On the Performance of Cooperative Spectrum Sensing of Cognitive Radio Networks in AWGN and Rayleigh Fading Environments

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Received April 24, 2013; revised July 7, 2013; accepted August 8, 2013; published August 30, 2013

Abstract

For the purpose of enhancing the spectrum efficiency, cognitive radio (CR) technology has been recently proposed as a promising dynamic spectrum allocation paradigm. In CR, spectrum sensing is the key capability of secondary users in a cognitive radio network that aims for reducing the probability of harmful interference with primary users. However, the individual CRs might not be able to carry out reliable detection of the presence of a primary radio due to the impact of channel fading or shadowing. This paper studies the cooperative spectrum sensing scheme as means of optimizing the sensing performance in AWGN and Rayleigh channels. Results generated from simulation provide evidence of the impact of channel condition on the complementary receiver operating characteristic (ROC). Based on the results, it was found that with constant local SNRs at the secondary users, the probability of missed detection (P_m) of cooperative spectrum sensing in a cognitive radio network, calculated using a closed form expression, can be significantly minimized. Thus, the paper illustrates that improvement of the detection performance of the CR network can be achieved by establishing a centralized cooperation among neighboring cognitive radio users. Finally, verification of the validity of the fusion schemes utilized for combining the individual CR decisions is provided.

Keywords: Cognitive radio, Spectrum sensing, Dynamic spectrum access, Cooperative sensing, AWGN channel, Rayleigh fading channel.

http://dx.doi.org/10.3837/tiis.2013.08.001

1. Introduction

Due to the rapid advances in a wireless communication system, there has been an increasing demand for the new wireless services in both the used and unused frequency spectrum. However, this increasing demand faces a great barrier which is the limitation of radio resources. In attempting to overcome this challenging problem, cognitive radio (CR) has been cited in as one of the most promising technologies that can offer a support for the increasing demand for spectrum availability and it is capable of increasing the spectral efficiency [1]. Thus, providing opportunities for researchers in obtaining further understanding and exploring the opportunities presented by idle frequencies as the first concept of opportunistic spectrum access based on the CR technology. A CR is also capable of adapting to the dynamic radio environment and the network parameters with the aim of maximizing the extent to which the limited radio resources are utilized, while at the same time making wireless access more flexible. CR technology is recommended for researching the unlicensed use of free bands. Thus, one of the core functions of CR is detecting the free bands through the spectrum sensing functionality. Spectrum sensing is known as a key enabling practicality in cognitive radio networks (CRNs) which performs detection of existence of primary user (PU) signals in the concerned bands, as well as identification the available channels that are useable. In determining the free and employed bands, the unlicensed systems analyze the signals received from the licensed system [2-3]. In cognitive radio with spectrum sensing, when the licensed user (LU) abruptly wishes to have an access to the frequency band already allocated to the LU, the cognitive user (CU) starts the process of searching for the idle spectrum again. According to [4], it is suggested that enhancing radio RF front-end sensitivity or digital signal processing techniques including energy detection, matched filtering, and cyclostationary feature detection can be one way of improving the execution of spectrum sensing. To achieve high performance for cognitive radio, collaborative spectrum sensing is required to improve the detection probability and diminish the detection time, thereby improving the sensitivity of the cognitive receiver [5]. in [6], the examined optimizing the cooperative spectrum sensing using energy detection for the purpose of minimizing the total error rate in cognitive radio networks (CRNs) was studied. Another investigation of the cooperative spectrum sensing using an improved energy detector in multiple antenna based CRNs along with Rayleigh fading primary user (PU-CR) links and imperfect reporting channels for enhancing the reliability in detecting a spectrum hole was also carried out by [7]. However, the study described in the current paper used different fusion rules (e.g. AND and OR) and closed form expressions as to provide a more realistic picture of cooperative energy detection in Rayleigh fading channel. This paper also attempted to provide an explanation of the performance degradation of the CRNs in fading and low SNR environments.

Thus, this paper is organized as follows: Section 2 offers the analysis of the deployment of CRNs including the spectrum sensing concept and energy detector. In Section 3, we derive of detection and false alarm probabilities for local sensing. Section 4 provided a discussion on the performance of the energy detection with numerical and simulation results. Section 5 presents brief concluding remarks of the study.

