AN OFDM BASED SENSING INFORMATION EXCHANGE FOR COOPERATIVE SENSING IN COGNITIVE RADIO SYSTEMS

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ABSTRACT

In cognitive radio systems, secondary cognitive users have to recognize wireless environment around the users. As one of the methods for improving the recognition sensitivity of the wireless environment, cooperative sensing techniques have attracted attention. The cooperative sensing requires exchanging the observed information like the detected primary user's signal level at each sensing node to the master detection node. However, conventional cooperative sensing techniques have not considered information exchange methods. In this paper, we propose a novel information exchange method based on mapping the information to a subcarrier signal of an OFDM signal structure for reducing the required information symbols for the cooperative sensing. We confirm that the proposed method obtains almost the same sensing performance compared to the soft information based cooperative sensing with perfectly exchanging the observed information.

1. INTRODUCTION

Recent years, cognitive radio systems have attracted researchers' attention for improving the spectrum efficiency at the crowded spectrum [1]. Cognitive radio systems can increase the chance of communication by adapting the system parameters, like communication method, modulation method, frequency, data rate and so on, according to the surrounding wireless environment. A spectrum sharing system between a primary user and a secondary user is known as one of the key cognitive radio systems. In this system, in order to surely detect the primary signals at the secondary system, sensing technologies are important [2].

In traditional spectrum allocation strategies, the primary systems occupy the spectrum allocated by a regulator of each country. On the other hand, in the primary and secondary system, cognitive secondary users can utilize the spectrum allocated to the primary users when the primary users do not use the same frequency spatially or temporally. In order to realize such primary and secondary system, the interference toward the primary users from the secondary users should be minimized by recognizing the surrounding radio environment. Therefore, secondary users must exactly observe the presence or absence of primary users. Such observation is known as spectrum sensing techniques. Many kinds of spectrum sensing techniques have been proposed for detecting the presence of primary system [3][4][5]. Among them, the cooperative sensing technologies, in which the sensing results of the surrounding nodes are used for decision of the existence of the primary system, have attracted attention because the cooperative sensing has tolerance to the fading and the shadowing environment. Many cooperative sensing techniques have been proposed [6][7]. However, almost all methods assume the sensing information is perfectly exchanged among nodes. In realistic environment, the sensing information should be exchanged among nodes by using some information exchange methods. Although a simple information exchange method can be realized by using packet communication among nodes, the header of a packet occupies the channel and some collision avoidance methods among secondary nodes are required. These redundancies degrade the total secondary system performance.

In this paper, in order to solve the information exchange problem of the cooperative sensing, we propose a novel information exchange method based on mapping the information to a subcarrier signal of an OFDM signal structure. In the proposed method, the sensing result of each cooperative secondary node is converted to the subcarrier number of OFDM signal. Then the secondary sensing nodes simultaneously transmit a tone signal at the selected subcarrier. The transmitted OFDM signals have subcarrier components at the selected subcarriers. These OFDM signals are received at the master sensing node and the subcarriers have energy more than a certain threshold. The subciarrer number information can be recovered to the sensing results of the surrounding sensing nodes. Finally, a cooperative sensing processing is performed at the master node for detecting the presence of the primary signal. The performance of the proposed information exchange method is evaluated by using computer simulation to confirm the effectiveness of the proposed method.

2. ENERGY DETECTION BASED COOPERATIVE SENSING METHOD

In conventional cooperative sensing technologies, the methods exchanging the sensing information have not been studied. Therefore, in this paper, we focus on a novel idea for information exchange to realize the cooperative sensing by collecting the sensing information from the surrounding sensing nodes. Here, we utilize a subcarrier number of OFDM signal instead of raw sensing information. First of all, in this section, we briefly introduce the fundamental cooperative sensing method to detect the signals of the primary user. Lots of primary detection methods have been proposed in order to detect unknown signals embedded in the noise [3][4][5]. Because of its simple implementation and adequate performance, an energy detector is often used for sensing algorithm. In this paper, we utilize the sensing technique by using the energy detector.

