Alleviating Interference through Cognitive Radio for LTE-Advanced Network

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ABSTRACT

In the LTE-Advanced network, some femtocells are deployed within a macroecell for improving through put of indoor user equipments (UEs), which are referred to as femtocell UEs (FUEs). Cross-tier interference is an important issue in this deployment, which may significantly impact signal quality between Macrocell Base Stations (MBSs) and Macrocell User Equipments (MUEs), especially for MUEs near the femtocell. To relieve this problem, the Third Generation Partnership Project Long Term Evolution-Advanced (3GPP LTE-Advanced) defined the cognitive radio enhanced femtocell to coordinate interference for LTE-Advanced Network. Cognitive radio femtocells have the ability to sense radio environment to obtain radio parameters. In this paper, we investigated the performance of existing schemes based on fractional frequency reuse. Therefore, we proposed ascheme with cognitive radio technology to improve the performance of fractional fre-quency reuse scheme. Simulation results showed that our scheme can effectively enhance average downlink throughput of FUEs as well as the total downlink throughput in LTE-Advanced Networks.

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1. INTRODUCTION

In order to accommodate the rapid growth of wireless traffic, it is essential to improve thecapacity of current cellular networks for providing higher data rates and better qualityof service (QoS). Thus, the fourth generation (4G) moblie network use a promising modulation technology, it said that Orthogonal Frequency Division Multiplex (OFDM). The 4G mobile communication systems, including the Third Generation Partnership Project Long Term Evolution-Advanced (3GPP LTE-Advanced) [2] and IEEE 802.16m [3]. OFDM technology splited a high-rate data stream into several lower rate parallel streams that are transmitted simultaneously over a large number of orthogonal subcarriers. Because of its orthogonality feature, the intra-cell interferencecan be avoided.

The macrocell user equipment (MUE) far from macrocell base station (MBS) incurred poor indoor capacity in cellular networks, because the MUE suffered from higher power degradation (i.e., the path loss and penetration loss of walls are significant). Although deploying more macrocells seems to solve this problem, the problem could not be actually solved due to the extra interference introduced by these new base stations (BSs). Furthermore, the cost is also other critical concern to the operator. The deployment and operating expenses of femtocell are much lower than that of macrocells. To solve this problem, 3GPP proposed a small cell, called Femtocell. The femtocell with a low power, short range, and low cost base station. Due to short range, the femtocell user equipment (FUE) could notinterfered by FUEs in other femtocell. The same channel could be efficiently reused for multiple times by different femtocells. Therefore, femtocells could efficiently improve indoor coverage and enhance the capacity of cellular networks.

Femtocell networks are seen as end-user hotspots positioned under planned macrocell networks and operated in macrocellular provider's licensed spectrum [4, 5]. The femtocell base station connected to core network through cable or digital subscriber line (DSL) backhaul. The femtocell base station was a plug-and-play device and could be deployed by some subscribers. With this, heterogeneous networks (HetNets) was formed. Interference existed when two UEs used a common frequency resources in cells. Figure 1 illustrates a HetNet where a macrocell was overlaid with two femtocells. In this HetNet, interference could be classified into three types:Femtocell to Femtocell interference (Figure 1 (1)), Macrocell to Femtocell interference (Figure 1 (3) and (5)), and Femtocell to Macrocell interference (Figure 1 (2) and (4)). The first type of interference was co-tier interference, which occured between neighboring femtocells. It was usually neglected due to low transmit power and the penetration loss of walls. The other two types of interference were cross-tier interference, which could severely degraded the capacity of HetNets. The distance between an MUE and an MBS were usually larger than that of a MUE and afemtocell base station (FBS), so the MUE could be interfered form femtocells. The cross-tier interference was a important issue in HetNets. In this paper, we mainly focus on the interference mitigation for cross-tier interference.

