SPECTRUM SHARING AMONG MULTIPLE SECONDARY USERS USING CHANNEL ASSIGNMENT METHOD OF HIGH SPATIAL EFFICIENCY BASED ON MUTUAL INTERFERENCE

Takashi Kosugi (Advanced Wireless Communication research Center (AWCC), The University of Electro-Communications, Choufu-shi, Tokyo, Japan; t-kosugi@awcc.uec.ac.jp)
Kei Inage (Advanced Wireless Communication research Center (AWCC), The University of Electro-Communications, Choufu-shi, Tokyo, Japan; inagek@awcc.uec.ac.jp)
Takeo Fujii (Advanced Wireless Communication research Center (AWCC), The University of Electro-Communications, Choufu-shi, Tokyo, Japan; fujii@awcc.uec.ac.jp)

ABSTRACT

The most important target of a spectrum sharing is maximizing the performance of an unlicensed user (secondary user: SU) under the protection of licensed users (primary user: PU). A lot of researchers have been proposed spectrum sharing methods of maximizing the SU performance while protecting the PU. However, the spectrum sharing among multiple SUs with considering spatial efficiency has not been considered. When multiple SUs exist, channel assignment methods are required to maximize each SU performance under the limitation of the aggregated interference toward the PU. However, the minimization of mutual interference among SUs causes sparsely spectral utilization of spectrum in a point of spatial domain. In this paper, in order to realize high dense SUs with keeping interference constraint, we propose a novel channel assignment method targeting high spatial efficiency while keeping minimum required signal power to interference power plus noise power ratio (SINR) of each SU. In order to achieve high spatial efficiency, the central control server is prepared and it assigns the channel of white space (WS) to SUs based on relative distance among SUs and interference conditions. The central control server assigns the channels to shorten the distance among SUs under considering aggregated interference to be kept less than the allowable interference at cell boundaries of SUs. We confirm the effectiveness of the proposed method through computer simulations.

1. INTRODUCTION

In recent years, the demand of frequency resource increases with diversification of wireless communication systems. The current frequency resource allocation policy is exclusively allocating the dedicated spectrum to each wireless communication system. Therefore, it is difficult to allocate sufficient frequency resources to new application services and to enhancing existing systems. In a future wireless communication, it is necessary to bring a new paradigm shift of the spectrum resource allocation. According to a report of Federal Communications Commission (FCC), there is temporal and spatial vacant spectrum and the current utilization ratio of spectrum is less than 15 percent [1]. Therefore, spectrum is not always used fully and unused licensed bands called White Space (WS) exist.

In order to improve the spectral efficiency, a spectrum sharing using cognitive radio technology has been proposed. Cognitive radio is able to change communication parameters according to the surrounding wireless environment [2]. In the spectrum sharing, unlicensed user (secondary user: SU) can only access licensed band which is not used by licensed user (primary user: PU) if the interference toward the PU can be avoided. In other words, the SUs have to access the WS with lower priority than the PU. In order to meet the condition, the method that protects the PU by controlling the transmit power of the SU has also been proposed [3]. The constraint of the PU protection is also applied when multiple SUs exist. In this case, it is necessary to control aggregated interference toward the PU. Furthermore, in the case of multiple SUs use the same channel, it has to be noted that there is a possibility each SU communication quality decreases due to mutual interference among SUs. The performance of SUs has to be assured under protecting PU. In [4], the medium access control protocol that tries not to degrade the PU communication quality by limiting the

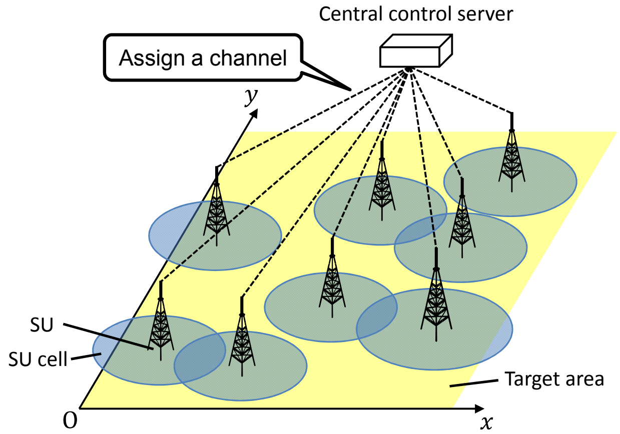

Fig. 1 Image of the system model.