2. Deployment of Cognitive Radio Network

This section introduces information about the spectrum sensing concept and then, it provides a survey of the energy detection scheme so that analyzing how the probability of detection and probability of false alarm are related can be described in the next section.

2.1 Spectrum Sensing Concept

Fig. 1 displays the system model of the present study, and it is noticed that it is probable for some of the CR users to make detection of the primary signal whereas some other CR users cannot detect the presence of the primary signal due to the impact of deep fading and shadowing.

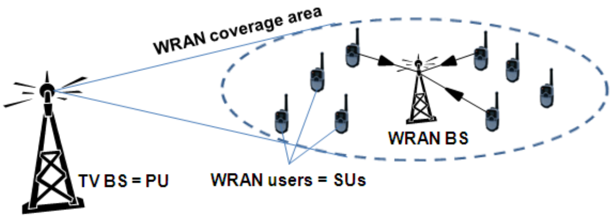

Fig. 1. Cooperation in cognitive radio network.

As shown in **Fig. 1**, there is a potential realization of enabling CR users who are WRAN users or secondary users (SUs) to opportunistically access to unused TV bands of primary users (PUs). In such a case, the possibility of enhancing the signal detection probability through the cooperative signal detection is high. In reality, detecting the PUs which receives the data in the communication range for the user is considered as the most effective means of detecting the spectrum holds. It becomes difficult for any SU to directly measure the channel between the primary transmitter and receiver, and therefore, the detection of the primary transmitter has become the major focus of the recent work is dependent on the local nodes of users. Thus, each CR has to make a distinction between employed and non- employed spectrum bands [8]. In the cooperative spectrum sensing scheme, every secondary user SU is able to make several executions of the local spectrum sensing and then, sends a binary local decision to the base station. Following this, the base station fuses the local decisions and makes a final decision in order to make determine the absence or presence of the primary user PU. In general, the sampled received signals of the secondary users contain two different hypotheses, H_1 and H_0 in CRNs [9]. The function of the energy detector is measuring the existing energy on the licensed channel during a notice interval and announces a white space if the measured energy is less than a threshold. Thus, the spectrum sensing problem can be designed as a binary hypothesis problem illustrated as follows:

H_1: primary user *PU* does exist and H_0: primary user *PU* does not exist

For simplicity of the implementation, the work is limited to the energy detection in the spectrum sensing. The local spectrum sensing provides options to be selected between the following two hypotheses [10]:

$$y_i(t) = \begin{cases} n_i(t), & H_0 \\ h_p x(t) + n_i(t), & H_1 \end{cases} \tag{1}$$

Where $y_i(t)$ refers to the signal which is received by the secondary user (SU), $x(t)$ refers to the signal transmitted to the primary user's (PU's), $n_i(t)$ is the additive white Gaussian noise (AWGN) received by *i*-th SU, and h_p is the channel gain. Thus, after the energy detection is used for cooperative spectrum sensing, the results of the sensing for the secondary users (SUs) are transferred to a fusion center by using decision fusion. Therefore, each secondary user has to make a decision on the primary user activity, and all these decisions produced by the secondary users are reported to the fusion center by using the reporting channel. The fusion rules generalized as the "*k*-out-of-*n* rule" (where *k* is the number of the users utilized for cooperation and n is the total number of users in the network). Where if there is *k* or more cognitive relays that separately decide the presence of the primary activity, therefore, the fusion centre decide the presence of primary user (PU). Where, if k = 1(e.g., the central unit decides a PU is utilizing the channel if more than one SU's result are 1), $k = n$ (e.g., the central unit decides that the observed channel is occupied by a PU if all sensing results for the SU's should be 1), and $k = n/2$ (e.g., the fusion central decides a PU is utilizing the channel if half of or more secondary users results is 1), the "*k*-out-of-*n* rule" represents OR rule, AND rule, and Majority rule, respectively [11-12].

2.2 Energy Detector

Energy detection is represent the most well-known spectrum sensing schemes, aims at determining whether H_0 or H_1 is true; this is achieved by sensing the energy of signal y. **Fig. 2** displays the block diagram of the typical energy detector.

