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Spectrum allocation scheme on multi-user MIMO cognitive radio systems

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Abstract

In this paper, the spectrum allocation scheme has been proposed to enable complete spectrum sharing in multi-user MIMO cognitive radio (CR) systems. Performance analysis has been developed to evaluate bit error rate (BER) of each secondary user (SU) because of the effect of node member positions in multi-user CR network. In order to achieve this SUs which are ready to receive data and can communicate by ignoring any damage caused to the primary user (PU)'s communication at the same time. The authors have successfully used this method to process each frequency channel and to allocate channel to the appropriate SUs. The advantages of this system are as follows: 1) the performance analysis is able to support multi-user CR systems, 2) this research can clearly indicate the effect of the positions of node members in the CR network on their service quality, 3) the impact on both downlink and uplink operations are combined in order to make the final decision for communication, and 4) the spectrum allocation scheme which is able to allocate frequency channels for all users in CR systems is presented. The simulation results that are provided, show the performance of SU in term of BER inside their coverage areas along with the effect of GPS error. The results present the complete allocation of spectrum sharing for multi-user CR systems. The outcome of this research is very useful in further development of CR systems. In addition to this, it can be easily implemented in practice at the stage of spectrum sharing. Each SU can decide for themselves whether their position is adequate for good quality communication or not.

Keywords: Cognitive radio, MIMO, spectrum sharing

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1. Introduction

Currently, CR concept put emphasis on opening new ways of communication. Many researchers have proposed spectrum sensing as the basic function to operate CR systems, the work in [1] has presented the spectrum sensing enhancement methods in terms of theory and the work in [2] has presented the optimization techniques for spectrum sensing using node member cooperation in CR network. The work in [3] has developed a cooperative decision technique to support the imperfect feedback channel in which the work can reduce the wrong identifying on the channel statuses. The work in [4] has proposed the privacy-preserving protocols enabling SUs to operate with the reliable performance and efficient spectrum sensing. The work in [5] has proposed the control channel on media access control (MAC) protocol employed by SUs to share the spectrum sensing results. Then, SUs can create the self-schedule to achieve the better throughput. Furthermore, the work in [6] has presented the CR broker concept in which PUs open the opportunity for SUs to access idle channel by exchanging the formal payment. When the spectrum sensing process has been developed to be reliable enough, SUs can access the available channel by ignoring harm to primary link or access the occupied channel under the acceptable level of interference. Thus, there have been various works that introduce the ways to reduce interference for spectrum sharing [7, 8]. The works in [9, 10] have proposed the performance analysis for spectrum sharing in MIMO CR systems employing transmit antenna selection (TAS) at the secondary transmitter (ST) and maximum ratio combining (MRC) at secondary receiver (SR). It can be seen that the interference level is up to transmitted power of each node member in CR network. Furthermore, energy management is an important issue for current technology [11]. Hence, many works have focused on power control scheme. Such as in [12-15], the works have introduced power allocation schemes to support CR systems. Because the existing performance analysis does not support multi-user systems, the work in [16] has developed the performance analysis to support multi-

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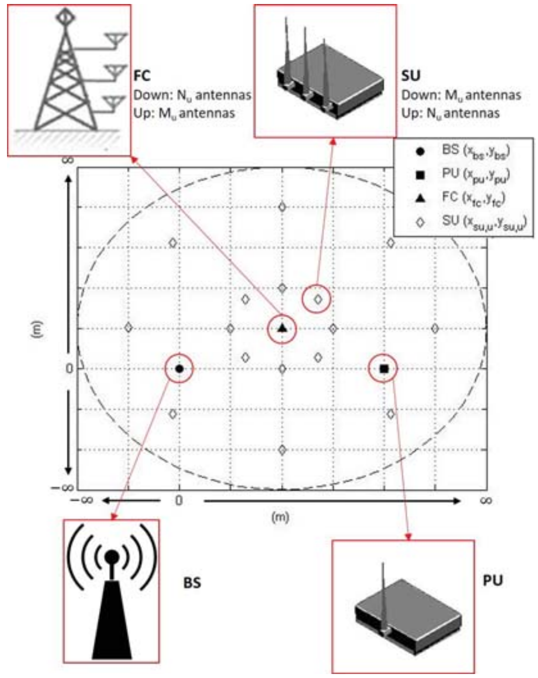