aggregated interference at PU has been proposed and improves SU performance. In [5], [6], the PU is protected by controlling the transmit power of SUs. The medium access control protocol for avoiding collision of signals among SUs has been studied in [7]. In [8], the channel assignment method for maximizing the throughput of each SU with constraint of aggregated interference toward PU has been proposed. However, such the channel assignment causes a spatially sparse utilization of frequency resources if multiple SUs exist, because the relative distance between SUs on the same channel is maximized in order to minimize the mutual interference among SUs. As a result, communication opportunities of SUs which want to start communication are reduced. To solve this problem, it is better that SUs have to be packed densely as much as possible. Therefore, in this paper, we propose a novel channel assignment method targeting high spatial efficiency while keeping minimum required SINR of each SU. In the proposed method, the central control server assigns WS channels to SUs based on relative distance among SUs and interference conditions. The central control server makes channel allocation to shorten the distance among SUs under limitation of the aggregated interference less than allowable interference at the cell boundaries of SUs. We confirm the effectiveness of the proposed method through computer simulations. In simulation results, we confirm that it is possible to perform the channel assignment with high spatial efficiency while keeping every SU communication quality by using the proposed method.

2. SYSTEM MODEL

In this section, the detail of the system model is described. This paper focuses on the spectrum sharing among multiple SUs under multiple candidate channels. The coexistence environment model of multiple SUs is considered as shown in Fig. 1. In this model, each SU has a fixed cognitive base station like a base station of cellular communication system.

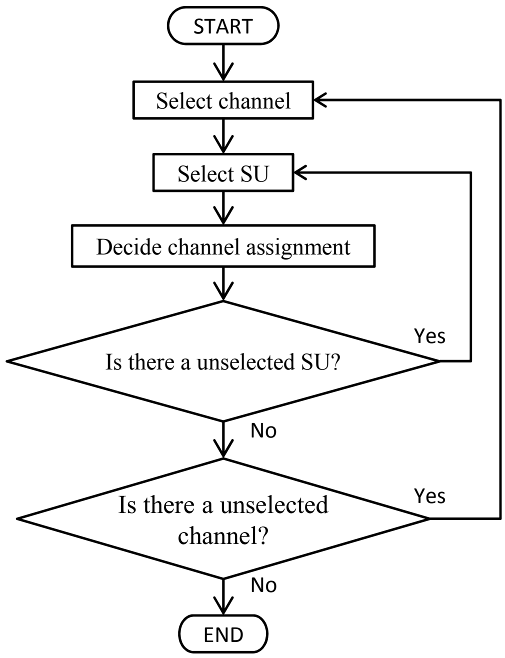

Fig. 2 Flow diagram the proposed method.

Furthermore, in our assumption, all SUs are registered to the central control server with parameter information as location information, transmit power, cell radius and minimum required SINR of the cell boundary. Communication link of each SU is established on the selected channel from multiple candidate channels. These cognitive base stations of the SUs can access only available channel assigned by the central control sever.

In this paper, the central control sever calculates channel conditions whether the WS can access the channel with satisfying the constraint or not, and only approved WS channels are listed as available channels for SU communication. Here, the mutual interference between the PU and each SU is ignored, because we consider the SU is located far enough away from the PU. Therefore, we just require considering spectrum sharing among SUs. The terminals of the SU are interfered by the cognitive base station of other SUs accessing the same frequency band. The central control server decides the target area for spectrum allocation based on the location information of all SU, and selects an anchor point as the origin O which is located one corner of the target area.

3. PROPOSED CHANNEL ASSIGNMENT METHOD

In this section, the detail of the proposed channel assignment method is described. In order to achieve high spatial efficiency of spectrum, it is necessary to minimize the relative distance between SUs accessing the same channel. Additionally, to maintain SU communication

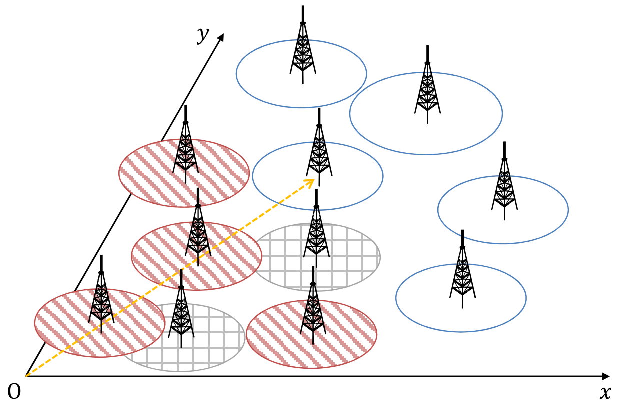

Fig. 3 Example of selecting the SU.

quality, the minimum required SINR of SUs has to be kept at the SU cell boundary. Figure 2 shows the flow diagram of the proposed channel assignment method. Three blocks drawn in Fig. 2, "Select channel", "Select SU" and "Decide channel assignment" are shown detail as follows.