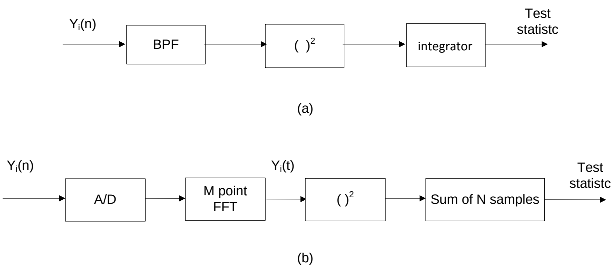

Fig. 2. The block of traditional energy detector. (a) In time domain and (b) In frequency domain.

Fig. 2(a) illustrates the traditional energy detector in time domain, and as reported by [13], the application of a band-pass filter to the objective signal is made first and this is followed by squaring the received signal and integrating it in the integrator so that the test statistic can be obtained. **Fig. 2(b)** shows how the A/D converter replaces the band pass filter while maintaining the M points of FFT and the others as they are at the same time. After that, the last result is compared with the threshold and gave the decision. So, the output of energy detector is:

$$Z = \frac{1}{N}\sum_{j=1}^{N}\left|y_j(t)\right|^2 \qquad (2)$$

Thus, based on the central limit theorem, when N is large enough (e.g. $N > 100$), the value of Z approximates Gaussian distribution. The mean and variance of Z is given as [13]:

$$E(Z) = \begin{cases} \hat{\sigma}^2, & H_0 \\ \hat{\sigma}^2 + P, & H_1 \end{cases} \qquad (3)$$

$$V_{ar}(Z)=\begin{cases}\frac{1}{N}2\hat{\sigma}^{4}, & H_0\\ \frac{1}{N}2\hat{\sigma}^{4}+\frac{1}{N}4\hat{\sigma}^{2}P, & H_1\end{cases} \tag{4}$$

Where E(.) and Var(.) denote mean and variance, and $P=\frac{1}{N}\left|h^2\right|\sum_{j=1}^{N}\left|x(t)\right|^2$ is the signal energy detected by the cognitive sensing node. Although Gaussian distribution provides a good approximation in general, it might not be practically the choice as assuming large number of samples, N, might not be correct when short sensing time is targeted. This is because in time-varying fading environments, the sensing time cannot be too long (and thus the number of samples cannot be too large) as this makes the process of monitoring PU activities inefficient. Therefore, in the subsequent sections, chi-square distribution is used and is not approximated by a Gaussian distribution to ensure a more practical scenario that can benefit the readers.

3. Derivation of Detection and False Alarm Probability for Local Sensing

At each SU, the decision statistic of energy detection, *Z*, has the following distribution:

$$Z_i=\begin{cases}x^2{}_{2m} & H_0\\ x^2{}_{2m}\left(2\delta_i\right) & H_1\end{cases} \tag{5}$$

Where *Z* means the collected energy by a cognitive user, *m* refers to the time- bandwidth product of the energy detector. For simplicity, it is assumed to be an integer, and $x^2{}_{2m}$ represents a central chi-square distribution with 2*m* degrees of freedom while $x^2{}_{2m}(2\delta)$ represents a non-central chi-square distribution with 2*m* degrees of freedom and a non-centrality parameter 2δ for H_1 and δ_i is the instantaneous SNR received at the i-th SU [14-15]. In this paper, we use the chi-square distribution in the subsequent discussion. The probability density function (pdf) of Z_i can be formulated as the following:

$$f_{Z_i}(y)=\begin{cases}\frac{1}{2^m\Gamma(m)}y^{m-1}e^{-\frac{y}{2}} & H_0\\ \frac{1}{2}\left(\frac{y}{2\delta_i}\right)^{\frac{m-1}{2}}e^{-\frac{2\delta_i+y}{2}}I_{m-1}\left(\sqrt{2\delta_i y}\right) & H_1\end{cases} \tag{6}$$

Where $\Gamma(*)$ is the gamma function and $I_u(*)$ is the *u*th-order modified Bessel function of the first kind. There are two probabilities regarding in spectrum sensing: under hypothesis H_1, probability of detection, according to which, the probability of the algorithm correctly detecting the exits of primary signal, and under hypothesis H_0, the probability of false alarm, which defines the probability of the algorithm as a process of incorrectly pronouncing the presence of the primary signal. From the primary user's PU's perspective, the higher probability of detection means the best protection received by it. From the secondary user's SU's perspective, the lower probability of false alarm indicates that the secondary users have more opportunities to use it when the frequency bands are available. It is obvious that in obtaining a better detection algorithm, it is important that the probability of detection to be as high as possible when the probability of false alarm is low [5, 16]. The following equations illustrate probabilities of detection, miss detection, and false alarm for SU_i over non-fading channels in the case of the CR users with the energy detector when the detecting channels are presumed to be the AWGN channels [17]:

