A Novel Frequency Planning for Femtocells in OFDMA-Based Cellular Networks Using Fractional Frequency Reuse*

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Abstract. Femtocells are expected to be one of the emerging technologies for next generation communication systems. For successful deployment of femtocells in the pre-existing macrocell networks, there are some challenges such as the cell planning for interference management, handoff, and power control. In this paper, we focus on frequency planning which can provide interference avoidance for the co-existence of macrocells and femtocells. We propose a novel frequency planning for femtocells in cellular networks using fractional frequency reuse (FFR). We consider downlink performance of cellular systems based on Orthogonal Frequency Division Multiplexing Access (OFDMA), e.g., WiMAX and 3GPP Long Term Evaluation (LTE). Simulation results show that our scheme indeed reduces the effect of additional co-channel interference (CCI) between a given macrocell and deployed femtocells as well as neighboring macrocells.

1 Introduction

The concept of indoor cellular networks using home base stations (BSs), femtocells, with low transmission power is drawing much interest. Femtocells are one of the emerging cost-effective technologies for both operators and users to enhance coverage and to support higher data rate by bridging existing handsets and broadband wired networks. However, deployment of femtocells in pre-existing cellular networks causes some problems to be addressed. One of them is that it requires intelligent frequency allocation for femtocells and traditional macrocells when they operate simultaneously in the same network [3]. So it is important to efficiently allocate frequency resources for femtocells considering the effect of co-channel interference. Since frequency resources are usually limited, some methods to enhance the efficiency are desirable.

Traditionally, there exist frequency allocation mechanisms which allocate frequency resources according to frequency reuse factors (RFs) in multi-cell environment. One is

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the shared frequency allocation mechanism, in which frequency is shared with adjacent cells, i.e., universal frequency reuse or frequency RF of 1. The other is the orthogonal frequency allocation mechanism which allocates frequency according to the predetermined frequency patterns among multi cells with the frequency RF of 1 or more. The former may be viewed as more efficient because all frequency resource can be utilized in each of cells. However, it can suffer from performance degradation since the performance of users located at the edge of a cell is degraded due to co-channel interference (CCI) from neighboring cells. So the frequency RF of 3 or above is generally employed to mitigate CCI in 2G systems. The reduction of CCI is typically gained at the cost of efficiency in frequency resource allocation [6].

Fractional frequency reuse (FFR), which is the mixture of the shared and orthogonal frequency allocation, becomes one of the solutions to improve frequency efficiency in OFDMA-based cellular systems, e.g., WiMAX and 3GPP Long Term Evaluation (LTE). In most of FFR schemes, each cell is partitioned into two regions: *inner region and outer region*. The inner region around a base station (BS) in a cell can use the frequency RF of 1 due to low CCI from adjacent cells. The outer region far from a BS in a cell uses different frequency bands with those in adjacent cells with the frequency RF of 3 to reduce CCI [11].

FFR can be implemented easily in OFDMA-based cellular systems because the frequency band of a cell is divided into subchannels and can be handled by the unit of subchannel, a group of orthogonal subcarriers. Han et al. propose an FFR scheme to enhance the flexibility of frequency assignment and cell performance, in which mobile stations (MSs) in the inner region can use the subchannels assigned to both the inner and the outer region of a cell according to the frequency partitioning [4]. Another FFR scheme is introduced by noting that the inner region and the outer region are differently served by not only frequency bands but also time slots [5].

While the performance of the users located at the edge of a cell is important in the macrocell networks with FFR, interference management between macrocells and femtocells is a main issue in femto / macro co-deployment environment with different channel operation strategies: orthogonal channel allocation and shared channel allocation [1]. So the frequency assignment for femtocells is one of the key issues [2]. The authors in [2] propose that femtocells in the inner region of a macrocell use different subcahnnels with those for macrocell users to minimize interference, and femtocells in the outer region of a macrocell use the same subcahnnels as those for macrocell users. They suppose cell environment without FFR, in which the frequency RF of macrocells is greater than 1.

