A Cooperative Spectrum Sensing Scheme with an Adaptive Energy Threshold in Cognitive Radios

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***Abstract*—Cognitive radio (CR) technique is a useful tool for improving spectrum utilization by detecting and using the vacant frequency bands while avoiding interference to the primary user. The sensing performance in a CR network can be improved by allowing some CR users to perform cooperative spectrum sensing. In this paper, we propose a new sensing algorithm that utilizes an adaptive energy threshold for cooperative spectrum sensing in which a changeable energy threshold is adopted by the CR users for improving local sensing performance. Through the proposed scheme, the reliability of global decision can be enhanced mainly due to the improvement in local sensing performance.**

***Index Terms*—Cognitive radio, cooperative spectrum sensing, adaptive energy threshold.**

I.INTRODUCTION

WIRELESS communication has become an essential technology in the *21st* century. This technology is now applied to various fields, e.g., education, health, entertainment, and the military, which requires more frequency band and higher bit rate. However, because of the limited frequency resource and inefficiently utilized spectrum, it is necessary to use frequency band more efficiently.

Recently, CR technology has been proposed due to its efficient utilization of the frequency bands where both unlicensed and licensed users, called the CR user and the Primary User (PU) respectively, operate. Normally, an available vacant frequency from a PU can be detected and can be used by CR users. Otherwise, CR users should vacate their frequency when the presence of a PU is detected.

In order to ascertain the presence of a PU, CR users can use one of several common detection methods such as the following: matched filter detection, feature detection, energy detection, etc. [1], [2]. Among these detection methods, the optimal method would be energy detection [2] when the CR user has limited information about the signals of the PU (e.g., only the local noise power is known).

In the energy detection method, the frequency energy in the sensing channel is received in a fixed band width W over an observation time window T to compare with the energy threshold and further to decide whether or not the channel is utilized. However, the received signal power may severely fluctuate due to the effect of multipath fading and the shadow. Therefore, it is difficult to reach high reliable detection with only one CR user. Fortunately, we can obtain better usage detection by allowing some CR users to perform cooperative spectrum sensing [3], [4].

There are some common decision fusion rules such as Or-rule, And-rule, Half-Voting rule and Chair-Varshney rule [5] in which Chair-Varshney rule is considered as the optimal rule in the case of hard-decision. However, all most of these rules considered the fixed threshold for energy detection in local decision, which cannot improve the global sensing performance of cooperative spectrum sensing. In order to improve global sensing performance of a CR network, in this paper, we propose an adaptive energy threshold for cooperative spectrum sensing. In the proposed scheme, the energy threshold is changed adaptively according to the current local decision and the status of the PU that will be estimated at the FC. By this way, the proposed scheme can adapt to the fluctuation of the received signal power and further the local sensing performance can be improved. At the FC, all local decisions will be integrated to make a global decision by using Chair-Varshney rule. As a result, the global sensing performance is also enhanced because of the improvement in local sensing performance.

II. ADAPTIVE ENERGY THRESHOLD FOR COOPERATIVE SPECTRUM SENSING

We consider a CR network with n CR users. It is assumed that all CR users make a local decision on the presence of a PU using energy detection method, and that the status of the PU is not changed during the detection interval which is consisted of k sensing samples. Fig. 1 shows the flow chart of the proposed scheme which entails four steps discussed below:

Manuscript received June 11, 2011; revised July 17, 2011; accepted July 29, 2011.

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Step 1, making local and the temporary global decision. At the i^{th} sensing sample, the j^{th} CR user makes local decisions $g(i, j)$ and transmits this local decisions to FC, where i is index of sensing sample $(i = 1, 2,..., k)$ in the detection interval, and j is index of CR users $(j = 1, 2,..., n)$. After that, the FC combines all received local decisions for the i^{th} sensing sample into the temporary global decision $B_1(i)$.

