Optimal Channel Selection Rate of Slave Terminal for Rendezvous Channel Scheme based on Channel Occupancy Rate

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***Abstract*—In dynamic spectrum access based on cognitive radio, two terminals (master and slave) cannot recognize the accessing channel. For exchanging the control signal in order to recognize the accessing channel, the rendezvous channel scheme based on channel occupancy ratio (COR) is proposed. Master and slave select the channel with minimum COR and thus high speed rendezvous channel is achieved. The channel selection rate of slave to each channel is constant but it should be adaptively changed in accordance with the distribution of COR. This paper construct the optimal channel selection rate of slave based on theoretical analysis. The optimal channel selection rate achieves the minimum required time slots as well as satisfying the required probability of completing exchanging control signals.**

I. Introduction

Various applications based on wireless communication are attracting much attention, such as a vehicle to everything (V2X) [1] and Industry 4.0 [2]. As wireless systems are more widely spread over life space, a shortage of frequency spectrum is a much more serious problem. For improving the efficiency of frequency spectrum usage, a spectrum sharing among wireless systems is necessary. A distributed wireless system autonomously exploits the vacant frequency spectrum. It is dynamic spectrum access (DSA) type cognitive radio.

In DSA, each wireless system autonomously selects an accessing channel. Because fewer wireless systems share each channel, the opportunities of access channels increase. As a result, large throughput performance is achieved [3]. For exploiting the vacant channel with high opportunities, the average accessing rate to the channel by the other wireless systems is useful, where it is referred to as channel occupancy rate (COR) [4]. In the channel selection based on COR, each wireless terminal measures the COR and selects the channel with small COR. Since the vacant channel with local specific can be exploited, the frequency spectrum efficiency is improved [5]. However, since each terminal autonomously selects the accessing channel, the two terminals access the different channel and thus cannot construct the communication link. For recovering the dis-connection, the two terminals exchange the control signals for recognizing accessing channel. This signaling procedure is referred to as rendezvous channel scheme.

Various rendezvous channel schemes have been considered. The exclusive time period and the exclusive channel for exchanging the control signals are considered [3]. However, reserving the time period and the frequency channel is difficult because any other system uses them with high probability and the usage efficiency of frequency spectrum is degraded. A rule of selecting accessing channel satisfying that the required time for exchanging control signals is smaller than the certain time is proposed [6]. The terminals surely access the channel in accordance with the rule of accessing channel and thus the rendezvous channel scheme cannot be completed if the channel indicated in the rule is occupied by the other system. The authors propose the rendezvous channel scheme based on COR [7][8]. The two terminals, master and slave, selects the channel with the minimum COR, which is referred to as superior channel. Since the master and slave commonly can measure the COR, these select the common channel with high probability and the opportunities of accessing channel for exchanging control signals is high. As a result, the proposed scheme achieves high speed. In addition, the proposed scheme has the adaptation to the channel environment and thus it can select the suitable channel for exchanging control signals. However, as Ref. [6] satisfies, the proposed scheme does not satisfy that the required time for completing exchanging control signals is smaller than the certain time. In addition, the channel selection of slave uses ε- greedy. The optimal accessing rate among the superior channel and the others have not been constructed, yet.

This paper derives the complete probability of exchanging control signals with certain time period for rendezvous scheme based on COR, where the probability is referred to as the complete probability of rendezvous. In the ε- greedy, the accessing rate of slave to the superior channel and the others is optimized in the subject to the required complete probability of rendezvous for minimizing the time period. For optimization, we propose the protocol for finding the required time period and the optimal accessing rate of slave. From the computer simulation, the rendezvous channel scheme with the optimal accessing rate is not only more rapidly than the original rendezvous channel scheme but also satisfies the required complete probability of rendezvous. In addition, the proposed construction has adaptation to the various COR environment.

