

A Method of Avoiding Interference with Hidden Terminal in Cognitive Radio Network

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Abstract— In cognitive radio technology, detecting accurately primary users can improve the efficiency of cognitive radio (CR) network and reduce interference with primary users. This paper proposes a communication method of avoiding interference with hidden terminal in CR network. It determines the location and coverage of primary transmitter through the ranging, and then avoids effectively interference with primary hidden terminal and improves spectrum efficiency of CR network. Simulation results show that the proposed method performs excellently in improving spectrum efficient of CR network.

Keywords— cognitive radio; hidden terminal; energy detection; ranging; interference; spectrum efficiency

I. INTRODUCTION

Currently, wireless communication technology is developing rapidly; types of wireless business are increasingly abundant. These reasons caused tense of some wireless spectrum resources. But many studies show that spectrum utilization of the other spectrum is not high. That means spectrum utilization is unbalanced. Cognitive radio is considered to be the best solution to solve the problem of the wireless spectrum utilization. Therefore, cognitive radio technology is gaining more and more attention.

Cognitive radio technology as a spectrum sharing technology makes use of different vacant spectrum in different places and time with spectrum sensing function of the communication terminals. Secondary user has lower preferential right of spectrum access than primary user. Only primary user does not use the spectrum, secondary user can use it for communication. So, how to efficiently and reliability check vacant spectrum become an important technology of Cognitive Radio [1].

There are two kinds of sensing for primary user in cognitive radio network. The one is based on transmitter, another is based on receiver. The sensing method based on transmitter is that cognitive user senses the signal of primary user to judge whether there is a primary user who may be interfered by

secondary users in its communication area, and determines whether there is vacant spectrum. In CR network, cognitive radio equipment senses not only the primary user transmitter, but the primary user receiver which is more sensitive to interference. And we must use some methods to avoid interference with communication of the primary user. There is a kind of case in the actual application scenario: the primary user receiver only receives signals and not sends signals. We call it the hidden terminal. It is shown in figure 1. The hidden terminal is difficult to be sensed by the CR network. Therefore, the CR node may be interference to the hidden terminal [2].

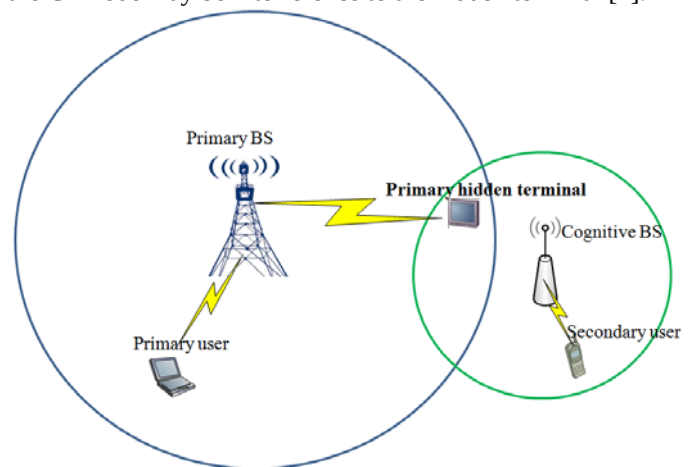


Figure 1. The hidden terminal problem

Now there are two kinds of methods of sensing the receiver signals: local oscillator leakage sensing and interference temperature sensing. We have a brief description [3].

1. Local oscillator leakage sensing. This method is based on the power of local oscillator leakage from the RF device of the primary user receiver to judge the primary user. In practice, let CR user senses local leakage power directly is impractical. There are two reasons: first, it is difficult to sense local leakage from too far away for the cognitive radio receiver. There is long time to get a high detection probability. The

detection speed can not meet the requirement. And in recent years, since receiver system has been continually improved, local oscillator leakage power is decreased step by step. It is more difficult to sense local oscillator leakage. Second, the local oscillator leakage power is constantly changing. If the secondary user finds the primary user receiver using change power, there will be a serious error occurred.