After *step 1*, the *correct condition* will be analyzed to decide whether the sensing process goes to *step 2* or *step 3*. If more than *80* percent of the CR users have the same decision as the temporary decision, we assume that the temporary decision is reliable. Subsequently, this decision will be used to update the energy threshold in *step 2*. Otherwise, the temporary decision is considered unreliable and will be updated in *step 3*.The correct condition is illustrated in Fig. 2.

Step 2, updating energy threshold thr(i+1, j). In this step, the temporary decision is presumed to be reliable according to the correct condition. Therefore, any local decision which is different to temporary global decision is presumed to be incorrect and its corresponding energy threshold needs to be updated.

Step 3, updating temporary decision $B_1(i)$. In this step, $B_1(i)$ is presumed to be incorrect according to the correct condition. Therefore, $B_1(i)$ need to be updated by using Chair-Varshney rule [5] and the i^{th} local decisions from CR users.

Step 4, determining the global decision B. After performing k times sensing in the detection interval for a global decision, the FC will combine temporary decisions to make a final global decision by using Chair-Varshney rule [5].

The process of the proposed scheme is explained in more details in the following sub-sections.

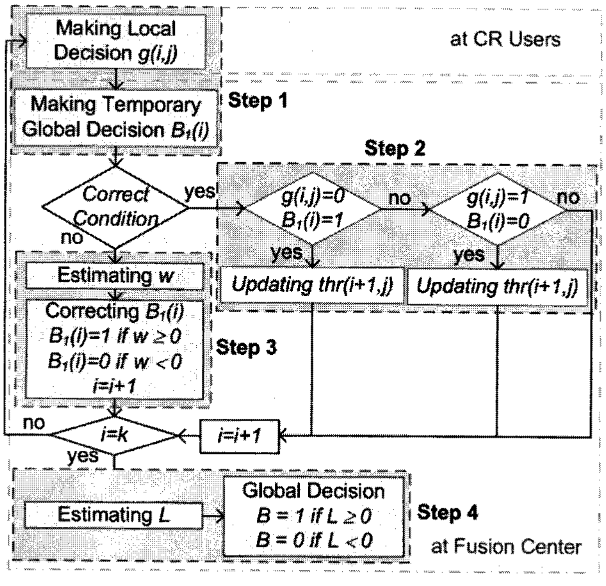

Fig. 1. The flow chart of the proposed scheme.

A. Making Local and Temporary Global Decision

Firstly, all CR users perform local observations to make local decisions. For the j^{th} CR user in the i^{th} sensing sample, the received signal energy is denoted by $E(i,j)$. Thereby, the local decision $g(i,j)$ will be determined by the following logic function :

$$\begin{cases} g(i,j)=1, \text{ if } E(i,j) \geq thr(i,j) \\ g(i,j)=0, \text{ if } E(i,j) < thr(i,j) \end{cases} \tag{1}$$

where $thr(i,j)$ is the local decision threshold of the j^{th} CR user for the i^{th} sensing sample.

As an initial energy threshold for the first sensing sample of each detection interval in the j^{th} CR user, the optimal energy threshold in the case of fixed threshold which minimizes the probability of error $P_{e,fix}(j)$ will be utilized. Subsequently, the initial energy threshold for the first sensing sample of each detection interval in the j^{th} CR user will be set as follows:

$$thr_{initial}(j) = \arg\min_{thr_{fix}(j)} (P_{e,fix}(j)) \tag{2}$$

where $P_{e,fix}(j) = 1 - P_{d,fix}(j) + P_{f,fix}(j)$, and $P_{d,fix}(j)$ and $P_{f,fix}(j)$ are given as following way [6]:

$$\begin{aligned} P_{d,fix}(j) &= \text{Prob}\{E(i,j) \geq thr_{fix}(j) | H_1\} \\ &= Q_u\left(\sqrt{2\gamma_j}, \sqrt{thr_{fix}(j)}\right) \end{aligned} \tag{3}$$

$$\begin{aligned} P_{f,fix}(j) &= \text{Prob}\{E(i,j) \geq thr_{fix}(j) | H_0\} \\ &= \frac{\Gamma\left(u, \frac{thr_{fix}(j)}{2}\right)}{\Gamma(u)} \end{aligned} \tag{4}$$