- Select channel

The central control server selects the candidate channels from the order of a lower frequency channel in the target area. Let C_{sel} denote the channels which are selected by central control server.

- Select SU

The central control server selects the nearest SU from the origin O from the SUs that satisfy the condition. The condition is that the SU does not have any assigned channel and has not been selected in order to assign the channel C_{sel}.

Figure 3 shows the example of selecting SU. In Fig.3, SUs of cell with a diagonal pattern denote SUs that already have an assigned channel. SUs of cell with a grid pattern denote SUs that do not have any assigned channel C_{sel} yet due to not satisfying the condition of channel assignment. SUs of plain cell denote SUs do not have already assigned channel because those SUs do not have a chance of processing channel assignment yet. In the case of Fig. 3, the central control server selects the SU that is arrowed by the dashed line.

Let s denote the SU that is selected by the central control server for starting channel assignment can be stated as

$$s = \arg\min_{i\in\Pi}\left(\sqrt{{x_i}^2 + {y_i}^2}\right), \quad (1)$$

where i is arbitrary SU, x_i, y_i denote coordinates of i-th SU, Π is a set of unprocessed SUs. Here, i, j, k are different arbitrary SU.

- Decide channel assignment

The central control server decides whether the channel C_{sel} can be assigned to SU with satisfying the interference

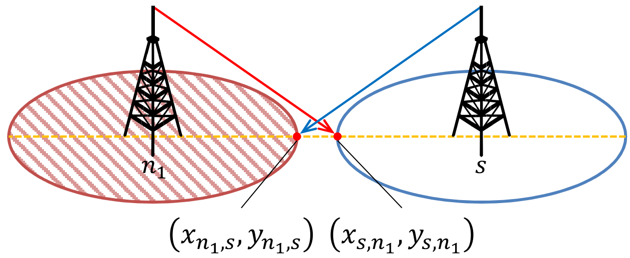

Fig. 4 Channel assignment decision ($n_A = 1$).

condition. Let s-th SU denote the SU which is selected by the central control server in "Select SU" process. The basic policy of the proposed method is that two adjacent SUs using the channel C_{sel} to s-th SU are chosen and the central control server checks the condition of channel assignment. The algorithm to check the condition for assigning the channel is different according to the number of SUs that already have the same channel C_{sel} in the field. Le n_A t denote the number of SUs with the channel C_{sel}. The algorithms for channel assignment are classified into three cases: (i) $n_A = 0$, (ii) $n_A = 1$ and (iii) $n_A \geq 2$. The channel assignment algorithms of each case are described below.

(i) $n_A = 0$

In the case (i), there is no SU that already has the channel C_{sel}. In this case, the central control server unconditionally assigns the channel C_{sel} to the s-th SU.

(ii) $n_A = 1$

When the number of SUs that already have the channel C_{sel} is one, it is necessary to consider the mutual interference between the s-th SU and the SU has the channel C_{sel} in order to keep the SU communication quality. In this case, it is necessary to consider the SINR of both the s-th SU and the SU has the channel C_{sel}, because the channel assignment affects not only the s-th SU but also the SU has the channel C_{sel}. Thus, in the case (ii), the central control server makes the channel allocation decision to satisfy the interference constraint at two points of cell boundaries. In this paper, transmit signal is affected by only the propagation loss depended on the distance. The propagation loss is calculated by

$$L(d)\ [\mathrm{dB}] = -10\log_{10}\left(\frac{\lambda}{4\pi d_0}\right)^2 + 10 n_{\mathrm{loss}}\log_{10}\left(\frac{d}{d_0}\right), \quad (2)$$

where λ is the wavelength of the carrier frequency, n_{loss} is propagation factor, d_0 denotes a reference distance, d is the distance from SU transmitter. Let $S_{\mathrm{BDRY},i}$ denote the signal power of i-th SU at cell boundary, $S_{\mathrm{BDRY},i}$ can be calculated as

