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Performance Evaluation of Cooperative and Non-cooperative Spectrum Sensing Scheme in Cognitive Radio Network Based on Decision Fusion Strategies

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Abstract— Cognitive Radio (CR) has become a realistic solution of the spectrum scarcity problem for wireless communication. CR is the key technology to use the unused spectrum of primary users (PU) more efficiently via opportunistic spectrum usage. This paper focuses on cooperative spectrum sensing and detecting signal in CR network by implementing hard decision combining in data fusion center (FC). To observe the presence of primary user (PU) energy detector is used in CR network. This paper compares three techniques (AND rule, OR rule and MAJORITY rule) of hard decision fusion scheme to estimate their performance. The OR-rule is appeared to be the highest detection performance in CR network. Those results are further compared to non-cooperative spectrum sensing for evaluating performance. . It has been showed that cooperative spectrum sensing has better performance by providing efficient spectrum's utilization than non-cooperative.

Index Terms— Cognitive radio (CR), Cooperative spectrum sensing, Energy detection, Fusion Center (FC), Hard decision fusion rule, Probability of detection, Probability of false alarm.

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1 Introduction

DUE to the the inadequate use of the radio frequency spectrum, cognitive radio has become the leading technology to utilize the unused radio spectrum .Shortage of frequency spectrum cannot maintain the high requirement of spectrum usage. FCC (Federal Communications Commission) has implied that in a particular location and at particular time the radio frequency spectrum is fully occupied by its primary users (PU) but in some location and at some time it is heavily underutilized [1].CR allows secondary user (SU) to get the chance of using the unused spectrum of primary user (PU) more efficiently. Spectrum sensing is the fundamental function of cognitive radio for improving the spectrum's utilization by detecting spectrum holes. To avoid interference, SU in CR technology, is allowed to use the underutilized spectrum of PU only when PU is not using the spectrum. So, it becomes a critical aspect for cognitive radio to detect the presence of the PU in credible manner. To accomplish better performance for CR, cooperative spectrum sensing is highly required to enhance the probability of detecting PU correctly by minimizing detection time. Fig 1 shows the cooperation of CR network among PU and CR users.

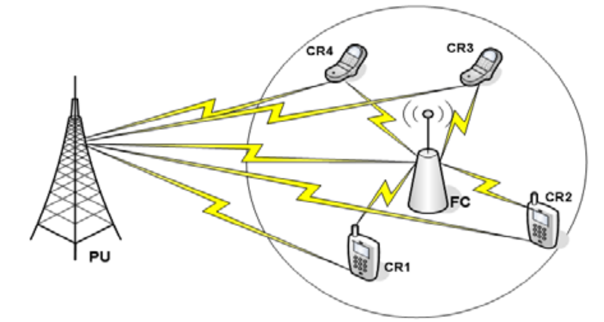

Fig. 1. Cooperative Cognitive Radio Network

The spectrum sensing technique can be divided into three categories [2], [3]: energy detection technique, matched filter detection technique, and cyclostationary detection technique. Among of these techniques, energy detection has been widely utilized as it has not the necessity of any prior knowledge of the primary signals. Cooperative spectrum sensing uses energy detection technique to minimize total error rate in CR network [4]. It has lower complexity than others two techniques. Therefore, energy detection technique is considered in this research. The accuracy of spectrum sensing can be degraded by hidden node problem, fading and shadowing. These problems are mainly resolved by introducing cooperative spectrum sensing in CR network [5].Various elements are required to take into account to carry out cooperative spectrum sensing as shown in Fig. 2.