$$P_{d,i} = P(Z_i > \mu_i | H_1) = \int_x Q_m(\sqrt{2\delta_i}, \sqrt{\mu_i}) \, f_{\delta_i}(x) \, d(x) \tag{7}$$

$$P_{m,i} = P(Z_i \le \mu_i | H_1) = 1 - P_{d,i} \tag{8}$$

$$P_{f,i} = P(Z_i > \mu_i | H_0) = \int \frac{\Gamma(m, \mu_i / 2)}{\Gamma(m)} f_{\delta_i}(x) \, d(x) \tag{9}$$

where μ_i refers to the detection threshold for the *i*-th SU which is, for simplicity, assumed to be the same for all users. The probability of detection can be obtained from Eq. (6) to evaluate Eq. (7). This evaluation of the cumulative distribution function (cdf) of Z_i for even degrees of freedom, which in our case is 2*m*, can be illustrated as follows:

$$F_{Z_i}(y) = 1 - Q_m(\sqrt{2\delta_i}, \sqrt{y}) \tag{10}$$

Therefore,

$$P_{d,i} = Q_m(\sqrt{2\delta_i}, \sqrt{\mu_i}) \tag{11}$$

$$P_{m,i} = 1 - P_{d,i} \tag{12}$$

Using Eq. (6) to evaluate Eq. (9), the probability of false alarm over an AWGN channel is given as [10]:

$$P_{f,i} = \frac{\Gamma(m, \mu_i / 2)}{\Gamma(m)} \tag{13}$$

We note that Eq. (9) is derived due to the fact that $\Gamma(m, \mu_i / 2) / \Gamma(m)$ is freelancer of δ_i, $\Gamma(*)$ and $\Gamma(*,*)$ are complete and upper incomplete gamma function, δ_i the instantaneous signal-to-noise-ratio of the detecting channel (SNR), $f_{\delta_i}(x)$ is the pdf of δ_i under certain fading model, and $Q_m(a,b)$ refers to the generalized Marcum *Q-function* defined as follows:

$$Q_m(a,b)=\frac{1}{a^{m-1}}\int_b^{\infty} x^m \exp\left(-\frac{x^2+a^2}{2}\right) I_{m-1}(ax)\,dx \tag{14}$$

Where I_{m-1} refers to the modified Bessel function of the first type and order $(m-1)$. When the complex received signal consists of a large number of plane waves, for some types of scattering environments, the received signal has a Rayleigh distribution. δ_i would have an exponential distribution under Rayleigh fading as follows:

$$f(\delta_i)=\frac{1}{\bar{\delta}_l} e^{-\frac{\delta_i}{\bar{\delta}_l}} \qquad \delta_i \geq 0 \tag{15}$$

Besides, the instantaneous SNR of a wireless channel between transmitter and receiver is also identified as:

$$\delta_i = SNR_i = h^2 E_s / N_0 \tag{16}$$

Where, E_s is the transmit energy, N_0 is the variance of additive white Gaussian noise (AWGN) and h is the channel gain. Thus, the average SNR is referred as:

$$\bar{\delta} = SNR_{avg} = E(h^2 E_s / N_0) = E(h^2) E_s / N_0 \tag{17}$$

The detecting channels in wireless propagation environments are affected by fading, thus, the sensing execution of a single SU should be denoted by the average P_d of a single SU over Rayleigh fading detecting channel and a closed-form formula for the probability of detection over Rayleigh fading channel can be found by substituting Eq. (15) in Eq. (7),

$$P_{d,i} = e^{-\frac{\mu_i}{2}} \sum_{k=0}^{m-2} \frac{1}{k!}\left(\frac{\mu_i}{2}\right)^k + \left(\frac{1+\bar{\delta}_i}{\bar{\delta}_l}\right)^{m-1} \left[e^{-\frac{\mu_i}{2(1+\bar{\delta}_l)}} - e^{-\frac{\mu_i}{2}} \sum_{k=0}^{m-2} \frac{1}{k!} \left(\frac{\mu_i\, \bar{\delta}_i}{2(1+\bar{\delta}_l)} \right)^k \right] \tag{18}$$

Since $P_{f,i}$ is assumed for the case H_0 and hence free-lancer of the SNR of detecting channel, so that, $P_{f,i}$ of Eq. (13) remains the same [18].

