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Based On Optimal Merging Criteria for Spectrum Sensing Techniques in Femtocell System

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Abstract

In the two-tier network constituted by Femtocell and Macrocell, using share spectrum method to save the shortage of spectrum resources , which has brought serious cross-layer interference problem, However, most current studies focus on the management of spectrum resources, and very few efficient spectral detection methods to reduce interference. In this paper, the cognitive radio technology is introduced into the Femtocell system to solve this interference problem, A two-layer cooperative spectrum sensing algorithm based on optimal fusion rule is proposed to improve the probability of spectral loopholes detection ， Not only improve the spectral efficiency, but also inhibit cross-layer interference. The simulation results show that the proposed algorithm is better than the traditional double threshold detection method in detection probability, and improve the performance of user detection and anti-noise ability by using the optimal fusion rule to merge multiple sensing Femtocell users.

Keywords: *Cooperative sensing, double threshold, optimal fusion rule, Femtocell, spectrum sharing*

1. Introduction

In recent years, with the rapid development of mobile communications and mobile Internet, wireless communication with people's lives more and more closely. Indoor signal coverage and signal quality has always been a difficult problem in wireless communications, so femtocell came into being. Femtocell is a femtocell base station, with low cost and low transmit power and other characteristics, through the IP network , indoor user's voice, data and other information be transmitted to the mobile core network, the wireless operators in the existing authorized spectrum of operation, and macro cellular network share the same spectrum[1-2]. In recent years, with the popularity of radio applications, the femtocell network using radio technology to solve the problem of spectral resource reuse more and more, so as to avoid the macrocell and other surrounding femtocell mutual interference[3-4].

In [5], the necessity of using spectrum sensing techniques in a home base station is described. In [6] [7], it is proposed to use cognitive radio technology to manage spectrum resources to suppress the same layer interference between Macrocell and Femtocell two-tier heterogeneous networks, using dirty paper coding techniques and game theory to eliminate Interference with the same layer, but the spectrum detection efficiency is not high. In [8], the author investigates the problem of resource management in the Femtocell system under orthogonal frequency division multiplexing, and proposes a location-based allocation scheme between the macrocell and the Femtocell to accommodate the number of users. In [9], a two-threshold spectral sensing method is proposed, which uses two thresholds to judge the signal energy. However, when the energy is between the two thresholds, it does not participate in the final decision. Although the algorithm is also a certain degree Solved the problem of interference, but ignored some useful sense of information. In [10], it is proposed that the reliability of each perceptual user is different, so it is not appropriate to distribute the feedback channel evenly to each user.

In this paper, a two-layer cooperative spectrum sensing based on dual weighting is proposed in the two-layer network composed of Macrocell and Femtocell. Compared with the traditional two-threshold spectrum sensing technology, when the perceptual information falls between the two thresholds , Using the second layer of spectrum perception, the effective use of the two thresholds between the two sensing information, saving network overhead, and improve the probability of detection. At the same time, the use of a weight to distinguish between Femtocell perceived users fall outside the two thresholds or two thresholds, and the use of another weight to distinguish each Femtocell perceived user's reliability of the difference, the final two weighted And sent to the fusion center, in the fusion center to make a main user whether there is a judgment, so Femtocell according to the perceived information for spectrum resource allocation, and ultimately achieve the purpose of improving the spectrum utilization and suppression of interference. The simulation results show that the two-layer spectrum sensing based on dual weighting can effectively improve the probability of spectrum detection. Through multi-user cooperation, it can effectively prevent noise and improve the performance of the whole system.

2. System model

Considering the great advantages of Femtocell in indoor wireless communication and the widespread use of cognitive radio in spectrum sharing in recent years, this paper combines Femtocell with cognitive radio to form a cognitive home base station, which is referred to as the cognitive Femtocell base station (cognitive femtocell base station). The users in the Macrocell network are the primary users in the cognitive radio. The users in the Femtocell network are the secondary users (perceptual user), which has the function of sensing the spectrum usage of the surrounding environment compared with the traditional Femtocell base station. This article considers that the primary users share the entire spectrum with the secondary users, and the cognitive Femtocell users (secondary users) can only be used if the macro user (primary users) does not exist. The system model is shown in Figure 1 below.