$$\begin{aligned} S_{\mathrm{BDRY},i}\ [\mathrm{dBm}] &= W_i\ [\mathrm{dBm}] \\ &\quad - L\left(\sqrt{{h_i}^2 + {R_i}^2}\right)[\mathrm{dB}], \end{aligned} \quad (3)$$

where R_i means the cell radius of i-th SU, W_i denotes the transmit power of i-th SU, h_i is the antenna height of i-th SU. Therefore, the allowable interference of i-th SU is given by

$$P_i = \frac{S_{\mathrm{BDRY},i}}{\gamma_i} - N, \tag{4}$$

where P_i denotes the allowable interference of i-th SU, γ_i means the minimum required SINR of i-th SU, N denotes the average noise power. In eq. (4), all parameters are a true value. In order to assign the channel under the SINR constraint, it is necessary to calculate the SINR of the SU at the closest cell boundary to other cognitive base station. Because, the closest cell boundary to other cognitive base station is the minimum SINR point within the cell coverage. Let n_1 denote the SU is the closest to s-th SU. Here, $(x_{i,j}, y_{i,j})$ denotes the closest cell boundary point of i-th SU to the cognitive base station of j-th SU. $(x_{i,j}, y_{i,j})$ is the intersection point of the cell boundary with the line connecting the centers of the two adjacent cells. Figure 4 shows the case of $i = s$ and $j = n_1$. In this case, (x_{s,n_1}, y_{s,n_1}) is the closest cell boundary point of s-th SU to the cognitive base station of n_1-th SU. Let $D_{i,j}$ denote the length of the line connecting the centers of the two cells. $(x_{i,j}, y_{i,j})$ can be written by

$$x_{i,j} = x_i + \frac{R_i}{D_{i,j}}(x_j - x_i), \tag{5}$$

$$y_{i,j} = y_i + \frac{R_i}{D_{i,j}}(y_j - y_i). \tag{6}$$

Since, the closest cell boundaries of n_1-th SU and s-th SU are expressed as (x_{s,n_1}, y_{s,n_1}), $(x_{n_1,s}, y_{n_1,s})$ illustrated in Fig. 4. In this paper, we consider the assignment conditions as the 95% interference limit based on SINR is the threshold for decision of channel assignment when the $n_A = 1$ for taking the SINR margin. The reason for this margin is that it is difficult to satisfy the condition of which the channel C_{sel} is assigned to s-th SU and there are possibility that the channel C_{sel} is not assigned to s-th SU in the case (iii) if the interference is nearly equal to allowable interference at cell boundary in the case (ii). From the above, if the interference from n_1-th SU is lower than $0.95P_s$ at (x_{s,n_1}, y_{s,n_1}) and the interference from s-th SU is lower than $0.95P_{n_1}$ at $(x_{n_1,s}, y_{n_1,s})$, the channel C_{sel} is assigned to the s-th SU by the central control server. Let $I_{i,j}^k$ denote the interference from the k-th SU to $(x_{i,j}, y_{i,j})$, it is given by

$$I_{i,j}^k[\mathrm{dBm}] = W_k[\mathrm{dBm}] - L\left(\sqrt{{h_k}^2 + \left(x_{i,j} - x_k\right)^2 + \left(y_{i,j} - y_k\right)^2}\right)[\mathrm{dB}]. \tag{7}$$

Therefore, the condition of which the channel C_{sel} is assigned s-th SU is expressed following equations,

$$\begin{cases} I_{s,n_1}^{n_1} \le 0.95P_s \\ I_{n_1,s}^{s} \le 0.95P_{n_1} \end{cases}. \tag{8}$$

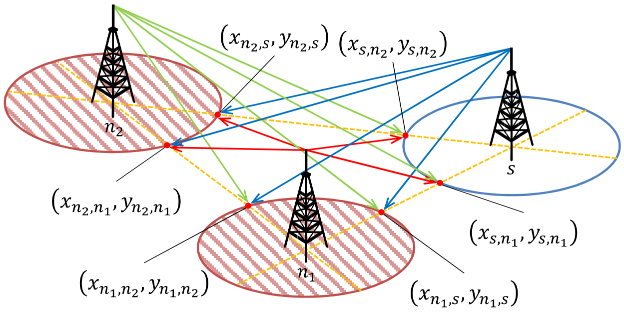

Fig. 5 Channel assignment decision ($n_A \ge 2$).