The energy detector decides the presence of unknown signals comparing two hypotheses. One is H_0, which means the primary user is absent (noise only), and the other is H_1, which means the primary user is present (signal plus noise). The probability of exactly detecting presence of the primary user is denoted as P_D. On the other hand, when the primary signal is not transmitted from the transmitter, the receiver wrongly decides the signal is transmitted. The probability of above wrong detection expresses as a false alarm P_{FA}. These hypotheses can apply to the cooperative sensing by using the plural surrounding sensing nodes. The cooperative sensing technologies can be classified into two types. One is soft information based cooperative sensing and the other one is hard information based cooperative sensing. We show an image of cooperative sensing in Fig. 1. The secondary node collects the sensing information is named as a master node and the secondary nodes for cooperation are named as secondary sensing nodes.

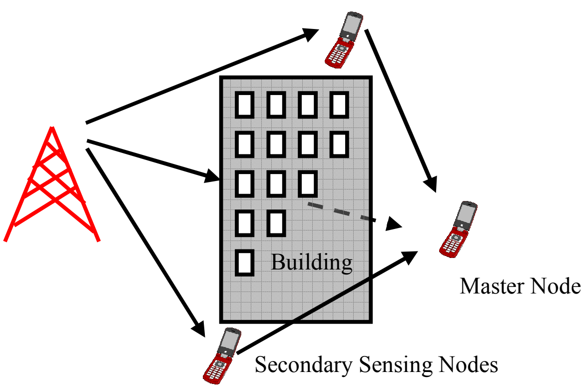

Fig. 1. Image of cooperative sensing

2.1. Soft Information Based Cooperative Sensing

In the soft information based cooperative sensing, each sensing node observes the received power of the signals transmitted from the primary user and reports the value to a master node. The master node detects the presence of the primary user by collecting the information of the observed signal level of the primary user from the surrounding sensing nodes. Then the master node finally detects the presence of the primary user. The cooperative sensing statistic by using energy detection can be written as [8]:

$$\begin{aligned} H_0 &: x = \frac{1}{NI}\sum_{i=0}^{I-1} x_i = \frac{1}{NI}\sum_{i=0}^{I-1}\sum_{n=0}^{N_i-1}\left|w_i[n]\right|^2 \\ H_1 &: x = \frac{1}{NI}\sum_{i=0}^{I-1} x_i = \frac{1}{NI}\sum_{i=0}^{I-1}\sum_{n=0}^{N_i-1}\left|A_i s_i[n] + w_i[n]\right|^2 \end{aligned}, \qquad (1)$$

where i is the node number, I is the number of all sensing nodes and x is the test statistic of the cooperative sensing. $w_i[n]$ denotes the noise of the n th sample, the amplitude of the received signal is $A_i s_i[n]$ when the transmitter transmits the signal $s_i[n]$, N_i is the number of sample of i th node, N is the number of all samples.

The decision function of the presence of the primary user can be written as:

$$x > \gamma \ . \qquad (2)$$

When the equation (2) is true, the primary user is judged to be present. This threshold γ is decided to satisfy the certain P_{FA} as shown in [8]. Then the threshold γ is given by:

$$P_{FA} = \int P(x > \gamma | H_0) dx \ . \qquad (3)$$

In general, the probability of the false alarm P_{FA} uses 0.1 for evaluation the performance of the cooperative sensing. Therefore, in this paper, P_{FA} =0.1 is used in the simulation.

2.2. Hard Information Based Cooperative Sensing

In the hard information based cooperative sensing, each sensing node observes the received power of the signals from the primary user, and the node individually judges the presence of the primary user by using non-cooperative sensing. For example, the detection statistic B_i can be written as:

$$\begin{aligned} H_0 &: B_i = 0 \\ H_1 &: B_i = 1 \end{aligned}, \qquad (4)$$

where, B_i=0 means the primary user is absent. B_i=1 means the primary user exists. These values are collected to the master node. At the master node, the presence of primary user is decided by the following equation,

$$\sum_{i=0}^{I-1} B_i > \gamma_h \ . \qquad (5)$$

We set the value of the threshold γ_h is zero [9].

