

A Novel Power Controlled Sensing Information Gathering for Cooperative Sensing on Shared Spectrum with Primary Spectrum

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Abstract—This paper proposes a novel power controlled sensing information gathering for cooperative sensing on shared spectrum with primary system while jointly using individual sensing results at each node. We apply simultaneous sensing information gathering by using an orthogonal frequency signal. This method can keep the interference power to the primary receiver low. Simulation results show that the power controlled cooperative sensing can obtain good sensing performance without harmful interference toward the primary system.

I. INTRODUCTION

Dynamic Spectrum Access (DSA) of cognitive radio (CR) technologies can share vacant spectrum of a primary system with a secondary system [1]–[4]. Energy detection is a sensing method checking the received power with a simple implementation, and can successfully detect vacant spectrum even if the structure of the primary signal is unknown. However, due to the wireless channel locality caused by fading and shadowing, the sensing performance degrades. In order to reduce the effect of such kind of wireless channel locality, the cooperative sensing techniques have been studied by many researchers [5]–[7]. The cooperative sensing uses sensing information from surrounding secondary sensing nodes for primary signal detection.

In order to consider a realistic cooperative sensing, a method to gather the cooperative sensing information is very important. We have proposed high efficient information gathering method called orthogonal frequency based sensing information gathering method (OF-SIG) in [8]. Because this method maps the sensing result of each node to the frequency of tone signal, the giving interference is low. This method can also gather the sensing information simultaneously from surrounding sensing nodes. Therefore, our method has potential to share the spectrum with a primary system for gathering the sensing information from surrounding sensing nodes. However, the sensing nodes cannot safely transmit the sensing information without appropriate transmit power design. The sensing nodes would utilize larger transmit power in the spectrum shared channel. Therefore, this paper proposes a novel cooperative sensing method with transmit power control based on local

individual sensing of each node. We design the appropriate transmit power of the sensing node while keeping the detection performance without harmful interference.

The proposed transmit power design considers the cooperation probability based on the sensing result in each sensing node and aggregated interference is considered. By using this design, the proposed cooperative sensing method can share the spectrum with the primary system. As a result, this cooperative sensing with OF-SIG can achieve good primary detection performance without the harmful interference, even if on the same spectrum of the primary system.

II. COOPERATIVE SENSING WITH ENERGY DETECTION

In this paper, we use an energy detection for spectrum sensing method because it is a simple implementation and has adequate performance [9]. The energy detection method detects unknown signals embedded by comparing the observed received signal power level with a threshold. The threshold is decided based on the probability of false alarm, which is the signal detection probability when the primary user is not existent.

The energy detector of the master node decides the presence of unknown signals comparing two hypotheses, H_0 and H_1 . These detection statistics in the cooperative sensing can be written as [9]:

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

where i is the node index 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, N is the number of all samples. The amplitude of the received signal is $A_i s_i[n]$ when the transmitter transmits the signal $s_i[n]$ and the channel gain is A_i .

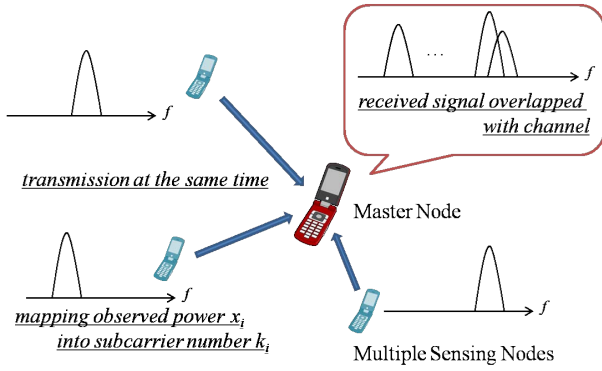


Fig. 1. Simultaneous sensing information transmission using OF-SIG.

The detection function of the presence of the primary user at the master node can be written as:

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

When Eq. (2) is true, the primary user is judged to be present. This threshold γ is decided to satisfy the certain probability of false alarm, p_{fa} , if we assume the summed signal is regarded as Gaussian as shown in [7]. Then the threshold γ is given by:

$$p_{fa} = \int p(x > \gamma | H_0) dx. \quad (3)$$

Here, the false alarm probability, p_{fa} , denotes that the master node detects the primary signals, nevertheless the primary user is not existence.

III. PROCEDURE OF SENSING INFORMATION GATHERING

For the cooperative sensing, when the sensing nodes transmit the sensing information, a communication channel for sensing information is required. In general, conventional researches consider the dedicated channel for sensing information. However, it reduces the frequency utilization efficiency. Therefore, in this study, we propose a novel power controlled sensing information gathering for cooperative sensing. This paper considers the sensing information on the same spectrum of the primary system without causing the large interference to the primary receiver.

