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SPECTRUM SHARING METHOD USING FREQUENCY PRIORITY TABLE FOR REDUCING INTERFERENCE AMONG SECONDARY SYSTEMS

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ABSTRACT

Due to the rapid development of Cognitive Radio technologies, the research about sharing the frequency resources allocated to primary users, with secondary users has attracted researchers' attention. If the frequency band is unutilized by the primary users, multiple secondary users are expected to share the spectrum in a future wireless communication. In order to efficiently share the spectrum among secondary systems, we propose a novel channel allocation method by using frequency priority table based on the location of the secondary system. By utilizing this method the interference to other systems is autonomously reduced by selecting channels. Moreover, a power control method is also proposed for protecting the secondary systems which are allocated to the channels by higher priority.

1. INTRODUCTION

Depletion of frequency resources becomes a big problem as of the rapidly increasing radio communication applications [1]-[5]. Recently cognitive radio has attracted attention for a solution of the frequency resources depletion problem [6]-[10]. In primary-secondary cognitive radio system, secondary users communicate with each other after finding availability of the channel in the PU bands. However, we consider multiple secondary systems which operate with different configurations, and share the same frequencies which are not used by the primary users.

In this paper, we aim on sharing the same frequencies efficiently among secondary systems. An autonomous frequency assignment method is investigated. Each secondary system creates a frequency priority table based on the location of the secondary system. By using this method, the interference can be reduced autonomously. Additionally, a power control method is proposed for protecting the secondary systems which are assigned to the higher priority channels.

The priority table for frequency assignment is made by registering frequency channels. Here, each frequency channel is attached with priority based on the location of the secondary system. The basic idea of frequency assignment based on the location was proposed in [11]. In this paper, we consider multiple frequency assignment for supporting multiple systems in the same location. Priorities are assigned to frequencies to minimize the interference power to the system utilizes the same frequency with higher priority users. Moreover, we consider a power control for protecting frequencies with higher priority users. By using this approach, the frequency with higher priority is protected when the same frequency is reused by different secondary systems in different places. In this paper, we confirm the effectiveness of the proposed transmission power control after determining surrounding existence of systems. By using the proposed power control method, the interference power at the system with higher priority can be kept less than the pre-defined level. We can assign frequencies attached with priorities depending on the intended purpose of applications by combining the frequency priority table and the power control. Therefore, in the proposed priority control, we can keep good communication quality for emergency communication by giving priority.

We evaluate the communication performance by using computer simulations considering the channels attached with priorities for confirming the effectiveness of the proposed method.

2. SYSTEM MODEL

Each secondary system assumed in this research has a base station, and a terminal which communicates with the base station. In this proposal, we create a frequency priority table based on the location of the secondary systems for frequency assignment, and then the assignment blocks are distributed without empty space by frequency reuse. Furthermore, overlapping usage of frequency is avoided by exchanging the information among secondary users, if the multiple secondary systems are located at the same block.

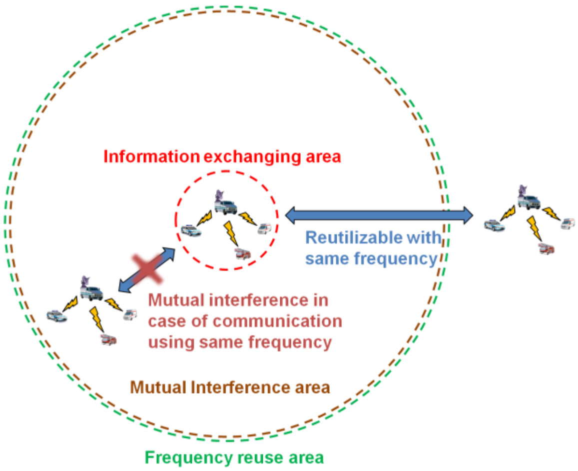

Fig1. Three areas for frequency assignment.

