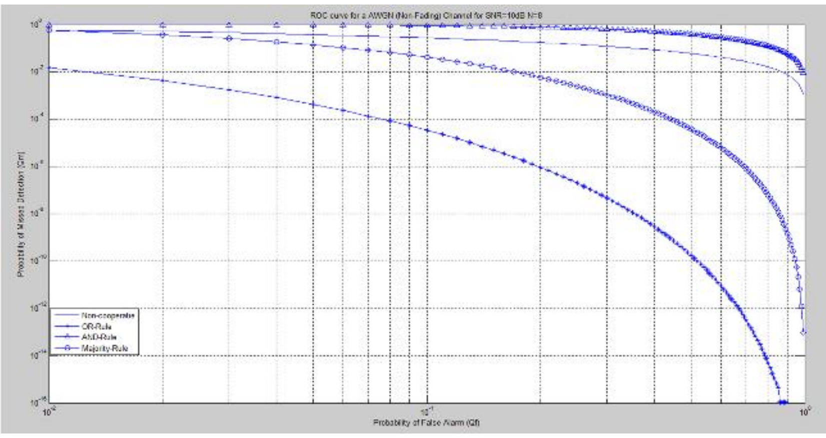

Figure 3: ROC for hard decision rule over non-fading (AWGN) channel for N=8 users,γ =10dB, Pf =0.05 and μ=5.

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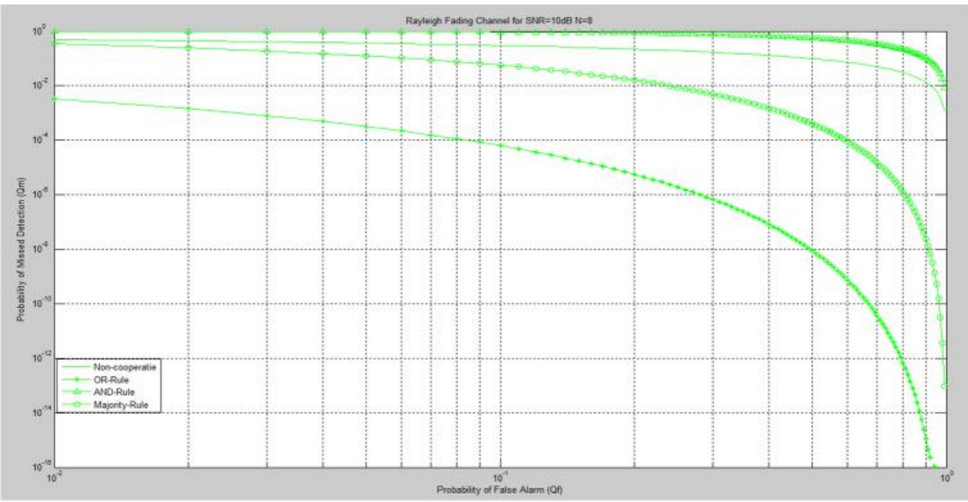

Figure 4: ROC for hard decision rule over Rayleigh fading channel for N=8 users,γ =10dB, Pf =0.05 and μ=5.

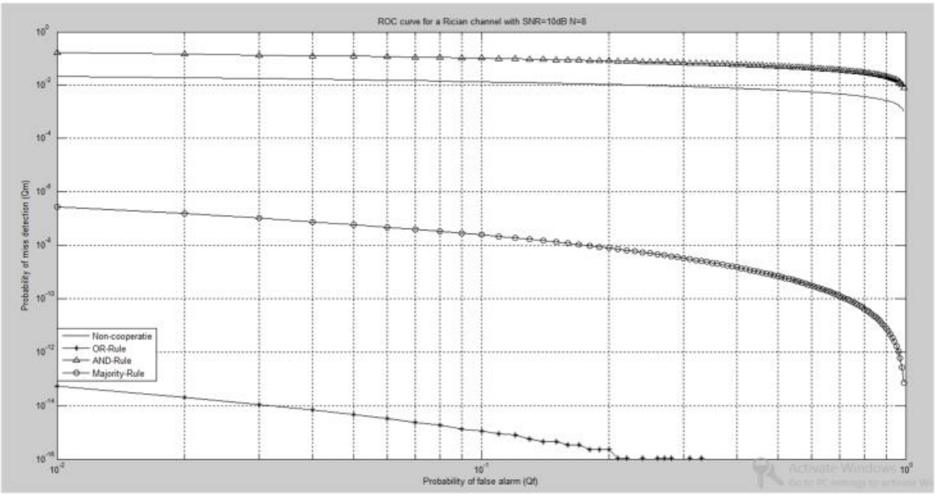

Figure 5: ROC for hard decision rule over Rician fading channel for N=8 users,γ =10dB, Pf =0.05 and μ=5.