Figure 1: System model for multi-user one-cell spectrum sharing in MIMO CR system.

user MIMO CR systems and displayed the BER based on the position of each SU on both downlink and uplink. The results can guide SUs to evaluate themselves at a certain frequency channel.

For the concept of multi-user CR systems, the first proper group from all SUs can access the first frequency channel. Hence, the rest SUs can pass the BER condition for the next channels due to the reduced interference factors. In this paper, the authors proposed the spectrum allocation scheme for multi-user MIMO CR systems. The simulation results describe the performance of each SU in term of BER based position on both downlink and uplink. The intersection result is brought to perform the spectrum allocation in order to thoroughly allocate the frequency channels to all users in CR system.

2. System Model

In this CR system as seen in Figure 1, there is only one primary link per one frequency channel that is composed of one antenna for both primary transmitter (PT) and primary receiver (PR). Nevertheless, there are U SUs inside the coverage area of a fusion center (FC) for $u = 1, 2, ..., U$. In this CR system as seen in Figure 1, there is only one primary link per one frequency channel that is composed of one antenna for both primary transmitter (PT) and primary receiver (PR). Nevertheless, there are U SUs inside the coverage area of a fusion center (FC). Each secondary link is composed of N_u and M_u antennas for secondary transmitter (ST) and secondary receiver (SR), respectively. For supporting the MIMO systems, the number of antenna elements of each secondary node has to be not less than 2 antennas.

For downlink, the base station (BS) is PT, FC is ST, PU is PR, and SUs are SRs. The channel between the selected antenna of FC and the k^{th} antenna of the u^{th} SU has a channel coefficient $h_{sk,u}$. The channel between the selected antenna of FC and an antenna of PU has a channel coefficient h_{sp}. The channel between an antenna of BS and the k^{th} antenna of the u^{th} SU has a channel coefficient

For uplink, BS is PR, FC is SR, PU is PT, and SUs are STs. BS is defined as PR while FC is defined as SR, and PU is defined as PT while SUs are defined as STs. The channel between the selected antenna of the u^{th} SU and the j^{th} antenna of FC has a channel coefficient $h_{sj,u}$. The channel between the selected antenna of the u^{th} SU and an antenna of BS has a channel coefficient $h_{sp,u}$. The channel between an antenna of PU and the j^{th} antenna of FC has a channel coefficient h_{pj}. The channel between the selected antennas of other SUs in the same coverage area and the j^{th} antenna of FC has an average channel coefficient $\bar{h}_{ij,u}$. From Figure1, the received power on both downlink and uplink of primary links are given as

$$P_p = P_{max}\left(\frac{\lambda}{4\pi R_p}\right)^2 G_t G_r, \quad (1)$$

where R_p is distance between PT and PR, λ is wavelength, P_{max} is maximum primary transmitted power, and G_t and G_r are transmitter gain and receiver gain, respectively.

For both downlink and uplink, the distance from PT to SR is $D_{ps,u}$, and the distance from ST to SR is $D_{ss,u}$

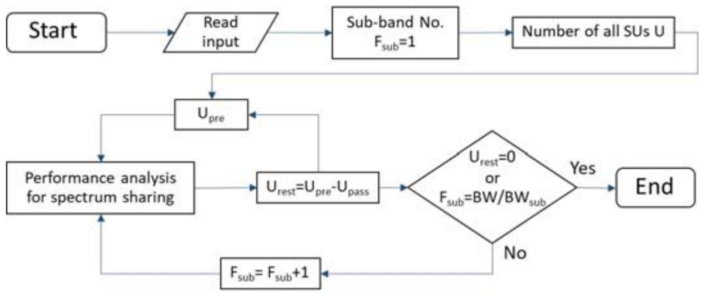

Figure 2: Block diagram of spectrum allocation scheme for overlapping spectrum sharing.