2.3. Characteristics of Each Cooperative Sensing

Here, in this subsection, we discuss advantages and disadvantages of conventional cooperative sensing methods using soft and hard information. One advantage of the soft information based cooperative sensing is that the detection performance is better, because it can exchange the raw information of the received power at each sensing node. However, to exchange this information between the sensing nodes and the master node, many symbols are required. In cooperative sensing techniques, many sensing nodes are cooperated to improve the detection probability of primary signals. Each sensing node requires a lot of symbols for exchange the information. On the other hand, the received signal power is converted to the binary data when the hard information based cooperative sensing is used. Therefore, only one bit is required in each sensing node for transmitting the information to the master node. However, the sensing performance becomes worse because the exchanged information is too little to decide the presence of the primary system with accuracy. The amount of the bits for the sensing information and the accuracy of the detection of the primary signal are tradeoff.

In addition, in conventional cooperative sensing techniques, we assume that the exchange (soft or hard) information is perfectly collected to the master node from all sensing nodes. We call these methods 'perfect soft information based cooperative sensing' and 'perfect hard information based cooperative sensing'.

However, in the realistic environment, some procedures for information exchange are required. If we consider packet based information exchange, the efficiency of the information exchange is quite low because header and collision avoidance protocol are required. Therefore, in this paper, in order to solve the problem of sensing information exchange for cooperative sensing, we propose a novel sensing information exchange method decreasing the amount of bit of the exchange information with keeping the performance of the soft information based cooperation sensing. The detail of the proposed method is shown in the next section.

3. PROPOSED OFDM BASED INFORMATION EXCHANGE METHOD

As shown in the previous section, the information exchange methods in the cooperative sensing are assumed to be perfect in the previous researches. However, the information exchange methods are very important to realize the practical cooperative sensing in the primary and the secondary system. In a simple method, the sensing information can be informed to the master node by generating a packet including the sensing data. However, the required channel traffic for transmission of these packets becomes large due to the header of the packet even if hard information based cooperative sensing is used. Therefore, we have to prepare a large capacity dedicated channel for exchanging the information. In order to solve the information exchange problem, in this section, we propose a novel practical information exchange method for secondary wireless networks without large amount of data to exchange. In the proposed method, information is transmitted to the master node by mapping the sensing result of secondary sensing node to a subcarrier number of OFDM.

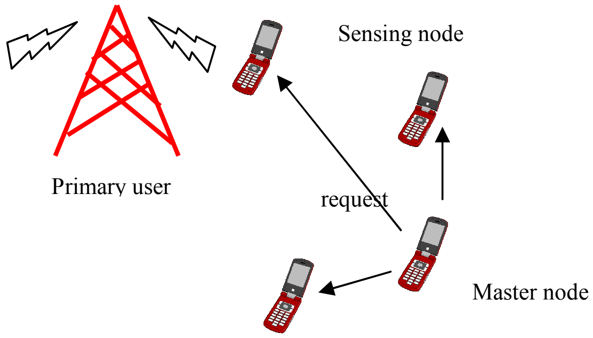

Fig. 2-a. Sensing request phase

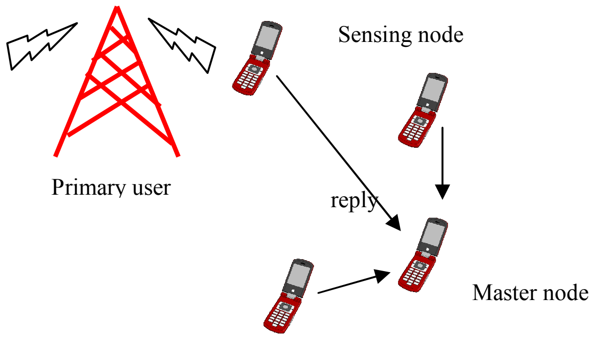

Fig. 2-b. Sensing reply phase

The system image of the proposed method is shown in Figures 2-a, 2-b and 3. First step is a request phase, the master node who wants to send the secondary data requests to the surrounding secondary nodes to reply the sensing information. At the surrounding secondary nodes, when the request for sending the sensing result is received, the surrounding sensing nodes convert the received signal power of the sensed spectrum to a subcarrier number of OFDM. After that in the second step (reply phase), the sensing nodes simultaneously transmit the tone signal at the selected subcarrier to the master node with adjusting the timing of all nodes by using the control signals included in the request packet from the master node. At the master node, these OFDM signals are simultaneously received. Then in this method, at least one OFDM symbol is required to information exchange. Therefore, the required number of symbol is less than that of the perfect soft information based cooperative sensing with packet communication. In this method, all sensing results of the surrounding nodes can be mapped to the subcarriers and are collected at the same time