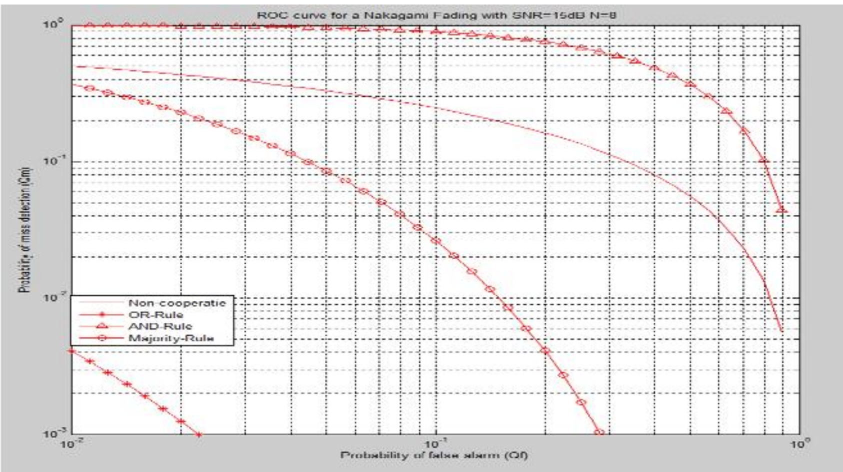

Figure 6: ROC for hard decision rule over Nakagami fading channel for N=8 users,γ =10dB, Pf =0.05 and μ=5.

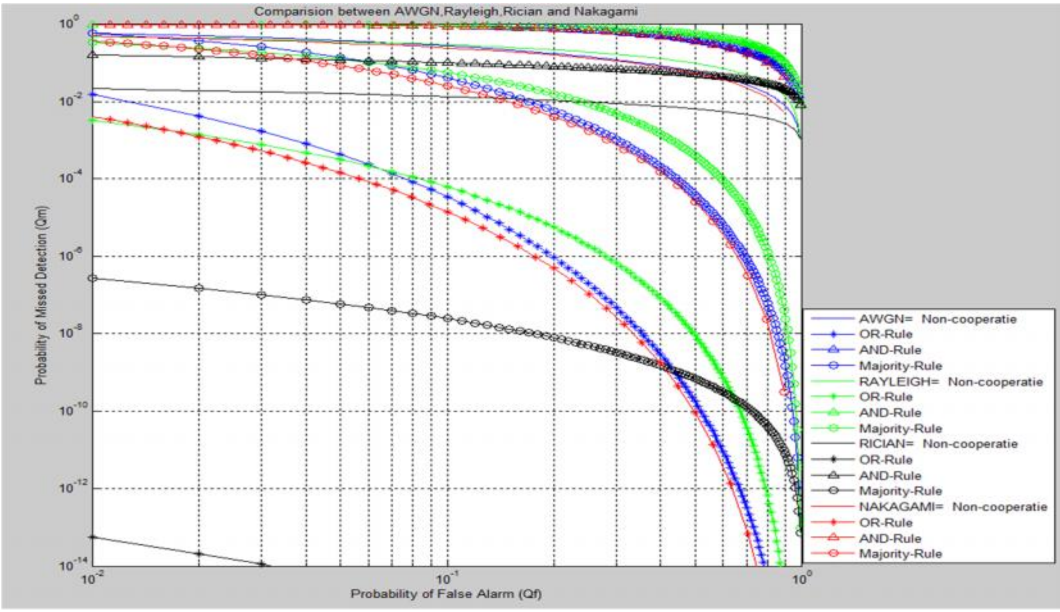

Figure 7: Comparison of ROC for hard decision rule over all fading channel and non-fading for N=8 users, γ =10dB, Pf =0.05 and μ=5.

CONCLUSION

We have studied hard decision fusion rule based on cooperative spectrum sensing and also non-cooperative spectrum sensing over different fading channel in cognitive radio. Performance of energy detection spectrum sensing over Rayleigh, Rician, Nakagami and AWGN channel are observed and compared in MATLAB simulation. It has been found that the probability of miss detection (P_m) is decreased by using different fusion rule. We observed that the OR-rule has better performance than Non-Cooperative (i.e. only for one CR), AND and MAJORITY rule in various fading channels. We also observed the performance energy detection of the signal is good in Nakagami than the Rayleigh and Rician channels. In Rician channel the energy detection is better because of LOS signal than the other channel model.

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