In this paper, we propose a frequency planning mechanism with FFR for macrocells and femtocells, in which co-channel operation is allowed in low CCI, and orthogonal frequency allocation is adopted in high CCI. To reduce the effect of CCI we utilize resource allocation in both frequency bands and time slots.

The remaining part of this paper is organized as follows. Section 2 describes the basic FFR scheme for macrocells and presents the proposed frequency planning mechanism for femtocells and macrocells. Performance evaluation of the proposed scheme is provided in Section 3. We conclude in Section 4.

2 Proposed Frequency Planning

2.1 FFR for Macrocells

In our proposed FFR for macrocells, a macrocell is grouped into two parts: *inner region and outer region*. The decision on whether an MS belongs to inner or outer region is made by the reported signal-to-interference-plus-noise-ratio (SINR) of the reference signal at the initial configuration or at the periodic state update. If sufficient SINR is observed, i.e., the reported SINR of an MS is above the pre-determined SINR threshold, the BS considers that the MS belongs to the inner region. Otherwise, i.e., the reported SINR of an MS is below the pre-determined SINR threshold, the BS considers that the MS is in the outer region. The reported SINR of an MS is largely dependent on its location, i.e., the farther an MS is from the BS in a cell, the larger the path-loss of the signal from the BS becomes.

Fig. 1 shows an example, in which MSs in the inner region use the RF of 1 and those in the outer region use the RF of 3. It illustrates the feasible frequency bands for macrocells according to the region that an MS belongs to. So the whole subchannels can be allocated to the inner region while the outer region uses just 1/3 of all subchannels in a cell. Furthermore, the service times of the inner and the outer region are separated by time slots. The MSs in the inner region of macrocells can be served simultaneously because CCI from neighbor macro BSs is limited. They can utilize the whole subchannels

