An Improved Cluster-Based Cooperative Spectrum Sensing Algorithm

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***Abstract*—These instructions give you basic guidelines for preparing camera-ready papers for AP's journals In the traditional cluster-based collaboration spectrum sensing algorithm, judgment threshold is only related to the false alarm probability. Besides, the cluster head use a simple OR-rule to execute information fusion, which limits the sensing performance to some extent. In this thesis, we propose an improved cluster-based cooperative spectrum sensing algorithm. The judgment thresholds are adjusted based on channel conditions, which can improve the local sensing performance. The cluster head use the half-weighted fusion rule by which the cluster head can treat their detection results based on the different reliability of the cognitive users. Finally, we verify that this improved algorithm can improve the spectrum sensing performance than the traditional algorithm through analyzing and simulating.**

***Index Terms*—Cognitive Radio, Spectrum Sensing, Half-weighted, Judgment Threshold.**

I. INTRODUCTION

Cognitive radio [1,2] which can sense the spectrum environment automatically in the multidimensional space (the frequency domain, the time domain, the airspace domain and so on) and use the idle spectrum effectively is an intelligent spectrum sharing technology. Spectrum sensing [3] means sensing the available bands, finding the spectrum holes and detecting the re-emergence of authorized user. The reliable, accurate and fast spectrum sensing technology is the key premise in the cognitive radio.

Spectrum sensing technology can be divided into single-user sensing [4-7] and multi-user cooperative sensing [8,9] based on the number of cognitive users. The performance of local single-user spectrum sensing may be affected by the shadow and other environmental factors. The collaboration sensing [10,11] means that the cognitive base station fuses sensing information of many cognitive users and finally determine whether the authorized user is using the spectrum or not.

In the reference[12], Sun proposed a cluster-based cooperative spectrum sensing algorithm in which he select the cognitive user which has the greatest reporting channel gain as the cluster head. The cluster head integrates the local sensing information of all the cognitive users in the cluster, and then makes the cluster head decision and sends the results to the cognitive base station which makes the final decision. The disadvantage of this algorithm is the judgment threshold for cognitive user is only related to the false alarm probability and the cluster head use a simple OR-rule to execute information fusion, which limits the sensing performance of the cluster-based cooperative spectrum sensing algorithm to some extent. In this paper, we propose an improved cluster-based cooperative spectrum sensing algorithm. In order to improve the local detection probability, we can reduce the judgment threshold while the perceived channel condition is better, and in order to reduce the local false alarm probability, we can improve judgment threshold while the perceived channel condition is poor. The local decision is made by the judgment threshold which is adjusted accordingly based on channel condition, through which can improve the local sensing performance. The cluster head use the half-weighted fusion rule which is proposed in this thesis to execute the information fusion, by which the cluster head can treat their detection results based on the different reliability of cognitive users, and then improve the spectrum sensing performance of the whole system.

II. THE TRADITIONAL CLUSTER-BASED COOPERATIVE SPECTRUM SENSING ALGORITHM

In the traditional cluster-based cooperative spectrum sensing algorithm, each cluster means a small cooperative spectrum sensing system, and the cluster head is the information fusion center. On the one hand, the cluster head fuses the sensing information which from cognitive users and then sends the judgment to the cognitive base station, that reduces the amount of information in reporting channel greatly. On the other hand, best channel condition, which can reduce the error probability of

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information transmission in reporting channel, thereby improve the sensing performance in the cognitive radio system.

In the actual cognitive radio environment, information transmitted in reporting channel may occurs distortion at the cognitive base station. Let $P'_{f,i}$ denote probability of receiving the binary bit 1(authorized user exists) while the *i-th* cluster head sends the binary bit *0* (authorized user does not exist) and $P'_{m,i}$ denote the probability of receiving the binary bit 0 while the *i-th* cluster head sends the binary bit *1*.

