Hard Combination Data Fusion for Cooperative Spectrum Sensing in Cognitive Radio

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ABSTRACT

This paper presents a study of hard combination data fusion for cooperative spectrum sensing in Cognitive Radio (CR). We evaluated the performance of cooperative spectrum sensing with the hard combination OR, AND and MAJORITY rules. Energy detection technique is used to sense the presence of primary user (PU) signal. Simulation result shows that cooperative spectrum sensing with OR rule is the best among hard combination data fusion in Cognitive Radio and gives the better performance than AND and MAJORITY rules.

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1. INTRODUCTION

In recent years, cognitive radio (CR) has emerged as a promising paradigm for exploiting the spectrum opportunity, which is restricted by the current rigid spectrum allocation scheme, to solve the spectrum scarcity problem [1][2]. One of the fundamental challenges in spectrum sensing is to reliably detect the primary users (PUs) signals. A number of different techniques have been proposed for identifying the presence of the PU. The existing spectrum sensing techniques can be broadly divided into three categories [2]: cyclostationary detection, matched filter detection and energy detection. Among them, energy detection has been widely applied since it does not require any a priori knowledge of the primary signals and has much lower complexity than the other two schemes. But spectrum sensing is a tough task because of shadowing, fading, and time-varying natures of wireless channels. To combat these impacts, cooperative spectrum sensing schemes have been proposed to obtain the spatial diversity in multiuser CR networks [5]–[8]. In cooperative spectrum sensing, information from different CR users is combined to make a decision on the presence or absence of the primary user. Cooperation among CR user is usually coordinated by a fusion center through hard or soft decision fusion strategies. In hard decision technique the individual CR user makes the one-bit decision regarding the existence of the PU. The bit-1 indicates the presence of PUs. After observing the PU signal, the local detection forwards them to data fusion centre for further process. The final decision then is taken by combining all local detection based on predefined rules. In the case of soft decision, the decision is taken by correlating the measurement made by individual users in signal detection. This paper considers the performance of hard decision fusion rules based on the AND, OR and MAJORITY rules. The performance of these fusion rules is evaluated under AWGN channels.

The rest of this letter is organized as follows. In section II a basic system model of energy detection is presented. Hard combination scheme with AND, OR and MAJORITY rules were discussed on section III. Section IV discusses the simulation result and finally conclusion is drawn in section V.

2. SYSTEM MODEL

The energy detector consists of a square law device followed by a finite time integrator (Figure 1). The noise pre-filter serves to limit the noise bandwidth and to select the bandwidth of interest. The noise at the input to the squaring device has a band-limited, flat spectral density [9]. The output of the integrator at any time is the energy of the input to the squaring device over the interval *T* in the past.

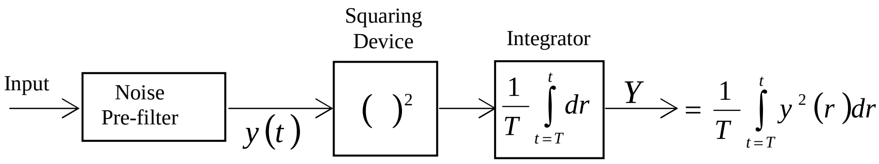

Figure. 1 Energy Detection

Finally, this output signal *Y* is compared to the threshold in order to decide whether a signal is present or not. The threshold is set according to statistical properties of the output *Y* when only noise is present.

Consider a CR network with *N* cooperative users and *M* samples are utilized. The energy detection [13] [14] is applied at each CR user. The received signal at the *i*th sample of the *j*th CR user r_{ji}, $1 \leq j \leq N$, $1 \leq i \leq M$, is given by

$$r_{ji} = \begin{cases} n_{ji,} & H_0 \\ \sqrt{\gamma_j}\, s_{ji} + n_{ji}, & H_1 \end{cases} \tag{1}$$

where $\sqrt{\gamma_j}\, s_{ji}$ denotes the received primary signal with the average power γ_j and n_{ji} denotes the white noise. In eq. 1, H_0 and H_1 denote the hypotheses corresponding to the absence and presence of the primary signal respectively. The goal of energy detection is to decide between the two hypotheses. The received signal r_{ji} is Gaussian with [15],

$$r_{ji} \approx \begin{cases} N(0,1), & H_0 \\ N(0,1+\gamma_j), & H_1 \end{cases} \tag{2}$$