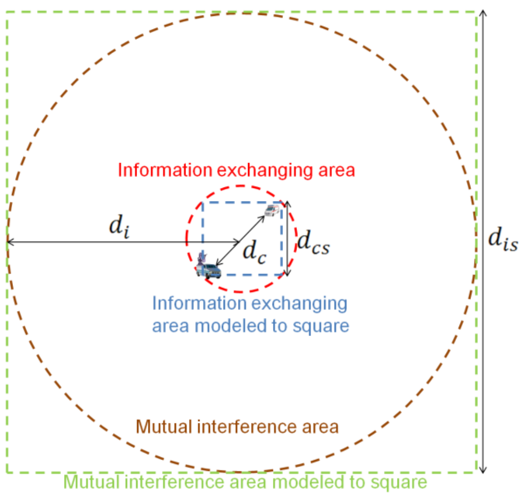

Fig.2 Considerable area modeled to square block.

At first, we define the information exchanging area. The area is defined by a circle with a diameter which is a maximum range for exchanging information stably among users in the same system as shown in Fig. 1. In this area, each system can use multiple frequencies by exchanging information with other secondary systems located in the same area to avoid the interference each other. Moreover, we define mutual interference area within this area in which frequency cannot be reused by using the same frequency channels without interference. The radius of the circular area is decided by the unsatisfied reuse distance of the frequency channel because the mutual interference power is beyond the acceptable value. In the outside of the mutual interference area, we can reassign the same frequency channels. Thus, the area is defined as frequency reuse area and we can reutilize the some frequency channels. Each area is modeled by square for making frequency assignment easy. When the information exchanging area is modeled to square, we make modeling a diameter of a circle as a diagonal length. On the other hand, when the mutual interference area

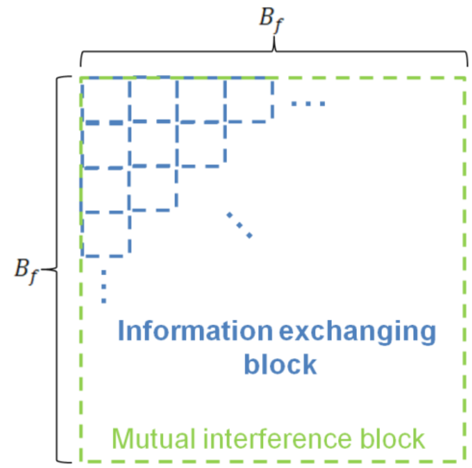

Fig.3 Information exchanging block and mutual interference block.

is modeled as a square, we make modeling a diameter of a circle as a side of square. By using this modeling, the information exchanging area can be modeled by the minimum communication distance, and the mutual interference area can be modeled by the maximum distance without happening the mutual interference. In this paper, we define the information exchanging area as a fundamental block. As illustrated in Fig.2, the maximum communication distance between terminals of a secondary system is defined as d_c, and the distance in which a signal level from the secondary system could be considered under the noise level, d_i. We define d_{cs} as a side length of information exchanging block, calculated by the information exchanging area as shown in Fig.2. d_{cs} is indicated by the following equation,

$$d_{cs} = \frac{d_c}{\sqrt{2}}. \tag{1}$$

Furthermore, d_{is}, which is a side length of mutual interference block, is expressed in the following equation,

$$d_{is} = 2 \times d_i. \tag{2}$$

As shown in Fig.3, we assume that $B_f \times B_f$ information exchanging blocks are modeled into a mutual interference block. In the information exchanging block within the mutual interference block, we assign different frequencies to different information exchanging block, depending on the location of secondary systems. Additionally, frequencies are repeatedly assigned outside of the mutual interference block. We define d_{cs} as a side length of information exchanging block and d_{is} as a side length of mutual interference block. Therefore, B_f can be calculated by the following equation,

$$B_f = \left\lceil \frac{d_{is}}{d_{cs}} \right\rceil, \tag{3}$$

where, $\lceil\ \ \rceil$ represents the ceiling function, which maps a real number to the smallest following integer.

3. FREQUENCY ASSIGNMENT BASED ON PRIORITY TABLE

It is necessary to assign different frequencies not to cause the mutual interference toward the different information exchanging blocks within a mutual interference block. Furthermore, multiple frequencies must be shared in the mutual interference block, when there are multiple secondary systems in one information exchanging block. Therefore, we propose a method for assigning multiple frequencies into one information exchanging block, after attaching priorities to frequencies to make mutual interference smaller.