We have proposed OF-SIG as an efficient sensing information gathering method on the primary spectrum. OF-SIG transmits tone signal with the decided frequency band according to the sensing result of each sensing node for gathering the sensing information [8]. In [8], we only show the performance of sensing results without considering the aggregated interference at the primary receiver. In general, interference caused by single signal is calculated when the one sensing node is on the nearest location within the secondary communication area. In the worst case like this, it is assumed that information gathering by using the transmit power controlled by this calculation can protect the primary receiver. However, in OF-SIG, the sensing information signals may become harmful interference toward the primary system, because multiple sensing nodes simultaneously transmit the signals. In particular, sensing nodes near the primary receiver

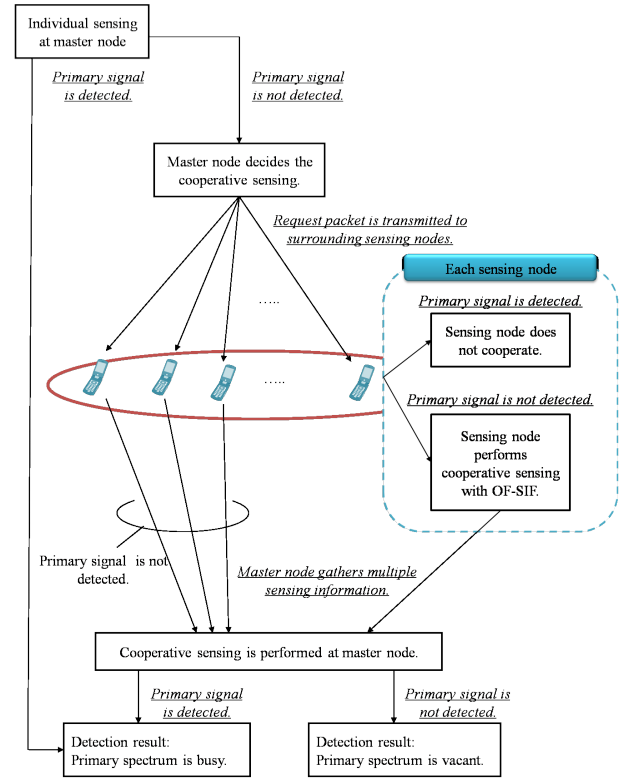


Fig. 2. Diagram of procedures of cooperative sensing with OF-SIG.

should not transmit the sensing information. Therefore, we must decide whether the sensing information can be transmitted or not. Then we consider installing an individual sensing at each sensing node and setting the appropriate power to transmit the sensing information for the cooperative sensing if the primary is not detected at the individual sensing.

For this calculation of the appropriate transmit power, we assume the secondary system already have some parameters. Given parameters are the transmit power of the primary transmitter, the radius of primary service area and the allowable interference power of the primary system. The secondary system can avoid the interference by using these parameters without the knowledge of location of the primary transmitters and receivers. In the proposed cooperative sensing, each sensing node decides whether they can transmit the sensing information or not by using the individual sensing result. Then the master node performs the cooperative sensing by using the received sensing information signal.

In this section, we explain a procedure of the proposed sensing information gathering by using OF-SIG without harmful interference toward the primary receiver. Figure 1 shows a simultaneous sensing information transmission using OF-SIG. In order to avoid harmful interference toward the primary system from multiple sensing nodes, sensing nodes control the transmission according to the result of the individual sensing. The diagram of the procedures is shown in Fig. 2.

- 1) The master node individually senses the received signals to check the status of the primary system in the band. If the master node detects the existence of the primary system, this spectrum is regarded as occupied by the

primary system. In this paper, we use the signal detection by using the power detector.

- 2) If the master node does not detect the primary signal, the master node transmits a request packet toward surrounding nodes for gathering sensing information.
- 3) The nodes which have received the request packet check their own situation by using the individual sensing. From this result, the secondary node near the primary system can avoid the harmful interference toward the primary receiver by withdrawing transmission of the sensing information.
- 4) The sensing node, which decides to transmit the sensing information, maps the sensing result into the orthogonal frequency signal.

The mapped function is given by [8]:

$$k_i = \left\lfloor x'_i \frac{N_c}{\alpha} \right\rfloor, \quad (4)$$

where k_i denotes the mapped orthogonal frequency like OFDM subcarrier number. x'_i means the received power at each sensing node normalized by the noise level of the node. N_c is the number of orthogonal information bins as N_c subcarrier OFDM signal and α denotes the parameter deciding the mapped subcarrier width in the information transmitting bandwidth.