With the above analysis, while reporting channel which transmit binary bits information has the attenuation characteristics, the false alarm probability, the detection probability and the missing probability can be given by [12]

$$P_f = 1 - \prod_{i=1}^{n}\left[\left(1-P_{f,i}\right)\left(1-P'_{f,i}\right)+P_{f,i}P'_{m,i}\right] \tag{1}$$

$$P_m = \prod_{i=1}^{n}\left[P_{m,i}\left(1-P'_{f,i}\right)+\left(1-P_{m,i}\right)P'_{m,i}\right] \tag{2}$$

$$P_d = 1 - \prod_{i=1}^{n}\left[P_{m,i}\left(1-P'_{f,i}\right)+\left(1-P_{m,i}\right)P'_{m,i}\right] \tag{3}$$

Let $Q_{e,i}$ denote the error probability of binary bits information which transmitted in reporting channel, and then $Q_{e,i} = P'_{f,i} = P'_{m,i}$. With (1) and (2), it is known that while the reporting channel is not ideal, cooperative spectrum sensing performance can be expressed as:

$$Q_f = 1 - \prod_{i=1}^{K}\left[\left(1-Q_{f,i}\right)\left(1-Q_{e,i}\right)+Q_{f,i}Q_{e,i}\right] \tag{4}$$

$$Q_m = 1 - \prod_{i=1}^{K}\left[Q_{m,i}\left(1-Q_{e,i}\right)+\left(1-Q_{m,i}\right)Q_{e,i}\right] \tag{5}$$

It is assumed that the cluster head use the BPSK modulation mode while sending the spectrum sensing results (binary bits) to the cognitive base station, then $Q_{e,i}$ can be expressed as [13]:

$$\begin{aligned} Q_{e,i} &= \int_0^{\infty} Q_{e,i|\rho} f(\rho) d\rho \\ &= \int_0^{\infty} Q\left(\sqrt{2\rho}\right)\frac{1}{\bar{\rho}}e^{-\frac{\rho}{\bar{\rho}}}d\rho = \frac{1}{2}\times\left(1-\sqrt{\frac{\bar{\rho}}{1+\bar{\rho}}}\right) \end{aligned} \tag{6}$$

Where $Q_{e,i|\rho}$ is the instantaneous bit error rate through the Gaussian channel, Q () is the Gaussian Q function, f(ρ) is signal-to-noise ratio (SNR) probability density function while the reporting channel is Rayleigh fading channel.

III. The Improved Cluster-Based Cooperative Spectrum Sensing Algorithm

In the traditional algorithm, the local sensing algorithm which is used by cognitive user in cluster is energy detection, so the detection probability and the false alarm probability of the *j-th* cognitive user in the *i-th* cluster are given by

$$P_{d,i,j} = P\left\{Y_{i,j} > \lambda_{i,j} \mid H_1\right\} = Q_u\left(\sqrt{2\gamma_{i,j}}, \sqrt{\lambda_{i,j}}\right) \tag{7}$$

$$P_{f,i,j} = P\left\{Y_{i,j} > \lambda_{i,j} \mid H_0\right\} = \frac{\Gamma\left(u, \lambda_{i,j}/2\right)}{\Gamma(u)} \tag{8}$$

With setting a false alarm probability for each cognitive user in the cluster, we can calculate judgment threshold by the formula (8), and then use the judgment threshold to judge whether the authorized user is present or not. We determine the authorized user is present as the energy value perceived by cognitive user is greater than the judgment threshold and absent while the energy value perceived is less than the threshold. If we use the same judgment threshold to make judgment for different cognitive users which have different SNR, the result may be not accurate enough. Detection probability may be too small for the cognitive user with larger SNR, while the false alarm probability is too big who has smaller SNR. Hoping improve the sensing performance, if the cognitive user with better channel condition, we can reduce the threshold to improve the detection probability further, and with poorer channel condition, we can improve the judgment threshold to reduce the false alarm probability further.

Based on the above analysis, we adjust judgment thresholds using the channel conditions, which make the judgment threshold become associated with SNR, rather than the false alarm probability. With that, we improve the spectrum sensing performance.