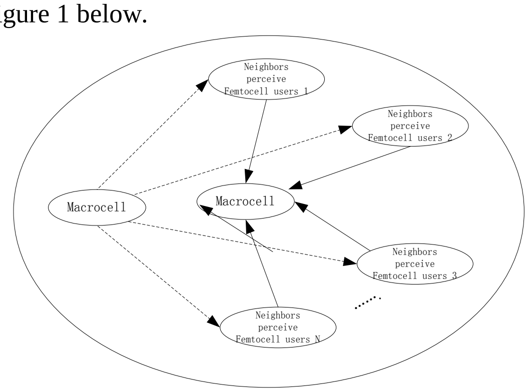

Fig. 1: A two-tier heterogeneous network model consisting of Macrocell and Femtocell

Assuming that only one macro base station and one macro user in the current Macrocell network interfere with the target Femtocell home base station, the signal (n) received by the ith Femtocell user in the nth slot can be expressed as follows:

$$y_i(n) = \begin{cases} w_i(n) & H_0 \\ s_i(n) + w_i(n) & H_1 \end{cases} \tag{1}$$

Where $w_i(n)$ is the additive white Gaussian noise whose mean is 0 and variance is σ_w^2; The $s_i(n)$ is the signal transmitted from the Macrocell base station, the mean is 0 and the variance is σ_s^2; The H_0 indicates that the channel is not occupied by the primary user and that there is no macro user signal on the channel; The H_1 indicates that the channel has been occupied by the primary user and that there is currently a macro user signal on the channel.

If the number of sampling points is N, the energy statistics of the i-th Femtocell user in N time slot are:

$$\text{Y} = \frac{1}{N}\sum_{n=1}^{N} | y_i(n) |^2 \tag{2}$$

When the sampling points are large, the statistic information Y will approximately obey the normal distribution according to the central limit theorem:

$$\text{Y} = \begin{cases} \text{N}\left(s_w^2, \frac{2s_w^4}{\text{N}}\right) & \text{H}_0 \\ \text{N}\left((1+g)s_w^2, 2(1+g)^2 s_w^4/\text{N}\right) & \text{H}_1 \end{cases} \tag{3}$$

Where the $\gamma = \sigma_s^2 / \sigma_w^2$ is the Signal to Interference plus Noise Ratio (SINR) of the received signal.

From the distribution function of Y, we can know the false alarm probability P_f of the perceptual user, and the detection probability P_d is as follows:

$$P_f = P(Y > V_{th}|H_0) = Q\left(\frac{V_{th} - \sigma_w^2}{\sqrt{N/2\sigma_w^2}}\right) \tag{4}$$

Where the P_f indicates the probability that the macro user’s existence detected by the perceptual user in the case that the macro user does not exist.

$$P_d = P(Y > V_{th}|H_1) = Q\left(\frac{V_{th} - (1+\gamma)\sigma_w^2}{\sqrt{\frac{N}{2}}(1+\gamma)\sigma_w^2}\right) \quad (5)$$

Where P_d means the probability of the presence of the macro user detected by the perceptual user in the presence of a macro user. That the V_{th} is the threshold value of the decision, and $Q(x)$ represents the standard cumulative distribution function of the normal distribution, which is defined as follows:

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty}\exp\left(-\frac{t^2}{2}\right)dt \quad (6)$$

3. Weighted two-layer cooperative spectrum sensing in Femtocell System

Based on the traditional double threshold, a two-level spectrum sensing based on weight is proposed, and the detection probability and false alarm probability of the perceptual Femtocell user are deduced. At the same time, the paper provides weighted fusion criteria based on false alarm probability and detection probability and the specific method of two-level spectrum sensing based on dual thresholds in Femtocell network.