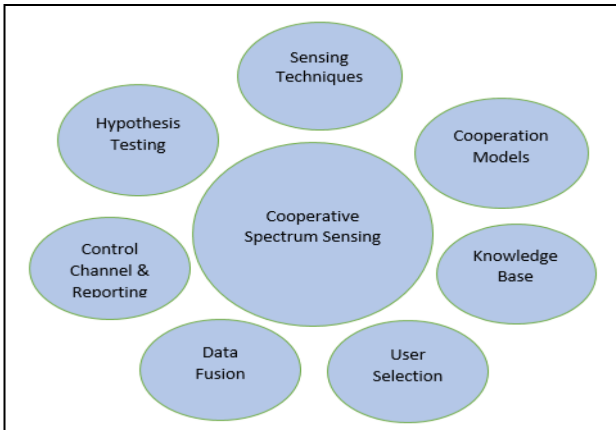

Fig. 2. Elements of Cooperative Spectrum Sensing

In cooperative spectrum sensing, the presence of PU is de-

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cided by the fusion center based on hard decision fusion (HDF) and soft decision fusion (SDF) [6], [7]. In HDF based method, each CR user first turn the local decisions into 1-bit decision and sends a 1- binary decision (1 or 0) regarding the presence or absence of primary user (PU) to the fusion center (FC).In SDF based method, CRs directly send their local observations of the received signals from the primary user (PU) to the fusion center (FC).The hard decision fusion rule (OR, AND, and MAJORITY rule) is performed at fusion center and counting rule is used to make the final decision in regard to whether PU is present or absence [8] , [9]. In this paper, comparative analysis of hard decision fusion rules at the basis of probability of detection, probability of miss detection probability of false alarm, and SNR are accomplished to evaluate the performance of cooperative spectrum sensing.

The rest of this paper is organized as follows. In section II System model related to Cooperative spectrum sensing is presented. In section III Hard decision fusion scheme; OR, AND, MAJORITY rule are described respectively. In Section IV simulation results are given in which different fusion rules are compared. Finally, we draw the conclusion in section V.

2 System Model

The primary goal of Cognitive Radio (CR) is to detect the presence or absence of primary users (PU) accurately in radio frequency spectrum and permit the secondary users (SU) to use the underutilized spectrum more efficiently without causing interference to primary users (PU) [10].Consider a CR network with N Cognitive Radio (CR) Users indexed by $\{n=1, 2,\ldots.N\}$ to sense the licensed frequency spectrum to identify the presence or absence of PU. Each CR independently carries out local spectrum sensing by using K samples of received signal. The local spectrum sensing can be represented by a binary hypothesis .Let $H0$ and $H1$ hypothesis denote absence and presence of PU in Radio frequency spectrum.ncouraged to refer to

$$\mathrm{H0}: y_n(k) = w_n(k) \tag{1}$$

$$\mathrm{H1}: y_n(k) = h_n s(k) + w_n(k) \tag{2}$$

Where $s(k)$ are the samples of the transmitted signal (PU signal), $w_n(k)$ is Additive white Gaussian noise for n^{th} CR user which has zero mean and variance σ^2_k and h_n is the complex gain of channel between PU and n^{th} CR user. Energy detection technique is used by CR user to compute the energy of the received signal (Fig 3). So the n^{th} CR user will calculate the receive energy by the following equation [11].

$$\mathrm{E}_n = \sum\nolimits_1^k y_n^2(k) \tag{3}$$

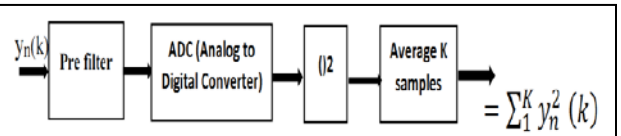

Fig. 3. Energy Detection

Energy detection is a detection technique which is non-coherent. There is need of prior knowledge of the data [12], [13]. The detection is based on the received signal. Energy of the received signal E_n is compared to a predetermined threshold level γ_n .If the energy of received signal E_n exceeds the threshold level γ_n then it is decided that the signal is present otherwise it is absent. The one-bit decision of CR Users represented by β_n, so

$$\beta_n = \{1, \mathrm{E}_n > \gamma_n\} \tag{4}$$

$$\beta_n = \{0, otherwise\} \tag{5}$$

Probability of detection Pd and probability of false alarm Pfa are determined to evaluate detection performance. Pd and Pfa of n^{th} CR user is defined by

$$\mathrm{P}d = \mathrm{P}\{Decision = 1 | \mathrm{H1}\} = \mathrm{P}\{\beta_n = 1 | \mathrm{H1}\} = \mathrm{P}\{E_n > \gamma_n | \mathrm{H1}\} \tag{6}$$

$$\mathrm{P}fa = \mathrm{P}\{Decision = 1 | \mathrm{H0}\} = \mathrm{P}\{\beta_n = 1 | \mathrm{H0}\} = \mathrm{P}\{E_n > \gamma_n | \mathrm{H0}\} \tag{7}$$

