Interference Management in LTE Femtocell Systems Using Fractional Frequency Reuse

Poongup Lee and Jitae Shin

School of Information and Communication Engineering
Sungkyunkwan University, Suwon, 440-746, Korea
{poongup, jtshin}@skku.edu

***Abstract*— Recently, Long Term Evolution (LTE) has developed a femtocell for indoor coverage extension. However, interference problem between the femtocell and the macrocell should be solved in advance. In this paper, we propose an interference management scheme in the LTE femtocell systems using Fractional Frequency Reuse (FFR). Under the macrocell allocates frequency band using the FFR, the femtocell chooses sub-bands which are not used in the macrocell sub-area to avoid interference. Simulation results show that proposed scheme enhances the throughput and reduces the outage probability in overall network, especially for the cell edge users.**

***Keywords*— Femtocell, Interference management, Fractional Frequency Reuse (FFR), Long Term Evolution (LTE), Throughput**

I. INTRODUCTION

Long Term Evolution (LTE) is one of the most promising candidates for next generation communication standard. The LTE is technologically based on Orthogonal Frequency Division Multiple Access (OFDMA) to achieve higher data rates and enhanced spectral efficiency. The frequency and time resources are allocated to users in orthogonal manner. A key feature is Frequency Reuse Factor (FRF) 1 for maximal resource use. However, same sub-carriers are used by different users among adjacent cells, Co-Channel Interference (CCI) problem occurs, especially for cell edge users. Appropriate inter-cell interference coordination technique should be required to enhance the system capacity [1].

Recently, the LTE has developed a femtocell for indoor coverage extension. The femtocell is defined as very small size, low-power home base station that works in the licensed frequency bands, and it is connected to broadband Internet backhaul [2]. The femtocell brings various benefits to both consumers and operators, such as enlarged indoor coverage, enhanced system capacity, Quality of Service (QoS), and reduced capital and operation expense. Due to increasing indoor phone calls and data services, but insufficient macrocell coverage, the femtocell could be an attractive solution.

However, interference problem between the femtocell and the macrocell should be solved in advance, because the femtocell is deployed over the existing macro network, and it uses same spectrum with the macrocell. Dedicated channel approach is one of the easiest ways to solve this problem, but the frequency resources are not utilized effectively. Co-channel model is suitable for practical deployment, but the CCI problem should be solved [3]. The femtocell is often turned on and off, and installed at unknown location, because it is managed by a personal customer, not by a network operator. Therefore, many parameters should be automatically adjusted to avoid the CCI.

Fractional Frequency Reuse (FFR) is discussed in the OFDMA based network such as the LTE, to overcome the CCI problems [4-6]. In the FFR, whole frequency band is divided into several sub-bands, and each sub-band is differently assigned to center zone and edge region of the cell. While reuse factor of the center zone is one, the edge region adopts bigger reuse factor. As a result, intra-cell interference is removed, and inter-cell interference is substantially reduced. At the same time the system throughput is enhanced.

In this paper, we propose an interference management scheme in the LTE femtocell systems using the FFR. Under the macrocell allocates frequency band using the FFR, the femtocell chooses sub-bands which are not used in the macrocell sub-area to avoid interference.

The remaining part of this paper is composed as follows. Related work is explained in Section II. Section III describes the proposed interference management scheme. The simulation results are shown in section IV. Finally, we conclude our paper in section V.

II. RELATED WORK

Interference management issues for the femtocell systems have been actively discussed both in the LTE and in the Worldwide Interoperability for Microwave Access (WiMAX) [6].

Spectrum partitioning and Frequency ALOHA (F-ALOHA) scheme was proposed [7]. It removes interference between macrocells and femtocells by assigning orthogonal spectrum. Among the femtocells, each femtocell uses sub-channels in random manner. Optimal spectrum portion for the femtocells can be determined. However, this scheme is based on the dedicated channel approach. Although the spectrum is utilized adaptively, the full bands are not serviced for the macrocell.

Dynamic Frequency Planning (DFP) algorithm was another proposal for interference avoidance [8]. After dividing the OFDMA network into several sectors, it estimates the amount of sub-channels considering user bandwidth demand in each sectors. Interference among sectors are calculated when the sectors transmit the same frequency. Optimization function is run to minimize the overall network interference. However, this scheme follows a centralized network structure, which is not appropriate for femtocell managed by a personal owner.