. Hence, their received powers from both distances are given as

$$P_{ps,u} = P_{max}\left(\frac{\lambda}{4\pi D_{ps,u}}\right)^2 G_t G_r, \tag{2}$$

$$P_{ss,u} = P_{smax}\left(\frac{\lambda}{4\pi D_{ss,u}}\right)^2 G_t G_r, \tag{3}$$

in which P_{smax} is a maximum secondary output power. But only for uplink, it has the interference power vector due to other SUs in the same coverage area, which can be defined as

$$\mathbf{P'}_{ssI\_u} = \mathbf{P'}_{ss\_u} - [0 \ \ldots \ P_{ss,u\_u} \ 0 \ L \ 0], \tag{4}$$

where $P_{ss,u\_u} \in \mathbf{P}_{ss\_u}$. In order to avoid any confusion, we have added subscript $\_u$ into the power variables and power matrices representing for the uplink, and $\_d$ for downlink.

3. Performance Analysis

To evaluate BER, the $m-$QAM modulation is employed, where m is constellation size. Then the received power from ST to PR is given by

$$P_{sp} = \left(\frac{-1.5P_p G_c}{(m-1)\ln\left(5BER_p\right)} - N_o\right)\frac{1}{\bar{g}_{sp}}, \tag{5}$$

where $\bar{g}_{sp} = avg\left(\left|\mathbf{h}_{sp}\right|^2\right)$ is an average channel gain from ST-PR., G_c is the coding gain [17, Eq. 9.38], and N_o is the power spectral density of noise assumed to be constant and the same for all states. Next, by considering the power P_{sp} from (5), the BER region of primary network due to interference from ST in the same location can be found by

$$D_{sp} = \frac{\lambda}{4\pi}\left(\frac{P_{smax}G_t G_r}{P_{sp}}\right)^{\frac{1}{2}}. \tag{6}$$

By using PR as a reference position, the distance from ST to PR D_{sp} from (6) will show the possible position of ST that can be available to communicate with FC around PR. Thus, the positions of ST that affect PR satisfaction can be predicted.

Next, SNR from ST-SR link for both downlink and uplink are defined as

$$\gamma_{ss,u} = g_{ss,u}\frac{P_{ss,u}}{N_0}. \tag{7}$$

where $g_{ss,d} = \sum_{k=1}^{M_u}\left|h_{sk,u}\right|^2$ for downlink and $g_{ss,u} = \sum_{j=1}^{M_u}\left|h_{sj,u}\right|^2$ for uplink. When interference from PT-SR is considered, SNR from PT-SR on downlink is defined by

$$\gamma_{is,u\_d} = g_{ps,u}\frac{P_{ps,u\_d}}{N_0}, \tag{8}$$

where $g_{ps,u} = \frac{\left|\sum_{k=1}^{M_u} h^*_{sk,u}h_{pk,u}\right|^2}{g_{ss,u}}$ is the channel gain from PT-SR for downlink. For uplink, SNR is defined by

$$\gamma_{is,u\_u} = g_{ps}\frac{P_{ps,u\_u}}{N_0} + \bar{g}_{is,u}\sum_{u=1}^{U}\frac{P_{ssI,u\_u}}{N_0}, \tag{9}$$

where $g_{ps,u} = \frac{\left|\sum_{j=1}^{M_u} h^*_{sj,u}h_{pj}\right|^2}{g_{ss,u}}$ and $\bar{g}_{is,u} = \sum_{j=1}^{M_u}\left|\bar{h}_{ij,u}\right|^2$ for uplink. Then, the BER for both downlink and uplink is