4. Hard Fusion Schemes for Cooperative Spectrum Sensing

Letting M denote the number of users who are cooperating, for simplifying this, all M users are presumed to experience independent and identically distributed (i.i.d) fading/shadowing with same average SNR. At the base station, all 1-bit decisions are combined together in accordance with the following logic rule.

$$E = \sum_{i=1}^{M} Z_i \begin{cases} \geq k\,, & H_1 \\ < k\,, & H_0 \end{cases} \tag{19}$$

The CR base station receiving the decisions from M other users are performed and deciding H_1 when there is at least (k-out-of-M) cognitive radios (CRs) which carries out, otherwise, the base station decides H_0 [19].

For distinction, conflating the local decisions and forming global decision in cooperative spectrum sensing for CRs can be conducted by some classical algorithms such as "OR" rule and "AND" rule, which are utilized in the common receiver as to minimize the harmful interference to primary user. Afterward, the probability of detection and the probability of false alarm of the final decision are presented by [15-16], respectively.

4.1 OR Fusion Rule

In OR fusion rule, the assumption that the final decision H_0 is true if the absence of the primary user PU is indicated by all the secondary users SUs whereas H_1 is true if the presence of a primary user is pronounced by at least 1 out of M secondary users. This means that evaluation of the OR fusion rule can be carried out by setting (k = 1) in expression Eq. (19), where as there are M users which employed in cooperative spectrum sensing among k users, Where $1 \leq M \leq k$.

In assuming that all decisions are freelancer, so, for the final decision, the cooperative probability of detection $Q_d(M)$,the cooperative probability of missed detection $Q_m(M)$ and the cooperative probability of false alarm $Q_f(M)$ can be evaluated, respectively, as:

$$Q_d(M) = 1 - \prod_{i=1}^{M} (1 - P_{d,i}) \tag{20}$$

$$Q_m(M) = \prod_{i=1}^{M} P_{m,i} \tag{21}$$

$$Q_f(M) = 1 - \prod_{i=1}^{M} (1 - P_{f,i}) \tag{22}$$

4.2 AND Fusion Rule

In AND fusion rule, the final decision H_1 is true only if the presence of the primary user PU is indicated by all the M secondary users SUs. Otherwise, the absence of the primary user is assumed. In other words, the AND rule is correspondent to the case of (k = M) in expression Eq. (19). If assuming that all decisions are freelancer, then, for the final decision, the cooperative probability of detection $Q_d(M)$, the cooperative probability of missed detection $Q_m(M)$ and the cooperative probability of false alarm $Q_f(M)$ can be evaluated as, respectively:

$$Q_d(M)=\prod_{i=1}^{M}(P_{d,i}) \tag{23}$$

$$Q_m(M)=1-\prod_{i=1}^{M}(P_{d,i}) \tag{24}$$

$$Q_f(M)=\prod_{i=1}^{M}(P_{f,i}) \tag{25}$$

Where M is the number of SUs subscribing cooperation, and $P_{d,i}$ and $P_{f,i}$ the probabilities of detection and false alarm of the SU_i derived from Eq. (12) and Eq. (17).

5. Simulation Results and Discussion

Assessment of the performance of cooperative spectrum sensing is usually performed through its complementary receiver operating characteristic (ROC) curve $(P_f \; vs P_d)$, spectrum usage and SNR requirements for different situations of interest. In the computer simulation by using the Matlab program, the number of secondary users is set as (M = 6) and the sampling frequency of the received signal is assumed to be 12 MHZ and sensing time is set at 1 ms.
Fig. 3 provides explanation of the complementary ROC curves for local spectrum sensing for various SNR values and the time-bandwidth product of the energy detector (m = 20) under AWGN and Rayleigh fading channels. It was noticed that as the SNR decrease, there is a gradual decrease of the probability of detection for a fixed probability of false alarm under both AWGN channel and Rayleigh fading channel.