where γ_j denotes the instantaneous SNR of the j^{th} CR user, $\Gamma(a, x)$ is the incomplete gamma function and is given by $\Gamma(a,x) = \int_x^{\infty} t^{a-1} e^{-t} dt$. Γ(a) is the gamma function, and $Q_u(a,b)$ is the generalized Marcum Q-function which is given by $Q_u(a,x) = \frac{1}{a^{u-1}} \int_x^{\infty} t^u e^{-\frac{t^2+a^2}{2}} I_{u-1}(at) dt$. $I_{u-1}(.)$ is the modified Bessel functions of the first kind and order $u-1$ and $u=TW$ is the time-bandwidth product.

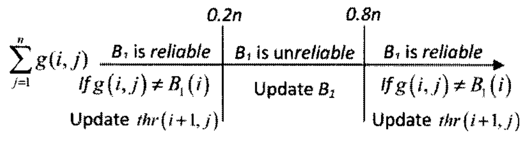

Fig. 2. Illustration of *correct condition.*

Secondly, the temporary global decision at the i^{th} sensing sample in the FC is determined by fusing all received local decisions from n CR users according to the following half-voting rule:

$$\begin{cases} B_1(i) = 1, \ \sum_{j=1}^{n} g(i,j) \geq \frac{n}{2} \\ B_1(i) = 0, \ otherwise \end{cases} \tag{5}$$

B. Updating the Adaptive Energy Threshold

When more than *80* percent of CR users have the same decision as the temporary decision, then we assume that the temporary decision is reliable and that all CR users which have local decision different to the temporary global decision are incorrect. There are two cases of incorrect decision as follows:

Case 1: The local decision of CR user is H_0 and the temporary decision is H_1. In this case, the energy threshold of this CR user is presumed to be high compared with the collected energy. Subsequently, we will reduce the energy threshold as follows:

$$thr(i+1,j) = thr(i,j) - (thr(i,j) - E(i,j))z \tag{6}$$

where z, *adaptive index,* will be chosen based on experiments of the system.

Case 2: The local decision of the CR user is H_1 and the temporary decision is H_0. In this case, the energy threshold is presumed to be low compared with the collected energy. Subsequently, we will increase the energy threshold as follows:

$$thr(i+1,j) = thr(i,j) + (E(i,j) - thr(i,j))z \tag{7}$$

C. Updating Temporary Global Decision

In this step, the temporary decision will be updated by using Chair-Varshney Rule, which is expressed by the logic functions below:

$$\begin{cases} B_1(i) = 1, \ if \ w = w_0 + \sum_{j=1}^{n} w_j \geq 0 \\ B_1(i) = 0, \ otherwise \end{cases} \tag{8}$$

Where

$$w_0 = \log\frac{P(H_1)}{P(H_0)} \tag{9}$$

$$w_j = \begin{cases} \log\frac{P(g(i,j)=1|H_1)}{P(g(i,j)=1|H_0)}, & if \ g(i,j)=1 \\ \log\frac{P(g(i,j)=0|H_1)}{P(g(i,j)=0|H_0)}, & if \ g(i,j)=0 \end{cases} \tag{10}$$

In general, it is difficult to calculate exact values for w_0 and w_j. In this paper, we propose estimating them as following ways:

- *Estimating the value of w_0.*

Let's define n_{H1} and n_{H0} as the times that H_1 and H_0 occupy in history of temporary global decision B_1 respectively. As a result, the value of w_0 can be estimated as follows:

$$w_0 = \log\frac{P(H_1)}{P(H_0)} \approx \log\frac{n_{H_1}}{n_{H_0}} \tag{11}$$

- *Estimating the value of w_j.*

For the j^{th} CR user, let D_{11} and D_{10} denote the state of current local decision $g(i,j)$, and d_{11} and d_{10} denote the corresponding times that D_{11} and D_{10} have been achieved. D_{11} and D_{10} are defined as follows:

$$\begin{cases} D_{11} : g(i,j) = 1 \ and \ B_1(i) = 1 \\ D_{10} : g(i,j) = 1 \ and \ B_1(i) = 0 \end{cases} \tag{12}$$