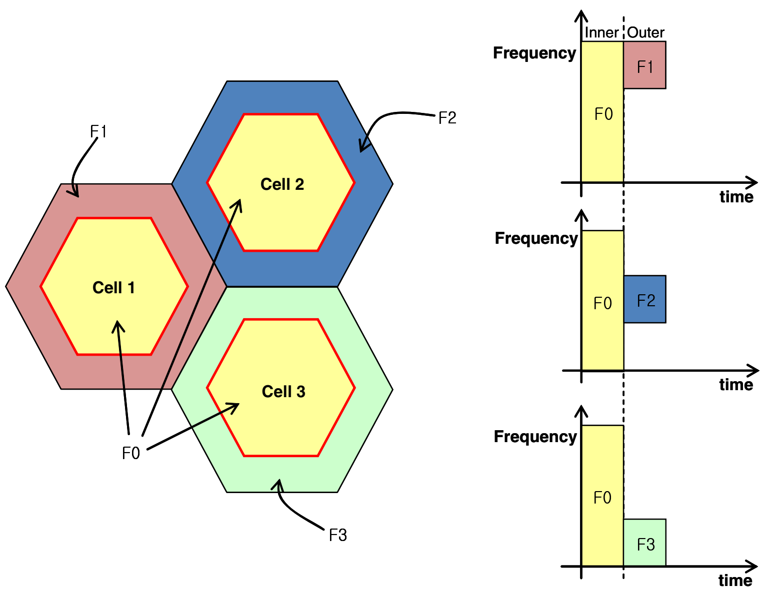

Fig. 1. Proposed frequency band/time slots allocation with FFR for macrocells

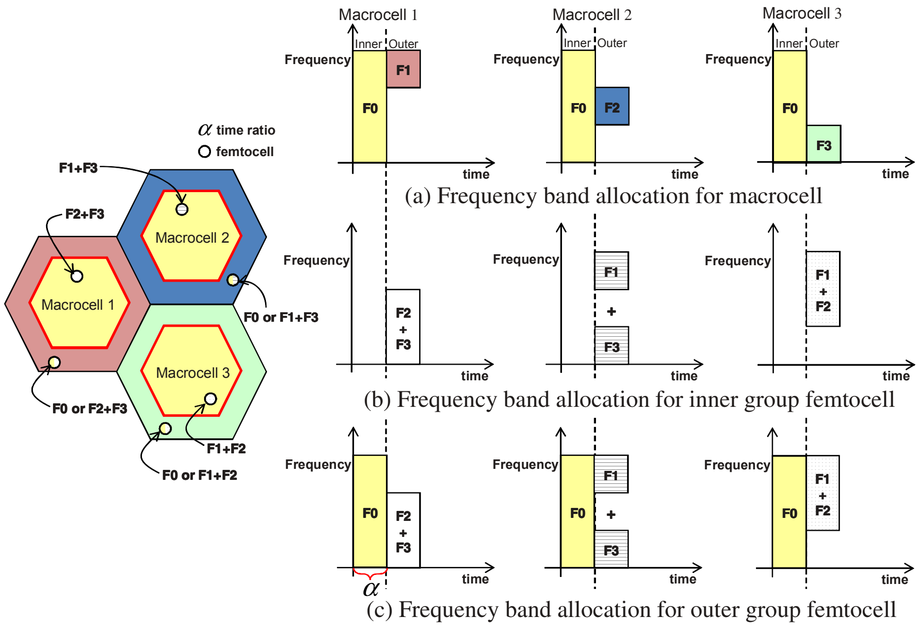

Fig. 2. Proposed frequency planning for femtocells

during their time slots. The MSs in the outer region of macrocells can also be served simultaneously but they must use the orthogonal subchannels in order to avoid high CCI from neighbor macro BSs. In summary, the inner region and the outer region are allocated shared or separate time slots and frequency bands to mitigate intra- and inter-cell interference among the inner and the outer regions as well as among cells.

2.2 Frequency Planning for Femtocells

In this section, we propose a novel frequency planning for femtocells under the macrocells with FFR. First of all, femtocells should be deployed harmoniously in order not to make minor impacts on the legacy macrocells but to maximize their performance. In our proposal, femtocells are divided into the inner group and the outer group depending on whether a femtocell is located in the inner region or the outer region of a mcarocell. A femto BS is assumed to support auto-configuration because it has to be able to setup a user controlled hot-spot. A femto BS reports the SINR of the reference signal of a macrocell to the macro BS by pilot sensing, which is similar to the macro MSs when they do in the setup procedure. Then the macro BS determines whether the femtocell belongs to the inner or the outer group and notifies the appropriate frequency bands to the femto BS. We assume that all macro and femto BSs are synchronized.

We now consider three factors for the frequency planning of femtocells: frequency, time, and spatial state. The femtocells in the inner group, i.e., *inner femtocells*, are served during the service time of the macro MSs in the outer region, i.e., *outer service time*, and the subchannels orthogonal to the macrocell frequency bands are allocated in order to avoid intra CCI from the macrocell that the femtocell belongs to. For the macro MSs in the outer region, only 1/3 of the overall frequency band is utilized to reduce CCI to adjacent macrocells. So these 2/3 unused subcahnnels can be allocated to the inner femtocells efficiently (see Fig. 2). The CCI between the inner femtocells and the neighboring macrocells is limited due to low transmission power of femtocells and relatively large path loss factors, e.g., high attenuation path-loss by long distance and wall-loss by the walls in buildings.

For the femtocells in the outer group, i.e., *outer femtocells*, we note that they use low transmission power and the CCI between the macrocell and the femtocells is small. So they are allowed to use the same frequency bands and time slots, i.e., *inner service time* as those of the macro MSs in the inner region. That is, the outer femtocells can utilize all the subchannels in the given time slots. As shown in Fig. 2(c), outer femtocells use the full frequency band during the inner service time and 2/3 of the band during the outer service time.