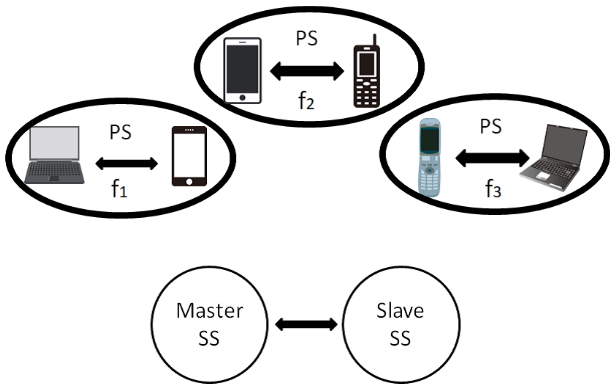

Fig. 1. System Overview of Assumed Wireless System.

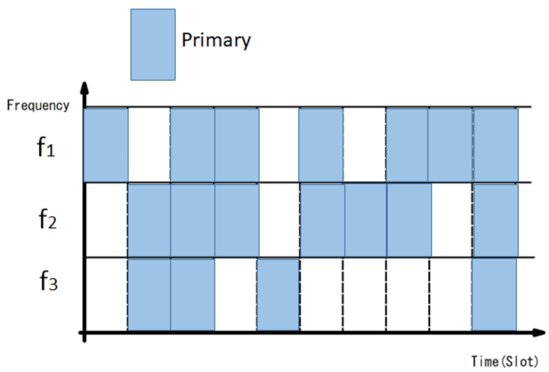

Fig. 2. Time slot model in Each channel.

II. Overview of Considerd System

Figure 1 shows the considered wireless environment. There are two type of wireless systems, primary system (PS) and secondary system (SS). PSs have completed the rendezvous channel scheme and started the communication. SS has not yet. Note that PS and SS have no priority to accessing the channel. If any system accesses the channel, any other system should stop accessing it for avoiding the collision. Therefore, PS and SS have the function of carrier sensing for confirming the occupation of channel. In this paper, the false alarm or the miss detection of carrier sensing is ignored.

We model the probability of mth $(m \in 1, 2, \ldots, N_{ch})$ channel accessed by PS is defined as ρ_m, where ρ_m is the same as the COR of mth channel and N_{ch} is the total number of channels. COR is independently decided for each channel. We define a time slot as the minimum resolution of time period. Figure 2 shows the image of time slot and the accessing channel of PS. The channel access of PS is modeled by the random process with a statistical independence in every time slot.

The SS is composed of two wireless stations, master and slave. We assume the master and the slave are distributed wireless systems and these can independently select the arbitral channel. Before accessing channel, the master and the slave perform carrier sensing for confirming no access from PS.

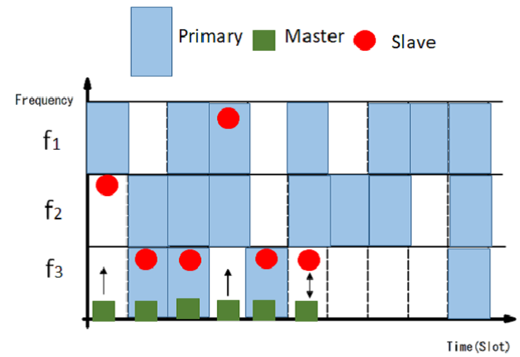

Fig. 3. Image of Exchanging Control Signals for Rendezvous Channel Scheme.

We assume the required time for exchanging the control signals between master and slave is one slot. Figure 3 shows the image of exchanging the control signal between master and slave.

This paper pays attention to the rendezvous scheme based on COR [7]. Before exchanging control signals, the master and the slave measures the COR in all the channels by carrier sensing. For measuring COR, the memory records the 1-bit carrier sensing result, occupy or vacant until all the bits are recorded in memory, where the length of memory is N_{mem}. One memory is set for one channel. After that, the COR can be measured as the total number of occupies divided by N_{mem}.

After measuring the COR of all the channels, the master and the slave select the superior channel with minimum COR, where it is referred to as the superior channel. Note that since the timings of carrier sensing by master and slave are different, the COR measured by master is not perfectly matched to that measured by slave. Therefore, the superior channel recognized by master could be different from that recognized by slave. Especially, the mismatch more easily occurs as the difference of COR among channels is smaller.

The channel selection of slave uses ε - greedy [7]. The instantaneous channel selection is a random and the average channel selections to the superior channel and the others are α and $(1-\alpha)/(N_{ch}-1)$. As α becomes larger, the slave selects the superior channels with larger probabilities [7].