Assumed that $\gamma_n = \gamma$ for all CR Users.The probability of detection Pd and probability of false alarm Pfa and Probability of miss detection Pmd over AWGN channel can be formulated by the following equation

$$\mathrm{P}d = Q_b\left(\sqrt{2\eta}, \sqrt{\gamma}\right) \tag{8}$$

$$\mathrm{P}fa = \Gamma(b, \gamma/2)/\Gamma(b) \tag{9}$$

$$\mathrm{P}md = 1 - \mathrm{P}d \tag{10}$$

Where η the signal-to-noise ratio (SNR) is, b is the time bandwidth factor, Q_b (.,.) is called generalized Marcum Q-function, $\Gamma(.)$ and $\Gamma(.,.)$ are complete and incomplete gamma function respectively.

3 Fusion Rules

As In hard decision fusion, each CR user sends one-bit decision to data fusion center by determining the existence of PU. The fusion center (FC) applies a fusion rule and reaches a final decision [14], [15]. Limited amount of bandwidth is required in hard decision fusion method. As 1 bit information is processed in fusion center for spectrum sensing decision, data transmission can be increased in a fixed frame. So using hard decision fusion rule throughput of the system will increase [16]. Three rules AND, OR, MAJOR can be used to make final decision [17].
In Logical AND Rule, FC decides 1 if all local decisions sent to FC from all CR users are 1. By applying this rule probability of false alarm will be minimized but probability of causing interference will be increased. AND rule can be defined as follows:

$$\mathrm{H1}: \sum\nolimits_{n=1}^{N} \beta_n = \mathrm{N} \tag{11}$$

$$\mathrm{H0}: otherwise \qquad (12)$$

In Logical OR Rule, FC decides 1 if any of the local decisions sent to FC from the CR users is 1. By using this rule probability of false alarm will be increased but probability of miss detection will be reduced. OR rule can be defined as follows:

$$\mathrm{H1}: \sum_{n=1}^{N} \beta_n \geq 1 \qquad (13)$$

$$\mathrm{H0}: otherwise \qquad (14)$$

In Half Voting (HV) Rule or MAJORITY Rule, FC decides *1* if local decisions sent to FC from least half of the CR users *(X)* out of all the CR users *(N)* are *1* ,where $1 \leq X \leq N$. MAJORITY rule can be defined as follows:

$$\mathrm{H1}: \sum_{n=1}^{N} \beta_n \geq \mathrm{X} \qquad (15)$$

$$\mathrm{H0}: otherwise \qquad (16)$$

MAJORITY rule is a special case of the voting rule for $X=N/2$. AND rule and OR rule are also special case of the voting rule for $X=N$ and $X=1$.

For MAJORITY rule cooperative detection probability *Qd* and cooperative false alarm *Qfa* can be formulated as where β is the final decision.

$$Qd = P\{\beta = 1 \mid H1\} = P\left\{\sum_{n=1}^{N} \beta_n \geq \mathrm{X} \mid \mathrm{H1}\right\} \qquad (17)$$

$$Qfa = P\{\beta = 1 \mid H0\} = P\left\{\sum_{n=1}^{N} \beta_n \geq \mathrm{X} \mid \mathrm{H0}\right\} \qquad (18)$$

For OR rule where $X=1$ cooperative detection probability *Qd* and cooperative false alarm *Qfa* can be formulated as follows:

$$Qd = 1 - \prod_{n=1}^{N} (1 - \mathrm{P}d) \qquad (19)$$

$$Qfa = 1 - \prod_{n=1}^{N} (1 - \mathrm{P}fa) \qquad (20)$$

AND rule can be defined by setting $X=N$ .Cooperative detection probability *Qd* and Cooperative false alarm *Qfa* can be formulated as follows:

$$Qd = \prod_{n=1}^{N} \mathrm{P}d \qquad (21)$$

$$Qfa = \prod_{n=1}^{N} \mathrm{P}fa \qquad (22)$$

4 SIMULATION AND RESULT

In this section, detection performance of hard combining techniques (AND, OR, MAJOR) are compared with each other through simulations. For the cooperative scenario, we consider 6 CR users performing spectrum sensing by means of 5000 samples of received signal. First we compare the performance of hard combining schemes .Then we compare the three hard combining schemes with non-cooperative spectrum sensing schemes. In Fig. 4. Receiver operating characteristics (ROC)