2. Interference temperature sensing. This method requires that CR base station controls consciously transmit power, makes the power of signals which is received by the receiver close to the noise level (statistical average of the noise power). Based on the interference temperature model, in a band, as long as interference of cognitive users accessing is less than the maximum threshold that primary user can tolerate (the interference temperature limit), this will not affect primary user's system. Therefore, if the number of cognitive user transmitters is not more than the decision threshold, secondary users can use this spectrum.

Difficulty of this method is that currently no effective way can be used to measure or estimate the interference temperature of primary user. In addition, the method must repeat the calculation of the characteristic spectrum in each target band. This means that algorithm is large amount of calculation in the realization process.

Because of the lack of the above methods, now the more commonly used method is when the spectrum of the primary user transmitter is sensed anywhere in the CR network, it will be disabled in the whole network. This method can achieve the purpose of avoiding interference with communication of hidden terminal. But it will be undoubtedly a waste of spectrum hole, and lead to reduce spectral efficiency.

This paper will propose a method which is based on energy decrement for determining the location and coverage to avoid interference with communication of hidden terminal. The method can also effectively improve the utilization ratio of the spectrum in whole CR network. The paper gives performance simulation and analyzes simulation results.

II. COMMUNICATION METHOD OF AVOIDING INTERFERENCE WITH HIDDEN TERMINAL

A. The problem description

In some scenario, primary user receivers are usually as hidden terminals. Itself only receives signals and doesn't send signals. In this case, cognitive nodes can't sense effectively hidden terminals. This will lead that cognitive nodes may interfere with normal communication of hidden terminals. This paper proposes a communication method of automatically adjusting the frequency or the coverage of CR base station according to detecting the location and coverage of the primary user transmitter. This can solve the interference problem.

In the CR network architecture described by this paper, we mainly apply the propagation loss principle to measure distance for primary user transmitter. Through multiple points ranging, we can determine the geography location of the

transmitter, and make a decision which CR base stations may interfere with communication of the primary user. Then the system can rebuild the CR network or readjust the vacant spectrum list according to the decision result. Finally, let the related CR base stations change the coverage or the spectrum which is used by the primary user. This moment, the CR base stations which are judged not to affect the communication of the primary users can continue to use the original spectrum. This method can improve the spectrum utilization of all CR network.

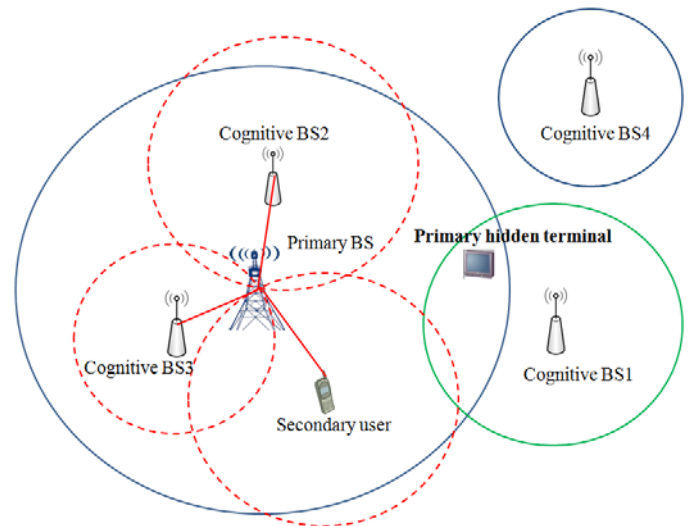


Figure 2. The network scenario of avoiding interference

The network scenario is expressed as figure 2, and explained as follows:

1. The large blue area is the coverage of the primary transmitter;
2. The green area is the coverage of a CR base station (Cognitive BS1 in figure 2). This area overlaps with the coverage of the primary transmitter, but Cognitive BS1 is not in the coverage of the primary transmitter, so can't sense its signals;
3. There is no CR user in the overlapping area of the CR base station and the primary base station. So no node can sense the signal of the primary transmitter;
4. There may be some hidden terminals in the overlapping area of the CR BS and the primary BS;
5. There are at least three CR nodes in the coverage area of the primary transmitter.