3.1. Channel assignment with frequency channel mapping function

Different frequencies have to be assigned into information exchanging blocks in the same mutual interference block not to cause the mutual interference. Therefore we define frequency mapping function based on the location coordinates and B_f which is the number of information exchanging blocks allocated to the side of mutual interference block.

In this research, the knowledge of the location information from GPS (Global Positioning System) is assumed, because we share frequencies based on the location information of each secondary system. Then, (x, y) of two dimensional locations coordinate is obtained by GPS. (x, y) is then normalized by d_{cs}, which is a side length of the information exchanging block, for adapting the system model. Then, the location coordinate x_i which is normalized by the side length of location coordinate x is expressed in the following equation,

$$x_i = \left\lfloor \frac{x}{d_{cs}} \right\rfloor, \tag{4}$$

where, $\lfloor \quad \rfloor$ represents the floor function, which maps a real number to the largest previous integer. Similarly, the normalized location coordinate y is indicated by the following equation,

$$y_i = \left\lfloor \frac{y}{d_{cs}} \right\rfloor. \tag{5}$$

If there are multiple secondary systems within one information exchanging block, different frequencies must be assigned to systems for avoiding interference. Then, we define $F(x_i, y_i, k)$ function for deciding the frequency number based on the location coordinate (x_i, y_i) of block and k priority. The frequency number is the number which is assigned to each band of communication channel for convenience sake. Frequency mapping function based on the location information (x_i, y_i) is proposed by the following equation, when frequencies are assigned iteratively, to prevent from causing mutual interference toward secondary systems in the mutual interference block,

$$F(x_i, y_i, 1) = B_f \times (y_i \bmod B_f) + (x_i \bmod B_f), \tag{6}$$

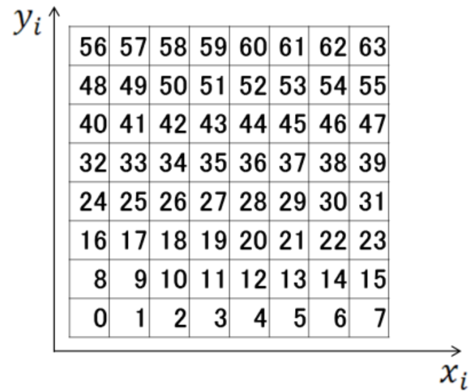

Fig.4 Frequency assignment example when B_f is 8.

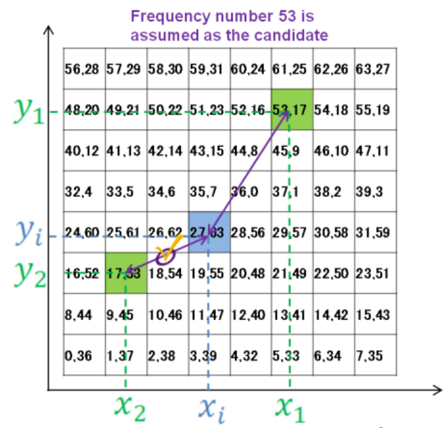

Fig.5 Frequency decision example with 2nd priority at the location with 1st priority frequency number as 27.

where, $F(x_i, y_i, 1)$ is the 1st priority frequency number at the location (x_i, y_i). Incidentally, mod is a remainder operator. The remainder ranges from 0 to $B_f - 1$ because the output of the remainder operator is the remainder of division by B_f. Thus range of F is expressed by the following inequality,

$$0 \leq F \leq B_f^2 - 1. \tag{7}$$

Now, frequencies assigned by frequency mapping function in equation (6) is shown in Fig.4 when B_f is 8. The number assigned to each block is the frequency number.