(iii) $n_A \ge 2$

In this case, two or more SUs already have the channel C_{sel} in the previous step. As well as the case (ii), it is necessary to consider the mutual interference among s-th SU and multiple SUs have the channel C_{sel} in order to keep SU communication quality. If the channel C_{sel} is assigned to the new SU, the mutual interference from the new SU affects all SUs that have the same channel C_{sel}. Therefore, in the case (iii), the central control server makes channel assignment decision whether the aggregated interference is less than the allowable interference at the affected cell boundaries. However, it is too complicate to calculate the interference situation caused by the effect of channel assignment results considering all SUs. Therefore, this paper proposes the simplified channel assignment evaluation for multiple SUs. In the proposed method, only two adjacent SUs using the same channel to s-th SU are chosen for the impact evaluation. Here, the SUs adjacent to s-th SU are decided by the closer distance SUs from the candidate SUs. In order to evaluate the interference, we have to consider six points at cell boundaries. Six points are six red dots that is intersection points of the line connecting the centers of the two SUs and each cell boundary, such as shown in Fig. 5. Let A is a set of the SUs that have the channel C_{sel}, n_1 is the closest SU to s-th SU, and n_2 denotes the second closest SU to s-th SU. Let n_1 and n_2 are given as follows.

$$n_1 = \arg\min_{i \in A}\left(\sqrt{(x_s - x_i)^2 + (y_s - y_i)^2}\right) \tag{9}$$

$$n_2 = \arg\min_{i \in A}\left(\sqrt{(x_s - x_i)^2 + (y_s - y_i)^2}\right)(i \ne n_1) \tag{10}$$

Namely, the six points are expressed as (x_{s,n_1}, y_{s,n_1}), $(x_{n_1,s}, y_{n_1,s})$, $(x_{n_1,n_2}, y_{n_1,n_2})$, $(x_{n_2,n_1}, y_{n_2,n_1})$, $(x_{n_2,s}, y_{n_2,s})$, (x_{s,n_2}, y_{s,n_2}) and illustrated in Fig. 5 and can be calculated by using eq. (5) and eq. (6). From the above, the condition of assignment channel to the SU can be written as following equations,

$$\begin{cases} I_{s,n_1}^{n_1} + I_{s,n_1}^{n_2} \le P_s \\ I_{n_1,s}^{s} + I_{n_1,s}^{n_2} \le P_{n_1} \\ I_{n_1,n_2}^{s} + I_{n_1,n_2}^{n_2} \le P_{n_1} \\ I_{n_2,n_1}^{s} + I_{n_2,n_1}^{n_1} \le P_{n_2} \\ I_{n_2,s}^{s} + I_{n_2,s}^{n_1} \le P_{n_2} \\ I_{s,n_2}^{n_1} + I_{s,n_2}^{n_2} \le P_s \end{cases}. \quad (11)$$

4. SIMULATION RESULTS

In this section, the performance of the proposed channel assignment method is evaluated through computer simulations. Here, we consider many SUs are uniformly distributed in the square area of 5×5 [km^2]. The same parameters are utilized among all SUs, such as transmit power, minimum required SINR and antenna height of a cognitive base station except cell radius. The cell radius of each SU is determined at random in the range of 100 ~ 150 [m]. Thus, in this environment, it is important to assign the channel considering the mutual interference in order to keep the required SINR under different coverage size. Five channels can be used for spectrum sharing among all SUs located in the same area. The center frequency of each channel can be selected from 500, 550, 600, 650 and 700 [MHz]. The other simulation parameters are shown in Table 1. The simulation results are obtained by averaging the thousand trials.

In simulations, we evaluate the ratio of the number of successful channels assigned to SUs to the total number of SUs in the area. In a channel assignment algorithm, it is important to keep the SINR constraint. In order to evaluate whether the proposed algorithm satisfies the minimum required SINR in the cell boundary of SUs that have assigned channel, the ratio of the satisfied minimum required SINR at the cell boundary is calculated by checking SINR per 1 degree angle at the cell boundary of the SU have assigned channel. Moreover, the spectral efficiency in a space domain is evaluated. In order to evaluate the spectral efficiency, spatial distribution of interference and noise power are derived in the area when the number of SUs is 130. For deriving the distribution of interference and noise power, the target area is divided into blocks of 5×5 [m^2] and the interference and the noise power at the center of each block is calculated in each channel.