3 Performance Evaluation

We consider 2-tier cellular networks consisting of M(=19) macrocells. The macro BSs are located at the center of each cell. Femto BSs which have uniform separation with one another are densely deployed within a macrocell (see Fig. 3). We use the modified COST-Walfish-Ikegami (WI) urban micro model for the non-line-of-sight (NLOS) outdoor path-loss model [10].

$$P_{loss}^{out}[dB] = 31.81 + 40.5\log_{10}(d[m]) + \chi_{\sigma^{out}}, \tag{1}$$

where d is the distance between a sender and a receiver and $\chi_{\sigma^{out}}$ represents the outdoor shadowing (log-normal fading), which is characterized by the Gaussian distribution

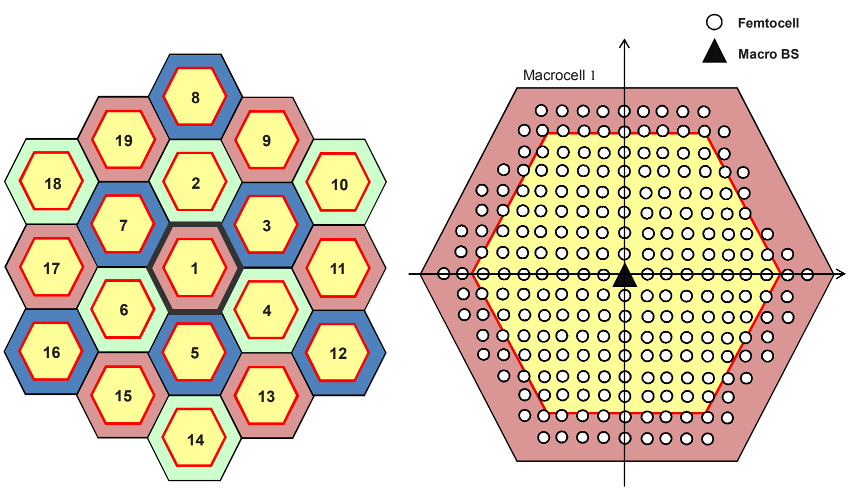

Fig. 3. 2-tier cellular networks and 234 uniformly separated femtocells in a macrocell

Table 1. Modulation and Coding Scheme (MCS) table

SINR	Code rate	Mod.	SINR	Code rate	Mod.
-4.34	1/12	QPSK	6.35	2/3	QPSK
-2.80	1/8	QPSK	9.50	1/2	16QAM
-1.65	1/6	QPSK	12.21	2/3	16QAM
0.31	1/4	QPSK	13.32	1/2	64QAM
1.51	1/3	QPSK	16.79	2/3	64QAM
4.12	1/2	QPSK	20.68	5/6	64QAM

Table 2. Simulation Parameters

Parameter	Value
Inter macro cell distance (ICD)	1000 m
Radius of a femtocell	20 m
FFT size	1024
Total number of data subcarriers in one cell	768
Down-link symbol rate	9.76 k symbols/sec
Total frequency bandwidth in one cell	10 MHz
AWGN power density (N_0)	-174 dBm/Hz
Macro BS power	20 W
Femto BS power	20 mW
Outdoor Log-Normal fading (σ^{out})	10 dB
Indoor Log-Normal fading (σ^{in})	4 dB

with zero mean and standard deviation (σ^{out}). And the modified COST 231-multi wall (MW) model one floor building [7] is employed for indoor propagation,

$$P^{in}_{loss}[dB] = 37 + 3.2 \cdot 10 \log_{10}(d[m]) + \sum_{t=1}^{T} L^t_w n^t_w + \chi_{\sigma^{in}}, \tag{2}$$

where d, T, L^t_w, n^t_w, and $\chi_{\sigma^{in}}$ are the distance between a sender and a receiver, the number of wall types, the wall loss according to wall type t, and the number of penetrated type t walls, and the shadowing, which is characterized by the Gaussian distribution with zero mean and standard deviation (σ^{in}), respectively. We assume each of the buildings with femto BSs has 1 outer (heavy) wall at 10m from the femto BS, L^1_w=15dB, and 1 inner (light) wall at 5m from the femto BS, L^2_w=3dB. We have K data subcarriers and F_i femtocells in macrocell i.