Many solutions have been proposed for the interference mitigation schemesin recent years [6, 7]. In strict fractional frequency reuse (St FFR) scheme, each macrocell only used a half band. On the other hand, in other fractional frequency reuse (i.e. So FFR, and FFR-3), each femtocell used insufficient subbands. The above schemes may severely degraded the capacity of HetNets. To slove this problem, this paper proposed a resource management scheme for FUEs. The FBS was designed to have the capability to self-organize. Cognitive radio (CR) was an effective technique to provide the capability of self-organization. CR-enhanced femtocells could obtain the information of macrocells by spectrum sensing and access the channels without cooperating with macrocells [8, 9, 10]. In this way, femtocells could use subbands efficiently.

The rest of the paper was organized as follows. In Section II, the Related work was presented. In Section III, we presented details of our proposed scheme to handle interference. Simulation results were presented in Section IV to evaluated system performance of our proposed scheme. Finally, Section V concluded this paper.

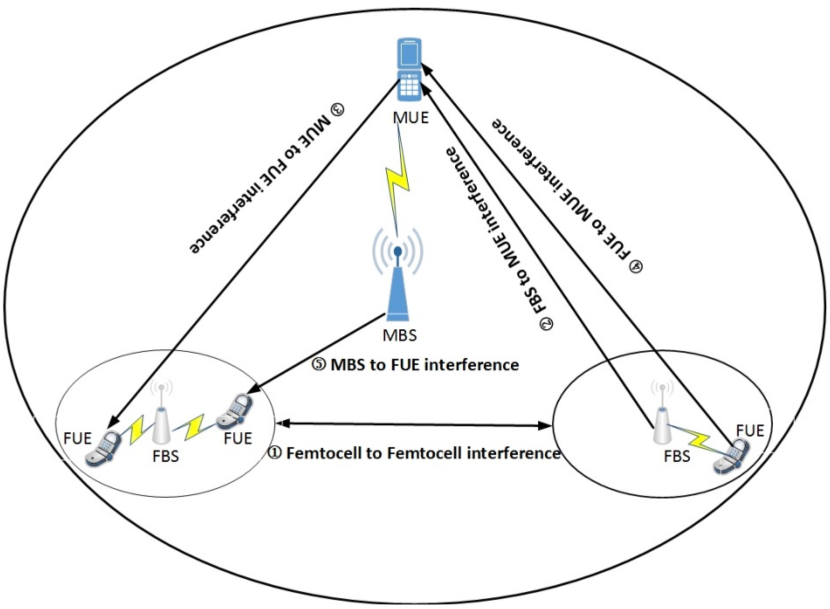

Figure 1. Interference scenario of Heterogeneous network

2. RELATED WORKS

In this chapter, we introduce popular fractional frequency reuse schemes [8] [6] [12]. Then we introduce a cognitiveradio technology in my literature.

2.1. Traditional Frequency Planning

In the traditional frequency planning scheme, the MUEs and FUEs can use entire spectrum in each cell. MUEs and FUEs can use entire spectrum without any inter-cell interference coordination schemes, so this scheme is alsocalled No ICIC scheme. This simple frequency planning scheme maximizes the total cellular network capacity and spectrum utilization, but fails to guarantee the MUEs' performance surrounding femtocells. (e.g., when the MUEs use the same PRB with FUE surrounding femtocells)

2.2. Fractional Frequency Reuse

2.2.1 Strict Fractional Frequency Reuse (St FFR)

In Strict Fractional Frequency Reuse (St FFR), a macrocell is partitioned intocell-center and cell-edge according to Reference Signal Receiving Power (RSRP) reported by MUE periodically. An RSRP threshold is dened for cell-center. IfRSRPreported by the MUEs are higher the RSRP threshold, the MBS considers that theMUEs belong to the cell-center.Others MUEs are considered as cell-edge MUEs. The available frequencyband is partitioned into 4 subbands. Because the cell-center MUEs are not interferedby any other cell-center MUEs, the cell-center MUEs use the common subband. Onthe other hand, the cell-edge MUEs are close to other cell-edge MUEs. In this case, thecell-edge MUEs should ues the dierentsubbands in diernetmacrocell. To mitigatecross-tier interference, FBSs located in the cell-center choose subbands assigned to the MUEs in the cell-edge, and vice versa. For such a subband allocation, the cross-tier interference is eectively mitigated.

