Performance of Cooperative Spectrum Sensing for Different Number of CR users in Cognitive Radio

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Abstract: ***We have studied the performance of cooperative spectrum sensing for different number of CR users in cognitive radio over non-fading channel AWGN and fading channels such as Rayleigh and Nakagami. This paper presents a simulation comparison of these fading channels based on fusion OR-rule. We observe that spectrum sensing for different number of CR users is harder in presence of Rayleigh and Nakagami fading than non-fading AWGN channel. It also shows that spectrum sensing gives better performance when more number of CR users is cooperated.***

Keywords: cognitive radio, cooperative spectrum sensing, fading channels, energy detection

1. Introduction

Cognitive radio is defined as software defined radio which is aware of its environment, learns from and has the ability to change its parameters according to these changes in its environment and the networks requirements [1]. The concept of cognitive radio has been introduced to alleviate the spectrum under-utilization problem of wireless communications. One of the most challenging tasks in cognitive radio networks is spectrum sensing, which is required to opportunistically access the idle radio spectrum. Existing spectrum sensing techniques can be divided into three types [2]: energy detection, matched filter detection and cyclostationary detection. Among them, energy detection has been widely applied since it does not require any a priori knowledge of primary signals and has much lower complexity than the other two schemes. The radio channel is characterized by two types of fading effects: large scale fading and small scale fading [3], [4]. Small scale fading models include the well-known Rayleigh, Rice, and Nakagami-m [5]-[6] distributions. For large scale fading conditions, it is widely accepted that the probability density function (PDF) of the fading envelopes can be modeled by the well-known Log-normal distribution [7], [8]. Due to the several multipath fading, a cognitive radio may fail to notice the presence of the PU and then will access the licensed channel and cause interference to the PU. To combat these impacts, cooperative spectrum sensing schemes have been proposed to obtain the spatial diversity in multiuser CR networks [9-11]. The performance of single CR user based spectrum sensing in fading channels such as Rayleigh, Nakagami, Weibull has been studied in [12]. The performance of cooperative spectrum sensing with censoring of cognitive radios in Rayleigh fading channel has been evaluated in [13-15]. Cooperative spectrum sensing improves the detection performance. All CR users sense the PU individually and send their sensing information in the form of 1-bit binary decisions (1 or 0) to Fusion center (FC). The hard decision combining rule (OR, AND, and MAJORITY rule) is performed at FC using a counting rule to make the final decision regarding whether the primary user present or not [16]-[18]. Cooperative spectrum sensing has been addressed in [19-22]. However, the existed works examined the additive white Gaussian noise (AWGN) channel and the Rayleigh fading channel. In this paper, we study performance of cooperative spectrum sensing for different number of CR users in cognitive radio.

The rest of this paper is organized as follows. In Section II, the system model is introduced. In Section III, detection and false alarm probabilities of non-fading AWGN and fading channel such as Rayleigh and Nakagami are described. Cooperative spectrum sensing over various fading channels is derived in Section IV. The simulation result and discussion are presented in section V. Finally, we draw our conclusions in Section VI.

2. System Model

The local spectrum sensing is to decide between the following two hypotheses,

$$x(t) = \begin{cases} n(t) & H_0 \\ hs(t) + n(t) & H_1 \end{cases} \qquad (1)$$

where *x(t)* is the signal received by secondary user and *s(t)* is primary user's transmitted signal, *n(t)* is the additive white Gaussian noise (AWGN) and h is the amplitude gain of the channel.

The energy collected in the frequency domain is denoted by Y which serves as a decision statistic. Following the work of Urkowitz [23], Y may be shown to have the following distribution,

$$Y = \begin{cases} \chi^2_{2TW} & H_0 \\ \chi^2_{2TW}(2\gamma), & H_1 \end{cases} \tag{2}$$

where χ^2_{2TW} and $\chi^2_{2TW}(2\gamma)$ denote central and non-central chi-square distributions respectively, each with $2TW$ degrees of freedom and a non-centrality parameter of 2γ for the latter distribution. For simplicity we assume that time-bandwidth product, TW, is an integer number which we denote by u.

3. Detection and False Alarm Probabilities

In this section, we give the average detection probability over Rayleigh and Nakagami fading channels and in closed form [24]. In communications theory, Nakagami distributions and Rayleigh distributions are used to model scattered signals that reach a receiver by multiple paths. Depending on the density of the scatter, the signal will display different fading characteristics. Rayleigh and Nakagami distributions are used to model dense scatters. Nakagami distributions can be reduced to Rayleigh distributions, but give more control over the extent of the fading.