- 5) All selected sensing nodes simultaneously transmit the orthogonal tone signals with limiting the transmit power which can be decided according to the method shown in Sect. IV.
- 6) The master node receives the transmitted signals from multiple sensing nodes at the same time and the orthogonal signals are detected in each subcarrier bin. The detection test of each frequency band is given by:

$$P_k > \gamma_d, \quad (5)$$

where P_k is the received power of k th orthogonal frequency.

When Eq.(5) is true, the master node decides that some primary user sends the sensing information related to this orthogonal frequency. Then the master node reconverts the subcarrier signals to the original sensing information as shown in the following equation:

$$\hat{x}_j = (k + 0.5) \frac{\alpha}{N_c}, \quad (6)$$

where \hat{x}_j denotes the value of the reconverted information mapped from the subcarrier number of orthogonal frequency signals, j is the sensing node index. After that, the cooperative sensing is performed.

From above procedure, the primary signal detection is performed with the cooperative sensing combined with the individual sensing result.

IV. TRANSMIT POWER DESIGN FOR COOPERATIVE SENSING BASED ON AGGREGATED INTERFERENCE

This section shows the transmit power design which is possible to protect the primary system from the sensing

information signals using the primary spectrum.

For simplicity, this section analytically derives the allowable transmit power level by considering our cooperative sensing based on the individual sensing. Figure 3 shows the location of the primary transmitter and receiver and secondary master node. The primary receiver on the boundary of the primary service area should achieve a desired SIR. The averaged interference power, I_a , is given by:

$$I_a = \int_0^{2\pi} \int_0^{d_c} P_m \rho_s(r, \theta) r \left(\frac{\lambda}{4\pi d_0} \right)^2 \left(\frac{d_0}{z} \right)^{n_{pl}} p_c(r, \theta) dr d\theta, \quad (7)$$

$$z = \sqrt{(d_m - d_p)^2 + 2r(d_m - d_p) \cos \theta + r^2}. \quad (8)$$

Here, n_{pl} is path loss factor, P_s denotes the allowable transmit power, λ is the wave length, d_0 is reference distance, $p_c(\cdot)$ is the cooperation probability. d_c is the radius of the cooperative sensing area depending on the allowable transmit power of the sensing node, P_m , in OF-SIG. d_m is the distance between the master node and the primary receiver, d_p is the radius of the primary service area. z is the distance between the primary receiver and the master node. The number of cooperative sensing nodes is decided by transmission probability of the sensing information at each cooperative sensing node. d_c and the cooperative sensing node density $\rho_s(r, \theta)$ are given by:

$$d_c = d_0 \sqrt{n_{pl} \frac{P_m}{P_r} \left(\frac{\lambda}{4\pi d_0} \right)^2}, \quad (9)$$

$$\rho_s(r, \theta) = \rho_0 p_c(r, \theta) = \rho_0 (1 - p_{nc}(r, \theta)). \quad (10)$$

Here, P_r is the sensing information received power at the master node and is derived from the sensing SNR, γ_m , and ρ_0 is the density of the sensing nodes.

The cooperation probability decided by individual sensing result of each sensing node, $p_c(\cdot)$, is shown by:

$$p_c(r, \theta) = 1 - p_{nc}(r, \theta) \quad (11)$$

p_{nc} is derived primary SNR at the sensing node, $\gamma_p(z_i)$. $Erfc$ and $Erfc^{-1}$ shows the complementary error function and the inverse of the complementary error function. N_i is the number of samples and p_{fnc} denotes false no cooperation probability. p_{fnc} means false transmitting the sensing information as a result of individual sensing, when the primary signal does not exist on the channel. p_{fnc} is decided by the sensing function of the secondary system, because the detection threshold for individual sensing derives signal detection function. Because we consider the worst case, flat Rayleigh fading channel should be considered. Then the probability of no cooperation p_{nc} is given by [10]:

$$p_{nc}(r, \theta) = \int_0^{\infty} \frac{1}{2} Erfc \left(\frac{Erfc^{-1}(2p_{fnc}) - \sqrt{\frac{N_i}{2}} \gamma_p(r, \theta)}{\sqrt{2\gamma_p(r, \theta) + 1}} \right) \frac{1}{\gamma_p(r, \theta)} \exp \left(-\frac{\gamma}{\gamma_p(r, \theta)} \right) d\gamma \quad (12)$$

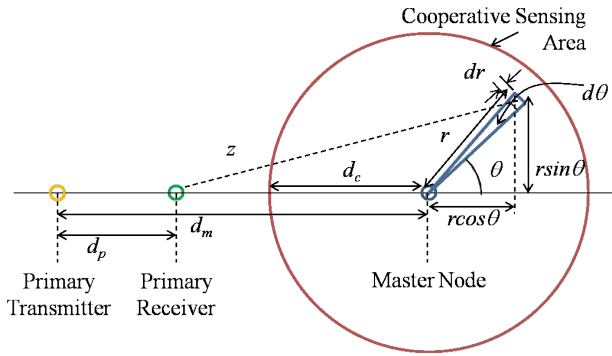


Fig. 3. Primary transmitter and receiver and master node location.

