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Improved Resource Allocation Scheme in LTE Femtocell Systems based on Fractional Frequency Reuse

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Abstract

Femtocells provide high quality indoor communications with low transmit power. However, when femtocells are applied in cellular systems, a co-channel interference problem between macrocells and femtocells occurs because femtocells use the same spectrum as do the macrocells. To solve the co-channel interference problem, a previous study suggested a resource allocation scheme in LTE cellular systems using FFR. However, this conventional resource allocation scheme still has interference problems between macrocells and femtocells near the boundary of the sub-areas. In this paper, we define an optimization problem for resource allocation to femtocells and propose a femtocell resource allocation scheme to solve the optimization problem and the interference problems of the conventional scheme. The evaluation of the proposed scheme is conducted by System Level Simulation while varying the simulation environments. The simulation results show that the proposed scheme is superior to the conventional scheme and that it improves the overall performance of cellular systems.

Keywords: Femtocell, OFDMA, resource allocation, fractional frequency reuse, capacity

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1. Introduction

Wireless communication and multimedia technology fields have developed, and so the demand for high data rate has increased and several techniques to meet the demand for high data rate have been applied in mobile communication systems. There are several solutions to increase data rate. One is more frequency allocation, but that is difficult to implement because frequency bands are finite and demand for frequency resources has increased, recently. So solutions that enhance the data rate without additional resource allocation are needed [1].

One of these solutions is to reduce the cell coverage. Designing small cells provides more high quality service of wireless communications environment to user. Femtocells ,which connect to a mobile communications core network through installed broadband(internet), are used in an indoor base station that has small transmit power and coverage(10~50 meters). Hence, femtocells are appropriate for a small cell environment. Femtocells provide high indoor communication services owing to the short distance between the mobile station and the femtocell BS. Moreover, there are cost benefits because femtocells can be simply installed by Plug and Play without any additional infrastructure [2]. Thus, several standards organizations, such as 3GPP, WiMAX Forum, and IEEE 802.16, have started to develop standardization femtocell networks [3][4].

However, there are some technical challenges in femtocell systems. When femtocells are applied in OFDMA based network such as LTE, there is a cross-tier interference problem between the macrocells and the femtocells because the femtocells use the spectrum of the macrocells [5]. There are two typical models of spectrum assignment for macrocells and femtocells. The first is the dedicated channel model. In this model, femtocells are assigned a separate spectrum that remains after allocating to the macrocells. So, it is easy to avoid CCI (Co-Channel Interference); however, efficiency of the spectrum utilization is not good. The second model is the co-channel model. This model provides better performance than the first one in terms of efficiency of spectrum utilization. However, there is CCI in this model, so the CCI problem should be solved [6].

Fractional Frequency Reuse(FFR) is one of the solutions that resolve CCI problems. In FFR, the whole area of a macrocell is divided into a center and an edge region. The center region uses a reuse factor of one and the edge region uses the larger reuse factor. According to the above description, the total frequency band splits into some sub-bands, and each sub-band is differently allocated to each sub-area. By using a reuse factor larger than one in the edge region, inter-cell interference is reduced. Because a reuse factor of one is used in the center region, the efficiency of the frequency band utilization is enhanced. So, the throughput of the entire cellular system is increased [7][8][9][10].

Although overall throughput is enhanced by using FFR, CCI problems between macrocells and femtocells should be solved when femtocells are applied in LTE cellular networks, as mentioned above.

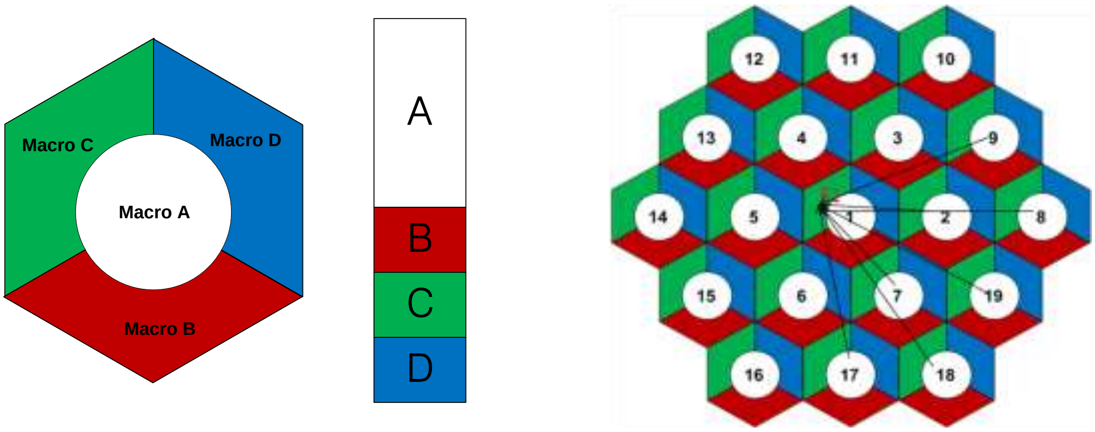
In this paper, we look at the problem of interference between macrocells and femtocells in LTE femtocell systems using FFR, and define the optimization problem on sub-band assignment to femtocells in order to maximize the total throughput. Then, we propose a resource allocation scheme according to the optimization problem that we defined.