2.2.2 Soft Fractional Frequency Reuse (So FFR)

The cell partitioning technique of this scheme is similar to that of the St FFR.However, the cell-center MUEs of any macrocellisallowed to use the subbands of cell-edge MUEs of neighboring cells within the cluster. For a cluster of 3 macrocells, the total available band is divided into 3 subbands. Three sub-band assignedto the three cell-edge to avoid interference between macrocells. The cell-center MUEsof any macrocell choose the subbands of cell-edge MUEs of neighboring cells withinthe cluster. To mitigate cross-tier interference, FBSs located in the cell-center needto choose the subbands that are assigning to the MUE in the cell-edge, and vice versa. In this scheme, the FUEs in macrocell cell-center suffer from cross-tier interference. Therefore, the SINR of the FUE in macrocell cell-center is lower than that of the FUEin macrocell cell-edge. Because the distance between the FUE and the serving FBS is shorter than the distance between the FUE and the MBS, the SINR of the FUE inmacrocell cell-center is acceptable.

2.2.3 Fractional Frequency Reuse-3 (FFR-3)

In this scheme, the macrocell coverage is partitoned into cell-centerand cell-edge, including three sectors each. The entire frequency is divided intofour sub-bands Onesubbands is assigned to MUE in the cell-center, while the others are assigned to MUE in cell-edge. To diminishcross-tier interference, FBSs choose subbands that are not uesd by the MUEs in thesame macrocell subarea. For example, when a FBS is located in a subarea, it wouldonly use subband A, B, and D and exclude subband C since subband C is used bythe MUEs in this subarea. Compared with So FFR, the FUEs in macrocell cell-centerwould not suffer from cross-tier interference since the MUEs in cell-edge and the FUEs in macrocell cell-center are notusing the same subband.

2.3 Cognitive Radio

Cognitive radio has been considered as a key technology for interference mitigationin future mobile network. Cognitive radio is an intelligent radio that is aware of its surrounding environment, which senses useful information from the environments withuser's channel characterization. Then, BSs analyze it and adjust the system parameters conforming to certain policies and regulations. In this paper, we consider that FBS shave three abilities: radio environments sense, radio environments analyzation, andsystem parameter adjustment. These three abilities are described in the following threesubsections.

2.3.1 Radio Environments Sense

FBS can sense some downlink reference signals to monitor the downlink trans-mission. Among these downlink reference signals, the Reference Signal Receive Power (RSRP) is most important for resource management and interference mitigation. TheRSRP is the average power of RE that carry cell-specific Reference Signals (CRS) overthe entire bandwidth. The CRS are predned signals occupying specific resource ele-ments for channel estimation. The CRS transmitted in every downlink subframe and in every resource block in the frequency domain, thus covering the entire cell band-width. The RSRP provides information about signal strength that implies the distance between receiver and transmitter.

2.3.2 Radio Environments Analyzation

After FBS senses radio environments, FBS can obtain useful information from its surrounding cells. Then, FBS analyzes these informations to obtain parameters thatcan be used in resource allocation scheme. In [4], the authors proposed a non-cooperative path loss estimation method. The FUEs independently estimate the path loss between itself and MUEs in hierarchical network. The basic idea is that the FUE senses the broadcasting signal from theMBS, and demodulates the channel assignment information and adaptive modulationand coding (AMC) settings for the MUE. Adaptive modulation and coding is a keytechnology for channel quality maintenance. AMC provides the exibility to matchthe modulation-coding scheme to the average channel conditions for each user. ThisAMC is used to construct modulation and coding scheme (MCS). The MCS containsthe path loss between MBS and MUE information. For example, the small path lossleads to higher signal-to-interference-plus-noise ratio (SINR), and vice versa. The MCScan be mapping to path loss, although MCS selection may also be affected by someother factors (e.g., fading, shadowing, noise, and sometimes interference). The MUE's transmit power can be estimated from the MCS information by SINR formula, while FUE can sense received power from MUEs directly. In this way, the FUE can estimatethe value of the path loss between FUEs and MUEs.