3.2. Frequency priority table for frequency sharing

The assigned frequencies by equation (6) will not cause mutual interference, if only one secondary system exists in the information exchanging block. However, we create the frequency priority table for one information exchanging block to share frequencies in the mutual interference block, if there are multiple different systems in the information exchanging block. Multiple frequencies are assigned to one information exchanging block based on the frequency priority table. Frequency mapping function is expressed by the following equation for making frequency priority table from the location coordinate (x_i, y_i) of information exchanging block,

$$F(x_i, y_i, k) = \underset{f \neq F(x_i, y_i, l)}{arg\max} \{ \min_{1 \le l \le k-1} (\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} | F(x_j, y_j, l) = f) \}. \tag{8}$$

Priorities are decided to minimize the mutual interference among information exchanging blocks in the mutual interference block. Therefore, we assume that the frequency with frequency number of f with kth priority number and use this frequency number at the block whose location coordinate is (x_i, y_i), when kth priority is selected. When, (x_j, y_j) is the location coordinate of blocks using frequencies from 1st priority until $k-1$ th priority, we compare the distances among (x_j, y_j) with its own location coordinates, and then select the minimum distance among these distances to decide the kth priority frequency of this location. We can select the frequency with minimum mutual interference from block using f as higher priority frequency than k priority. The other frequencies with lower priority are also decided as the same way by calculating the minimum distances and deciding the maximum distance frequency among the selected minimum distances. Now, the frequency of f with the maximum distance is registered to frequency priority table as k priority frequency.

The example of the process for deciding the 3rd priority frequency is shown in Fig.5. In this figure, the example of frequency priority table is shown, when frequency number 27 is assigned to 1st priority table. In Fig. 5 the number illustrated in each block shows frequency number. It shows 1st priority frequency, 2nd priority frequency starting from the left to right. 1st and 2nd priority frequency has been selected when 3rd priority frequency is selected, so 1st and 2nd are registered to the frequency priority table. For example, we consider frequency number 53 as the candidate at information exchanging block with frequency number 27 as 1st priority frequency, when 3rd priority frequency is selected. Now, we compare distances to blocks using frequency number 53 as 1st priority frequency or 2nd priority frequency around the information exchanging blocks, and then select minimum distance in these distances. In Fig.5, the distance in the block using frequency number 53 as the 2nd priority frequency is minimum distance. Also as to all frequencies except the 1st priority frequency number 27 and the 2nd priority frequency number 63, the minimum distance is calculated as the same way, and then we select frequency number with maximum distance among these minimum distances generated by different frequency numbers as the 3rd priority frequency. In the example of Fig.5, we select the 3rd priority frequency is frequency number 31.

4. POWER CONTROL FOR AVOIDING INTERFERENCE TOWARD THE HIGHER PRIORITY CHANNEL

Although the interference toward the higher priority channel can be minimized theoretically, it cannot make sure to satisfy interference condition if multiple frequencies are used within the same mutual interference block. In order to avoid this interference, we propose a power control method combined with the above proposal which will not interfere toward the system using the higher priority channel. The proposed power control method is summarized as following. At first, each secondary system senses the other secondary system signals independently, and it observes the usage of frequency channel by other secondary systems. In this case the communication must be terminated to avoid giving interference toward the other secondary systems except the system using 1st priority frequency. In order to continue to communicate in the lower priority frequency, the system has to control the transmit power. In the proposed power control method, the transmit power of secondary system is controlled not to give the interference toward the higher priority channel. Incidentally, the power is controlled to the same level of the noise power at the nearest location of the system using higher priority in the same frequency channel. In this paper, the area of enabled spectrum sensing is assumed as the whole mutual interference block of the system with sensing. In the actual system, the spectrum sensing area should be decided by its own sensing ability. However, in this paper, we assume above condition for the simplification. Therefore, since we consider the secondary system can sense the frequency channel usage in the mutual interference block, it protects the system using higher priority frequency channel by using the proposed simple power control. In this method, if other systems are detected by the spectrum sensing, the transmit power is controlled not to give the interference toward the nearest system using the higher priority frequency channel. Here, the power is reduced to the same level of the noise power at the nearest location of the system using the higher priority frequency channel. The nearest distance with the information exchanging block of the system using the higher priority frequency channel is obtained with location coordinate (x_i, y_i) and priority k by the following equation,