In this simulation, random assignment method is chosen to compare with the proposed channel assignment method. In this random assignment method, the central control server does not exist. Each SU decides the access channel if the aggregate interference is lower allowable interference at cell boundary in all direction. In detail, as first step, the SU is selected randomly from all SU. Secondly, the selected SU select a channel at random. Thirdly, the selected SU decides the access channel based on whether condition is sufficient. If the condition is not sufficient, s-th SU randomly reselects other channel.

Table 1 Simulation parameters.

Transmit power of SU: W_i	20 [dBm]
Average noise power: N	-100 [dBm]
Minimum required SINR: γ_i	10 [dB]
Propagation factor: n_{loss}	3.5
Reference distance: d_0	10 [m]
Antenna height: h_i	10 [m]

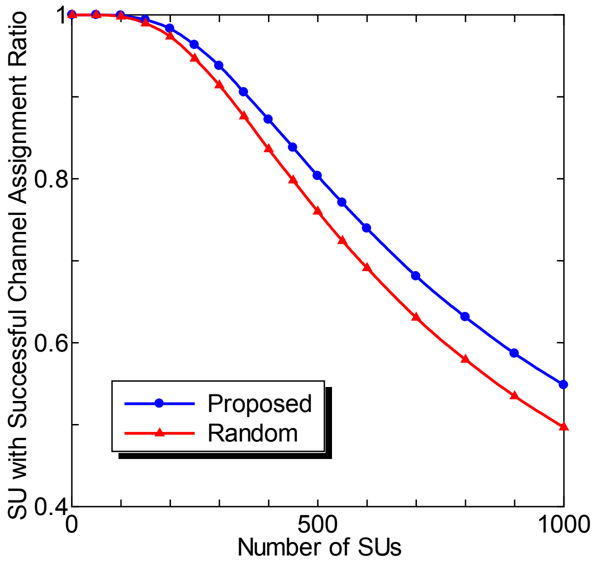

Fig. 6 SU with successful channel assignment ratio.

Figure 6 shows SU with successful channel assignment ratio. In Fig. 6, we can confirm that SU with successful channel assignment ratio of the proposed method is 5 percent higher than that of random channel assignment method when the number of SUs is 1000. Therefore, the proposed method can efficiently assign the channels to SU compared with random assignment method. It can be also seen that the improvement effect is increased as the number of SU increases.

Figure 7 shows the outage probability of the minimum required SINR at cell boundary 10 [dBm]. In Fig. 7, we can find the outage probability of SINR at cell boundary is less than 10 [dBm]. The proposed method achieves lower outage probability than that of random assignment method. Moreover, as the number of SUs increases, it is confirmed that the decrease of this ratio is small in the proposed method compared with random assignment method. Thus, the proposed method can improve spatial efficient channel assignment with satisfying the required SINR.

Figure 8 shows the distribution of the interference and the noise power in the case the number of SUs is 130. In Fig.8, there is one peak at around -85 [dBm] in the random

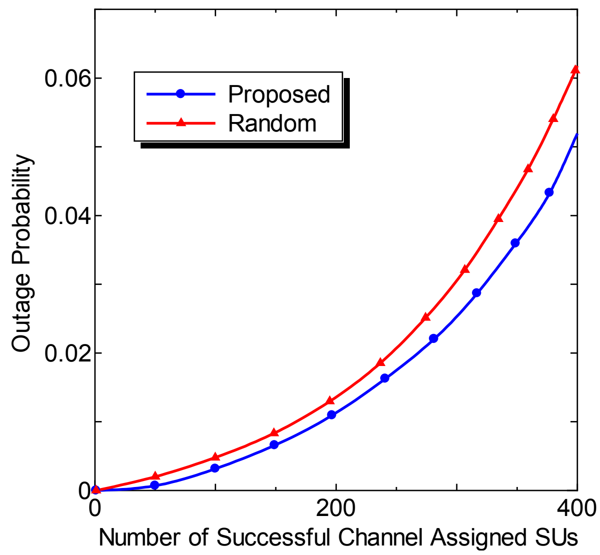

Fig. 7 Outage probability of the minimum required SINR at cell boundary.