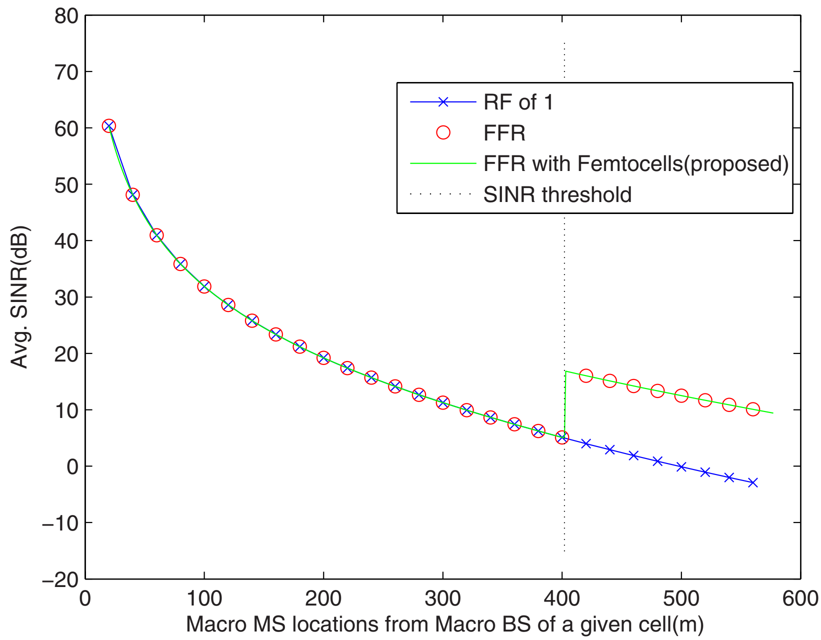

Fig. 4. Average (Avg.) SINR of a macro MS according to the distance from the macro BS in a given cell

The downlink SINR of user l in macrocell $i \in \{1, .., M\}$ on subcarrier $k \in \{1, .., K\}$ is

$$SINR_{l,k}^{(i)} = \frac{P_{l,k}^{(i)}}{\sum_{\eta=1,\ \eta\neq i}^{M} c_k^{\eta} \cdot I_k^{\eta} + \sum_{j=1}^{F_i} c_k^{j} \cdot I_k^{j} + N_0 \Delta f}, \tag{3}$$

where $P_{l,k}^{(i)}$, I_k^{η}, I_k^{j}, and $N_0 \Delta f$ are the received power of user l on subcarrier k in macrocell i, CCI from macrocell $\eta \in \{1, .., M\}$, CCI from femtocell $j \in \{1, .., F_i\}$ in macrocell i, and Additive White Gaussian Noise (AWGN) on a subcareier, respectively. And $c_k \in \{0, 1\}$ is defined as the collision coefficient having the value 1 if subcarrier k is allocated to a specific cell so that it generates CCI to a reference cell, i.e., macrocell i, and 0 otherwise. The downlik SINR of user m on subcarrier k in femtocell j of macrocell i can be found as

$$SINR_{m,k}^{(i,j)} = \frac{P_{m,k}^{(i,j)}}{\sum_{\eta=1}^{M} c_k^{\eta} \cdot I_k^{\eta} + \sum_{\nu=1,\ \nu\neq j}^{F_i} c_k^{\nu} \cdot I_k^{\nu} + N_0 \Delta f}, \tag{4}$$

where $P_{m,k}^{(i,j)}$ and I_k^{ν} are the received power of user m on subcarrier k in femtocell j of macrocell i, CCI from femtocell $\nu \in \{1, .., F_i\}$ in macrocell i, respectively. We adopt