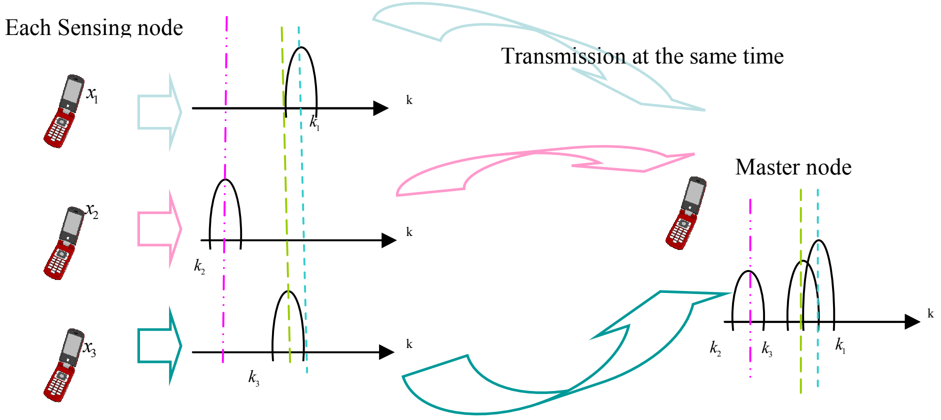

Fig. 3. Image of proposed information exchange method by using OFDM signal structure.

to the master node. At the master node, the large power subcarrier is regarded as the information subcarrier and the subcarrier number is converted to the sensing results of each transmitted node. By using these sensing results, the soft information based cooperative sensing can be performed.

Here, we show the procedure of the proposed sensing information exchange method using OFDM structure as follows,

1. The master node requests the sensing information to the surrounding sensing nodes.
2. Each sensing node observes the received power level of the spectrum of which the master node wants to send the secondary data.
3. In each sensing node, the received signal power is converted to the subcarrier number of the OFDM signals. The converted equation is given by:
$$k_i = \left\lfloor x_i{}' \frac{N_c}{\alpha} \right\rfloor , \qquad (6)$$
where k_i denotes the subcarrier number, $x_i{}'$ means the received power at each sensing node normalized by the noise level of the node. N_c denotes the number of the OFDM subcarriers, and α denotes the parameter deciding the converted subcarrier width. $\lfloor\ \rfloor$ means the integer that does not exceed the inside value.
4. The OFDM signal with signal at the selected subcarrier is generated in each sensing node and is simultaneously transmitted from all surrounding nodes to the master node.
5. The master node receives the OFDM signal and checks the subcarrier number whose signal power is larger value compared with a subcarrier detected threshold γ_m. The decision function is given by:
$$P_k > \gamma_m , \qquad (7)$$
where P_k is the received power of k th subcarrier. When the equation (7) is true, the master node decides that some primary user sends the information at the subcarrier.
6. Collected subcarrier number k is converted into the soft sensing information. The converted function is given by:
$$\hat{x}_j = (k+0.5)\frac{\alpha}{N_c} , \qquad (8)$$
where $\hat{x}_j$ denotes the value of the soft information converted from the detected subcarrier number of OFDM signal, j is the detected sensing node index.
7. Soft information based cooperative energy detection is performed by using equation (2) and $\hat{x}_j$.
8. According to the sensing results, the master node decides the communication spectrum for secondary system.

4. SIMULATION RESULTS

Since the proposed method uses OFDM subcarrier tone signals for exchanging the sensing information, the detected subcarrier error at the master node degrades the total sensing performance. In order to evaluate the effectiveness of the proposed method, we perform the computer simulations.