The remainder of this paper is organized as follows. In section 2, we explain the system model for LTE femtocell systems using FFR; problem formulations for maximizing the performance in the overall cellular systems mentioned above are also described. Section 3 presents resource allocation schemes for femtocells including both the conventional and the proposed scheme, in accordance with optimization problems. The simulation results and analysis are presented in section 4. Finally, section 5 presents the conclusion of this paper.

2. System Model

2.1 OFDMA Femtocell Model based on FFR

Resources are allocated to macrocell users before they are allocated to femtocell users in OFDMA cellular systems using FFR because macrocell users have fundamentally priority over femtocell users. In this paper, the system model of optimal resource allocation for macrocells refers to previous research [9]. Reference [9] analyzes optimal resource allocation systems according to inter-cell interference coordination so as to determine the optimal reuse factor and the portion of the center and edge region in the macrocell. The authors in [9] derive optimization problems that have the objective function of maximizing the overall throughput and constraints of each user's data rate that satisfies the minimum bit rate. Then, the problems mentioned above are solved by the Primal-Dual Interior Method. As a result, the radius of the center region is found to be 0.63 km (cell radius = 1km) and the reuse factors of the center region and the edge region are one and three, respectively.



(a) (b)

Fig. 1. (a) Frequency band allocation, **(b)** Multi-cell structure for OFMDA systems

According to research results in [9], we set the coverage of the center region to 63% of the macrocell and the reuse factors of the center region and the edge region to one and three, respectively. Furthermore, as depicted in **Fig. 1-(a)**, the frequency band is divided into two groups, and one group of the two groups is partitioned into three groups. Then, each frequency sub-band is diffently allocated to macrocell users in each of the sub-areas, which were divided following FFR. **Fig. 1-(b)** shows the multi-cell structure with FFR for OFDMA systems such as LTE. Although every macrocell uses the entire frequency band, the macrocell base stations use the omni-directional antennas and 3-directional antennas for sub-band A and sub-band B, C, and D, respectively. Macrocell users in the center region of macrocell 1 are interfered with by all adjacent 18 macrocells; however, macrocell users in sector E1 are interfered with by only seven macrocells nubered {2, 7, 8, 9, 17, 18, 19} because the propagation for sub-band C is forwarded to only angle of green color and macrocell users in sector E1 use only sub-band C. So, the performance of the macrocell can be improved because the inter-cell interference in the edge region is reduced [11].

When femtocells are applied in macrocell systems as described above, there are additional intereference scenarios because femtocells share the spectrum of macrocells; there are problems of interference from femtocells to macrocells, from macrocells to femtocells, and from femtocells to femtocells. Thus, we need to allocate optimal resources to femtocells in light of the above mentioned interference scenarios, in order that the interference from femtocells to macrocell users, who have priority, can be reduced and the overall performance of cellular systems can be enhanced.

2.2 Propagation Model

In the case of downlink systems, there are four propagation models in cellular systems in which macrocells and femtocells coexist; the model of a macrocell base station to a macrocell user, a macrocell base station to a femtocell user, a femtocell base station to a macrocell user, and a femtocell base station to a femtocell user. These four propagation models are shown as follows [12][13].

First, in the model of a macrocell base station to a macrocell user, the path loss is calculated as follows:

$$PL = 128.1 + 37.6 \log_{10} d \tag{1}$$

where d is the distance between the macrocell base station (MNB) and the marcocell user (MUE) in kilometers.

In the model of macrocell base station to femtocell user, there are two cases, namely, femtocell user (HUE) located inside and outside the house. In the case of the outdoor HUE, path loss calculation is same as the MNB to the MUE model. But, in the case of indoor HUE, the path loss is calculated as follows, considering wall penetration loss:

$$PL = 128.1 + 37.6 \log_{10} d + L_{ow} \tag{2}$$

where L_{ow} is wall penetration loss and this value is 10dB with a probability of 0.8 and is equal to 2dB with a probability of 0.2, in order to account for windows.

In the model of the femtocell base station to the macrocell user, wall penetration loss occurs between the femtocell base station(HNB) and the MUE because HNB is installed in the house and MUE is outdoors. So, path loss in this case is caculated as

$$PL = \max(15.3 + 37.6 \log_{10} d, 37 + 20 \log_{10} d) + L_{ow} \tag{3}$$

where L_{ow} is the same as mentioned above and d is the distance between HNB and MUE in meters.

Finally, in the model of the femtocell base station to the femtocell user, there are three cases in this model; 1) HNB and HUE in the same house, 2) HUE outside the house, and 3) HNB and

HUE in the different houses. In the first case, there is no wall penetration loss and path loss is calculated as

$$PL = 37 + 20\log_{10} d \tag{4}$$

The case of outdoor HUE is identical to the HNB to MUE model. In the case of HNB and HUE in a different house, wall penetration loss between HNB and HUE occurs twice. So, path loss can be calculated as follows:

$$PL = \max(15.3 + 37.6\log_{10} d, 37 + 20\log_{10} d) + L_{ow}^{(1)} + L_{ow}^{(2)} \tag{5}$$

where the unit of d is also meters.