2.3.3 System Parameter Adjustment

In order to improve cellular network capacity, BS has to adjust cellular network system parameters (ie., FBS transmit power, UE transmit power, and RB schedule) eciently. After BS senses radio environments and analyze it, BS obtains useful pa-rameters about radio environments. For example, in [4], the FBS obtains the path lossbetween the FBS and interfered MUEs, so the FBS can schedule unoccupied RB byMUEs to FUEs or adjust its transmit power to diminish cross-tier interference. FBSscan adjust these parameters periodically to optimize the HeNet.

3. SYSTEM MODEL

The system model of our scheme is illustrated in Figure 2, including illustrate a hierarchical network with our proposed scheme deployment and a macrocell with our proposed scheme deployment.The system model contained seven MBSs with three 120° directional transmit antennas at the center of each cell respectively, as shown in Figure 3. A Reference Signal Recieved Power (RSRP) [11] is defined for cell-centerin every cell. If RSRP reported by the MUEs are higher RSRP threshold, the MBS considered that the MUEs belong to the cell-center. Others MUEs are considered as cell-edge MUEs [4]. In this way, every macrocell coverage is partitioned into cell-center and cell-edge, including three sectors each.

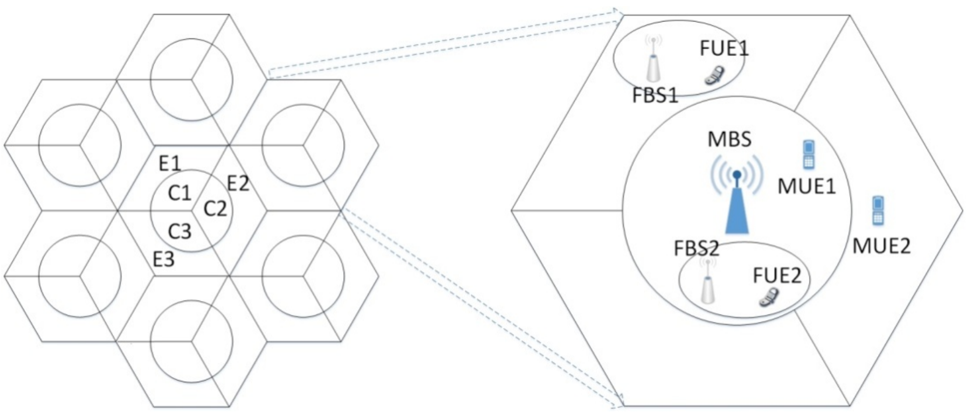

Figure 2. System model

Thirty FBSs are deployed uniformlyin every macrocell. The MUE would suffer from serious cross-tier interference because the MUE is closed to FBSs. Therefore, interference could be considered in the achievable channel capacity of MUE. The achievable channel capacity of MUE could be computed by the Shannon's capacity formula as

$$C^{x} = BW \cdot \log_{10}(1 + SINR^{x}) \quad (1)$$

where C^x indicated the theoretically achievable channel capacity ofMUE x . BW indicated the available bandwidth for communication. $SINR^x$ indicated the signal-to-interference-plus-noise ratio of theMUE x .Thesignal-to-interference-plus-noise ratio of the MUE x can be represented as

$$SINR^x = \frac{P_m \cdot G_{x,m}}{N \cdot \sum_{i=1}^{K} P_i \cdot G_{x,i} + \sum_{j=1}^{L} P_j \cdot G_{x,j}} \quad (2)$$

where P_m indicated the transmiting power of MBS m . $G_{x,m}$ indicated thechannel gain between the MUE x and its serving MBS m . N indicatedthe thermal noise power. P_i indicated the transmit power of interfering MBSs i . K indicatedthe total number of interfering MBSs. L indicated thetotal number of interfering FUEs within the same MBS. P_j indicatedthe transmit power of interfering FBSs j . $G_{x,i}$ indicated the channel gain between the MUE x and interfering MBS i , and $G_{x,j}$ is the channel gain between the MUE x and interfering FBS j . In [8], the authors assumed that no other cell interfers this sensed MUE. Therefore, $\sum_{i=1}^{K} P_i \cdot G_{x,i} + \sum_{j=1}^{L} P_j \cdot G_{x,j}$ canbe ignored.