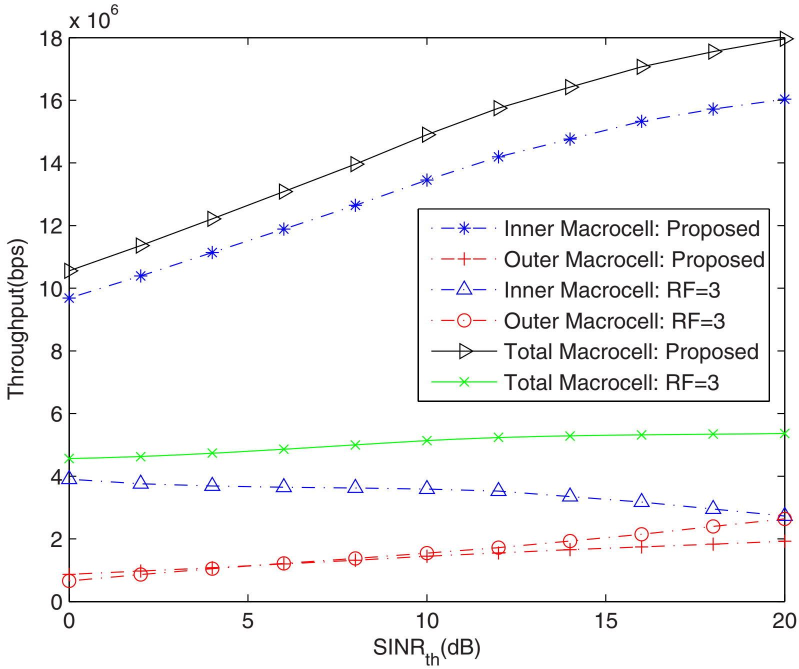

Fig. 5. Downlink throughput of a macrocell according to different SINR thresholds

Modulation and Coding Scheme (MCS) in Table 1 [8] and use simulation parameters in Table 2. The simplified proportional fairness allocation algorithm with the same power for subcarriers is considered in [9] to allocate subcarriers.

We present the average (Avg.) SINR variation of a macro MS in Fig. 4 as it moves on the x-axis from the center to the border when the macro BS is positioned at (x, y)=(0,0). We consider the case where all macrocells use the same frequency band without femtocells, i.e., frequency RF of 1. In this case, we observe the Avg. SINR of a macro MS at the cell edge is relatively low as we expect. On the other hand, the basic FFR scheme without femtocells, shows that the Avg. SINR of a macro MS at the cell edge is greater than that of the RF of 1 due to CCI avoidance from tier-1 cells. We set the SINR threshold 5dB as the criterion to distinguish the inner and the outer region. We can observe the Avg. SINR of a macro MS with 234 femtocells is similar to that without femtocells. In the inner region there does not exist any effect of the deployment of femtocells at all because the inner femto BSs and the macro BS operate at different time slots. The outer femto BSs with co-channel operation do not interfere with the macro MSs much due to their low transmission power, high attenuation by long distance, and wall-losses. In the outer region, there is no additional CCI because all femto BSs and the macro BS are served at different frequency bands. We can conclude the performance of macro MSs with the numerous co-existing femtocells is not sacrificed in our proposed mechanism.

In Fig. 5, we evaluate the downlink throughput of a macrocell according to different SINR thresholds when there exist 36 active macro MSs in the cell. We compare ours