The master selects the channel with minimum COR as the superior channel and then it starts sending the control signals. After starting sending control signals, the master does not change the channel.

III. Theoretical Analysis for Complete Probability of Rendezvous

The master and the slave commonly select nth channel as the superior channel. The complete probability of exchanging control signals in 1st time slot, $P_{com,1}$, is as follows.

$$P_{com,1,n} = (1-\rho_n)\alpha. \tag{1}$$

From this, the complete probability of exchanging control signals within K time slots is

$$\begin{aligned} P_{com,K,n} &= \sum_{k=1}^{K} P_{com,1,n} \cdot (1-P_{com,1,n})^{k-1} \\ &= 1-(1-P_{com,1,n})^{K}. \end{aligned} \tag{2}$$

Next, if the master and the slave select the nth channel and the others, respectively, the complete probability of exchanging control signals in 1st time slot is

$$P_{diff,1,n} = \frac{(1-\rho_n)(1-\alpha)}{N_{ch}-1}. \tag{3}$$

Similarly, the complete probability of exchanging control signals within K time slots is

$$\begin{aligned} P_{diff,K,n} &= \sum_{k=1}^{K} P_{diff,1,n} \cdot (1-P_{diff,1,n})^{k-1} \\ &= 1-(1-P_{diff,1,n})^{K}. \end{aligned} \tag{4}$$

In measuring COR, the total number of occupy decisions for mth channel ($m \in \{1,2,\ldots,N_{ch}\}$) is $l_m(l_m \in \{1,2,\ldots,N_{mem}\})$. As a result, the probability for the terminal recognizing the mth channel as the superior channel, $P_{sup,m}$, is

$$\begin{aligned} P_{sup,m} = \quad & \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi N\rho_m(1-\rho_m)}} e^{-\frac{(l_m-N\rho_m)^2}{2N\rho_m(1-\rho_m)}} \\ & \prod_{\forall j=1\backslash m}^{N_{ch}} \left\{ \frac{1}{2} erf\left(\frac{\sqrt{N}(1-\rho_j)}{\sqrt{2\rho_j(1-\rho_j)}}\right) \right. \\ & \left. -\frac{1}{2} erf\left(\frac{l_m-N\rho_j}{\sqrt{2N\rho_j(1-\rho_j)}}\right) \right\} d_{l_m}. \end{aligned} \tag{5}$$

Finally, the complete probability of rendezvous within K time slots, $P(k \le K)$, is given as

$$\begin{aligned} P(k \le K) \quad &= \sum_{m=1}^{N_{ch}} \left\{ {P_{sup,m}}^2 \cdot P_{com,K,n} \right. \\ & \left. + P_{sup,m}(1-P_{sup,m})P_{diff,K,n} \right\}. \end{aligned} \tag{6}$$

For the convenience of explanation, K is referred to as the required total slots for completing the exchanging of control signals.

IV. Protocol for Optimizing Channel Access Probability of Slave in ε- Greedy

The channel access probability of slave, α, is constructed for minimizing the required slots of rendezvou, K as well as satisfying the required complete probability of rendezvous, where η is defined as the required complete probability of rendezvous. The protocol of construction is given as follows.

1) $K = 1$, which is the required of total time slots for exchanging control signals, is set.
2) The following optimization problem with the construction parameter α is recoverd.

$$\begin{aligned} P_{\max}(k \le K) = \max_{\alpha} P(k \le K) \\ \text{Subject to} \\ \alpha \in [0,1]. \end{aligned} \tag{7}$$

3) If $P_{\max}(k \le K) \ge \eta$ is satisfied, the optimal α is given as follows.

$$\alpha^* = \arg_{\alpha} P_{\max}(k \le K). \tag{8}$$

As a result, the optimization is completed.
4) If $P_{\max}(k \le K) \ge \eta$ is not satisfied, $K = K+1$ and then go to the step 2.

The motivation of this protocol is finding the optimal α as the required of total time slots, K, becomes larger in one by one. Once the suitable α satisfies the required complete probability of rendezvous, it is optimal in terms of minimum slots. For recovering the optimization problem of α, the nonlinear optimization scheme, such as Newton Method, is available.