Propagation models described above are shown as **Table 1**.

Table 1. Propagation Model

Cases of Model	Cases of users	Path Loss (dB)
MNB to MUE	MUE is outside	Equation (1)
MNB to HUE	HUE is outside	Equation (1)
	HUE is inside a house	Equation (2)
HNB to MUE	MUE is outside	Equation (3)
HNB to HUE	HUE is inside the same house as HNB	Equation (4)
	HUE is outside	Equation (3)
	HUE is inside a different house	Equation (5)

2.3 Problem Formulations

Because femtocells use the frequency band of macrocells, unlike WLAN using the ISM band, CCI problems between macrocells and femtocells occur. Thus, in order to reduce interference to macrocell users who have priority and to enhance cell performance, a scheme of frequency resource allocation to femtocells in OFDMA cellular systems, as mentioned above, is needed. So, in this section, we formulate problems related to cell performance such as SINR and capacity and define optimization problems for an optimal resource allocation scheme.

In a multi-cell systems, as illustrated in **Fig. 1-(b)**, the received SINR of a macrocell user m, can be expressed as

$$SINR_{m,k} = \frac{P_{M,k} G_{m,M,k}}{N_0 \Delta f + \sum_{M'} P_{M',k} G_{m,M',k} + \sum_{F} P_{F,k} G_{m,F,k}} \tag{6}$$

where $P_{M,k}$ and $P_{M',k}$ are the transmit power of the serving macrocell M and the macrocell M', respectively, and the macrocell M' interferes with the macrocell user m on the sub-carrier k. If the macrocell user is in the center region, then M' is adjacent to 18 macrocells, and if the macrocell user is in sector E1 as in **Fig. 1-(b)**, M' represents the macrocells numbered {2, 7, 8, 9, 17, 18, 19}. $G_{m,M,k}$ is the channel gain between the macrocell user m and the macrocell M on the sub-carrier k. Similarly, $P_{F,k}$ is the transmit power of femtocell F on the sub-carrier k, and $G_{m,F,k}$ is the channel gain between the macrocell user m and the adjacent femtocell F on the sub-carrier k. N_0 is the white noise power spectral density and Δf is the sub-carrier spacing.

In the case of femtocell users, they are interfered with by 19 macrocells and adjacent femtocells that use the same frequency band. Similar to macrocell users, femtocell users f have received SINR, which can be shown as follows:

$$SINR_{f,k} = \frac{P_{F,k} G_{f,F,k}}{N_0 \Delta f + \sum_{M'} P_{M',k} G_{f,M',k} + \sum_{F'} P_{F',k} G_{f,F',k}} \tag{7}$$

Channel gain G is dominantly affected by the path loss and path loss can be calculated by the above Propagation Model in section 2.2. PL refers to path loss; channel gain G can be expressed as

$$G = 10^{-PL/10} \tag{8}$$

Through received SINR, we can define the practical capacity of macrocell user m and femtocell user f on sub-carrier k as below [11].

$$C_{m\ or\ f,k} = \Delta f \bullet \log_2(1 + \beta SINR_{m\ or\ f,k}) \tag{9}$$

where β is constant for target Bit Error Rate (BER) and is defined as $\beta = -1.5/\ln(5BER)$. In this paper, we set the BER to 10^{-6}.

Using the practical capacity, the overall throughput of the serving macrocell M can be expressed as follows.

$$T_M = \sum_m \sum_k \rho_{m,k} C_{m,k} \tag{10}$$

where $\rho_{m,k}$ indicates whether sub- carrier k is assigned to macrocell user m. If $\rho_{m,k} = 1$, sub- carrier k is allocated to macrocell user m. Otherwise, $\rho_{m,k} = 0$. Because of the property of OFDMA systems, each sub-carrier is assigned to only one user. This means that $\sum_{m=1}^{N_m} \rho_{m,k} = 1$ for all k, where N_m is the total number of macrocell users in the serving macrocell.

Similarly, overall throughput of femtocell F can be defined as below.

$$T_F = \sum_{f} \sum_{k \in \Phi_F} \rho_{f,k} C_{f,k} \tag{11}$$

where $\rho_{f,k}$ is also a factor that notifies whether sub-carrier k is assigned to femtocell user f and Φ_F denotes the sub-band that femtocell F uses. This implies that $\sum_{f=1}^{N_f} \rho_{f,k} = 1$ for $k \in \Phi_F$, where N_f is the total number of femtocell users in one serving femtocell.

Using the above throughput of the macrocell and the femtocell, the overall throughput in one serving macrocell can be expressed as follows.

$$T_{total} = T_M + \sum_{F=1}^{N_{FBS}} T_F \tag{12}$$

where N_{FBS} is total number of femtocell base stations in a serving macrocell.