2.1A two-layer spectrum sensing based on two-threshold of the Femtocell users

According to the formula (4) in the previous section, when the false alarm probability P_{f1} and P_{f2} （$P_{f1} > P_{f2}$） are given, the two discriminant thresholds V_{th1} and V_{th2} are calculated respectively as follows.

$$V_{th1} = \left(\sqrt{\frac{2}{N}}Q^{-1}(P_{f1}) + 1\right)\sigma_w^2 \quad (7)$$

$$V_{th2} = \left(\sqrt{\frac{2}{N}}Q^{-1}(P_{f2}) + 1\right)\sigma_w^2 \quad (8)$$

For the spectrum perception of the first layer, each neighbor Femtocell user and the Femtocell user calculate the energy statistics Y_1 through energy detection, and then compare them with the threshold values V_{th1} and V_{th2} and make the decision on whether there is the presence of a macro user. H_0 represents that the macro user does not exist and H_1 represents that the macro user exists:

$$Y_1 \begin{cases} \geq V_{th2} & H_1 \\ \leq V_{th1} & H_0 \\ Other: the\ second\ sensing \end{cases} \quad (9)$$

For the spectrum sensing of the second layer, each neighbor Femtocell user and the Femtocell user obtain the information Y_2 through the energy, and then compare them with the threshold values V_{th1} and V_{th2}, and make a decision on whether the macro user is present:

$$Y_2 \begin{cases} \geq V_{th2} & H_1 \\ \leq V_{th1} & H_0 \\ Other: (Y_1 + Y_2)/2 \begin{cases} \geq V_{th3} & H_1 \\ \leq V_{th3} & H_0 \end{cases} \end{cases} \quad (10)$$

Where $V_{th3} = \frac{V_{th1} + V_{th2}}{2}$. The whole process is as follows:

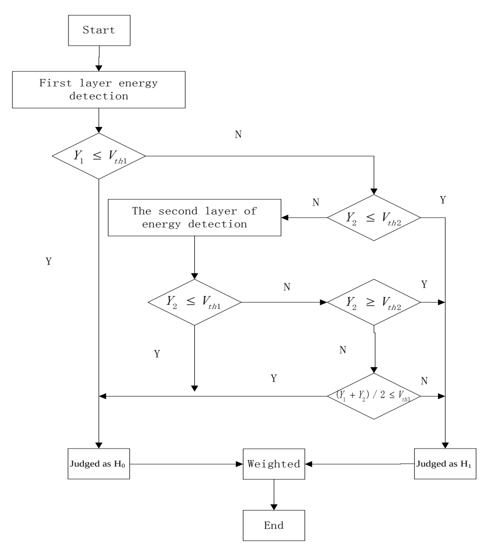

Fig. 2 The flow chart of the two-layer spectrum sensing of the Femtocell user

2.2 False alarm probability and detection probability of the two-layer spectrum sensing of the Femtocell user

The false alarm probability and detection probability of the Femtocell user are P_{if} and P_{id} respectively, that is:

$$\begin{aligned} P_{if} = & P(Y_1 \geq V_{th2}|H_0) + P(V_{th1} \leq Y_1 \leq V_{th2}|H_0)^* \\ & \{P(Y_2 \geq V_{th2}|H_0) + P(V_{th1} \leq Y_2 \leq V_{th2}|H_0)^* \\ & P\left(\frac{Y_1+Y_2}{2} \geq V_{th3}|H_0\right)\} \end{aligned} \tag{11}$$

Where $P(Y_1 \geq V_{th2}|H_0)$ means the probability where the energy detected is larger than V_{th2} when the perceptual macro user in the first layer does not exist; $P(V_{th1} \leq Y_1 \leq V_{th2} \mid H_0)$ means the probability where the energy detected is within V_{th1} and V_{th2} when the perceived macro user in the first layer does not exist; $P(Y_1 \geq V_{th2}|H_0)$ means the probability where the energy detected is larger than V_{th2} when the perceived macro user in the second layer does not exist; $P(V_{th1} \leq Y_2 \leq V_{th2}|H_0)$ means the probability where the energy detected is within V_{th1} and V_{th2} when the perceived macro user in the second layer does not exist; The $P((Y_1+Y_2)/2 \geq V_{th3}|H_0)$ represents the probability that the two perceptual mean values are greater than the two threshold mean values.