TABLE I
COR Model.

Case1	0.3, 0.4, 0.5, 0.6, 0.7
Case2	0.3, 0.32, 0.34, 0.36, 0.38

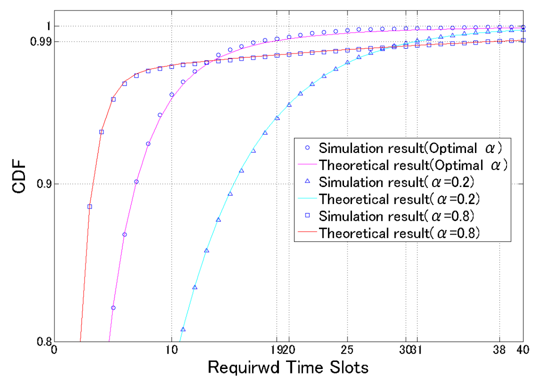

Fig. 4. Performance between the required slots for completing exchanging control signals, K, and the probability of completing rendezvous in Case 1.

V. Numerical Results

The effect of proposed optimization for channel access probability of slave is clarified by theoretical analysis and computer simulation. Table I shows the COR model of each channel as it is same as Ref. [7]. There are two cases and each COR is static.

We use a three dividied scheme as nonlinear optimization scheme [9].

Figure 4 shows the performance between the required slots for completing exchanging control signals, K, and the probability of completing rendezvous. The COR model is the

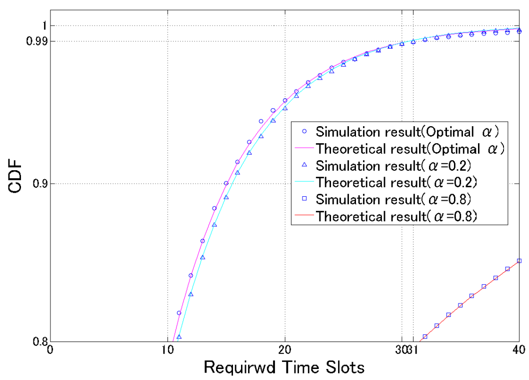

Fig. 5. Performance between the required slots for completing exchanging control signals, K, and the probability of completing rendezvous in Case 2.

Case 1 in table I. In the conventional rendezvous scheme based on COR [7], the channel selection probability of slave, α, are 0.2 and 0.8. In the former, the channel selection probabilities to each channel is equivalent. The required probability for completing rendezvous, η, is 0.99. The performances with plot and solid line indicate the simulation and theoretical results, respectively. From this figure, the performance of theoretical analysis is matched to that of computer simulation. Therefore, we confirm the adequacy of theoretical analysis.

When the probabilities for completing rendezvous is 0.99, the rendezvous scheme with proposed optimal α achieves half and 2 / 3 fewer slots than the conventional schemes with $\alpha = 0.8$ and $\alpha = 0.2$. When it is 0.9, the conventional with $\alpha = 0.8$ achieve the minimum required time slots. Therefore, the channel selection probabilities of slave should be adaptively changed for the required probability for completing rendezvous. The proposed construction take the required probability of completing rendezvous into consideration in constructing α and thus it achieves minimum slots.

Figure 5 shows the performances in the case 2 of table I. In the assumed COR, the COR of each channel is almost balance. Therefore, it is more difficult for master and slave to specify the superior channel. From this figure, the performance with the proposed optimization is almost as good as that with the conventional of $\alpha = 0.2$ but the performance with the conventional of $\alpha = 0.8$ is significantly degraded. It is suitable that the slave access each channel with the equal probabilities for avoiding the mismatch of superior channel between master and slave. The proposed optimization has adaptation to the COR model and thus it achieves a high speed for completing exchanging control signals.

VI. Conclusion

This paper proposed the optimal construction of channel selection ratio for high speed rendezvous channel scheme based on channel occupancy ratio. For construction, we derive the probability for completing exchanging control signals by theoretical analysis. After that, we propose the construction protocol for optimizing the channel selection ratio. We confirm the effect of proposed construction by computer simulation and theoretical analysis.

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