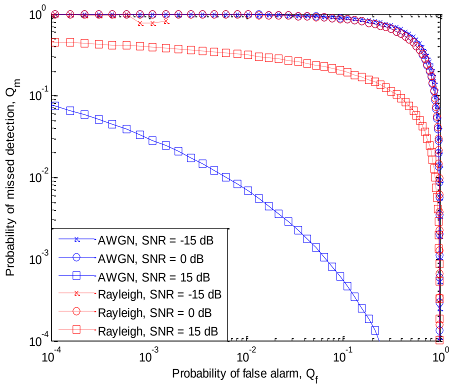

Fig. 3. Complementary ROC curves for local spectrum sensing under AWGN and Rayleigh channel with different values of SNR and (m=20).

Fig. 4, shows the executions of computer simulations to the complementary receiver operating characteristic (ROC) curves for Rayleigh fading channel over the average SNR, when P_f varies from 0.01 to 1, where the sensing performance of one secondary user for different values of SNR, and the secondary user's SNR's are assumed to be SNR = [-18, -20, -22, -24] dB.

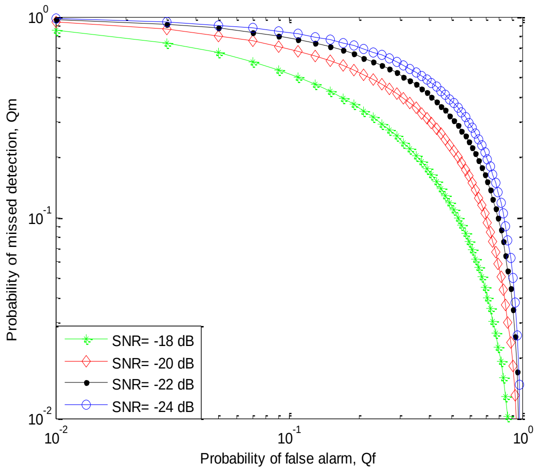

Fig. 4. Cooperative spectrum sensing performance with different SNR under the Rayleigh fading channel.

As displayed by **Fig. 4**, it can be noticed that when there is an increase in the local SNR, there is a steady decrease in the probability of missed detection. Moreover, it can be seen that the overall improvement of the performance is significant whereas roughly four time-improvement is detected from (-24) dB to (-18) dB. There will be also a degradation of the spectrum sensing execution when the SNR decreases. It can be observed that as there is a decrease in the SNR, the probability of miss detection becomes larger, and this will be the case when the SU tolerates heavy shadowing or fading, which will cause low SNR.

Fig. 5, shows how the cooperative spectrum sensing is executed to different numbers of SU with SNR = -15 dB. It indicates that there is a rapid degradation of the detection performance when there is an increase in the number of SU. Therefore, the increase in the number of SUs can enhance the detection capability dramatically. Moreover, a great decrease in the probability of missed detection can be seen as the secondary users (SUs) are cooperating for a given probability of false alarm. Thus, in case when the number of cooperative users M increases, the performance of the cooperative sensing performance can be enhanced under Rayleigh fading channel.

The aim of using the complementary ROC curves of one SU sensing over Rayleigh fading detecting channel is to evaluate the fading impact of detecting channel on the execution of local spectrum sensing at a one SU, and this is provided by the curves with M equal to (1, 2, 3, and 6). It indicates that fading on the detecting channel results into severely degrading the execution of local spectrum sensing.

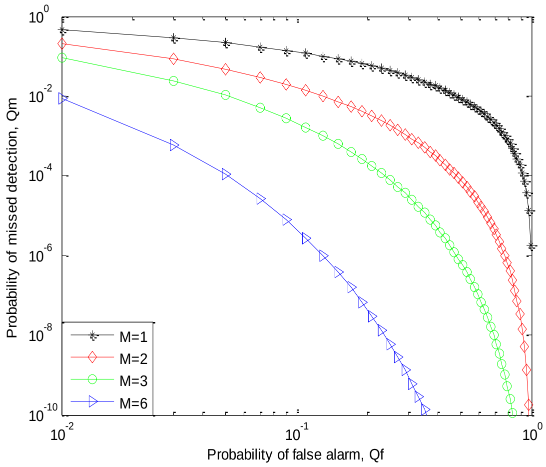

Fig. 5. Cooperative spectrum sensing performance for different number of secondary users under the Rayleigh fading channel.