On the basis of Equations (6) to (12), explained above, an optimization problem for sub-band allocation to femtocells with the objective of maximizing the overall throughput can be defined as follows.

$$\max_{\Phi_F} \left(\sum_{m=1}^{N_m} \sum_{k} \rho_{m,k} C_{m,k} + \sum_{F=1}^{N_{FBS}} \sum_{f=1}^{N_f} \sum_{k \in \Phi_F} \rho_{F,f,k} C_{F,f,k} \right)$$
$$\text{subject to} \begin{cases} \sum_{m=1}^{N_m} \rho_{m,k} = 1, \ for \ \forall k \\ \sum_{f=1}^{N_f} \rho_{F,f,k} = 1, \ for \ k \in \Phi_F \end{cases} \tag{13}$$

According to optimization problem expressed as Equation (13), an optimal femtocell sub-band allocation method is needed to maximize the overall cell throughput. Therefore, we propose the sub-optimal femtocell sub-band allocation scheme, which solves the above optimization problem by reducing the interference between femtocells and macrocells.

3. Resource Allocation Scheme for Femtocells

3.1 Conventional Resource Allocation Scheme

In the conventional scheme, which was proposed earlier so as to solve the problems described above, femtocells in the sub-area of the macrocell use the sub-band that macrocells in the same sub-area do not use as depicted in **Fig. 2** [14]. The details of the conventional scheme are explained as follows.

In the macrocells, reuse factors of one and three are applied in the center region and the edge region, respectively. Then, the sub-band A is allocated in the center region and the sub-bands B, C, and D are assigned to sectors E1, E2, and E3, which are the sub-areas of the edge region, respectively.

Under these circumstances for macrocells, femtocells basically use a sub-band that macrocells in the same sub-area do not use. Especially, when femtocells are in the center region, the sub-band that macrocells in the edge region of the same sector use is subtracted. For example, when a femtocell is in sector E1, it uses sub-band A, C, or D because macrocell uses sub-band B. If femtocell is in the sector C1, it uses sub-band C or D because the macrocell in the center region uses sub-band A and the macrocell signal strength of the sub-band B used in sector E1 is stronger than that of the femtocell.

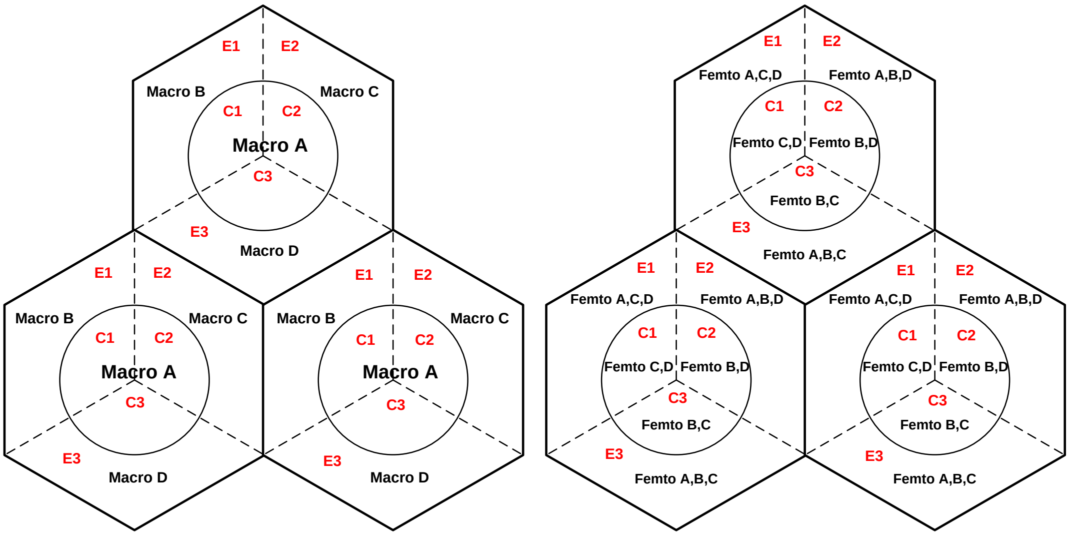


Fig. 2. Conventional resource allocation scheme

However, in the conventional scheme, femtocells near the boundary of the sub-area give relatively more interference to macrocell users. For example, if a femtocell in sector E1 uses sub-band C near the boundary of the sub-area, macrocell users in sector E2 are more interfered with by it. When a femtocell in the edge region uses sub-band A, it interferes with macrocell users in the center region near the boundary between the center and the edge region. Thus, we propose a femtocell resource allocation scheme that solves the problem of the conventional scheme and improves the performance of LTE cellular systems.

Another conventional approach is the power control method that is needed to mitigate the interference from femtocells to macrocell users when achieving the femtocell coverage [15]. In this method, the transmit power of the femtocell *F* is set according to the received power from the macrocell base station and is given as

$$P_F = \min(P_M - PL_m(d) + PL_f(r), P_{F,\max}) \tag{14}$$

where P_F and P_M is the transmit power of femtocell and macrocell, respectively and $PL_m(d)$ is the path loss between the femtocell and macrocell base station. $PL_f(r)$ is the path loss at the target cell radius r (excluding any wall losses) and $P_{F,\max}$ is the maximum power of the femtocell.

3.2 Proposed Resource Allocation Scheme

In this section, we present a proposed resource allocation scheme that can enhance the overall performance of cellular systems by solving the optimization problem expressed in Equation (13) and the problem of the conventional resource allocation scheme.