Then, the values of w_j can be estimated as follows:

$$w_j \approx \begin{cases} \log\frac{d_{11}.n_{H_0}}{d_{10}.n_{H_1}}, & if \ g(i,j)=1 \\ \log\frac{1-\frac{d_{11}}{n_{H_1}}}{1-\frac{d_{10}}{n_{H_0}}}, & if \ g(i,j)=0 \end{cases} \tag{13}$$

D. Determining Final Global Decision

After performing k times sensing for each detection interval, we obtain k temporary decisions. All of the k decisions will be combined into a global decision by using Chair-Varshney Rule. Subsequently, we have:

$$\begin{cases} B = 1, \ if \ L = L_0 + \sum_{i=1}^{k} L_i \geq 0 \\ B = 0, \ otherwise \end{cases} \tag{14}$$

Where

$$L_0 = \log\frac{P(H_1)}{P(H_0)} \tag{15}$$

$$L_i = \begin{cases} \log\frac{P(B_1(i)=1|H_1)}{P(B_1(i)=1|H_0)}, & if \ B_1(i)=1 \\ \log\frac{P(B_1(i)=0|H_1)}{P(B_1(i)=0|H_0)}, & if \ B_1(i)=0 \end{cases} \tag{16}$$

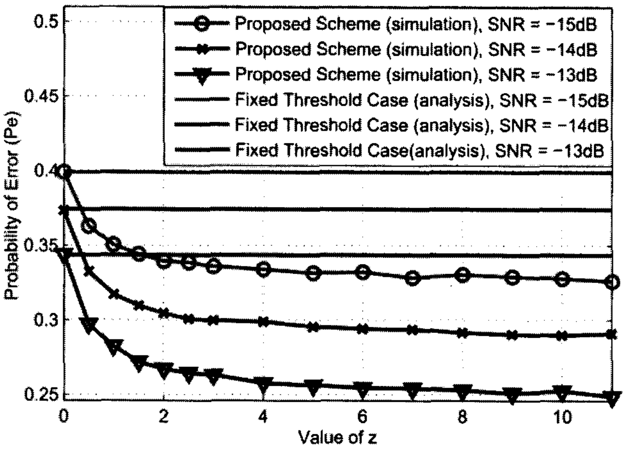

Fig. 3. Error probability at the CR User.

In order to estimate the values of L_0 and L_i, we define a new variable B_{11}, which can be determined as follows:

$$\begin{cases} B_{11}=1, & \sum_{i=1}^{k} B_1(i) \geq \frac{k}{2} \\ B_{11}=0, & otherwise \end{cases} \tag{17}$$

For the i^{th} sensing sample, let S_{mn} denote the state of current temporary decision where $S_{mn} \in \{S_{11}, S_{10}, S_{01}, S_{00}\}$. S_{mn} is defined as follows:

$$\begin{cases} S_{11}: B_1(i)=1 \; and \; B_{11}=1 \\ S_{10}: B_1(i)=1 \; and \; B_{11}=0 \\ S_{01}: B_1(i)=0 \; and \; B_{11}=1 \\ S_{00}: B_1(i)=0 \; and \; B_{11}=0 \end{cases} \tag{18}$$

Let b_{11}, b_{10}, b_{01} and b_{00} represent the times that S_{11}, S_{10}, S_{01} and S_{00} have appeared in the history of B_1, respectively. Eventually, the estimated value of L_i and L_0 can be expressed according to below equations, respectively.

$$L_0 \approx \log \frac{b_{11}+b_{01}}{b_{10}+b_{00}} \tag{19}$$

$$L_i \approx \begin{cases} \log \dfrac{b_{11}.(b_{10}+b_{00})}{b_{10}.(b_{11}+b_{01})}, & if\, B_1(i)=1 \\ \log \dfrac{1-\dfrac{b_{11}}{b_{11}+b_{01}}}{1-\dfrac{b_{10}}{b_{10}+b_{00}}}, & if\, B_1(i)=0 \end{cases} \tag{20}$$

With the estimated values of L_0 and L_i, a global decision B will be made according to the Eqn. (14).