$$\begin{aligned} P_{id} = & P(Y_1 \geq V_{th2}|H_1) + P(V_{th1} \leq Y_1 \leq V_{th2}|H_1)^* \\ & \{P(Y_2 \geq V_{th2}|H_1) + P(V_{th1} \leq Y_2 \leq V_{th2}|H_1)^* \\ & P((Y_1+Y_2)/2 \geq V_{th3}|H_1)\} \end{aligned} \tag{12}$$

That $P(Y_1 \geq V_{th2}|H_1)$ means the probability that the energy detected than V_{th2} when the perceived macro user in the first layer does not exist； $P(V_{th1} \leq Y_1 \leq V_{th2} \mid H_1)$ means the probability that the energy detected is within V_{th1} and V_{th2} when the perceived macro user in the first layer; $P(Y_2 \geq V_{th2}|H_1)$ means the probability that the energy detected is larger than V_{th2} when the perceived macro user in the second layer exists ； $P(V_{th1} \leq Y_2 \leq V_{th2}|H_1)$ indicates the probability that the energy detected is within V_{th1} and V_{th2} when the perceived macro user in the second layer does exist. $P(V_{th1} \leq Y_2 \leq V_{th2}|H_1)$ shows the probability that the energy detected is within V_{th1} and V_{th2} when the perceived macro user in the second layer exists. $P((Y_1+Y_2)/2 \geq V_{th3} \mid H_1)\}$ means that the probability that the perceived means of the two times is larger than the two thresholds when the macro user exists.

Because Y_1 and Y_2 approximately obey to the normal distribution, it can be seen that:

$$P(Y_1 \geq V_{th2}|H_0) = P(Y_2 \geq V_{th2} \mid H_0) = P_f \mid_{V_{th}=V_{th2}} \tag{13}$$

$$P(Y_1 \geq V_{th2}|H_1) = P(Y_2 \geq V_{th2} \mid H_1) = P_d \mid_{V_{th}=V_{th2}} \tag{14}$$

$$\begin{aligned} & P(V_{th1} \leq Y_1 \leq V_{th2}|H_0) \\ & = P(Y_1 \geq V_{th2}|H_0) - P(Y_1 \geq V_{th1}|H_0) \\ & = P_f|_{V_{th}=V_{th2}} - P_f|_{V_{th}=V_{th1}} \end{aligned} \tag{15}$$

$$\begin{aligned} & P(V_{th1} \leq Y_2 \leq V_{th2}|H_1) \\ & = P(Y_2 \geq V_{th2}|H_1) - P(Y_2 \geq V_{th1}|H_1) \\ & = P_d|_{V_{th}=V_{th2}} - P_d|_{V_{th}=V_{th1}} \end{aligned} \tag{16}$$

$$\begin{aligned} & P(V_{th1} \leq Y_1 \leq V_{th2}|H_1) \\ & = P(Y_1 \geq V_{th2}|H_1) - P(Y_1 \geq V_{th1}|H_1) \\ & = P_d|_{V_{th}=V_{th2}} - P_d|_{V_{th}=V_{th1}} \end{aligned} \tag{17}$$

$$\begin{aligned} & P(V_{th1} \leq Y_2 \leq V_{th2}|H_0) \\ & = P(Y_2 \geq V_{th2}|H_0) - P(Y_2 \geq V_{th1}|H_0) \\ & = P_f|_{V_{th}=V_{th2}} - P_f|_{V_{th}=V_{th1}} \end{aligned} \tag{18}$$

Similarly, for the sake of convenience, suppose:

$$P_0 = \mathrm{P}\left\{\frac{Y_1+Y_2}{2} > V_{th3}|H_0\right\} = \mathrm{Q}\left(\frac{V_{th3}-\sigma_w^2}{\sqrt{1/N}\sigma_w^2}\right) \quad (19)$$

$$P_1 = \mathrm{P}\left\{\frac{Y_1+Y_2}{2} > V_{th3}|H_1\right\} = \mathrm{Q}\left(\frac{V_{th3}-\sigma_w^2}{\sqrt{1/N}\sigma_w^2}\right) \quad (20)$$