3.1 Non-fading environment (AWGN channel)

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 [24]

$$P_d = P\{Y > \lambda \mid H_1\} = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{3}$$

$$P_f = P\{Y > \lambda \mid H_0\} = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \tag{4}$$

and

$$P_m = 1 - P_d \tag{5}$$

where λ denotes the energy threshold. $\Gamma(.)$ and $\Gamma(.,.)$ are complete and incomplete gamma functions respectively [25] and $Q_u(.,.)$ is the generalized Marcum Q-function defined as follows,

$$Q_u(a,b) = \int_0^\infty \frac{x^u}{a^{u-1}} e^{-\frac{x^2+a^2}{2}} I_{u-1}(ax)dx$$

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_f to a specific constant. By equation (4), the detection threshold λ can be determined. Then, for the fixed number of samples $2TW$ the detection probability P_d can be evaluated by substituting the λ in (3). As expected, P_f is independent of γ since under H_0 there is no primary signal present. When h is varying due to fading, equation (3) 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 (3) over fading statistics [19],

$$P_d = \int_x Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) f_\gamma(x)dx \tag{6}$$

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

3.2 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 [26]. If the signal amplitude follows a Rayleigh distribution, then the SNR γ follows an exponential PDF given by

$$f(\gamma) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right), \; \gamma \geq 0 \tag{7}$$

In this case, a closed-form formula for P_d may be obtained (after some manipulation) by substituting $f_\gamma(x)$ in (6),

$$\bar{P}_{dRay} = e^{-\frac{\lambda}{2}} \sum_{k=0}^{u-2} \frac{1}{k!}\left(\frac{\lambda}{2}\right)^k + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{u-1} \times \left(e^{-\frac{\lambda}{2(1+\bar{\gamma})}} - e^{-\frac{\lambda}{2}} \sum_{k=0}^{u-2} \frac{1}{k!}\left(\frac{\lambda\bar{\lambda}}{2(1+\bar{\gamma})}\right)\right) \tag{8}$$

3.3 Nakagami Fading Channel

Although Rayleigh and Ricean distributions are the most popular distributions to model fading channels, some experimental data does not fit well into neither of these distributions. Thus, a more general fading distribution was developed whose parameters can be adjusted to fit a variety of empirical measurements [25]. This distribution is called the Nakagami fading distribution. The Nakagami distribution was introduced by Nakagami in the early 1940's to characterize rapid fading in long distance HF channels [27]. It is possible to describe both Rayleigh and Rician fading with the help of a single model using the Nakagami distribution. The Nakagami m-distribution is used in communication systems characterize the statistics of signal transmitted through multipath fading channels.

The Nakagami distribution is often used for the following reasons. First, the Nakagami distribution can model fading conditions that are either more or less severe than Rayleigh fading. When m=1, the Nakagami distribution becomes the Rayleigh distribution, when m=1/2, it becomes a one-sided Gaussian distribution, and when m=∞ the distribution becomes an impulse (no fading). Second, the Rice distribution can be closely approximated by using the following relation between the Rice factor K and the Nakagami shape factor m [27];

$$K = \frac{\sqrt{m^2 - m}}{m - \sqrt{m^2 - m}} \qquad m > 1$$

$$m = \frac{(K+1)^2}{(2K+1)}$$

Since the Rice distribution contains a Bessel function while the Nakagami distribution does not, the Nakagami distribution often leads to convenient closed form analytical expressions that are otherwise unattainable. Using the alternative representation of Marcum-Q function given in [28, eq. (4.74), pp. 104], (1) can be written as,

$$Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) = \sum_{n=0}^{\infty} \frac{\gamma^n e^{-\gamma}}{n!} \sum_{k=0}^{n+u-1} \frac{e^{-\frac{\lambda}{2}}}{k!} \left(\frac{\lambda}{2}\right)^k \qquad (9)$$

If the signal amplitude follows a Nakagami distribution, then the PDF of γ follows a gamma PDF given by