According to eq. 2, the observed energy in at the *j*th CR user is given by [15]

$$Y_j = \sum_{i=1}^{M} r_{ji}^{\ 2} = \begin{cases} b_{j0,} & H_0, \\ (1+\gamma_j) b_{j1}, & H_1, \end{cases} \tag{3}$$

where random variables b_{j0} and b_{j1} follow a central chi-square distribution with *M* degrees of freedom. Let λ be the local decision threshold for each CR user, then the local false alarm probability P_f and detection probability P_f can be obtained from eq. 3 as,

$$P_d = \Pr(Y > \lambda \mid H_1) = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{4}$$

$$P_f = \Pr(Y > \lambda \mid H_0) = \frac{\Gamma\left(u, \frac{\lambda}{2}\right)}{\Gamma(u)} \tag{5}$$

where $\Gamma(\cdot)$, $\Gamma('.')$, γ and Q_u denote the gamma function, upper incomplete gamma function, signal to noise ratio (SNR) and generalized Marcum's Q function respectively.

3. HARD COMBINATION METHOD

In the hard combination scheme, local decisions of the CR user are sent to the decision maker. Every CR user first performs local spectrum sensing and makes a binary decision on whether a signal of interest is present or not by comparing the sensed energy with a threshold. All CR users send their one-bit decision result to the decision maker. Then, a final decision on the presence of the signal of interest is made by the decision maker in described [12]. 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 *n* out of the *M* local decisions indicate H_1. Assuming uncorrelated decisions, the probability of detection at the fusion center [13] is given by

$$P_d = \sum_{n}^{M} \binom{M}{k} P_{d,i}{}^{k} \left(1 - P_{d,i}\right)^{M-k} \tag{6}$$

where $P_{d,i}$ is the probability of detection for each individual node.

3.1. Logical-and rule

In this rule, if all of the local decisions sent to the decision maker are one, the final decision made by the decision maker is one. The fusion center's decision is calculated by logic AND of the received hard decision statistics. Cooperative detection performance with this fusion rule can be evaluated [13] by setting *n*=*M* in eq. (6).

$$P_{d,AND} = P_{d,i}{}^{M} \tag{7}$$

3.2. Logical-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 [13] by setting *n*=1 in eq. (6).

$$P_{d,OR} = 1 - \left(1 - P_{d,i}\right)^{M} \tag{8}$$

3.3. Logical-majority rule

In this rule, if half or more of the local decisions sent to the decision maker are the final decision made by the decision maker is one. Cooperative detection performance with this fusion rule can be evaluated [13] by setting $n = \lfloor M/2 \rfloor$ in eq. (6).

$$P_{d,MAJ} = \sum_{\lfloor M/2 \rfloor}^{M} \binom{M}{k} P_{d,i}{}^{k} \left(1 - P_{d,i}\right)^{M-k} \tag{9}$$

where $\lfloor . \rfloor$ represents the floor operator.

4. SIMULATION RESULT

All simulation was done on MATLAB version R2011a under AWGN channel by taking time bandwidth factor u=1000, observing signal samples N= 2000 and probability of false alarm is used from 0.01 to 1 by increasing 0.01, where 100 Pfa is used. By setting n=M for AND rule, n=1 for OR rule and n=M/2 for MAJORITY rule are used in eq. (6) for all the simulation.

Fig. 2 shows complementary ROC of cooperative spectrum sensing with 2(a) AND, 2(b) OR and 2(c) MAJORITY rules with 10 CR users and SNR=15dB. Simulation result shows that the performance of the AND & MAJORITY rules providing approximately same at low Pfa before 0.5. When Pfa is about 0.5 then performance of OR is better than AND & MAJORITY rules. After this Pfa to 1, performance of MAJORITY rule is better than AND rule and considerably worse than OR rule.