The false alarm probability and detection probability of the two-layer spectrum sensing obtained by bringing (13)~(18) into (11) and (12) are:

$$\mathrm{P_{if}} = \mathrm{P_f}|_{\mathrm{V_{th}=V_{th2}}} + \left(\mathrm{P_f}|_{\mathrm{V_{th}=V_{th1}}} - \mathrm{P_f}|_{\mathrm{V_{th}=V_{th2}}}\right) * \left[\mathrm{P_f}|_{\mathrm{V_{th}=V_{th2}}} + \left(\mathrm{P_f}|_{\mathrm{V_{th}=V_{th1}}} - \mathrm{P_f}|_{\mathrm{V_{th}=V_{th2}}}\right) * \mathrm{P_0}\right] \quad (21)$$

$$\mathrm{P_{id}} = \mathrm{P_d}|_{\mathrm{V_{th}=V_{th2}}} + \left(\mathrm{P_d}|_{\mathrm{V_{th}=V_{th1}}} - \mathrm{P_d}|_{\mathrm{V_{th}=V_{th2}}}\right) * \left[\mathrm{P_d}|_{\mathrm{V_{th}=V_{th2}}} + \left(\mathrm{P_d}|_{\mathrm{V_{th}=V_{th1}}} - \mathrm{P_d}|_{\mathrm{V_{th}=V_{th2}}}\right) * \mathrm{P_1}\right] \quad (22)$$

2.3 Optimal combination criteria based on weight

The combination criteria takes advantage of the information provided by the neighbor Femtocell perceptual user and the perceptual user of this Femtocell, and the perceptual energy is between the two thresholds and the two thresholds are different from the perceptual results, therefore, the perceptual energy information is distinguished according to different weight; meanwhile, the reliability of the perceived user is different, so it is unreliable to evenly distribute the feedback channel to each user. In this article, the reliability of the user is distinguished by using different weights. The specific implementation method is as follows:

2.3.1 Weighted information analysis of the two-layer perceptual user

For the spectrum perception of the first layer, all the partners of the Femtocell perceptual users involved in the collaboration and the Femtocell perceptual users calculate the energy statistics Y_1 through energy detection, and compare it with the thresholds V_{th1} and V_{th2} , and then measure the weight μ_i according to the comparison results:

$$Y_1 \begin{cases} \le V_{th1} : \text{Judge result } \mu_i = 2 \\ \ge V_{th2} : \text{Judge result } \mu_i = -2 \\ \text{Other : second sensing} \end{cases} \quad (23)$$

For spectrum sensing of the second layer, the energy statistics Y_2 is calculated through energy detection and compare them with the thresholds V_{th1} and V_{th2} and measuring the weight μ_i according to the comparative result:

$$Y_2 \begin{cases} \ge V_{th2} : \text{Judge result } \mu_i = 2 \\ \le V_{th1} : \text{Judge result } \mu_i = -2 \\ \text{Other : } (Y_1+Y_2)/2 \begin{cases} \ge V_{th3} \text{ Judge result } \mu_i = 1 \\ \le V_{th3} \text{ Judge result } \mu_i = -1 \end{cases} \end{cases} \quad (24)$$

Where, $V_{th3} = \frac{V_{th1}+V_{th2}}{2}$.

2.3.2 The reliability analysis of the Femtocell perceptual user

There are H_0 and H_1, the two test hypotheses for the merging criteria. When the Femtocell perceptual user senses the presence of main user, $\mu = 2$ or $\mu = -2$ should be reported, otherwise $\mu = 1$ or $\mu = -1$ should be reported; the weighting coefficient a_i is given to the reported information of Femtocell by the perceptual Femtocell, and the judgment will be made by multiplying the weight by the reported information of the sense user.

$$\mathrm{a_i} = \begin{cases} \lg\frac{\mathrm{P_d}}{\mathrm{P_f}}, & \mu_i = \{1,2\} \\ \lg\frac{1-\mathrm{P_f}}{1-\mathrm{P_d}}, & \mu_i = \{-1,-2\} \end{cases} \quad (25)$$

Where P_f and P_d represents the false alarm probability and detection probability respectively.