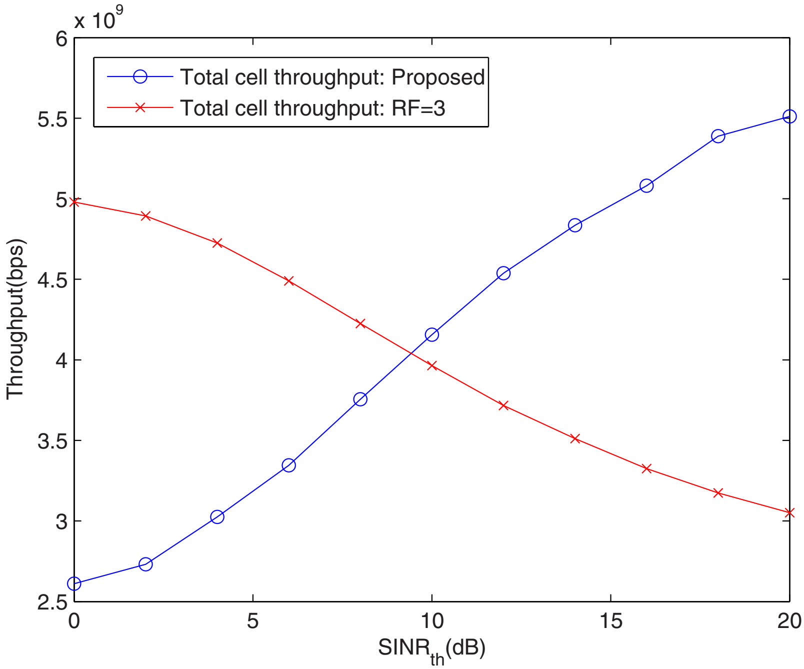

Fig. 6. Total throughput in a given cell area

with the scheme in [2] assuming that the RF of 3 is adopted. Note that the total bandwidth of FFR is much wider than that of the RF of 3 since the inner region adopt the RF of 1 and can use the full bandwidth for the macro MSs. So the throughput performance of macrocell by using FFR is highly enhanced. In our proposal, as the SINR threshold increases, Avg. SINR of the macro MSs in the inner region becomes higher. Thus the spectral efficiency is improved. Moreover, the throughput performance of the macro MSs in the outer region also increases thanks to the alleviation of CCI. However, if the SINR threshold is set to a high value, the frequency resource may be insufficient because many macro MSs may be included in the outer region but the bandwidth for the outer region is limited.

The scheme in [2] serves femtocells and macrocell simultaneously, especially, femtocells in the outer region and the macrocell share the frequency bands but the femtocells in the inner region and the macrocell use different frequency bands. If a macro MS is in an outer femtocell, it may experience high interference from the femto BS due to the co-channel operation. As the SINR threshold increases, the number of outer femtocells which may interfere with the macro MSs in the outer region also increases. This degradation is observed in the inner macrocell: RF=3 in Fig. 5. However, this interference scenario can be avoided in our proposed mechanism because macro MSs and outer femtocells are served by orthogonal frequency bands and time slots.

Fig. 6 shows the total cell throughput for downlink, i.e., the sum of throughput of all macro MSs and femto MSs in a given cell. Total cell throughput depends on the throughput of femto MSs because femtocells are densely deployed and the spectral efficiency of femto MSs are much higher than that of macro MSs. We observe a trade-off in Fig. 5 as the SINR threshold varies. In our proposed mechanism, a femtocell in the outer region can use wider frequency band and longer time slots than a femtocell in the inner region while in the scheme in [2] with the RF of 3 a femtocell in the inner region use wider frequency bands than a femtocell in the outer region. The distribution of inner and outer femtocells is determined by the SINR threshold and the total cell throughput is shown to vary by the degree of distribution of femtocells.

4 Conclusion

In this paper, we have proposed a novel frequency planning for femtocells in OFDMA-based cellular networks using FFR. FFR scheme is an efficient method not only to enhance performance of edge users in a given cell but also to increase the spectral efficiency by adopting the mixture of reuse factors according to different region in a cell. Moreover, the basic rule of FFR, i.e., co-channel operation in low CCI or orthogonal channel operation in high CCI, is considered as a useful policy for frequency planning of femtocells when they are deployed in pre-existing macrocells. There may exist some difficulties and risks in sharing frequency among macrocells and femtocells, which cause performance degradation of macro MSs resulting from the effect of the deployment of femtocells. So we utilize unused frequency band in a given macrocell to inner femtocells for specific time slots in order to harmoniously serve macrocells and femtocells by maximizing diversity gains.

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