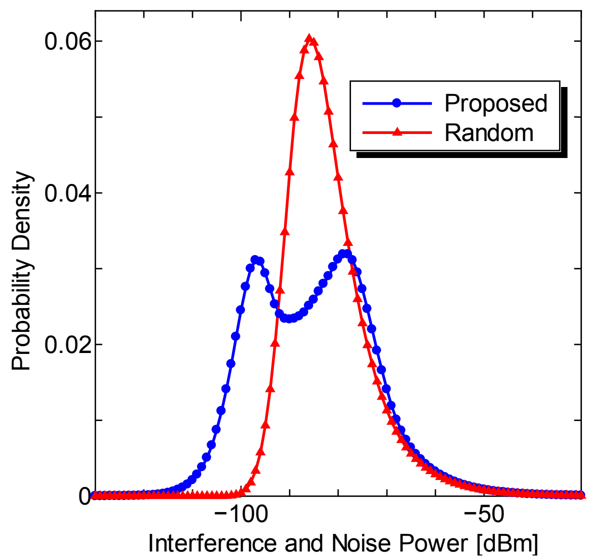

Fig. 8 Distribution of the interference and the noise power.

assignment method. On the other hand, in the proposed method, there are two peaks at approximately −80 and −100 [dBm]. In the proposed method, the central control server assigns low frequency channel preferentially. As a result, the channels assigned to SUs are packed densely in lower frequency channels and a peak appears at approximately −80 [dBm]. On the other hand, the number of SUs that with assigned channel is a few and a peak appears at approximately −100 [dBm]. This level is equivalent of the noise level. From these results, we can confirm that the proposed method enables the spatially dense utilization of spectrum and much room can be remained for the other wireless communication systems using the same spectrum as secondary systems.

5. CONCLUSION

In this paper, we propose a channel assignment method targeting for high spatial efficiency while keeping the minimum required SINR of each SU. In the proposed method, the central control server assigns WS channels to SUs based on relative distance among SUs and interference conditions. The central control server makes a channel allocation to shorten the distance among SUs with keeping aggregated interference less than the allowable interference at the cell boundaries of SUs. In our simulation results, we can confirm that it is possible to perform the channel assignment with high spatial efficiency while keeping every SU communication quality by using the proposed method.

6. REFERENCES

[1] Federal Communications Commission, “Spectrum policy task force report, FCC 02-155,” Nov. 2002.

[2] J. Mitola III and G. Q. Maguire, “Cognitive Radio: Making Software Radios More Personal,” *IEEE Pers. Commun.*, vol. 6, pp. 13-18, Aug. 1999.

[3] X. Kang, Y. Liang, A. Nallanathan, H. K. Garg and R. Zhang, “Optimal Power Allocation for Fading Channels in Cognitive Radio Networks: Ergodic Capacity and Outage Capacity,” *IEEE Trans. Wireless Commun.*, vol. 8, no. 2, pp. 940-950, Feb. 2009.

[4] H. A. B. Salameh, M. M. Krunz and O. Younis, “MAC Protocol for Opportunistic Cognitive Radio Networks with Soft Guarantees,” *IEEE Trans Mobile Computing*, vol. 8, no. 10, pp. 1339-1352, Oct. 2009.

[5] Z. Chen, C. Wang, X. Hong, J. S. Thompson, S. A. Vorobyov, X. Ge, H. Xiao and F. Zhao, “Aggregate Interference Modeling in Cognitive Radio Networks with Power and Contention Control,” *IEEE Trans. Commun.*, vol. 60, no. 2, pp. 456-468, Feb. 2012.

[6] S. Huang, X. Liu, and Z. Ding, “Decentralized Cognitive Radio Control Based on Inference from Primary Link Control Information,” *IEEE J. Sel. Areas Commun.*, vol. 29, no. 2, pp. 394-406, Feb. 2011.

[7] S. C. Jha, U. Phuyal, M. M. Rashid and V. K. Bhargava, “Design of OMC-MAC: An Opportunistic Multi-Channel MAC with QoS Provisioning for Distributed Cognitive Radio Networks,” *IEEE Trans. Wireless Commun.*, vol. 10, no. 10, pp. 3414-3425, Oct. 2011.

[8] A. T. Hoang, Y. Liang and M. H. Islam, “Power Control and Channel Allocation in Cognitive Radio Networks with Primary Users' Cooperation,” *IEEE Trans. Mobile Computing*, vol. 9, no. 3, pp. 348-360, March 2010.