Resource allocation to macrocells is the same as in the conventional scheme. Under this environment, each sub-band is allocated to femtocells as shown in **Fig. 3**. In the proposed scheme, new sub-areas for femtocells are applied in macrocells. Femtocells in each new sub-area choose sub-bands used in a macrocell sub-area that is far away from the new sub-areas for femtocells. The proposed scheme described above can solve interference problems near the boundary of the sub-area mentioned in the conventional scheme and can improve the performance.

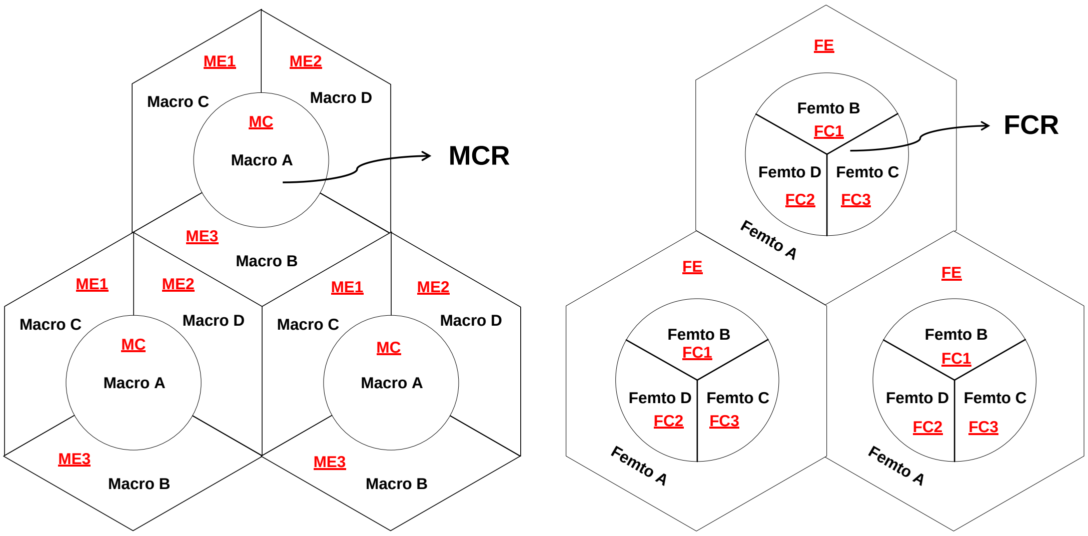


Fig. 3. Proposed Resource Allocation Scheme

However, if the center region in the sub-areas for macrocells, referred to as MCR, and the center region in the new sub-areas for femtocells, referred to as FCR, are the same with respect to size, an interference problem near the boundary between the center and the edge region occurs. So, we need to find the optimal size of FCR that can solve that interference problem and give better performance. When R_F refers to the radius of FCR that we find, an optimization problem considering the optimal radius of FCR for maximizing the throughput can be expressed as follows,

$$\max_{R_F} \left(\sum_{m=1}^{N_m}\sum_{k}\rho_{m,k}C_{m,k}+\sum_{F=1}^{N_{FBS}}\sum_{f=1}^{N_f}\sum_{k\in\Phi_F}\rho_{F,f,k}C_{F,f,k}\right)$$

$$\text{subject to}\begin{cases}\sum_{m=1}^{N_m}\rho_{m,k}=1,\ for\ \forall k\\ \sum_{f=1}^{N_f}\rho_{F,f,k}=1,\ for\ k\in\Phi_F\\ 0\le R_F\le ISD/2\\ \Phi_F=sub-band\ A, if\ d_F>R_F\end{cases} \qquad (15)$$

where ISD is the Inter Site Distance and d_F is the distance between the macrocell base station and the femtocell F.

Thus, in this paper, the optimal R_F described in Equation (15) is solved by System Level Simulation in order to enhance the overall capacity; details of optimal R_F are presented in section 4.

If the proposed scheme is applied in practical systems, femtocells sense the signal of neighbor macrocells when they are turned on. Then, femtocells get the RSSI (Received Signal Strength Indication) by sensing the results. Once $RSSI_{th}$ is decided according to R_F, femtocells can judge whether they are inside or outside the FCR through comparison between $RSSI_A$ and $RSSI_{th}$ (where $RSSI_k$ is the RSSI of sub-band k). If $RSSI_A$ is larger than $RSSI_{th}$, the femtocell is inside the FCR. Otherwise, the femtocell is outside the FCR. Depending on the proposed scheme, if the femtocell is outside the FCR, the sub-band A is allocated to the femtocell. If not, the sub-band whose RSSI is the smallest value other than $RSSI_A$ is assigned to the femtocell. For example, when the femtocell is in sub-area FC1, as shown in **Fig. 3**, $RSSI_B$ is the smallest of the sensing RSSI values except for $RSSI_A$. Thus, a practical algorithm for the proposed resource allocation scheme is expressed as shown in **Table 2**.