$$BER_{Int,u}(a,b) = \frac{a}{2}\sqrt{\frac{b}{2\pi}}\frac{1}{\Gamma(M_u+1)} \left[I_{1,u} + I_{2,u} + I_{3,u} + I_{4,u}\right], \tag{10}$$

where

$$I_{1,u} = \frac{(-1)^{M_u(N_u-1)+1}}{(M_u(N_u-1)-1)!}e^{\frac{1}{\gamma_{is,u}}}\left(\frac{\gamma_{is,u}}{\gamma_{ss,u}}\right)^{M_uN_u} \frac{\Gamma\left(M_uN_u+1,\frac{1}{\gamma_{is,u}}\right)}{\left(M_uN_u+\frac{1}{2}\right)}\frac{\Gamma\left(M_uN_u+\frac{1}{2}\right)}{\left(\frac{1}{\gamma_{ss,u}}+\frac{b}{2}\right)^{M_uN_u+\frac{1}{2}}} {}_2F_1\left(1, M_uN_u+\frac{1}{2}; M_uN_u+\frac{3}{2}; \frac{b\gamma_{ss,u}}{2+b\gamma_{ss,u}}\right), \tag{11}$$

$$I_{2,u} = (-1)^{M_u(N_u-1)}(M_uN_u)!\Gamma\left(M_uN_u+\frac{1}{2}\right) e^{\frac{b\gamma_{ss,u}+2}{4\gamma_{is,u}}}\sum_{k=1}^{M_uN_u}\frac{(k-1)!}{k!}\sum_{m=0}^{k-1}\frac{\left(\frac{1}{\gamma_{is,u}}\right)^m}{m!} \left(\frac{1}{\gamma_{ss,u}}+\frac{b}{2}\right)^{-\frac{1}{2}\left(M_uN_u+m-k+\frac{3}{2}\right)}\left(\frac{\gamma_{ss,u}}{\gamma_{is,u}}\right)^{\frac{1}{4}(2k+2m-2M_uN_u-1)} \mathrm{W}_{\frac{1}{2}\left(m-k-M_uN_u-\frac{1}{2}\right),-\frac{1}{2}\left(M_uN_u+m-k+\frac{1}{2}\right)}\left(\frac{b\gamma_{ss,u}+2}{2\gamma_{is,u}}\right), \tag{12}$$

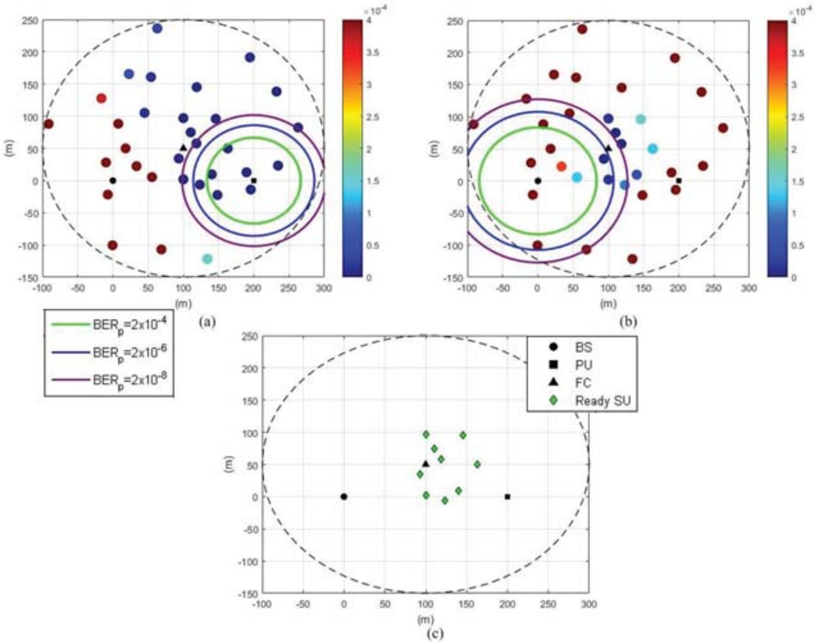

Figure 3: Spectrum sharing in multi-user MIMO CR systems, (a) downlink, (b) uplink, and (c) their intersection.