TABLE I
SIMULATION CONDITIONS.

Channel model	Rayleigh fading
Primary system	512 subcarrier OFDM
Required SIR of primary receiver	25.0 [dB]
Primary transmit power P_p	25.0 [dBm/512subcarriers]
Radius of primary service area d_p	100 [m]
Noise level	-90.0 [dBm/512subcarriers]
Sensing information transmission method	The same frequency based signal space with primary 512 subcarrier OFDM
Frequency	2.4 [GHz]
Path loss model	Exponential decay model (Path loss factor 3, reference distance d_0 1 [m])
Probability of false alarm p_{fa}	0.1
Probability of false no cooperation p_{fnc}	0.01
Density of sensing nodes ρ_0	0.005 [nodes/m ²]
Subcarrier detection threshold γ_d	11.5
SNR at master node γ_m	30 [dB]
Mapping parameter α	2
Number of samples per node	512

In this paper, in order to design the allowable transmit power under the worst condition, we consider the flat Rayleigh fading and use p_{nc} as shown in Eq. (12). From these equations, we can decide the transmit power of sensing node, P_m , with keeping I_a at the primary receiver by using Eq. (7).

V. ANALYTICAL EVALUATION AND SIMULATION RESULTS

The system parameters used in the analysis and the simulation are shown in Table I. We simulate the performance by changing the distance between the master node and the primary transmitter d_m . In this paper, primary system information is assumed to be announce from the external server, which gives parameters of the primary system to the secondary receiver nodes. However the location of the primary receivers and transmitter is not required to be known at the secondary system. The secondary system knows the existence of the primary system. The sensing nodes within the area achieve SNR at the master node more than certain SNR requires to cooperate the sensing information.

Figure 4 shows the result of the allowable sensing node transmit power to keep the primary SIR = 25dB which is

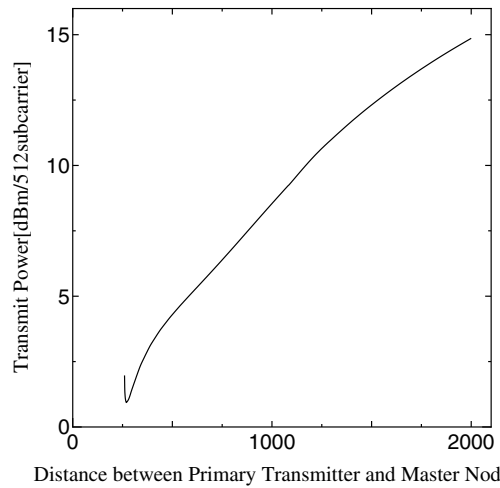


Fig. 4. Secondary transmit power to keep SIR = 25 dB at primary receiver.

derived from Eq. (7). From this figure, the minimum allowable secondary transmit power to avoid the interference is decided as 0.94dBm/512subcarriers. This is worst location results of the primary transmitter and the receiver. By using this transmit power, the sensing node can protect the primary receiver from the harmful interference even if the secondary nodes cannot know the primary location.

This figure shows that the sensing node near the primary transmitter can utilize large power. This is because the number of cooperation nodes is almost zero by the result of individual sensing result. That is to say, in this case, the probability of cooperation at these nodes, p_c , is very low, because almost all nodes detect the primary signal. In this location, because the sensing node can certainly receive the signal with the individual sensing, the sensing information is not transmitted. On the other hand, if the secondary nodes are located far away from the primary transmitter, almost all nodes can transmit the information without causing harmful interference due to path loss. The relationship between the number of the cooperative sensing nodes and the location of sensing node is shown in Fig. 5.

From the minimum allowable transmit power of secondary sensing node as 0.94dBm/512subcarriers. The radius of the cooperative sensing area is calculated as 39.77m, the number of average cooperative nodes is calculated as 24 nodes. The exact number of cooperative sensing nodes is decided by including the probability of no cooperation, p_{nc} , at each sensing node.