According to **Fig. 5**, and with increasing the number of *M*, the cooperative sensing performance can be improved under the Rayleigh fading channel, also, the probability of miss detection (Q_m) is greatly reduced if the secondary users are cooperated.

Based on **Fig. 6**, it is obvious with the increase in the probability of false alarm, the curve of detection probability will increase, and detection probability is highly improved.

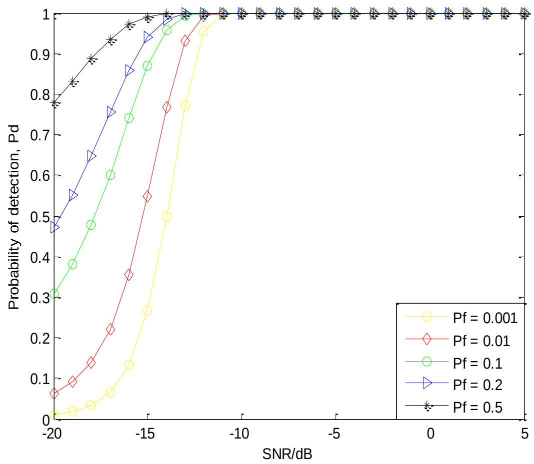

Fig. 6. Cooperative spectrum sensing performance for different values for probability of false alarm.

Fig. 7, shows the complementary ROC curves of cooperative spectrum sensing for various decision fusion rules when the conventional energy detector (ED) using OR and AND decision fusion rules are applied for the case *M* = 6 and SNR =15 dB. It is observed that, for the stationary Q_f, the probability of missing OR decision rule is the smallest in comparison to AND decision rule for the case *M* = 6, whereas it is the same for M = 1.

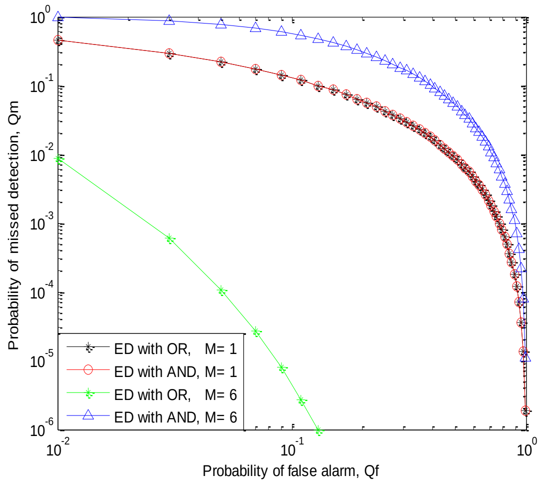

Fig. 7. Performance comparison of cooperative spectrum sensing between OR and AND rules over an AWGN channel when (M=1&6).

It also shows that OR fusion rule can limit the interference to the primary user. However, this paper concentrates on describing the receiver execution through its ROC curves $(Q_d\ vs Q_f)$ or complementary ROC curves ($(Q_m\ vs\ Q_f)$ for dissimilar situation of interest.

Fig. 8 shows the complementary ROC over Rayleigh channel for different average SNR values and the number of cooperating users' M equal to (1, 2, 6, and 8). From $Q_m - Q_f$ curve, low slopes for $Q_f < 0.1$ can be deduced. With each step increase in SNR values starting from 12 to 22 dB, it can be noticed there is improvement in the probability of missed detection (Q_m).

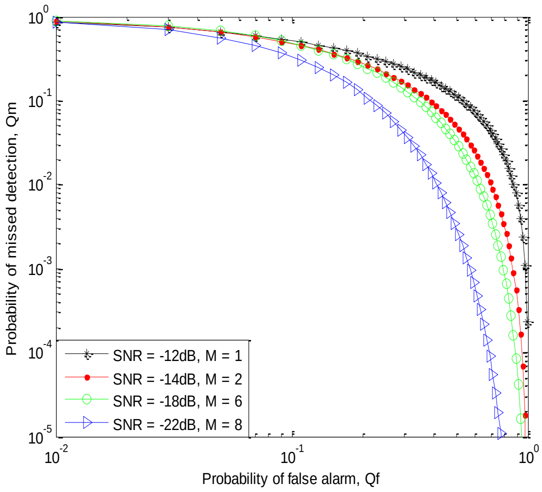

Fig. 8. Complementary ROC curves for the Rayleigh channel at different SNR and M values.