$$I_{3,u} = \left(\frac{1}{\gamma_{is,u}}\right) e^{\frac{b\gamma_{ss,u}+2}{4\gamma_{is,u}}} \sum_{k=0}^{M_u(N_u-1)-2} (-1)^{M_u(N_u-1)+k} k!\left(M_uN_u-k-1\right)!\Gamma\left(M_uN_u-k-\frac{1}{2}\right)\times \sum_{m=0}^{M_uN_u-k-1} \frac{\gamma_{ss,u}{}^{1-m}}{m!}\left(\frac{1}{\gamma_{ss,u}}+\frac{b}{2}\right)^{-\frac{1}{2}\left(m+\frac{1}{2}\right)}\left(\frac{\gamma_{ss,u}}{\gamma_{is,u}}\right)^{\frac{1}{2}\left(m-\frac{3}{2}\right)} \mathrm{W}_{\frac{1}{2}\left(2k-2M_uN_u+m+\frac{3}{2}\right),\frac{1}{2}\left(-m+\frac{1}{2}\right)}\left(\frac{b\gamma_{ss,u}+2}{2\gamma_{is,u}}\right), \tag{13}$$

and

$$I_{4,u} = M_u!\left[\sqrt{\frac{2\pi}{b}} - \left(\frac{1}{\gamma_{is,u}}\right) e^{\frac{b\gamma_{ss,u}+2}{4\gamma_{is,u}}} \sum_{k=0}^{M_u} \Gamma\left(k+\frac{1}{2}\right) \sum_{m=0}^{k} \frac{\gamma_{ss,u}{}^{-m+1}}{m!}\left(\frac{1}{\gamma_{ss,u}}+\frac{b}{2}\right)^{-\frac{1}{2}\left(m+\frac{1}{2}\right)}\left(\frac{\gamma_{ss,u}}{\gamma_{is,u}}\right)^{\frac{1}{2}\left(m-\frac{3}{2}\right)} \mathrm{W}_{\frac{1}{2}\left(m-2k-\frac{1}{2}\right),\frac{1}{2}\left(-m+\frac{1}{2}\right)}\left(\frac{b\gamma_{ss,u}+2}{2\gamma_{is,u}}\right)\right], \tag{14}$$

where a and b are the modulation-specific constants, such as (a, b) =(1,2) for BPSK, $(a, b) = (1, 1)$ for BFSK, and $\left(2\left(m-1\right)/m, 6\log_2\left(m\right)/\left(m^2-1\right)\right)$for $m-$PAM. $\Gamma(.)$ is the gamma function, $\Gamma(.,.)$ and $\gamma(.,.)$ are the upper incomplete gamma function and the lower incomplete gamma function, respectively. ${}_2F_1\left(.,.;.;.\right)$ is the hypergeometric function, and $W_{\varepsilon,\mu}\left(.\right)$ is the Whittaker W-function [16].

4. GPS Error

Although the current GPS devices have the high accuracy, there are still some errors that cannot be ignored in practical spectrum sharing process. The GPS error can be inserted into the performance analysis using

$$\hat{\mathbf{x}}_{su} = \mathbf{x}_{su} \pm \mathbf{rand}[0, error_{GPS}]_{U\times Q} \cos\left(\tan^{-1}\left(\frac{\mathbf{y}_{su}}{\mathbf{x}_{su}}\right)\right), \tag{15}$$

$$\hat{\mathbf{y}}_{su} = \mathbf{y}_{su} \pm \mathbf{rand}[0, error_{GPS}]_{U\times Q} \sin\left(\tan^{-1}\left(\frac{\mathbf{y}_{su}}{\mathbf{x}_{su}}\right)\right), \tag{16}$$

to replace in the distance equations of the above sections. The GPS error is in meters which has the value between 0 and $error_{GPS}$, where $error_{GPS}$ is the highest GPS error according to the accuracy of each GPS device.