We consider that the false alarm probability combined with both influence of the individual sensing and the cooperative sensing. The each false alarm probability of the individual and the cooperative sensing is p_{fa} and $(1 - p_{fa})p_{fa}$, respectively. Therefore, combined false alarm probability p_{fa_c} is given by:

$$p_{fa_c} = p_{fa} + (1 - p_{fa})p_{fa}. \quad (13)$$

In Fig. 6, we compare the performance of only individual sensing and the primary detection with the perfect soft infor-

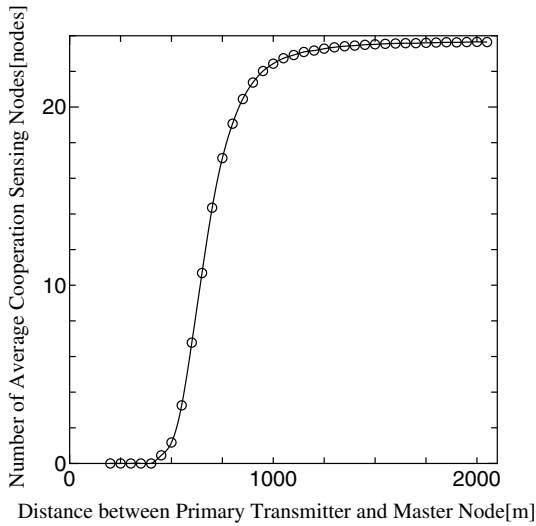


Fig. 5. Number of cooperative sensing nodes.

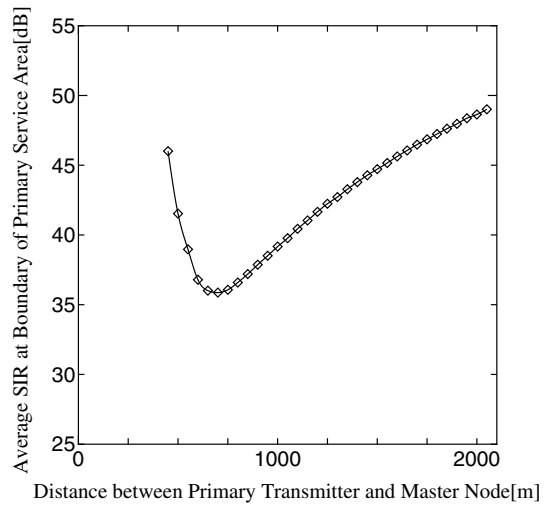


Fig. 7. SIR performance at the worst location primary receiver.

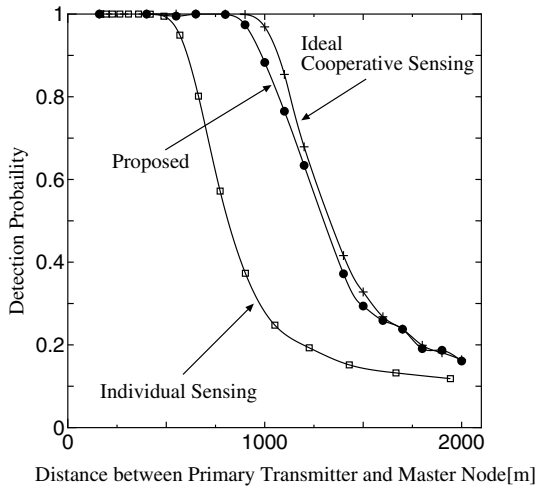


Fig. 6. Comparison of detection performance by simulation.

information based cooperative sensing. Here, the perfect soft information means that the master node receives the perfect sensing information. From Fig. 6, the performance of the proposed OF-SIG by sharing the spectrum with the primary system is improved compared with the non-cooperative sensing. The performance of the proposed method compared with that of the perfect soft information based cooperative sensing is slightly decreased due to information gathering error with OF-SIG. However, the proposed method can share the channel with the primary system without harmful interference toward the primary system. Moreover, our proposed method does not require the information of the primary location, because we calculate the transmit power considered the worst case.

Figure 7 shows the SIR performance at the primary receiver on the boundary of the primary service area by considering the interference from the sensing nodes for the sensing information transmission with OF-SIG. From this figure, we can confirm that SIR is kept larger than 25dB by considering the flat Rayleigh fading. This figure shows the average value so

that the SIR is larger than the requirement $SNR = 25\text{dB}$.

VI. CONCLUSIONS

We have proposed a novel power controlled sensing information gathering method based on OF-SIG for cooperative sensing on shared spectrum of the primary system. We analytically design the allowable transmit power of the secondary sensing nodes to share the spectrum with the primary system. We confirm that the primary system is protected from harmful interference by using the proposed transmit power design of sensing nodes with considering the effect of individual sensing.

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