$$d_{min}(x_i, y_i, k) = \min_{1 \le l \le k-1} \left\{ \sqrt{(x_l - x_i)^2 + (y_l - y_i)^2} | F(x_l, y_l, l) = F(x_i, y_i, k) \right\}, \tag{9}$$

where, $F(x_i, y_i, k)$ is the priority kth frequency channel. In this equation, it calculates the distances from information exchanging blocks in which systems utilize the same frequency channel F until the $k-1$th priority from the 1st priority frequency channel. Then, it selects the minimum distance among those distances. Thus, the transmit power P_{PC} is derived with $d_{min}(x_i, y_i, k)$ by the following equation,

$$P_{PC} = P_I - K + 10\gamma \log_{10}\left[\frac{d_{min}}{d_0}\right], \tag{10}$$

where, P_I is the interference power toward the system located at the information exchanging block which has distance d_{min} from the system controlling the transmit power. In this paper, we assume the allowed interference power is the noise power level. Furthermore, K is the free space propagation attenuation until reference distance, γ is the attenuation exponent and d_0 shows the reference distance.

5. SIMULATION RESULT

We have evaluated the mutual interference and the throughput performance of the proposed method compared with the random frequency channel assignment by computer simulations. The mutual interference performance is observed with respect to the priority differences. The throughput is calculated from SINR (Signal to Interference plus Noise Ratio) by the Shannon-Hartley channel capacity. In this paper, we set the attenuation exponent is 3.5, the reference distance is 10m. The interference power is calculated with the distance attenuation. Moreover, we assume the maximum transmit power of each secondary system is 37dBm, the desired receiver power is -80dBm and the frequency is 187.5MHz. By using these parameters, we calculate the side length d_{cs} of the information exchanging block is 1286m, the side length d_{is} of the mutual interference block is 9762m and B_f is 8. Other simulation conditions are shown in Table 1.

As depicted in Fig.7, in the mutual interference evaluation, we evaluate the interference power given from 9×8×8 information exchanging blocks. This is because one mutual interference block is constructed as 8×8 information exchanging blocks and 8 mutual interference blocks around the evaluation block could interfere toward the evaluation block. Thus, totally 9 mutual interference blocks are considered as shown in Fig.7. Then, 576 secondary systems are randomly located to information exchanging blocks. Furthermore, in order to increase the throughput by keeping the performance of the higher priority systems, the proposed power control is applied and each system can aggregate multiple frequency channels. In channel aggregation, secondary systems utilize multiple channels in the order of the priority from highest to lowest. Here, the number of channels is decided by Poisson random value. For the interference calculation, we assume the systems assigned to the information exchanging blocks are located with the closest distance from the evaluation block. Thus, we can consider the worst interference condition.

Figs. 8 and 9 shows the interference performance of the higher priority channels and the lower priority channels, respectively, when the number of systems is changed at the horizontal axis and the average number of channel

Table1. Simulation Conditions.

Channel Models	Distance Attenuation
Attenuation Exponent γ	3.5
Reference Distance	10m
Transmit Power	37dBm
Desired Receive Power	-80dBm
Allowed Noise Power	-95dBm
Frequency	187.5MHz
Bandwidth	35MHz
d_{cs}	1286m
d_{is}	9762m
B_f	8
Number of Channels	64
Bandwidth per Channel	546.875KHz