Based on the above weighting factor, the final decision is:

$$\mathrm{Z} = \sum_{i=1}^{M_p} a_i^+ \mu_i + \sum_{j=1}^{M_n} a_j^- \mu_j \quad (26)$$

Then:

$$F(Z) = \begin{cases} 1, & Z > 0 \\ -1, & \text{other} \end{cases} \quad (27)$$

The detection probability of the optimal combined criterion can be expressed as:

$$P_{d,opt} = \int_0^{\infty} f(z) \tag{28}$$

Where $f(z)$ is the distribution function.

4. Simulation results and performance analysis

The simulation compares the detection probability of a single Femtocell perceived user and the detection probability of multi-user cooperation. The traditional single-threshold and double-threshold are adopted for comparison. For simplicity, the simulation environment in this paper considers a two-tier heterogeneous network consisting of a Macrocell and M Femtocell, and each Femtocell has a base station and a perceptual user. In Matlab simulation, assume the means of the noise is 0, and the variance $\delta_{\omega}^2 = 1$ is the additive Gaussian white noise, and the transmitted signal of the Macrocell base station to be detected is a narrow-band signal, center frequency $f_c = 200MHZ$, bandwidth $B = 5MHZ$, modulated by BPSK, sampling frequency, s $f_s = 12MHZ$ ampling points of the signal in the energy detection $N = 1000$.

As is shown in Fig.3, it compares the changing curve of the detection probability of a single Femtocell perceived user with the SINR under the double threshold in this article and the general double threshold. It can be seen from the chart that with the increase of SINR, the detection probability of a single Femtocell perceived user increases with the increase of SINR;

At the same time, when the false alarm detection probability of the double threshold in this article is the same as that of the traditional double threshold, it can be seen that the double threshold in this article is superior to the traditional double threshold and when the P_{f1} is fixed, the detection probability will increase with the increase of P_{f2} .

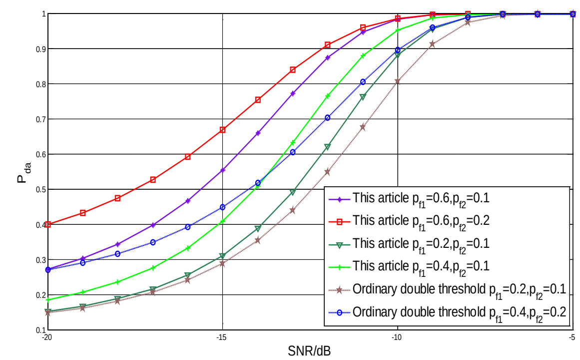

Fig. 3 The changing curve of the detection probability of a single Femtocell user with SINR

As is shown in Fig. 4, assume the Femtocell perceived user perceives that SINR=-12dB, and $\Delta = 0.2$ $\Delta = p_{f1} - p_{f2}$, it compares the changing curve of the detection probability of a single Femtocell perceived user with the false alarm probability under the methods of double-threshold, traditional threshold and single threshold.

It can be seen from the figure that in the case of the same SINR, the detection probability of a single Femtocell perceived user in the double threshold is still below the single threshold in the case of the very low false alarm probability, but has been obviously improved compared to the traditional double threshold.

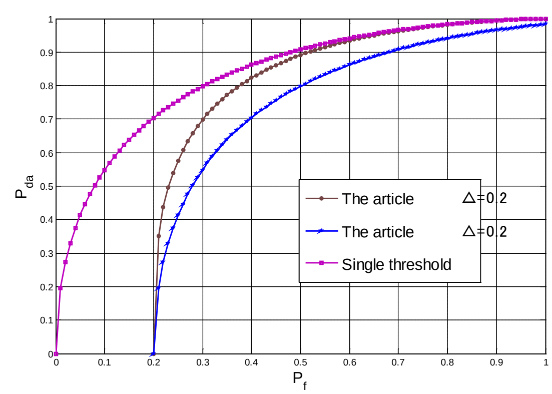

Fig. 4 The changing curve of the detection probability of a single Femtocell user with the false alarm probability