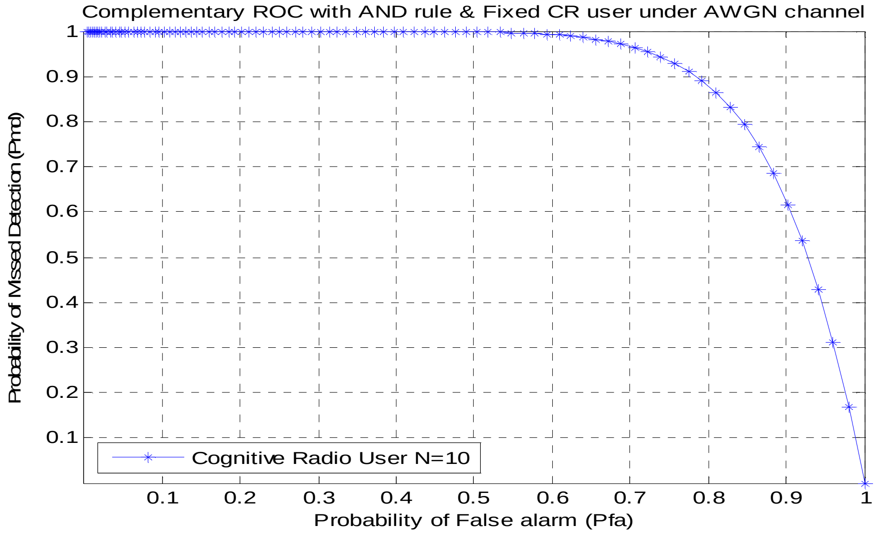

Fig. 2(a) Complementary ROC with AND rule and N=10.

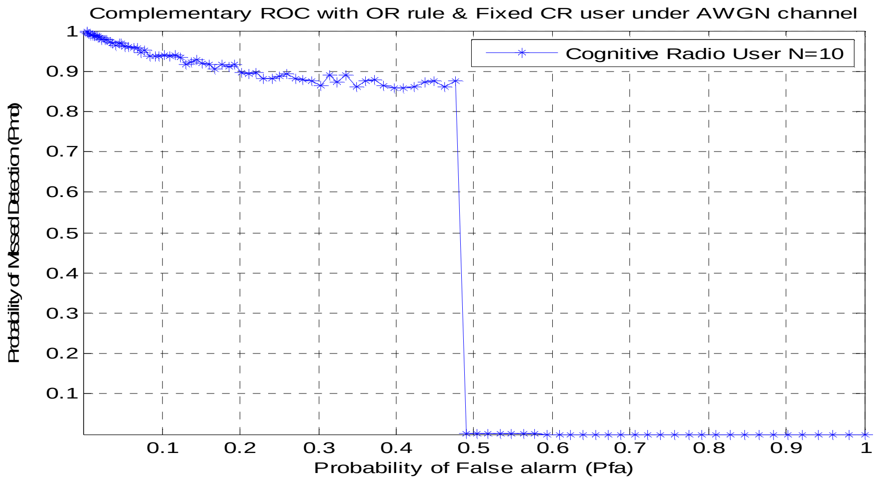

Fig. 2(b) Complementary ROC with OR rule and N=10.

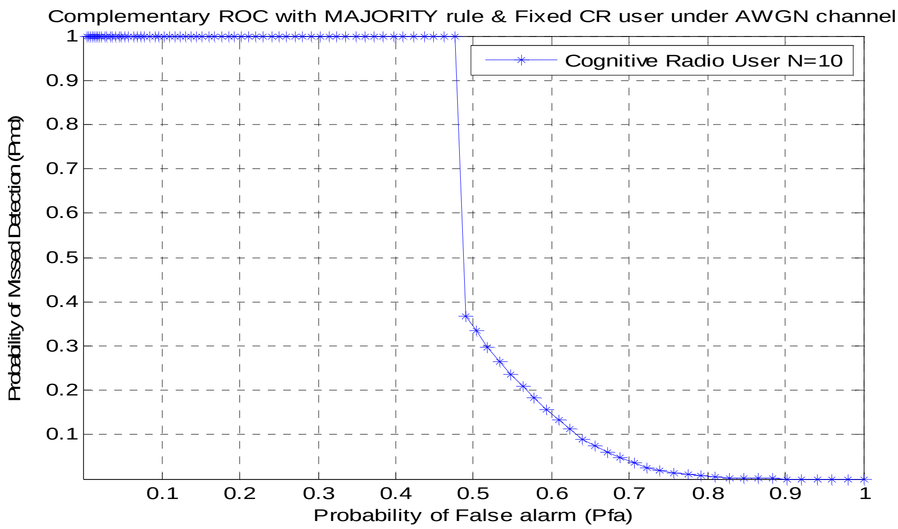

Fig. 2(c) Complementary ROC with MAJORITY rule and N=10.