Table 2. Practical algorithm of proposed resource allocation scheme

```
01. Femtocell $F$ is turned on
02. Get $RSSI_{th}$ calculated by $R_F$
03. Sense the whole frequency sub-bands $B_{sub}$ by pilot sensing and get the RSSI of
    each sub-band
04.     $B_{sub}=\{A,B,C,D\}$, $RSSI=\{RSSI_A,RSSI_B,RSSI_C,RSSI_D\}$
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```
if $RSSI_A < RSSI_{th}$
    $\Phi_F = \{A\}$
else
    $B_{sub} = B_{sub} \setminus \{A\}$[1]
    $RSSI = RSSI \setminus \{RSSI_A\}$
    $[\min\_value, \min\_index] = \min(RSSI)$
    $\Phi_F = B_{sub}(\min\_index)$
end
```

4. Simulation Results

4.1 Simulation Environments

We compose 19 macrocells whose ISD(Inter Site Distance) is 500 meters, as in **Fig. 1-(b)**, and the number of macrocell users per macrocell is 50. Femtocells are set inside a building of dimensions 12m X 12m and we change the number of femtocell base stations from 30 to 180 per one macrocell so as to vary the simulation environments. Also, the number of femtocell users in one femtocell is three. The distribution of macrocell users, femtocell base stations and femtocell users follows uniform distribution.

All the base stations are operated by OFDMA technology and available sub-carriers are assigned to macrocell and femtocell users following various resource allocation schemes. Because we use FFR, the center sub-area of the macrocell is set to 63% of macrocell coverage [9]. Macrocell base stations use omni-directional antennas for the center region and 3-directional antennas for the edge region; transmit power values for the center and edge regions are 15 W and 22 W, respectively. Transmit power of femtocells is 20mW.

Depending on the characteristics of the System Level Simulation, we consider path loss and shadowing. Path loss is calculated by the Propagation Model in section 2.2; shadowing is Lognormal shadowing, which has zero mean and 8dB standard deviation.

The simulation parameters described until now are listed in **Table 3**.

Table 3. Simulation Parameters

Parameters	**Values**	
	Macrocell	**Femtocell**
The number of cells	19	30~180/Macrocell
Cell coverage	500m(ISD)	10m(radius)
BS transmit power	15W(center), 22W(edge)	20mW
The number of users / cell	50	3
Channel Bandwidth	5MHz	
FFT size	512	
The number of occupied sub-carriers	300	
Sub-carrier spacing	15kHz	
White noise power spectral density	-174dBm/Hz	
Lognormal shadowing	0 mean, 8dB standard deviation	

4.2 Simulation Results

Fig. 4 and **Fig. 5** show the throughput of macrocell users and the average capacity of femtocell users according to the size of FCR in the proposed scheme in order to find the optimal R_F of the optimization problem described in Equation (15).

In **Fig. 4** and **Fig. 5**, we define the threshold values as the performance of conventional scheme and decide on the available range of the FCR size, because performances of macrocell users and femtocell users are different. For example, in the case of macrocell users, the available range of the FCR size is over 83% and is 77% of MCR when the number of femtocell base stations are 30 and 180, respectively, as shown in **Fig. 4**. So, in this case, the FCR size should be over 83% of the MCR as depicted in **Fig. 4**. In the case of femtocell users, the available range of the FCR size is below 115% and is 140% of the MCR when the number of femtocell base stations are 180 and 30, respectively, as in **Fig. 5**. Similarly, the FCR size should be below 115% of the MCR in case of femtocell users as depicted in **Fig. 5**. Considering the case of macrocell users and femtocell users, the available range of the FCR size is 83% to 115% of the MCR. Then, we find two optimal sizes of FCR and apply these values to the systems; this is the size of the FCR for macrocell users and femtocell users. The best size of the FCR for macrocell users is approximately 120% of MCR, but the available range of the FCR size should be below 115% of the MCR. The best size of the FCR for femtocell users is roughly 60% of the MCR, but the available range of the FCR size should be over 83% of the MCR. So, in this paper, the sizes of the FCR for macrocell users and femtocell users are set to 110% and 90% of MCR size, respectively, and the proposed scheme is divided into two modes according to the two optimal sizes of the FCR. The details of two modes are listed in **Table 4**.

Table 4. The details of two modes in the proposed scheme

Mode	**Advantageous User**	**The size of FCR**
Mode 1	Macrocell user	110% of MCR
Mode 2	Femtocell user	90% of MCR