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

where m is the Nakagami parameter. The average P_d in the case of Nakagami channels $\bar{P}_{dNak}$ can now be obtained by averaging (3) over (10) and then using again the change of variable $x = \sqrt{2\gamma}$ yielding

$$\bar{P}_{dNak} = \alpha \int_0^{\infty} x^{2m-1} \exp\left(-\frac{mx^2}{2\bar{\gamma}}\right) Q_u\left(x, \sqrt{\lambda}\right) dx \qquad (11)$$

where

$$\alpha = \frac{1}{\Gamma(m) 2^{m-1}} \left(\frac{m}{\bar{\gamma}}\right)^m \qquad (12)$$

In this case, a closed-form formula of Nakagami channels can be given by

$$\bar{P}_{dNak} = \alpha \left[G_1 + \beta \sum_{n=1}^{u-1} \frac{(\lambda/2)}{2(n!)} {}_1F\left(m; n+1; \frac{\lambda}{2} \frac{\bar{\gamma}}{m+\bar{\gamma}}\right)_1 \right] \qquad (13)$$

where ${}_1F_1(.;.;.)$ is the confluent hypergeometric function [18].

$$\beta = \Gamma(m) \left(\frac{2\bar{\gamma}}{m+\bar{\gamma}}\right)^m e^{-\lambda/2} \qquad (14)$$

and

$$G_1 = \int_0^{\infty} x^{2m-1} \exp\left(-\frac{mx^2}{2\bar{\gamma}}\right) Q_u\left(x, \sqrt{\lambda}\right) dx \qquad (15)$$

Where Q(.,.)=Q(.,.) is the first-order Marcum Q-function. G1 can be evaluated for inter m with the aid of [25, Eq.(25)]

$$G_1 = \frac{2^{m-1}(m-1)!}{\left(\frac{m}{\bar{\gamma}}\right)^m} \frac{\bar{\gamma}}{m+\bar{\gamma}} e^{-\frac{\lambda}{2}\frac{m}{m+\bar{\gamma}}} \left| \left(1 + \frac{m}{\bar{\gamma}}\right) \left(\frac{m}{m+\bar{\gamma}}\right)^{m-1} \right.$$

$$\left. \times L_{m-1}\left(-\frac{\lambda}{2} \frac{\bar{\gamma}}{m+\bar{\gamma}}\right) + \sum_{n=0}^{m-2} \left(\frac{m}{m+\bar{\gamma}}\right)^n L_n\left(-\frac{\lambda}{2} \frac{\bar{\gamma}}{m+\bar{\gamma}}\right) \right| \qquad (16)$$

where is the Laguerre polynomial of degree n [25, 8.970].

4. Cooperative Spectrum Sensing over various Fading Channels

In real communication environments, the hidden terminal problem, deep fading and shadowing, etc., would deteriorate the signal detection performance of cognitive users. To address this issue, multiple cognitive radios can be coordinated to perform spectrum sensing. Several recent works have shown that cooperative spectrum sensing can greatly increase the probability of detection in fading channels [19], [29].

Let N denote the number of users sensing the PU. Each CR user makes its own decision regarding whether the primary user present or not, and forwards the binary decision (1 or 0) to fusion center (FC) for data fusion. The PU is located far away from all CRs. All the CR users receive the primary signal with same local mean signal power, i.e. all CRs form a cluster with distance between any two CRs negligible compared to the distance from the PU to a CR. For simplicity we have assumed that the noise, fading statistics and average SNR are the same for each CR user. We consider that the channels between CRs and FC are ideal channels (noiseless).

Assuming independent decisions, the fusion problem where k out of N CR users are needed for decision can be described by binomial distribution based on Bernoulli trials where each trial represents the decision process of each CR user. With a hard decision counting rule, the fusion center implements an n–out-of-M rule that decides on the signal present hypothesis whenever at least k out of the N CR user decisions indicate H_1. Assuming uncorrelated decisions, the probability of detection at the fusion center [30] is given by

$$P_d = \sum_{l=k}^{N} \binom{N}{l} P_{d,i}{}^l \left(1 - P_{d,i}\right)^{N-l} \qquad (17)$$

where $P_{d,i}$ is the probability of detection for each individual CR user as defined by (3) and (6).

OR-rule *:* In this rule, if any one of the local decisions sent to the decision maker is a logical one, the final decision made by the decision maker is one. Cooperative detection performance with this fusion rule can be evaluated by setting k=1 in eq. (17).

$$P_{d,OR} = 1 - \left(1 - P_{d,i}\right)^N \qquad (18)$$

5. Simulation Result and Discussion

All simulation was done on MATLAB version R2011a over two different fading under Rayleigh and Nakagami channel and a non-fading channel AWGN. We described the receiver through its complementary ROC curves for different values of probability of false alarm and Cognitive Radio user.