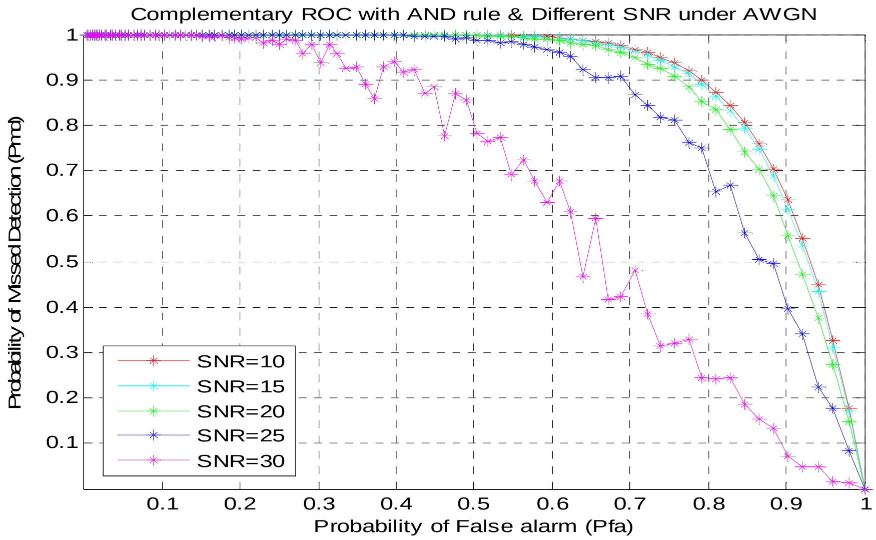

Fig. 3(a) Complementary ROC with AND rule and different SNR.

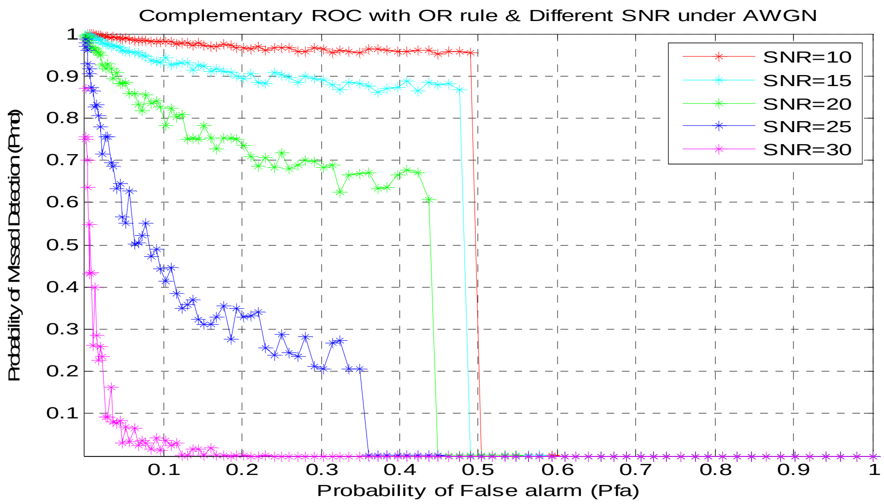

Fig. 3(b) Complementary ROC with OR rule and different SNR.