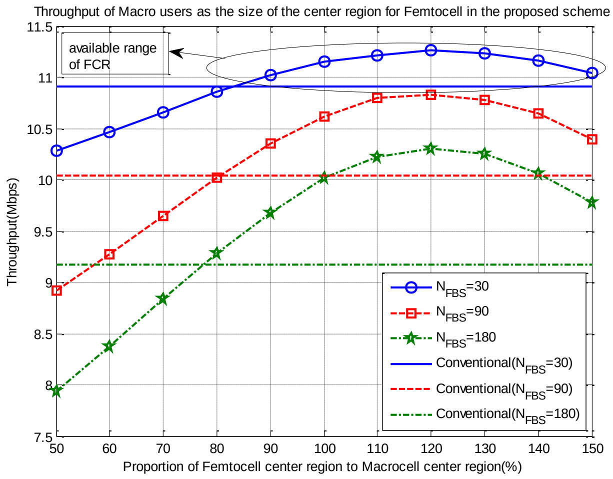

Fig. 4. Throughput of macrocell users as the size of FCR in the proposed scheme

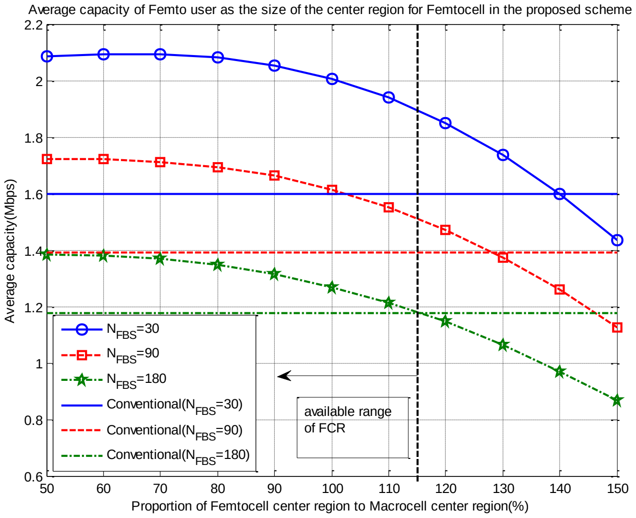

Fig. 5. Average capacity of femtocell user as the size of FCR in the proposed scheme

The mode 2 is the case that the radius of FCR is less than the radius of MCR. When the radius of FCR is less than the radius of MCR, the number of femtocells which use sub-band A is increased and the quantity of spectrum utilization of femtocells is increased. So, the performance of femtocell users in the mode 2 is better than mode 1 while the femtocells in the mode 2 give more interference to the macrocell users than the mode 1. However, in **Fig. 4**, the performance of the macrocell users is better than the conventional scheme when the size of FCR is 90% of MCR. This means that the performance of macrocell users in the mode 2 is better than the conventional scheme despite that interference problem.

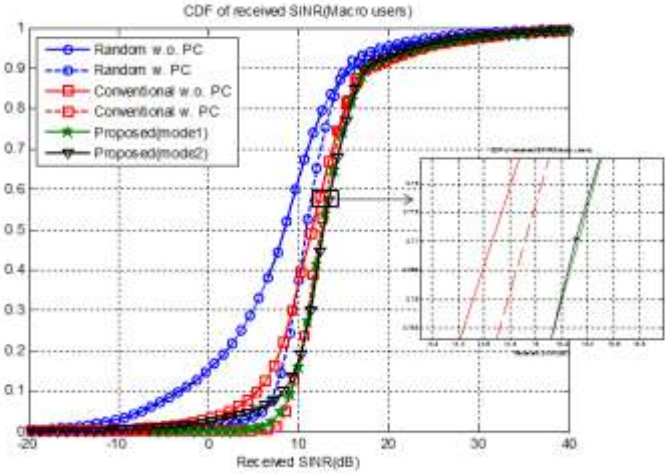

Fig. 6. CDF of received SINR(macrocell users)

In order to evaluate the performance of the proposed scheme, we conducted a simulation and comparative analysis of a random scheme with and without PC (Power Control), the conventional scheme with and without PC, and two modes of the proposed scheme(mode 1 and mode 2). The random scheme means that each sub-band is randomly allocated to femtocell users.

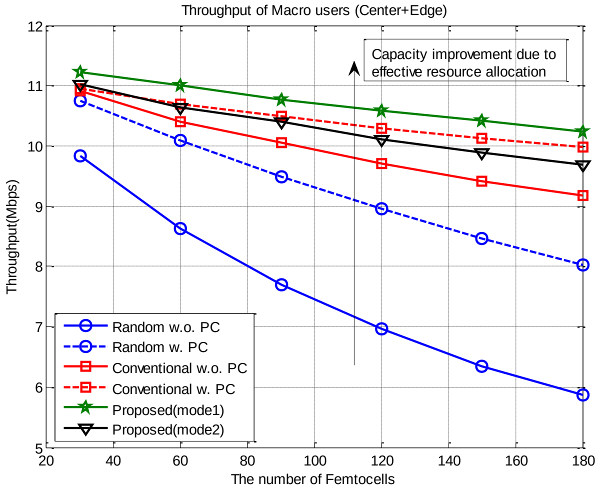

Fig. 7. Throughput of macrocell users

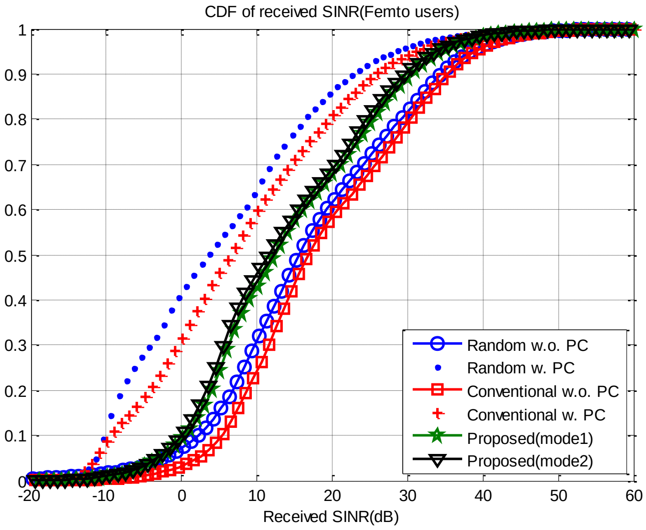

Fig. 8. CDF of received SINR(femtocell users)