Several heuristic algorithms for frequency assignment were investigated [9]. The recommended one is Least Interference Power (LIP) algorithm, where a powered up femto base station chooses a frequency segment that minimizes the interference level. In Turn-on Orders algorithm, frequency allocation is conducted according to the order of the femtocell turned on. Optimum Pattern (OPTM) and Random Scheme are described for comparison. However, the femtocells are deployed in the form of rectangular matrix, not in the random manner. Also, interference between the macrocell and the femtocell is not evaluated.

Isolated and Coupled model considering user location was discussed for OFDMA femtocells [10]. In the isolated model, macro and femto users are allocated different resources split by time and frequency slots. The coupled model reuses macro resources for femtocells which are located in the cell boundary, while the center zone femtocells use orthogonal resources from the macrocell. However, these schemes do not apply the FFR concept for the OFDMA system.

Frequency reuse and pilot sensing scheme was proposed to reduce the CCI [11]. After applying the FRF of 3 or above to the macrocells, the femtocells use the remaining frequency sub-bands. For example, if the reuse factor is three and the macrocell uses sub-band I among the three sub-bands I, II, and III, the femtocell chooses sub-band II and III. However, the macrocell throughput is reduced, even though the overall capacity is enhanced. Also the reuse factor in macrocell is against the OFDMA based network such as the LTE and the WiMAX, where the target of the reuse factor is one.

The FFR is one of the solutions to reduce inter-cell interference in macrocell system, especially for the cell edge users. Also it is helpful to achieve the reuse factor of one. Under this condition, the interference from the femtocell deployment should be minimized for the macro users. So, we focus on the interference management between the macrocell and the femtocell using the FFR.

III. PROPOSED SCHEME IN FEMTOCELL

A. Illustration of the Proposed Scheme

We allocate the frequency sub-bands into macrocell and femtocell as depicted in Figure 1. The macrocell coverage is divided into center zone and edge region including three sectors per each, denoted by C1, C2, C3, and E1, E2, E3. The whole frequency band is partitioned into two parts, and one part of them is classified into three pieces again, totally denoted by A, B, C, and D.

For macrocell, different frequency sub-band is allocated to the each macrocell sub-area according to the FFR. The reuse factor of one is applied in the center zone, while the edge region adopts the factor of three. The sub-band A is used in the center zone (C1, C2, and C3), and sub-band B, C, and D is applied in the E1, E2, and E3 regions, respectively.

Under this circumstance, the femtocell chooses sub-bands which are not used in the macrocell sub-area. Especially when the femtocell is located in the center zone, the femtocell additionally excludes a sub-band which is used by macrocell in the edge region of current sector. For example, when a femtocell is located in region E1, it uses sub-band A, C, and D, while the macrocell uses sub-band B. If a femtocell is positioned in zone C1, sub-band C and D is applied. The femtocell avoids sub-band A which is used by macrocell in zone C1. Also it avoids sub-band B which is used by macrocell in region E1, because the received signal power of sub-band B is relatively strong for that femtocell.

Due to the characteristics of the OFDMA, the macrocell is interfered by inter-cell, and that interference is further mitigated by the FFR. The femtocell uses different sub-band to avoid interference from the macrocell. The sub-band is reused in the macrocell coverage as much as possible, because transmit power of the femtocell is very small. Therefore, the interference between the macrocell and femtocell is greatly avoided. Also more sub-carriers are allocated to femtocell which is located in the edge region, in order to improve the performance of the edge users.

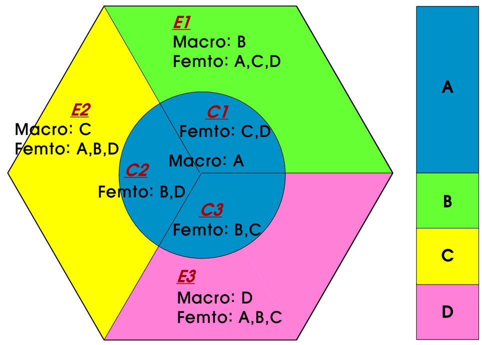

Figure 1. The proposed interference management scheme using FFR

B. Performance Formulation

We formulate downlink Signal to Interference and Noise Ratio (SINR) and system throughput. The overall network is composed of two-tier 19 macrocells, and many femtocells are randomly deployed over the macrocells. A macro user is interfered from neighboring 18 macrocells and all of the adjacent femtocells. Due to small transmit power, only femtocells which are located in the 1-tier macrocell area give interference to macro user. The received SINR of a macro user m on sub-carrier k can be expressed as