Assume the P_{f1} and P_{f2} is 0.6 and 0.2. As is shown in

Fig. 5, it compares the changing curve of the detection probability of the cooperative spectrum sensing of M Femtocell with the SINR under different fusion criteria. It can be seen from the Figure that, the cooperative spectrum sensing of the double threshold in the article under the fusion criteria of “Yu” is superior to the performance of the cooperative spectrum sensing under the fusion criteria of “Yu”, at the same time, the multi-user cooperative spectrum sensing based on double weight is superior to the detection probability of the general double-bit multi-user cooperative spectrum sensing. The detection probability of the multi-user cooperative spectrum sensing based on optimal combination criteria is much higher than the traditional fusion criteria “Yu” in the case of very low SINR, so it can be seen that it is of high noise resisting ability.

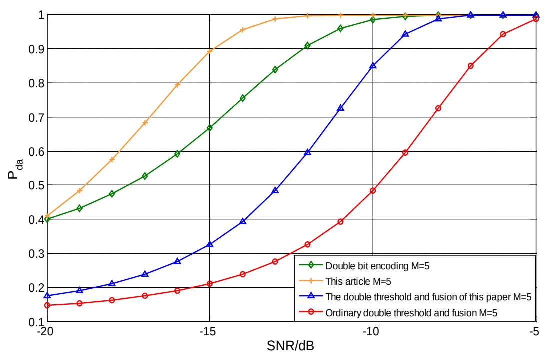

Fig. 5 The changing curve of the detection probability of a multiple Femtocell user with SINR

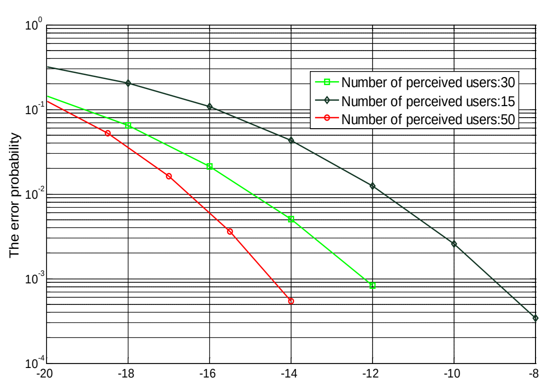

Fig.5 Optimal Combinatorial Criterion Performance for Different Number of Cognitive Users

Figure 5 shows the performance of the optimal combined criterion. By controlling the average signal-to-noise ratio of users participating in cooperative spectrum sensing, it is possible to indirectly change the shortcoming of single-band spectrum sensing performance, that is, the detection probability under fixed error probability. As can be seen from the simulation results, when the number of perceived Femtocell users is different, the performance of the optimal combining criterion will also change. The simulation results show that the more likely the Fenmtocell users to participate in the cooperation, the lower the probability of error, the better the performance. It can be seen from the figure, Femtocell perceived number of users increased from 15 to 30, different signal to noise ratio conditions, the performance has greatly improved, but at the same time, with the increase in the number of users continue to increase the number of users， the gain gradually becomes smaller. For example, when Femtocell perceives the number of users from 30 to 50, the rate of performance improvement is slightly smaller than before. It can be seen that the gain of the optimal combining criterion is due to the fact that a certain number of Femtocell perceives the user to take full advantage of the feedback information of each user participating in the cooperative spectrum sensing.

5. Conclusions

In this paper, cognitive radio technology is introduced into Femtocell to form a cognitive function of Femtocell double-layer network, through the detection of empty channels allocated to Femtocell users, so as to achieve the purpose of consistent interference. In this paper, a dual-weighted cooperative multi-user spectrum sensing algorithm is proposed. The two-level spectrum-aware false alarm probability and detection probability are analyzed theoretically, and the optimal combination criterion of two weights is given. The simulation results show that, compared with the traditional double - threshold spectrum sensing, this paper makes better use of the two - threshold perception data, improves the detection efficiency and saves the network overhead. The inaccuracy of the detection due to the different reliability of each user is solved by the weighting of the user once again. The simulation results are higher than the ordinary one-time two-bit coding, and the anti-noise ability is strong.

Acknowledgments

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