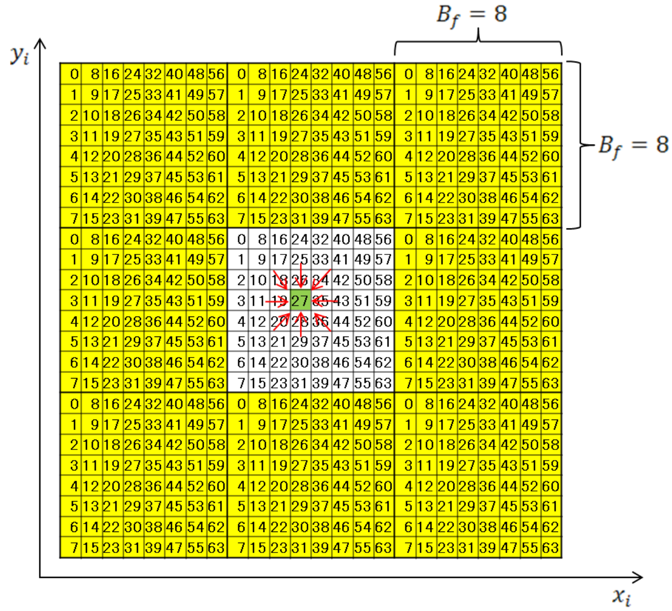

Fig.7 The evaluation area for the given interference.

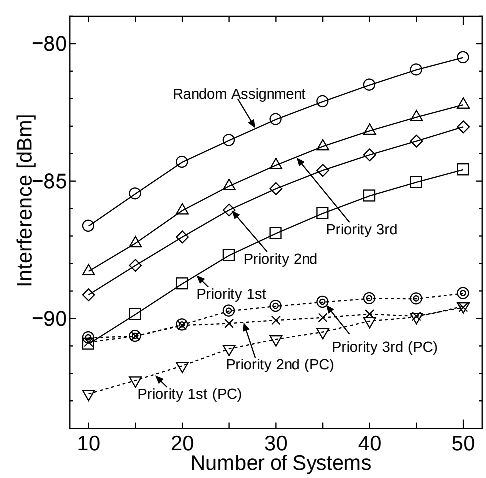

Fig.8 The given interference performance toward high priority channels while the average number of channel aggregation is 10.

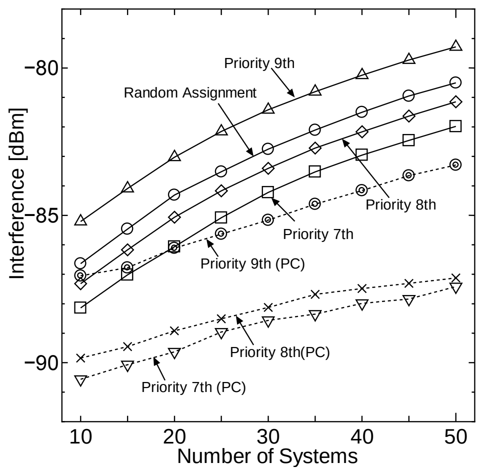

Fig.9 The given interference performance toward low priority channels while the average number of channel aggregation is 10.

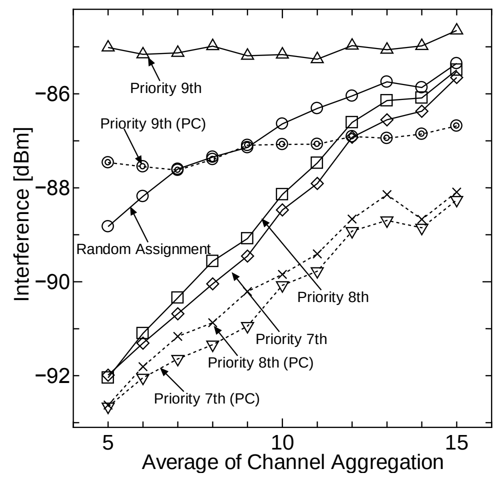

Fig.11 The given interference performance toward low priority channels while the number of systems is 10.

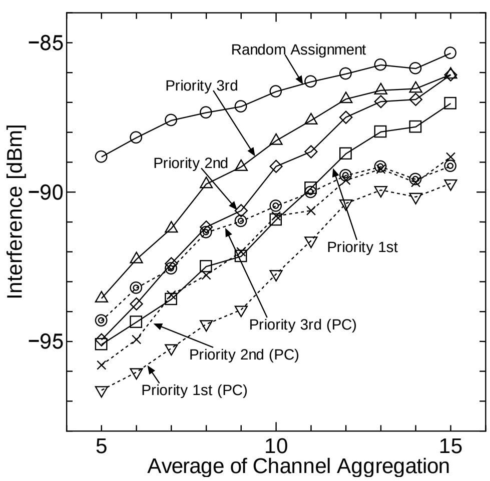

Fig.10 The given interference performance toward high priority channels while the number of systems is 10.