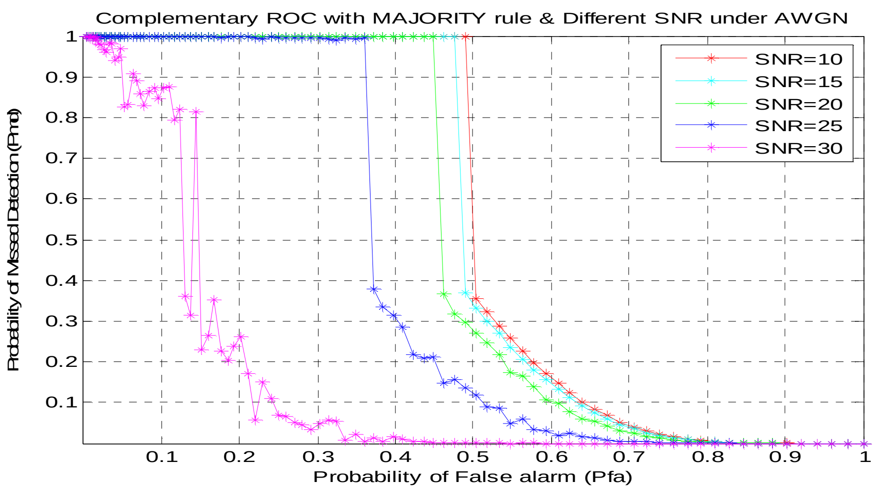

Fig. 3(c) Complementary ROC with MAJORITY rule and different SNR.

Fig. 3 shows complementary ROC of cooperative spectrum sensing with 3(a) AND, 3(b) OR and 3(c) MAJORITY rules with 10 CR users where SNR are 10dB, 15dB, 20dB, 25dB and 30dB. Simulation result show that probability of missed detection is decreasing when SNR increases. The probability of missed detection is approximately same among 10dB, 15dB and 20dB, but it abruptly changes in case of 25dB and 30dB. So SNR influences on the detection probability. For different number of SNR changes this characteristic significantly. The performance of the OR rule providing better performance at various SNR than AND & MAJORITY rules. The performance of MAJORITY rule is better than AND rule and considerably worse than OR rule.

Fig. 4 shows complementary ROC of cooperative spectrum sensing with 4(a) AND, 4(b) OR and 4(c) MAJORITY rules with SNR=15dB, CR user are N=5, 10, 25, 50 and 100. Simulation result shows that probability of missed detection for AND rule is increased when the CR user also increased. In OR rule, the missed detection is decreasing even CR users increase. For different number of CR users, the detection performance of OR is better than MAJORITY rule.

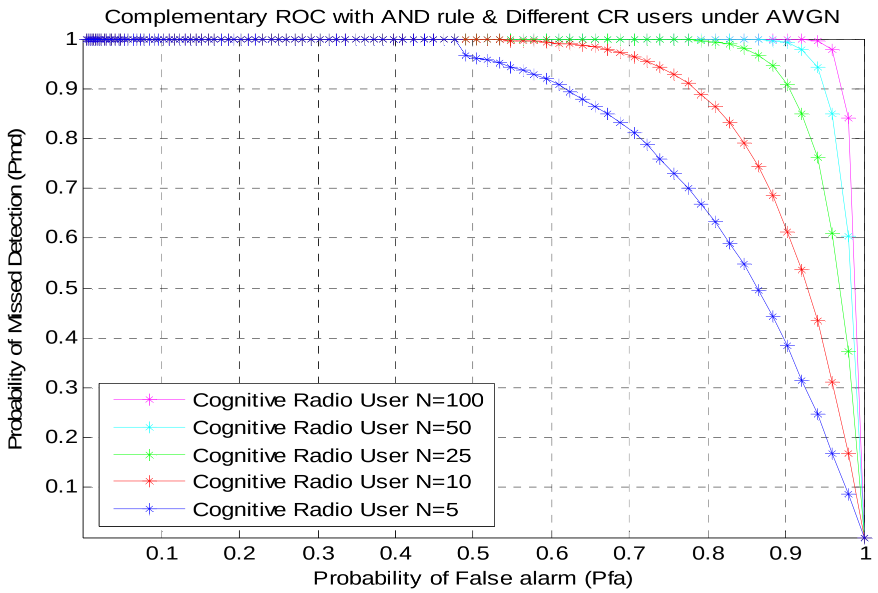

Fig. 4(a) Complementary ROC with AND rule and different CR user.