B. Algorithm steps

For the CR network described by the above scenario, we can complete the above described communication problem at three stages.

1. The first stage is spectrum sensing by secondary user. In the stage, CR nodes sense the licensed spectrum through periodic spectrum detection, and determine whether primary user exists. Sensing method may be one step sensing or two steps sensing, such as energy detection, matched filter detection and so on [5]. In order to reduce the decision time

and complexity of the system, the spectrum sensing algorithm we choose include at least energy detection.

First stage, the secondary users sense periodically the primary user. When the primary user is found, the secondary users record spectrum, energy and their own location information.

Second stage, the CR network determines the location and coverage of the primary transmitter.

Third stage, the CR network informs the cognitive BSs to change their spectrums according to the location and coverage of primary user.

Figure 3. The stages of the communication method

Assuming to not consider fading channels and assuming in the channel of Additive White Gauss Noise(AWGN) with a mean of 0, the dual hypothesis testing model of receiving signals by cognitive users is as follows[4]:

$$\begin{cases} H_0 : x(n) = v(n) \\ H_1 : x(n) = s(n) + v(n) \end{cases} \quad n = 1, 2, \dots, N \quad (1)$$

Where, $v(n)$ is AWGN with mean of 0 and variance of σ^2 , $s(n)$ is the authorized signal, $x(n)$ is the signal received by cognitive user, N is the times of cognitive user sampling in one process of spectrum sensing. Assuming H_0 represents that primary users don't exist in the detected spectrum band, and H_1 represents primary users exist in the detected spectrum band.

Let $\mathbf{x} = [x(1), x(2), \dots, x(N)]^T$, then CR user makes decision of whether authorized signals existing by the formula as follows:

$$T(\mathbf{x}) = \sum_{n=1}^N |x(n)|^2 \underset{H_0}{\overset{H_1}{>}} \gamma \quad (2)$$

Where, γ is the threshold. Because $x(n)$ obeys Gaussian distribution, $T(\mathbf{x})$ is the square sum of Gaussian variables by the number of N . So $T(\mathbf{x})$ obeys Chi-square distribution with the degree of freedom of N . According to the central limit theorem, if N is big enough ($N > 20$ is enough in the application), Chi-square distribution $T(\mathbf{x})$ obeys Gaussian distribution approximately. Hence

$$T(\mathbf{x}) \sim \begin{cases} H_0 : \text{Normal}(N\sigma^2, 2N\sigma^4) \\ H_1 : \text{Normal}(N\sigma^2 + Np_s, 4N\sigma^4 p_s) \end{cases} \quad (3)$$

Where, $p_s = \frac{\sum_{n=1}^N |s(n)|^2}{N}$ is average power of authorized signals received by cognitive users.

When the primary user is decided to appear, we can convert H_1 of (1), and get

$$s(n) = x(n) - v(n) \quad (4)$$

Where, $s(n)$ is the signal of CR node receiving from the primary transmitter. As soon as $s(n)$ is got, the CR node records its own location, and will use them in the next stage.

2. The second stage is the process of determining the location and the coverage of the primary transmitter. This stage is the important part of our algorithm. It completes most of calculations and decisions.

- CR nodes complete the process of spectrum sensing, and decide the primary transmitter exists. CR nodes report their location and the energy level of the transmitter to decision centre.
- The decision centre selects ranging nodes based on the type of secondary user (such as CR base station or CR user), signal strength detected (generally, CR nodes which have received stronger signals are preferred) and the dispersion of location information. Under normal circumstances, first, CR base station is preferred as ranging node. Second, in ensuring the first rule, CR user which has received the stronger signal is preferred as ranging node. Third, in ensuring the first two rules, CR users which locations are relative dispersion are selected.

We explain the selection algorithm in the case of the required minimum number of nodes (three nodes).