$$SINR_{m,k} = \frac{P_{M,k} G_{m,M,k}}{N_0 \Delta f + \sum_{M'} P_{M',k} G_{m,M',k} + \sum_{F} P_{F,k} G_{m,F,k}} \quad (1)$$

where, $P_{M,k}$ and $P_{M',k}$ is transmit power of serving macrocell M and neighboring macrocell M' on sub-carrier k, respectively. $G_{m,M,k}$ is channel gain between macro user m and serving macrocell M on sub-carrier k. Channel gain from neighboring macrocells are denoted by $G_{m,M',k}$. Similarly, $P_{F,k}$ is transmit power of neighboring femtocell F on sub-carrier k. $G_{m,F,k}$ is channel gain between macro user m and neighboring femtocell F on sub-carrier k. N_0 is white noise spectral density, and Δf is sub-carrier spacing.

In case of a femto user, it is interfered from all 19 macrocells and adjacent femtocells. The received SINR of a femto user f on sub-carrier k can be similarly given by

$$SINR_{f,k} = \frac{P_{F,k} G_{f,F,k}}{N_0 \Delta f + \sum_{M} P_{M,k} G_{f,M,k} + \sum_{F'} P_{F',k} G_{f,F',k}} \quad (2)$$

The channel gain G is dominantly affected by path loss, which is different for outdoor and indoor. The path loss for outdoor is modeled as $PL_{outdoor} = 28+35\log_{10}(d)$ dB, where d is the distance from a base station to a user in meters. Otherwise, indoor model is $PL_{indoor} = 38.5+20\log_{10}(d)+L_{walls}$ dB, where L_{walls} is 7, 10, and 15 dB for light internal, internal, and external walls, respectively [3]. So, the channel gain G can be expressed as

$$G = 10^{-PL/10} \quad (3)$$

The practical capacity of macro user m on sub-carrier k can be given by [4]

$$C_{m,k} = \Delta f \cdot \log_2(1 + \alpha SINR_{m,k}) \quad (4)$$

where, α is a constant for target Bit Error Rate (BER), and defined by $\alpha = -1.5/\ln(5BER)$. Here, we set BER to 10^{-6}.

The overall throughput of serving macrocell M can be expressed as

$$T_M = \sum_{m} \sum_{k} \beta_{m,k} C_{m,k} \quad (5)$$

where, $\beta_{m,k}$ notifies the sub-carrier assignment for macro users. When $\beta_{m,k} = 1$, the sub-carrier k is assigned to macro user m. Otherwise, $\beta_{m,k} = 0$. From the characteristics of the OFDMA system, each sub-carrier is allocated only one macro user in a macrocell in every time slot. This implies that $\sum_{m=1}^{N_m} \beta_{m,k} = 1$, where N_m is the number of macro users in a macrocell.

Similar expression for femto users related to the practical capacity and the overall throughput is possible except $\sum_{f=1}^{N_f} \beta_{f,k} = 3$. N_f is the number of femto users in a macrocell. This implies that the proposed scheme reuses the full frequency band three times in a macrocell.

C. Operational Algorithm

The macro users are allocated the sub-carriers according to the FFR as shown in Figure 1. The center zone and the three sectored edge region use the separated frequency sub-band.

Under this condition, a femtocell senses the neighboring macrocell signals, when it turns on. The Received Signal Strength Indication (RSSI) values are compared for each sub-band A, B, C, and D. When the RSSI of sub-band A is strong, the femtocell is located in the center zone. In addition, if the sub-band B signal is strong, the femtocell location is zone C1. The femtocell chooses sub-carriers from the sub-band C and D. It excludes the sub-band A and B, whose signal power is strong because these are used by the macro users. It is similar for zone C2 and C3.