4.1. Evaluation criteria

As mentioned above, if a primary user is presence, the probability P_D denotes the probability that a master node can detect correctly its presence, the probability P_{MD} denotes the probability that the master node cannot detect its presence. On the other hand, if the primary user is absence, the probability P_{FA} denotes the probability that the master node faultily detects the presence of the primary user. Moreover, in this paper, in order to evaluate the secondary information exchange performance at the master node, we define the following evaluation criteria. In the proposed method, the sensing information is mapped to the subcarrier, so that the probability that subcarrier number converted at the sensing node can be correctly estimated at the master node is denoted as a probability of subcarrier estimation P_{pce}.

Finally, nevertheless no sensing node selects the subcarrier number, the probability that the master node estimates the subcarrier number from the noise only subcarrier signal is denoted as a probability of false subcarrier estimation P_{fce}.

4.2. Simulation parameters

We compare the primary detection probability and the false alarm probability of the proposed method to the soft and the hard information based cooperative sensing methods with perfect information exchange. We assume that each sensing node receives the primary signal under the independent Rayleigh fading with the same average primary signal to noise ratio (SNR). The primary signal is BPSK single carrier signal and the threshold of sensing is decided as P_{FA} is 0.1. The simulation parameters are shown in Table 1. Because we assume that the sensing nodes are close to the master node and are far from the primary transmitter, we set 30[dB] to the secondary SNR for information exchange signals at the master node. On the other hand, as for the primary SNR at the surrounding sensing nodes, we set -20~10[dB] at the sensing nodes.

Table 1. Simulation Parameters.

Channel model	Rayleigh fading, Log-normal shadowing
Primary signal modulation	Single Carrier, BPSK
Number of subcarrier of OFDM signals N_c	512
Number of sensing node I	10
SNR at master node	30[dB]
Primary SNR at sensing nodes	-20~10[dB]
Threshold of OFDM signal detection γ_m	11.5[dB]
Subcarrier mapping parameter α	5
Range of subcarrier mapping	- infinite~20.1[dB]
Probability of false alarm P_{FA}	0.1
Number of plane wave for fading	128
Number of multi-path	18
Delay interval	5

4.3. Simulation results

In the proposed method, in order to detect the subcarrier signals at the master node, we have to decide the subcarrier detecting threshold of the secondary information signals at the master node. Therefore, at first, we explain how to decide the subcarrier detecting threshold from the subcarrier signals of the received OFDM signal at the master node.

Figure 4 shows the results of the probability of false subcarrier estimation P_{fce} versus the subcarrier detection threshold of OFDM signal. Figure 5 shows the results of the probability of subcarrier estimation P_{pce} versus the

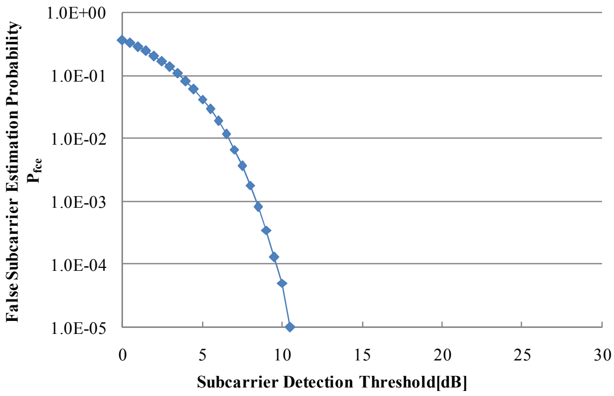

Fig. 4. False subcarrier estimation probability versus the subcarrier detection threshold at the master node. Primary SNR of each sensing node is -15[dB].

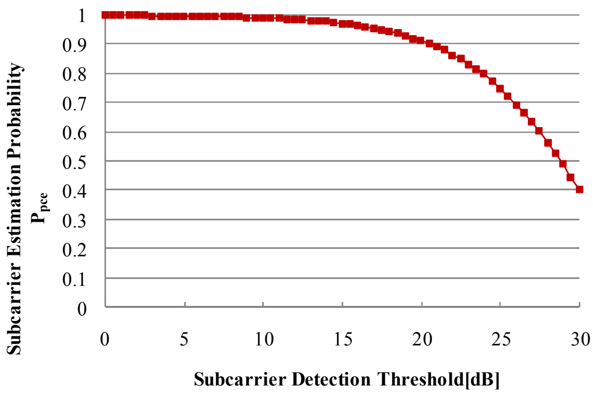

Fig. 5. Subcarrier estimation probability versus the subcarrier detection threshold at the master node. Primary SNR of each sensing node is -15[dB].