- When $N > 3$ (N is the number of CR base stations), the three of base stations of the strongest signal selected are as ranging nodes, and don't consider the rule of location information. The process of selection is as follows:

$$X = \{s(1), s(2), \dots, s(N)\}$$

for $n = 1:3$

$$x_n = \text{Max}(X)$$

$$X = X - \{x_n\}$$

end

$$Y = \{x_1, x_2, x_3\}$$

- When $0 < N < 3$, the cognitive BSs are principally chosen as ranging nodes while CR users work as substitute. There's also requirement that these users' received signal strength should be higher the threshold. Now, there are two cases:

- Two CR base stations can be as ranging nodes.
The users who have received the signal of the primary transmitter are descending sort according to the signal strength. We take the first half.

$$X = \{s(1), s(2), \dots, s(N)\}$$

$$\text{for } n=1: \frac{N}{2}$$

$$x_n = \text{Max}(X)$$

$$X = X - \{x_n\}$$

end

$$Y = \{x_1, x_2, x_3, \dots, x_{\frac{N}{2}}\}$$

According to calculation, we can get the distance between each CR user and the perpendicular bisector of two CR base stations. The user whose distance is shortest is as ranging node.

$$Y = \text{Min}\{d\} \quad (5)$$

Where, $d = \frac{|ax_0 + by_0 + c|}{\sqrt{a^2 + b^2}}$ is the distance

between the ranging node and the perpendicular bisector between two CR base stations, Y represents the selected ranging node.

- Only one CR base station can be as ranging node.

The users who have received the signal of the primary transmitter are descending sort according to the signal strength. We take the first half. In these users, the one who is farthest away from the CR base station is as the second node, and then the user who is closest to the perpendicular bisector between the CR base stations and the second ranging node is as the third node.

- The above method can be used to select more ranging nodes.

The decision centre calculates the location and the coverage of primary transmitter based on the energy information and their geographic information reported by the ranging nodes. This paper uses the Okumura-Hata model:

$$\begin{aligned} \text{Pathloss} &= 69.55 + 26.16 \log(f_c) - 13.82 \log(h_b) \\ &- \alpha + [44.9 - 6.55 \log(h_b)] \log(d) \end{aligned} \quad (6)$$

Where,

$$\alpha = 8.29 * (\log(1.54 * h_m))^2$$

Parameter Description: *Pathloss* is energy loss in the path, α is correction factor of mobile antenna, h_b is height of base station antenna, f_c is carrier frequency, and d is the distance between the ranging node and the primary transmitter.

In formula 6, α , h_b and f_c can be considered known. We can calculate d according to *Pathloss*.

According to three distances between the ranging nodes and the primary user transmitter, we can uniquely determine the location of the transmitter. If distance error was considered, we can choose more ranging nodes to synthetically determine the location of the transmitter.

In order to improve the accuracy of ranging, the decision centre may make ranging second time. The follow process is the second ranging. This process is optional, and can be done many times.

The decision centre can re-select CR nodes except the nodes of the first time according to the selection rule or use directly the nodes of the first time. Then the centre sends the selection result to the ranging nodes.

- According to three energy values, we can get three distance values, and then we can uniquely determine the location of the transmitter. Based on the location and transmit power, we can get the coverage of the primary user transmitter. If the distance measurement process has many times, the decision centre will associate with the results to calculate the coverage and location of the transmitter.

- The third of stage is the CR network informs the cognitive BSs which coverage overlaps with the coverage of the primary user to change their spectrums.

- According to the location and coverage of the primary user transmitter, CR system gets the CR base stations which coverage overlaps with the primary user.

$$Y = \begin{cases} H_0, & R_1 + R_2 \leq d \\ H_1, & R_1 + R_2 > d \end{cases} \quad (7)$$

Where, R_1 is coverage radius of the primary user transmitter, R_2 is coverage radius of a cognitive BS, d is distance between the cognitive BS and the primary transmitter.

H_0 represents that the coverage of cognitive BS doesn't overlap with the primary transmitter, H_1 represents the coverage overlaps.