On the other hand, if the RSSI of sub-band A is weak, the femtocell is positioned in the edge region. Moreover, if the sub-band B signal is strong, the femtocell position is region E1. The sub-carriers from the sub-band A, C, and D are selected by the femtocell. The sub-band B is excluded because its RSSI is high. Similar scheme is possible for the region E2 and E3.

IV. SIMULATION RESULTS

A. Scenarios and Environments

We evaluate the proposed scheme in terms of throughput and outage probability using SINR threshold in the range of 0 to 30 dB. We also concentrate on the performance of the cell edge users. The outage is determined when the SINR level of a sub-carrier do not exceed the designated threshold. The outage probability p_{out} is given by

$$p_{out} = \frac{\sum_u \sum_k \delta_{u,k} \cdot SINR_{u,k}}{\sum_u \sum_k \beta_{u,k} \cdot SINR_{u,k}} \quad (6)$$

where, $\delta_{u,k}$ indicates failed sub-carrier assignment for user u on sub-carrier k. If $\delta_{u,k} = 1$, the SINR of that sub-carrier is under the SINR threshold ($SINR_{u,k} < SINR_{threshold}$). So, the ratio between the number of sub-carriers under the SINR threshold and the number of total sub-carriers is the outage probability.

The proposed scheme is compared with several comparison schemes as follows. In *FFR-3* scheme, FFR is applied to the macro users, and femto users are randomly assigned from full frequency band. On the other hand, FFR is not adopted for macro users in *NoFFR-3* scheme. The amount of total available sub-carriers for femto users is three times of the full band, as equal to the proposed scheme. These features are summarized in Table 1. The *Amount* column implies the amount of used sub-carriers denoted by the sub-carrier assignment parameter β.

Table 1. Summary of Proposed and Comparison Schemes

Schemes	Macro user		Femto user	
	Frequency	Amount	Frequency	Amount
Proposed	FFR	1	Divide center and edges (Figure 1)	3
FFR-3	FFR		Random	
NoFFR-3	Random		Random	

Note: *Amount* column implies value of $\sum_{m=1}^{N_m} \beta_{m,k}$ and $\sum_{f=1}^{N_f} \beta_{f,k}$ for macro and femto users, respectively.

Table 2. Simulation Parameters

Parameters	Values	
	Macro	Femto
Number of cells	19 (two-tier)	30-180/macro
Cell coverage	280 m	30 m
BS transmit power	FFR: 15, 22 W w/o FFR: 20 W	20 mW
Number of users in one macro cell coverage	180	180
Channel Bandwidth	5 MHz	
FFT size	512	
Number of occupied sub-carriers	300	
Sub-carrier spacing	15 kHz	
White noise spectral density	-174 dBm/Hz	
Size of center zone	0.63 of macro coverage	
Channel model (Path loss, *PL*)	$PL_{outdoor} = 28+35\log_{10}(d)$ $PL_{indoor} = 38.5+20\log_{10}(d)+L_{walls}$ L_{walls} = 7 dB, if d in (0,10] L_{walls} = 10 dB, if d in (10,20] L_{walls} = 15 dB, if d in (20,30]	

The simulation parameters are listed in Table 2. The overall network is composed of two-tier 19 macrocells, and femtocells are randomly deployed over the macrocells. All the base stations are operated by the OFDMA technology. We vary the number of femtocells from 30 to 180 in one macrocell coverage to change simulation environment. The macro and femto users are randomly distributed in the overall network. The macro and femto users are randomly allocated the available sub-carriers from the designated range in each scheme. When the FFR is applied to macro user, a half of the full band is assigned for center zone, the other for edge region. An onmi-directional antenna and three sector antennas are installed at a macro base station, for center zone with transmit power of 15 W and for edge region with 22 W, respectively. On the other hand, if the FFR is not used by macro user, the transmit power of a macro base station is 20 W. All the femtocells use 20 mW as the transmit power. The different channel model is used for indoor and outdoor, where the path loss is dominant factor. Then, we find out the downlink received SINR values for each user and each sub-carrier. Using this value, the throughput and the outage probability are calculated via users located in the central serving macrocell of 19 cells.

B. Numerical Results and Comparison

Figure 2 shows the throughput of macro users located in the macrocell coverage as the number of femtocells varies. In proposed scheme, the femto users can get the sub-carriers which are not used by macro users at each location. So, the interference between macro users and femtocells is greatly avoided. The femtocells affect to macro users less than the comparison schemes. The gap of throughput between the proposed and the other schemes is bigger when more femtocells are deployed.