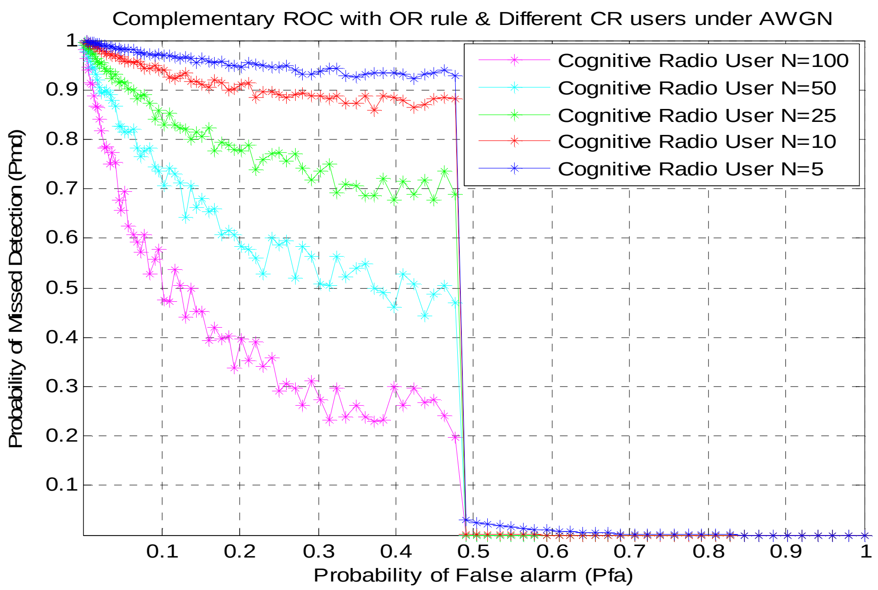

Fig. 4(b) Complementary ROC with OR rule and different CR users.

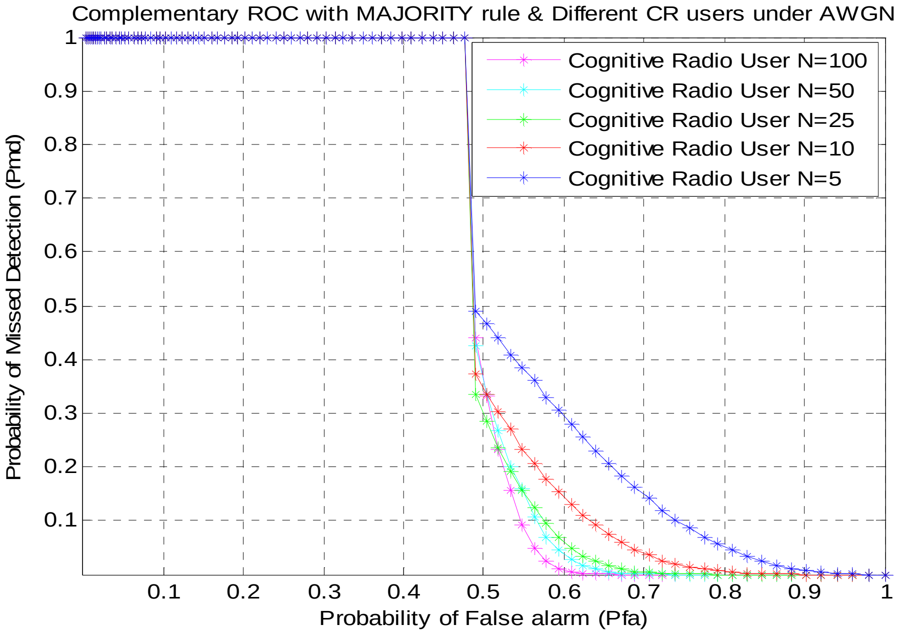

Fig. 4(c) Complementary ROC with MAJORITY rule and different CR users.

5. CONCLUSION

In this paper, the performance of cooperative spectrum sensing has been studied with hard combination fusion rules. Simulation result shows that the probability of missed detection for AND rule is increased when the CR user also increased. In OR rule, the probability of missed detection is decreasing even though CR users increase. The performance of the MAJORITY fusion rule is considerably worse but much better than the performance of the AND rule. So OR rule is the best among hard combination data fusion for cooperative spectrum sensing in Cognitive Radio and gives the better performance than AND & MAJORITY rules.

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