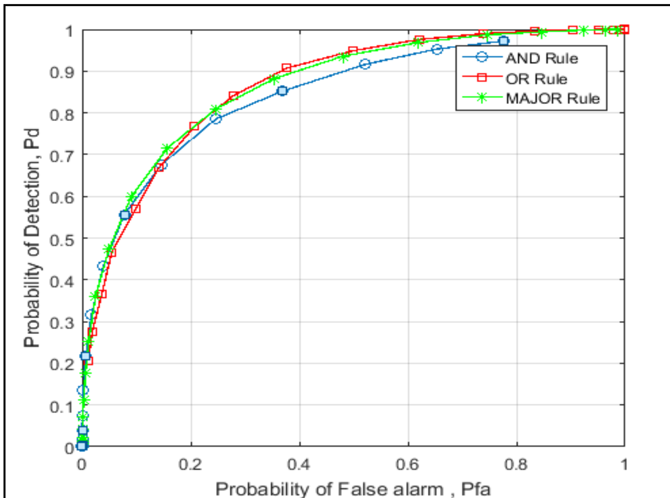

Fig. 4. ROC curve for different hard decision fusion rule for SNR =-8dB

curve for hard combining schemes for a signal to noise ratio (*SNR*) of -8dB are presented where AND, OR, MAJOR rule are compared each other . It can be seen that AND rule minimizes *Pfa* though it decreases the value of *Pd*. OR rule offers highest value of *Pd* but it increases the value of *Pfa* while MAJORITY rule offers an intermediate solution. OR rule has better detection performance than AND and MAJORITY rule. Complementary ROC curve for comparing hard combining schemes in terms of *Pfa* and *Pmd* is shown in Fig. 5. *Pmd* is defined as

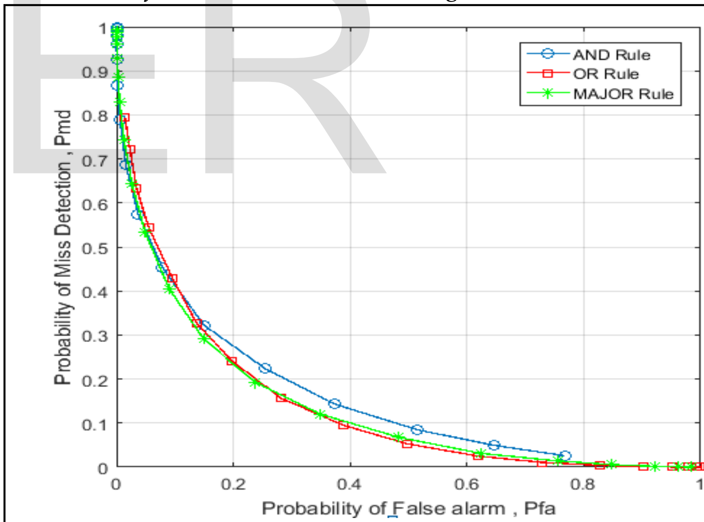

Fig. 5. Complementary ROC curve for different hard decision fusion rule for SNR =-8dB