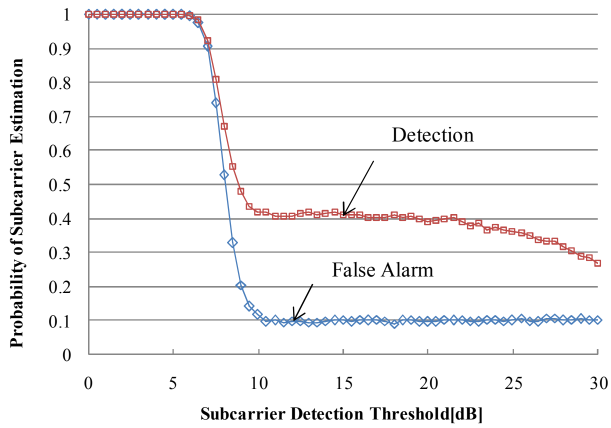

Fig. 6. Detection and false alarm probability versus the subcarrier detection threshold. Primary SNR of each sensing node is -15[dB].

subcarrier detection threshold of the OFDM signal. Figure 6 shows the results of the detection probability P_D versus the subcarrier detection threshold of OFDM signal. The performance of the detection probability and the false alarm probability is evaluated by using the proposed method with the fixed primary SNR at the sensing nodes as -15[dB]. These figures show that the low subcarrier detection threshold influences to the probability of false alarm because the master node can not judge whether the number of subcarrier is signal or noise. On the other hand, if the subcarrier detection threshold becomes too large, subcarrier estimation probability degrades because the master node can not detect the subcarrier number from the received signal.

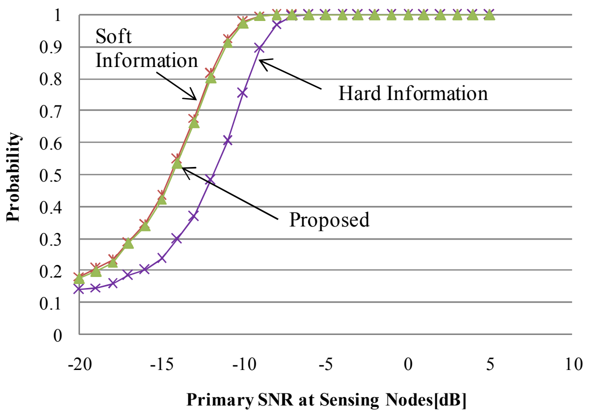

Fig. 7. Detection P_D of the proposed cooperative sensing. Subcarrier detection threshold is 11.5[dB].

Therefore, we can decide the suitable subcarrier detection threshold at the master node as γ_m =11.5[dB].

By using this value, we derive the results of total performance. Figure 7 shows the results of the detection probability P_D of the comparison among the proposed method, the perfect soft information based cooperative sensing, and hard information based cooperative sensing. In Fig. 7, the horizontal axis shows the primary signal SNR at the sensing nodes. From this figure, we can confirm that P_D of the perfect soft information based cooperative sensing and the proposed method have the almost the same performance. If we compare with the perfect hard information based cooperative sensing the proposed method takes better performance. Since the proposed method can exchange the sensing information with a small number of symbols, the plural nodes can send the information with at least one symbol. Therefore we can confirm the effectiveness of the proposed method.

5. CONCLUSION

In this paper, we propose a novel sensing information exchange method for cooperative sensing by using the OFDM signal structure. In the proposed method, the sensing information at each secondary sensing node is converted to a subcarrier number of the OFDM signal. In each sensing node, the signal that contains the tone signal at the selected subcarrier is transmitted to the master node at the same time of the other sensing nodes. Therefore, the master node can obtain all sensing information at the same time by detecting the OFDM signals from the surrounding sensing nodes. From the computer simulations, we can confirm that our proposed method can achieve almost the same sensing performance compared with the perfect soft information based cooperative sensing.

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