Fig. 6 and **Fig. 7** depict the CDF of the received SINR and the throughput as the performance measure of macrocell users. In **Fig. 6** and **Fig. 7**, the performance of the proposed scheme is better than random and conventional schemes because the proposed scheme can solve the interference problems in the conventional scheme and can enhance the received SINR and capacity, and the proposed scheme shows less degradation of performance than do the other schemes as the number of femtocells is increased. Furthermore, the mode 1 of the proposed scheme shows the best performance in spite of the performance improvement of the conventional schemes due to power control. This means that the proposed scheme can enhance the performance with low complexity because the complexity is increased when applying the power control.

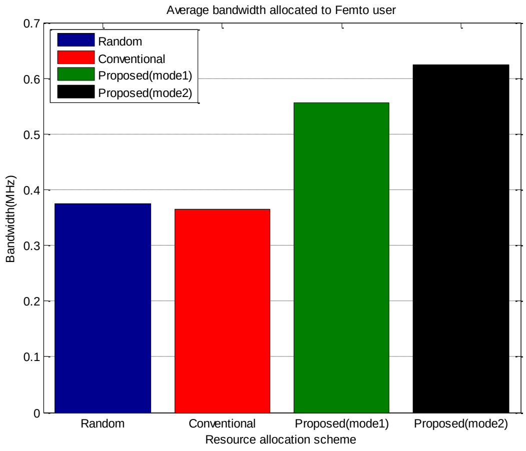

Fig. 9. Average bandwidth allocated to the femtocell user

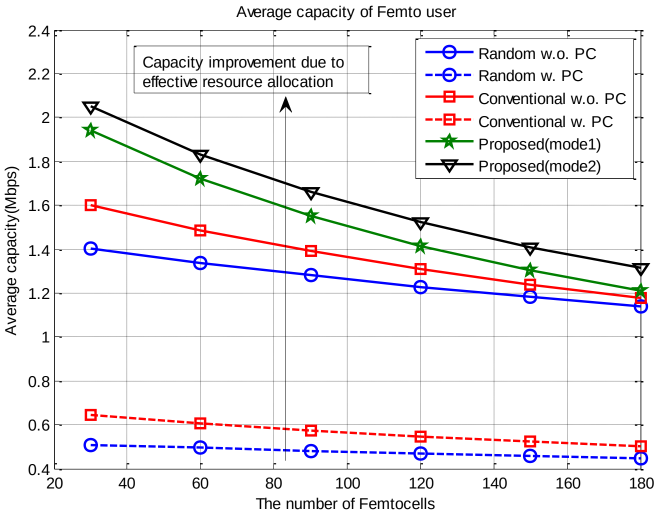

Fig. 10. Average capacity of femtocell user in an entire macrocell

The power control can enhance the performance of macrocell users, but the performance of the femtocell users is worst when applying the power control as depicted in **Fig. 8** and **Fig. 10**. This is because the overall transmit power of the femtocells is decreased. The proposed scheme is better than the others with respect to the interference from femtocells to macrocell users, but the proposed scheme is worse than the others as regards the received SINR of femtocell users as shown in **Fig. 8**. This is because the proposed scheme gives more interference between femtocells and this problem is drawback of the proposed scheme. However, the proposed scheme gives more average bandwidth to femtocell users than do the other schemes, as depicted in **Fig. 9**. This is because the number of femtocells which use sub-band A in the proposed scheme is larger than the conventional and random schemes, and sub-band A has wider bandwidth than sub-band B, C, and D. Thus, the proposed scheme shows the best performance with respect to the capacity of femtocell users, as depicted in **Fig. 10**; the performance of mode2 is the best in the proposed scheme. These results imply that femtocells in the proposed scheme give less interference to macrocell users while using more spectrum of macrocells than do the other schemes.

Through the performance of macrocell and femtocell users, the proposed scheme shows the best performance in terms of both macrocell and femtocell users.

5. Conclusion

In this paper, we consider the co-channel interference problem between macrocells and femtocells by sharing the same frequency resources when femtocells are applied in LTE cellular systems using FFR; we also define an optimization problem for resource allocation to femtocells. Then, we propose a resource allocation scheme to solve the optimization problem. The performance of the proposed scheme is evaluated via System Level Simulation. Through the simulation results, the proposed scheme is found to improve the capacity levels of both macrocell users and femtocell users. This is because the femtocells in the proposed scheme use more frequency resources simultaneously while giving less interference to macrocell users, although sharing more spectrum generally leads to more interference problems. Moreover, the proposed scheme can improve the performance with low complexity because the proposed scheme without power control is better than the conventional schemes with power control. Therefore, through this study, we found that the proposed scheme enhances the overall performance of LTE cellular systems in which macrocells and femtocells co-exist.

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