As displayed in **Fig. 9** and **Fig. 10**, it is clear that the detection performance of cooperative spectrum sensing utilizing OR-rule and AND-rule at SNR value are equal to 15 dB and the time-bandwidth product of the energy detector (m = 20) under both AWGN and Rayleigh fading channels.

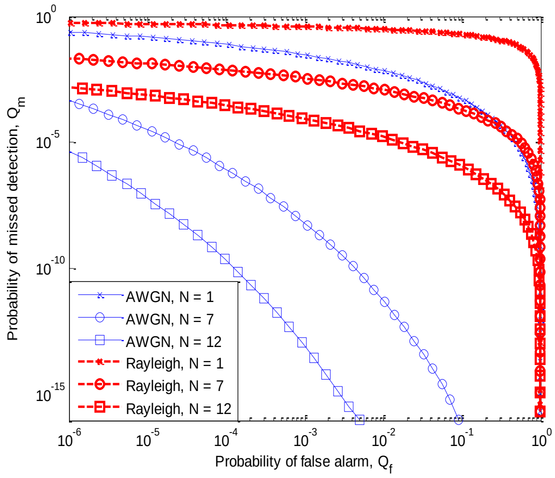

Fig. 9. Complementary ROC curves for cooperative spectrum sensing using OR-rule under AWGN and Rayleigh channel.

Moreover, a great improvement in the detection performance of cooperative spectrum sensing for Rayleigh fading channel compared with AWGN channel can be observed. For the cooperative spectrum sensing (e.g., M = 7 and 12), it does not show any kind of improvement as compared to the detection performance of local sensing (e.g., M=1).

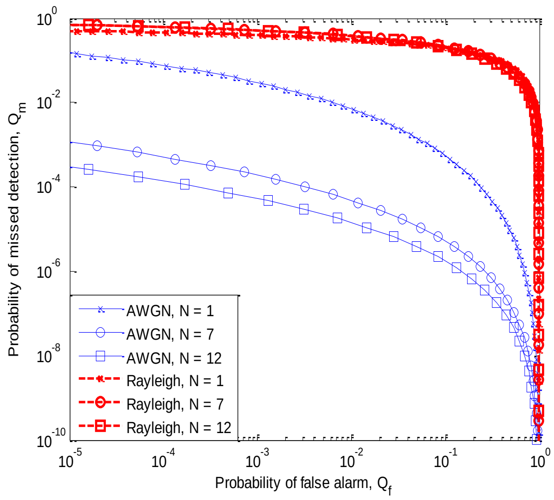

Fig. 10. Complementary ROC curves for cooperative spectrum sensing using AND-rule under AWGN and Rayleigh channel.

The popular k-out-of-n fusion rule is taken into consideration in the cooperative spectrum sensing for the decision fusion strategy, and in particular, the focus is on the OR-rule and AND-rule. While OR-rule always outperforms AND-rule, and in detecting, it is also more capable than AND-rule with error-free reporting channels.

6. Conclusion

This paper provided an evaluation of the detection performance for local spectrum sensing and cooperative spectrum sensing using OR-rule and AND-rule under AWGN and Rayleigh fading channel. Based on this evaluation, it was found that the cooperative spectrum sensing can hardly enhance the detection performance in low SNR environment. In CR perspectives, it is probable that the missed detection of PUs (licensees) by CR users cause severely interference while releasing false alarms by the CR users. This will definitely impact the spectrum accessibility, thus, reducing the throughput of the CR network. In this paper, the energy detector execution of spectrum sensing was evaluated under AWGN and Rayleigh fading environments. It has been found that the cooperative signal detection ensures the improvement of the detection execution by using different data fusion rules. Moreover, the channel behaviour can be more closely modelled by using a complex distribution which provides a description of shadowing and multipath fading. In these scenarios, ROC curve for the Rayleigh case provides a comprehensive picture of the detection performance of the cooperative spectrum sensing system. This paper also assessed the detection performance of a local-sensing CR user in low SNR environments. This assessment showed that the cooperation among CR users can result into significant improvement on the detection performance and compensating the degradation of the spectrum sensing execution caused by the possibly weak PU signals. Finally, the paper provided a verification of the validity of the OR- and AND-fusion schemes which were used for combining the individual decisions of CR users, where the deleterious impact for the fading effectively can be cancels by using these fusion decisions of various secondary users.

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