In Figure 3, it describes the throughput of total users located at the edge region only. In the OFDMA cellular network, the performance of the edge region is poor due to the inter-cell interference. Allocating the more sub-carriers to femtocells which are located in the edge region, the throughput of the edge region is improved. The gains are 27% and 47% in average, when compared with the *FFR-3* and *NoFFR-3* schemes, respectively.

Figure 4 depicts the outage probability of total users according to the SINR threshold, when 30 femtocells are deployed in the macrocell coverage. In a given SINR threshold, the proposed scheme indicates lower outage probability than other schemes. Also we decrease the outage probability more at low SINR threshold. This implies that the proposed scheme effectively supports more users, even though the interference is severe.

As shown in these results, our proposed scheme enhances the overall throughput and reduces the outage probability, especially for the cell edge users.

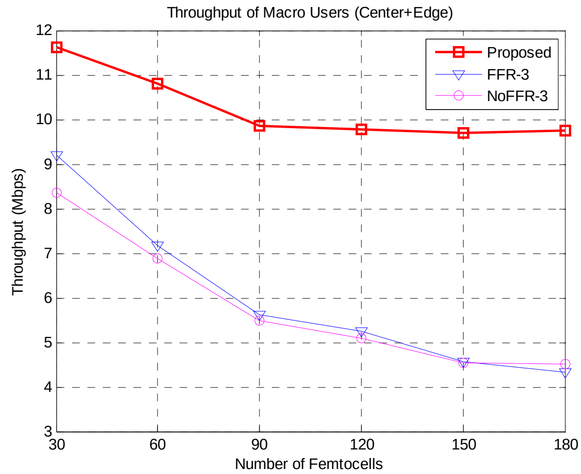

Figure 2. Throughput of macro users located in center zone and edge region as the number of femtocells varies

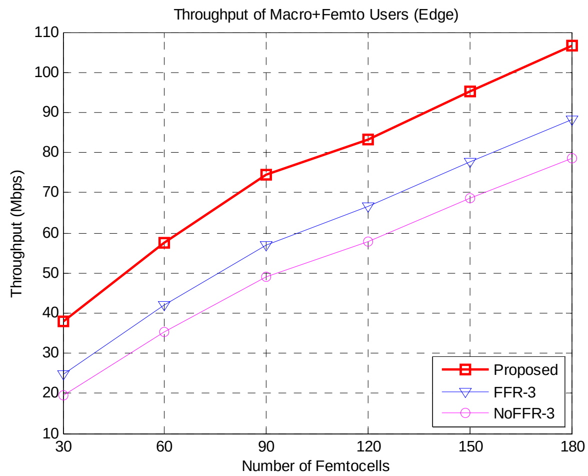

Figure 3. Throughput of macro and femto users located only in the edge region as the number of femtocells varies

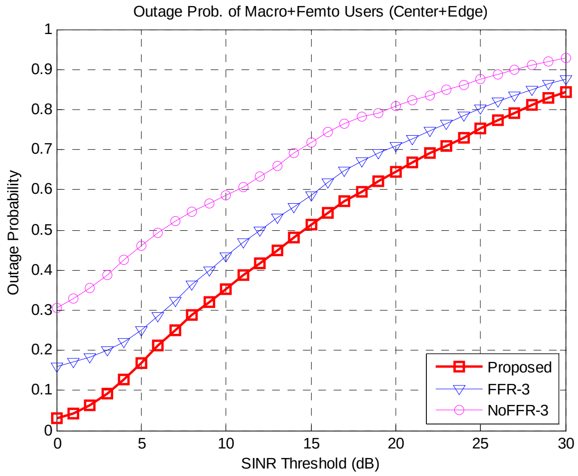

Figure 4. Outage probability of macro and femto users according to SINR threshold varies, when 30 femtocells are deployed

V. CONCLUSIONS

In this paper, we propose an interference management scheme in the LTE femtocell systems using the FFR. The proposed scheme enhances throughput and reduces outage probability, especially for the cell edge users. It is beneficial for the OFDMA network such as the LTE, where the FFR is applied.

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