Let $P_{f,i,j}$ denote false alarm probability of the *j-th* cognitive user in the *i-th* cluster. We calculate judgment threshold $\lambda_{i,j}$ based on $P_{f,i,j}$ and the formula (8), and then calculate the detection probability $P_{d,i,j}$. However, in this article, we calculate weighting coefficient $W_{i,j}$ according to the SNR of cognitive user:

$$W_{i,j} = \frac{\gamma_{i,j}}{\frac{1}{N_i}\sum_{j=1}^{N_i}\gamma_{i,j}} \tag{9}$$

Then we can adjust judgment threshold according to the weighting coefficient of the *j-th* cognitive user in the *i-th* cluster, the adjusted judgment threshold can be given by:

$$\lambda'_{i,j} = \lambda_{i,j} / W_{i,j} \tag{10}$$

Finally, we get the decision algorithm Ω :

$$\Omega\text{：}\ G_{i,j} = \begin{cases} 1, O_{i,j} \geq \lambda_{i,j} \\ 0, otherwise \end{cases} \tag{11}$$

While the perceived channel is AWGN channel, the detection probability of the j-th cognitive user in the i-th cluster can be expressed as:

$$P_{d,i,j}' = P\left\{Y_{i,j} > \lambda_{i,j}' \mid H_1\right\} = Q_u\left(\sqrt{2\gamma_{i,j}}, \sqrt{\lambda_{i,j}'}\right) \tag{12}$$

After the cognitive user make the local decision, the cluster head make the information fusion by using the OR-rule which does not discriminate judgments of different cognitive users. Based on such consideration , we propose a half -weighted fusion rule that the cluster head can treat the cognitive users' judgments based on their reliability by using $W_{i,j}$ as the weight of cognitive user' judgment. The expression as follows:

$$\Phi : \beta_i = \begin{cases} 1, \sum_{j=1}^{N_i} W_{i,j} G_{i,j} \geq N_i / 2 \\ 0, otherwise \end{cases} \tag{13}$$

The cluster head uses large number criteria, i.e. more than half of the cognitive users determine that the authorized user signal exists, and the final judgment is that the authorized user signal exists; otherwise the authorized user signal does not exist. Through the previous calculation, it can be seen that $\sum_{j=1}^{N_i} W_{i,j} = N_i$,so we take $N_i / 2$ as the judgment threshold.

Cluster head make the decision based on the received local decisions using the half -weighted fusion rule. So the detection probability, false alarm probability and missing probability of the *i-th* cluster head can be expressed as follows:

$$\begin{aligned} Q_{d,i} &= P\{H_1 \mid H_1\} = P\left\{\sum_{j=1}^{N_i} W_{i,j} G_{i,j} \geq N_i / 2 \mid H_1\right\} \\ &= \sum_{\sum_{j=1}^{N_i} W_{i,j} G_{i,j} \geq N_i / 2} \prod_{j=1}^{N_i} \left(P_{d,i,j}\right)^{G_{i,j}} \left(1 - P_{d,i,j}\right)^{1-G_{i,j}} \end{aligned} \tag{14}$$

$$\begin{aligned} Q_{f,i} &= P\{H_1 \mid H_0\} = P\left\{\sum_{j=1}^{N_i} W_{i,j} G_{i,j} \geq N_i / 2 \mid H_0\right\} \\ &= \sum_{\sum_{j=1}^{N_i} W_{i,j} G_{i,j} \geq N_i / 2} \prod_{j=1}^{N_i} \left(P_{f,i,j}\right)^{G_{i,j}} \left(1 - P_{f,i,j}\right)^{1-G_{i,j}} \end{aligned} \tag{15}$$

$$Q_{m,i} = 1 - Q_{d,i} \tag{16}$$

Finally, the cognitive base station makes the global judgment. On the one hand, information is sent by cluster heads which have the best reporting channel conditions, the results are relatively reliable. On the other hand, in order to reduce the complexity of global fusion and accelerate the fusion speed. So the cognitive base station should choose the OR-rule which is reliable and simple.