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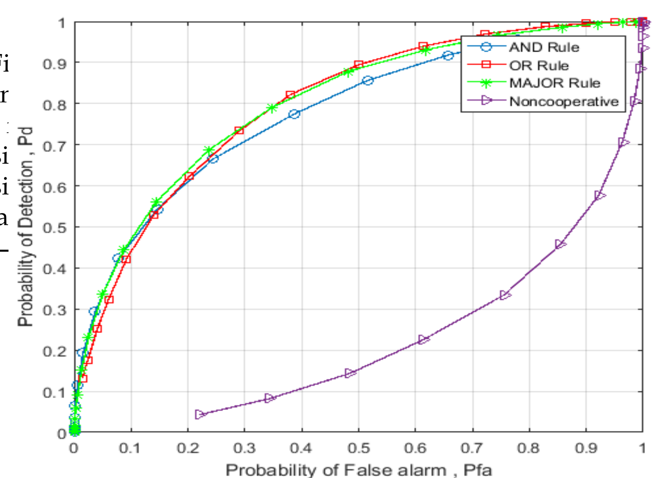

In Fig 7, complementary ROC curve for comparing different hard decision fusion rule with non-cooperative sensing in terms of *Pma* and *Pfa* are shown.

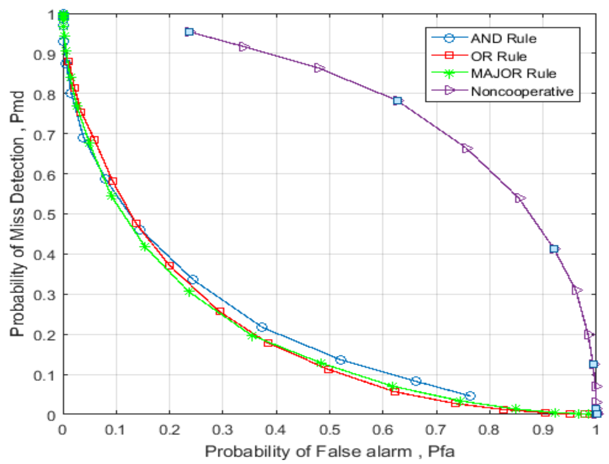

Fig. 7. Complementary ROC curve of comparing different hard decision fusion rule with non-cooperative sensing for SNR =-8dB

Fig 8 shows the performance of hard decision fusion rules with different SNR values and a fixed value of *Pfa* =0.02.With higher SNR levels every technique shows better performance. The OR rule shows better performance as it has highest value of *Pd*.

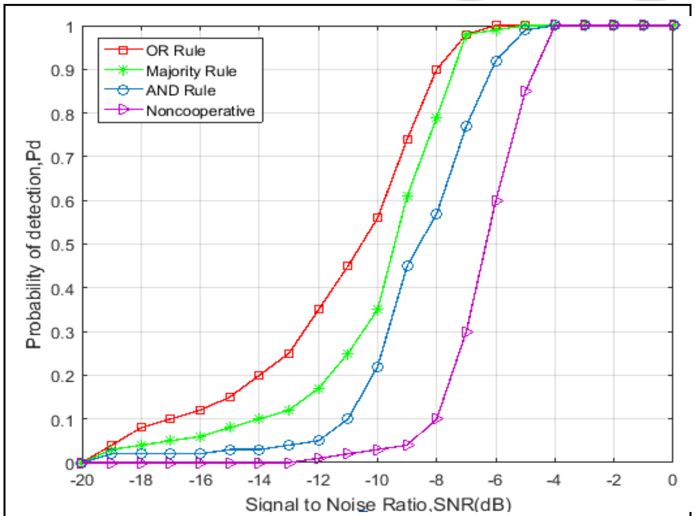

Fig. 8: Performance comparison of hard decision fusion rules with different SNR and Pfa =0.02

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5 Conclusion

This paper focuses on the performance evaluation of cooperative spectrum sensing based on hard decision fusion rule (AND, OR and MAJORITY rule) with non-cooperative spectrum sensing. In cooperative spectrum sensing AND, OR and MAJORITY rule are assigned to assess the system performance by probability of detection (*Pd*) ,probability of false alarm (*Pfa*) ,probability of miss detection (*Pma*) and *SNR* metric. From the numeric results of the simulations it can be said that that cooperative spectrum sensing shows better performance in comparison to non-cooperative one and applying OR rule can enhance the probability of detection than AND and MAJOR rule at different SNR values. This paper evaluated the detection performance at a low SNR. This evaluation showed that cooperation among CR users can result in momentous enhancement on the detection performance.

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