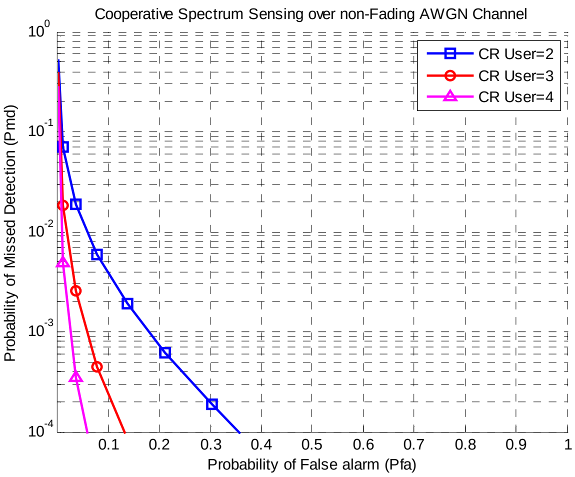

Figure 1: Complementary ROC of OR-rule over non-fading AWGN channel ($\bar{\gamma}$=10dB, u=5).

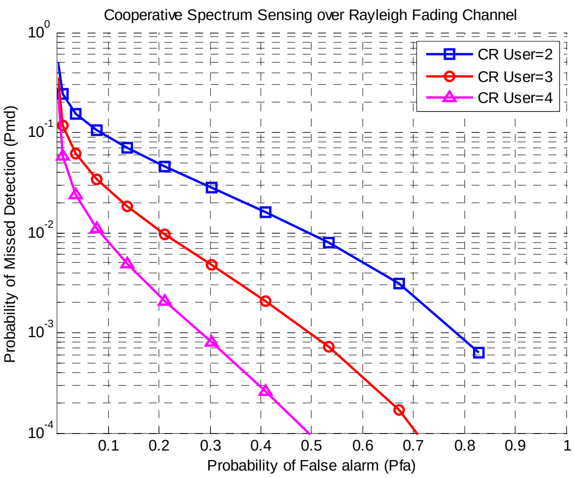

Figure 2: Complementary ROC of OR-rule over Rayleigh fading channel ($\bar{\gamma}$=10dB, u=5).

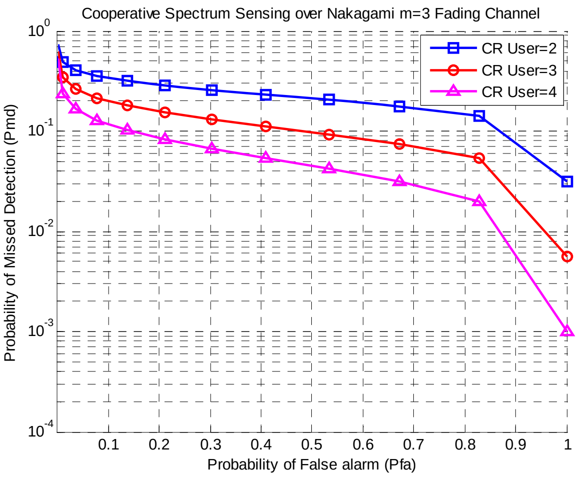

Figure 3: Complementary ROC of OR-rule over Nakagami fading channel ($\bar{\gamma}$=10dB, u=5, m=3).

Fig. 1, 2, and 3 show the complementary ROC of fusion OR rule for different number of cooperative users. CR users are taken 2, 4 and 6 for simulation. Simulation is done for cooperative spectrum sensing over non-fading AWGN channel, Rayleigh and Nakagami fading channel respectively. Average SNR and u are assumed to be 10 dB and 5 respectively. Nakagami parameter m are set to be 3. Simulation result shows that spectrum sensing is better when more number of users are cooperated. It also shows that in non-fading AWGN channel the sensing performance is better than in other channels.

6. Conclusion

We have studied the performance of cooperative spectrum sensing for different number of Cognitive Radio users in Cognitive Radio. Performance of cooperative spectrum sensing over Rayleigh and Nakagami fading are presented and compared. It has been found that probability of missed detection is decreased by using different number of CR users.

We used OR rule as this has better performance than AND and MAJORITY rule in various channels. We also observe that spectrum sensing for different number of CR users is harder in presence of Rayleigh and Nakagami fading and performance of energy detection degrades more in Nakagami channels than Rayleigh channel.

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