IV. SIMULATION RESULTS

In the front, we have analyzed the performance of the improved cluster-based spectrum sensing algorithm. And now we verify its performance by simulating, compare to the traditional algorithm, it can be clearly seen that this algorithm performs better.

Parameters are given as follows: the number of users N_1 = 5, N_2 = 10. u = 5, the SNR of the cognitive users in the first cluster $\gamma_{1,j}$=0dB, 1dB, 2dB, 3dB, 4dB, the SNR between the cluster head and the cognitive base station is 8dB. the SNR of the cognitive users in the second cluster $\gamma_{2,j}$ =0dB, 0.5dB, 1dB, 1.5dB, 2dB, 2.5dB, 3dB, 3.5dB, 4dB, 4.5dB, the SNR between the cluster head and the cognitive base station is 10dB. The simulation results can be shown by the following figures:

By testing the false alarm probability problem, we can see from figure 1 that the relationship between the false alarm probability and detection probability by using the traditional algorithm and improved algorithm respectively. Compared to the traditional algorithm, while the detection probability is identical, the false alarm probability of the improved algorithm is lower, and while the false alarm probability is identical, the detection probability of the improved algorithm is higher.

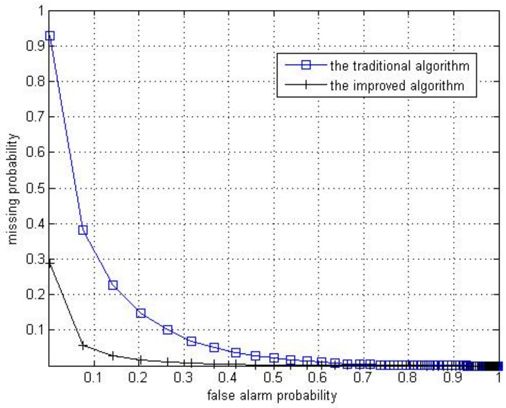

Fig.1 detection probability vs. false alarm probability

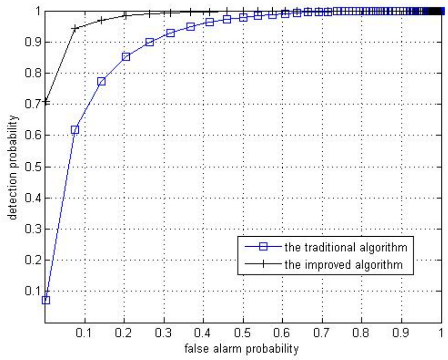

Fig.2 missing probability vs. false alarm probability

Figure 2 shows the relationship between the false alarm probability and missing probability. Compared to the traditional algorithm, while the missing probability is identical, the false alarm probability of the improved algorithm is lower, and while the false alarm probability is identical, the missing probability of the improved algorithm is lower. So the improved algorithm has a better performance compared with the traditional algorithm.

In the traditional algorithm, the judgment threshold of the cognitive user in cluster is only related to the false alarm probability. While in this paper, considering that the channel conditions of different cognitive users are also different, in order to improve the sensing performance, we can adjust the judgment threshold according to the SNR. Namely we reduce judgment threshold for cognitive user which has higher SNR and increase the judgment threshold for cognitive user with lower SNR. Then the cluster head treat the decisions of the cognitive users based on their reliability. It can be seen that this improved algorithm can significantly improve the cooperative spectrum sensing performance in the cognitive radio network from the simulation results.

V. CONCLUSIONS

In this paper, we have proposed an improved cluster-based collaborative detection algorithm. In the traditional algorithm, different cognitive users in cluster make the local judgments by using the same judgment threshold. While in the improved algorithm, we adjust the judgment threshold according to the SNR. Considering that the reliability of different cognitive users may be different, the cluster head treats the decisions of the cognitive users based on their reliability. Finally, simulation results show that the improved algorithm can improve the overall sensing performance.

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