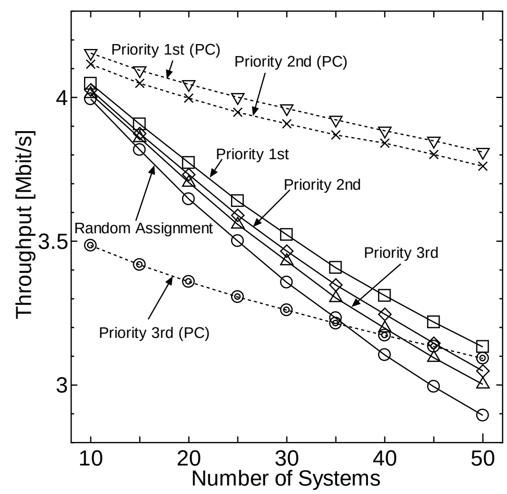

Fig.12 The throughput performance toward high priority channels while the average number of channel aggregation is 10.

aggregations is fixed to 10. Furthermore, Figs. 10 and 11 show the interference performance of the higher priority channels and the lower priority channels, respectively, when the average number of channel aggregation is changed at the horizontal axis and the number of systems is fixed to 10. From Figs. 8 and 9, we confirm that the interference power is reduced until the 8^{th} priority frequency channel, compared with the random assignment. Moreover, we identify that the power control scheme achieves the interference suppression while the number of secondary systems increases, compared with no power control. Similarly, in Figs. 10 and 11, the proposed scheme has decreased the interference power compared with the random assignment. Furthermore, we can confirm that the proposed power control scheme can suppress the giving interference toward other systems while the average number of channel aggregation increases.

Figs. 12 and 13 show the throughput performance of higher priority channel and the lower priority channel, respectively, when the number of systems is changed in the horizontal axis and the average number of channel aggregations is fixed to 10. Furthermore, Figs. 14 and 15 show the throughput performance of the higher priority channels and the lower priority channels, respectively, when the average number of channel aggregations is changed at the horizontal axis and the number of the systems is fixed to 10. Here, in the throughput performance, we assume the transmit–receiver distance is fixed to 1000m and the attenuation of the signal is only distance attenuation. Throughput is obtained by the Shannon-Hartley channel capacity. The interference is calculated for deriving the interference performance in the same way. We assume that the sum of the interference and noise power is the sum

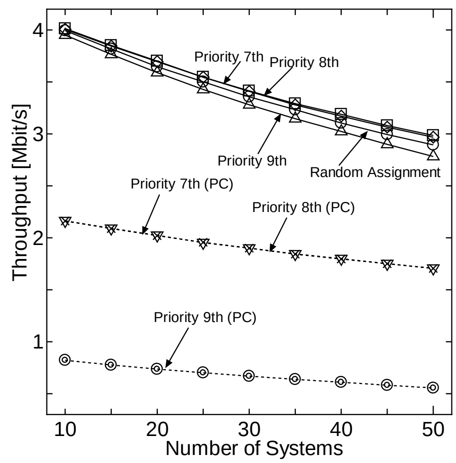

Fig.13 The throughput performance toward low priority channels while the average number of channel aggregation is 10.

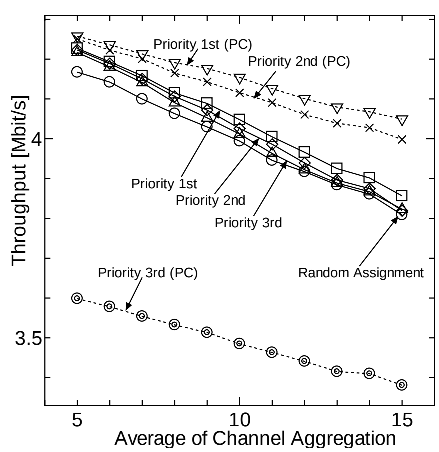

Fig.14 The throughput performance toward high priority channels while the average number of systems is 10.