5. Spectrum Allocation Scheme

The last process of CR system is spectrum decision in which appropriate frequency channel is chosen by the demand of users. This spectrum allocation scheme manages the appropriate frequency channel for each SU in the entire system. By the way, a diagram of this scheme is demonstrated in Figure 2 along with the steps as follows.

Step 1: Starting next to spectrum sensing process, there is the important information including the number of SUs and their positions, and the number of considered frequency channels defining from bandwidth value divided by sub-bandwidth value. Thus, the considered frequency channel $F_{sub} = 1, 2, ..., BW/BW_{sub}$, in which BW and BW_{sub} values are defined based on each communication standard. Incidentally, F_{sub} is called the sub-band number. Then, the first frequency channel is analyzed.

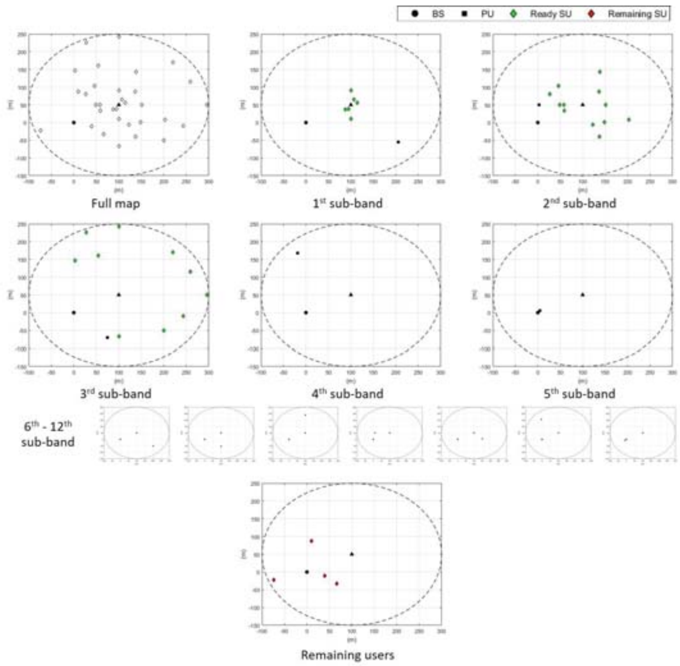

Figure 4: Full-system spectrum sharing with 32 secondary users inside the coverage area of fusion center.

Step 2: The number of all SUs and their positions are brought into the performance analysis process. The appropriate SU is SU that passes the BER condition on both downlink and uplink in the considered round. Therefore, the result of this step is the number of SUs that are ready for communication.

Step 3: The rest number of SUs U_{rest} is calculated by (17) in which these SUs still are not passing a BER condition on both downlink and uplink in the considered round.

$$U_{rest} = U_{pre} - U_{pass}, \quad (17)$$

where U_{pre} is the rest number of SUs from a previous round, and U_{pass} is the number of SUs that pass the BER condition on both downlink and uplink in the considered round and are ready to perform the communication. Note that U_{pre} is equal to a number of all SUs in the first round. Incidentally, U_{pre} and U_{rest} are the same but are in different rounds.

Then, the steps 2 and 3 will be repeated until the overall SUs is ready to perform the communication. If the process comes to the last round that $F_{sub} = BW/BW_{sub}$ but $U_{rest} \neq 0$, the rest SUs cannot operate the communication at this time

Step 4: The new term of spectrum sharing has to wait for the next observation time of spectrum sensing process.