III. SIMULATION RESULTS

In the section, the simulation results of the sensing performance for the proposed scheme are analyzed in a specific CR user (the j^{th} CR user) as well as in the FC. We consider a CR network including *ten* CR users with same SNR between each CR user and the PU. We also test *50.000* detection intervals where each detection interval is consisted of *8* sensing samples.

The local sensing performance at a CR user is how in Fig.3 where analytic results of error probability for the fixed energy threshold case and simulation results of error probability for the adaptive energy threshold case are shown according to different values of *z*. The figure illustrates the superior local performance of the proposed scheme in all cases. The figure shows that the local performance improves as *z* increases. However, it is noteworthy that the local performance of the proposed scheme flows when *z* more than *7* is used. In order to analyze the global sensing performance in the FC, subsequently we have selected *z=7*.

Fig.4 shows detection and false alarm probability of global detection at the FC, where Or-Rule, And-Rule, Half-Voting Rule and Chair-Varshney rule [5] are considered for performance comparisons. From Fig.4, it is observed that our proposed scheme can achieve better sensing performance comparison with Chair-Varshney rule by applying adaptive energy threshold for each CR user.

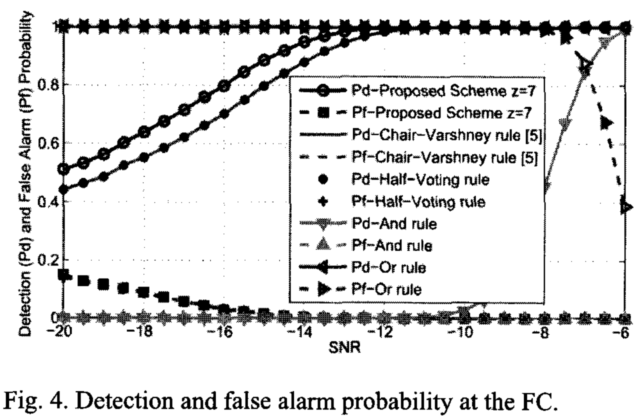

Fig. 4. Detection and false alarm probability at the FC.

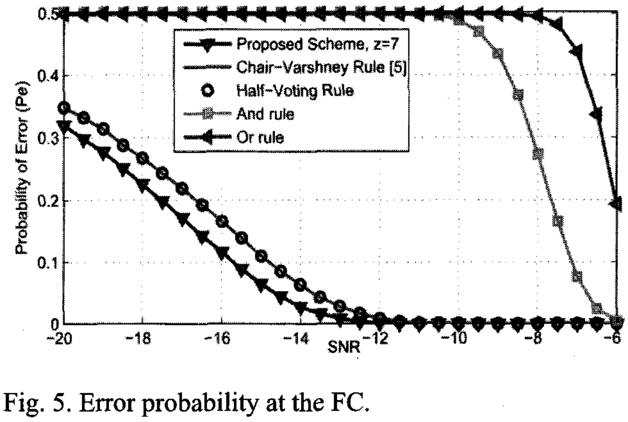

Fig. 5. Error probability at the FC.

Fig.5 shows that the proposed scheme also gets the best sensing performance in term of error probability of global decision at the FC.

IV. CONCLUSION

In this paper, the proposed scheme has focused on adaptive energy threshold in the energy detection method to improve the sensing performance of cooperative spectrum sensing in a CR network. The simulation results have demonstrated that the proposed scheme can improve the reliability of local sensing in the CR users and the global sensing performance at the FC is also improved.

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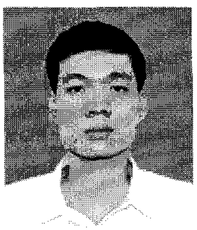

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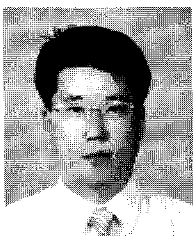

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