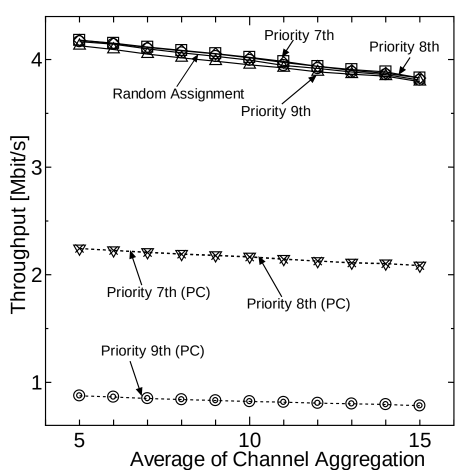

Fig.15 The throughput performance toward low priority channels while the average number of systems is 10.

of the interference and the thermal noise power -95dBm. In the proposed scheme, high throughput is achieved until the 8th priority frequency channel compared with the random assignment. Moreover, we can confirm that the proposed power control method improves the throughput until the 2nd priority frequency channel, compared with no power control. On the other hand, the throughput performance of 3rd priority channel and more becomes lower, this is because the transmit power of the frequency channel from 3rd priority and more is reduced due to the preservation of the secondary user with high priorities.

6. CONCLUSION

In this paper, we have proposed the autonomous frequency channel assignment using the frequency priority table based on the location of the secondary system and the power control scheme with preservation of higher priority channels. We evaluated the interference performance and the throughput performance by using computer simulations. From the results of computer simulations, we can confirm that the proposed method achieves low mutual interference and high throughput compared with the method using random assignment. Moreover, we can confirm that the systems with higher priority frequency channels are preserved by the power control, which can reduce the interference at the information exchanging blocks with existence of higher priority system.

7. REFERENCES

[1] T.A. Weiss, F.K. Jondral, “Spectrum pooling: an innovative strategy for the enhancement of spectrum efficiency,” IEEE Communications Magazine, vol.42, pp.S8-S14, March 2004.

[2] V. Valenta, R. Maršálek, G. Baudoin, M. Villegas, M. Suarez, F. Robert, “Survey on spectrum utilization in Europe: Measurements, analyses and observations,” Proc. CrownCom2010, June 2010.

[3] S.H. Ismail, Supangkat, B.Y. Hendrawan, Iskandar, “Calculation of spectrum utilization for cellular service in Indonesia,” Proc. Wireless VITAE 2009, pp.438-441, May 2009.

[4] B. Jankuloska, M. Pavloski, M. Zahariev, V. Atanasovski, L. Gavrilovska, “Efficient spectrum utilization: A cognitive approach,” Proc. COMM2010, pp.527-530, June 2010.

[5] R. Bacchus, T. Taher, K. Zdunek, D. Roberson, “Spectrum utilization study in support of dynamic spectrum access for public safety,” Proc. DySPAN 2010, April 2010.

[6] J. Mitola, III and G. Q. Maguire, “Cognitive radio: making software radios more personal,” IEEE Personal Commun., vol. 6, no.4, pp. 13–18, Aug. 1999.

[7] J. Mitola, III, “Cognitive radio for flexible mobile multimedia communications,” Proc. MoMuC 1999, Nov. 1999.

[8] T, Yucek, H, Arslan, “A survey of spectrum sensing algorithms for cognitive radio applications,” IEEE Communications Surveys & Tutorials, vol.11, pp.116-130, 2009.

[9] C. Qixing, W. Tianbao, Y. Hongbing, “The spectrum solutions of cognitive radios with a signaling channel,” Proc. WiCOM2010, Sept. 2010.

[10] Cuiran Li, Chengshu Li, “Dynamic channel selection algorithm for cognitive radios,” Proc. ICCSC2008, pp.275-278, May 2008.

[11] S. Jia, T. Fujii, “Two-dimensional location information exchange method based on time and frequency slot assignment in ITS system,” Proc. APWCS 2008, Aug. 2008.