- The decision centre needs to exclude the cognitive BS which has sensed the primary transmitter, and then send the decision result in the above step to the corresponding base stations. Those base stations change their spectrum and use vacant spectrum based on the list of the available spectrum.

III. ANALYSIS OF SPECTRAL EFFICIENCY

By the sensing of the primary transmitter, we can avoid interference with communication of hidden terminals. In addition, this communication method also substantially improved spectral efficiency of CR network.

According to the method in this paper, we simulate the spectrum efficiency for the CR network in the different false alarm probability and detection probability using Matlab. Simulation parameters: there are 100 CR users in the network.

When the primary user is here, there are thirty CR users to be interfered.

Suppose the false alarm probability varies in the 0.1 to 0.4. When the false alarm probability improves, the spectrum efficiency is down. But from figure 4, we can see that spectrum efficiency of using our communication method is better.

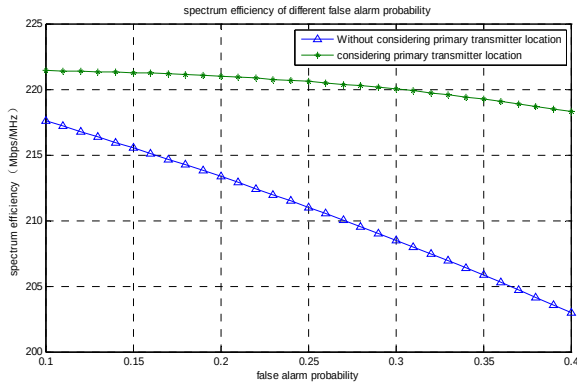


Figure 4. Comparison of spectrum efficiency of two kinds of the method with different false alarm probability

Suppose the detection probability varies in the 0.7 to 1. When the detection probability improves, the spectrum efficiency is down. But the method described by this paper is better performance.

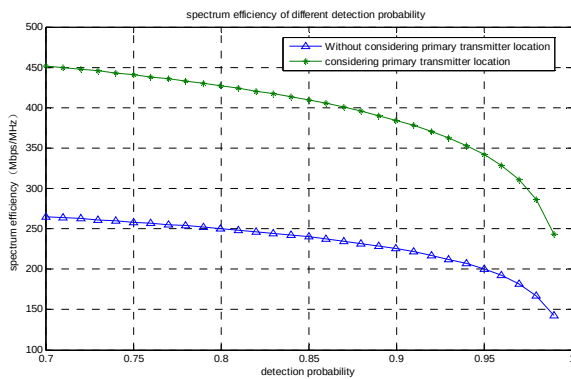


Figure 5. Comparison of spectrum efficiency of two kinds of the method with different detection probability

IV. CONCLUSIONS

In cognitive radio network, how to avoid interference with communication of primary hidden terminal has always been one of the problems we research. There is not a perfect solution at present. This paper tries to propose a communication method which can avoid interference with communication of primary hidden terminal and improve spectrum efficiency in CR network. The result of argumentation and simulation in this paper shows that the target is achieved.

The relatively simple wireless environment is considered in the simulations. So in future studies, we will improve the algorithm to adapt complex environment.

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VI. REFERENCES

- [1] He lihua and Xie xianzhong, Technology of Spectrum Sensing in the Cognitive Radio, Communications Technology, No.185, Totally.
- [2] Li hongyan, Research on Spectrum Sensing in Cognitive Radio, Modern Science & Technology of Telecommunications, 2008.10.
- [3] Guo caili, Feng chunyan and Zeng zhimin, Cognitive Radio Network Technologies and Applications, p44-48.
- [4] He qifeng, Wen wu, Research on Spectrum Sensing Technology of Cognitive Radios, Shanxi Electronic Technology.
- [5] Zhi quan, Shuguang Cui, H. Vincent Poor and Ali H. Sayed, Collaborative Wideband Sensing for Cognitive Radios, IEEE Signal Processing Magazine, November 2008, pp. 61-73.