6. Simulation Results and Discussion

The channel model under simulation is referred to LTE standard [18], which defines the system parameters including 1920 MHz – 1980 MHz for uplink operating band, 2110 MHz – 2170 MHz for downlink operating band, 23 dBm for maximum transmitted power, -103.535 dBm for minimum received power, and the tolerated BER = 2×10^{-4}. For this work, the authors have defined the number of antennas of SUs are random from 2 up to 4, $(a, b) = (1, 2)$, $G_t = 0$ dB, $G_r = 6$ dB, $G_c = 6$ dB, the transmitted power of BS is 10 dBW, $m = 16$, and the GPS error around $0-3$ m. There is a PU per one frequency channel that randomly appears inside the macrocell, and there are 32 SUs inside the coverage area of FC.

Figure 3 displays the BER of SUs. For downlink in Figure 3(a), there are some SUs that do not pass the BER condition due to the interference from BS. Especially, there are the circles around PU that indicate $BER_p = 2\times10^{-4}$, 2×10^{-6}, and 2×10^{-8}. If PU walks into FC too closely in which FC stays inside the circle $BER_p = 2\times10^{-4}$, the FC has to access other frequency channels in order to avoid the undesirable interference to primary link. For uplink in Figure 3(b), if any SU appears inside the circle $BER_p = 2 \times 10^{-4}$, SU cannot perform the communication at this frequency channel. And there are some SUs that do not pass the BER condition due to the interferences from PU and other SUs. Apart from these SUs, the others in different positions are available to operate MIMO CR communications. Finally, the intersection result of available SUs between Figure 3(a) and Figure 3(b) is shown in Figure 3(c). It is observed that some SUs can perform spectrum sharing under successful operation on both downlink and uplink. This is based on each SU position under the condition that BER of both PU and SU have to be less than 2×10^{-4}.

To achieve the goal of spectrum sharing operation, all processes in Figure 3 are performed in which the results are shown in Figure 4. Additionally, $BW_{sub=5}$ MHz. Thus, the number of sub-bandwidths is 12 referring to the bandwidth in LTE standard. Starting with the top left figure, it shows the full map of CR system which represents all of node member positions except PU that appears in a different position for each frequency channel. Then, PU appears in the next figure. As in Figure 3, after the performance analysis process of 1^{st} sub-bandwidth, the result is shown in the top center figure. The appropriate SUs achieves the permission first reducing the interference factor at the next sub-bandwidth. At the 4th-12th sub-bandwidths, there are no any SUs that can perform the communication in this spectrum. Because the spectrum allocation comes to the last round, the rest SUs cannot operate and have to wait for the new observation time of spectrum sensing process. As seen in the last bottom figure, the remaining SUs are shown. If analyzed by the location of those SUs, then it can be explained that it is the effect of powerful interference from the BS on downlink. If those SUs change their positions before the next observation time of the spectrum sensing process, they may have the occasion to pass the BER condition and can perform the communication. Note that the effect of GPS error of this result existed but not displayed and not focused due to the fact that the system does not know how much impact it has in reality. This effect of GPS error depends on the quality of each GPS device which is inexact.

7. Conclusions

The performance analysis based on the positions of node members for spectrum sharing techniques has been presented in this paper. The relationship between BER and positions of users is shown in the mathematical solution in which the users at the same frequency channel affect each other depending on their positions. The simulation results can describe the interference impact of each user in CR system related to a thorough performance analysis in terms of BER that supports both downlink and uplink operations. In addition, the system can allocate the frequency channels to all users as thoroughly as possible employing the spectrum allocation scheme. Because the primary link is the main priority in the system, this work is suitable for data transferring applications which can wait for the proper position of SU in communication. Hence, the proposed CR concept is very useful for multi-user MIMO CR implementation. It can decide for SUs in the appropriate positions offering them good quality communication. Moreover, the rest SUs can access the next channels due to the reduced interference factors.

Acknowledgements

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