The achievable channel capacity of FUE can be represented as

$$C^y = BW \cdot \log_{10}(1 + SINR^y) \quad (3)$$

where C^y indicated the theoretically achievable channel capacity of FUE y . $SINR^y$ indicated the signal-to-interference-plus-noise ratio of the FUE y . Thesignal-to-interference-plus-noise ratio of the FUE y can be represented as

$$SINR^y = \frac{P_f \cdot G_{y,f}}{N \cdot \sum_{i=1}^{K} P_i \cdot G_{y,i} + \sum_{j=1}^{L} P_j \cdot G_{y,j}} \quad (4)$$

where P_f indicated the transmit power of FBS f . $G_{y,f}$ indicated the channelgain between the FUE y and its serving FBS f . N indicated thethermal noise power. P_i indicated the transmit power of interfering MBSs i . K indicated the total number of interfering MBSs. L indicated thetotal number of interfering FUEs within the same MBS. P_j is the transmit power of interfering FBSs j . $G_{y,i}$ indicated the channelgain between the FUE y and interfering MBS i ., and $G_{y,j}$ is the channel gain between the FUE y and interfering FBS j .

4. PROPOSED SCHEME

Based on fractional frequency reuse (FFR) scheme, total band were partitioned into several subbands according to the location of every UE. If the resource blocks (RBs) were exhausted in femtocells, femtocells would use other subbands. In this way, MUEs suffered from cross-tier interference. For this reason, the proposed scheme introduced CR-enhanced femtocells to provide RBs lists of cross-tier interference RBs. In our proposed scheme, we defined six sets of RBs:

M : The set of total RBs of a macrocell

M_i : The set of RBs of macrocell subarea according to FFR-3 scheme, where $i \in \{C_1, C_2, C_3, E_1, E_2, E_3\}$. That is, $M = \bigcup_{i \in \{C_1, C_2, C_3, E_1, E_2, E_3\}} M_i$, as shown in Figure 3.

F_j : The set of RBs of femtocell j according to FFR-3 scheme, where is the femtocell sequence number per macrocell.

$F_j^{'}$: The set of RBs of MUE surrounding femtocell

R_j : The set of candidate RBs for femtocell

U : The set of RBs in use

When the RBs were exhausted in a femtocell (i.e., $F_j - U = \phi$), the following procedure was exercised at FBS:

Step1: When $R_j = F_j - U = \phi$, the FBS sensed some downlink reference signals to monitor the downlink transmission. According to the non-cooperative path loss estimation method [8], the FBS obtained useful link parameters. The link parameters included the downlink/uplink channel index and adopt downlink/uplink modulation and coding scheme (MCS) by demodulating broadcasting signal from the MBS. Otherwise, the procedure proceeds to Step 2.

Step2: The femtocell analyzed above parameters according to the non-cooperative path loss estimation method. Then, the FBS obtained the path loss between MUEs and itself. Otherwise, the procedure proceeds to Step 3.

Step3: Obtained R_j from

$$R_j = M - F_j^{'} - U$$

If $R_j \neq \phi$, the femtocell reallocated a RB in R_j to FUE. In Figure 3, $R_j = \{RB1, RB2, RB3, RB4, RB5\} - \{RB1, RB2\} - \{RB4, RB5\} = \{RB3\}$. Therefore, the femtocell reallocated RB3 to FUE3. After the femtocell rellocated RBs, the procedure was terminated. Note that MUE3 and FUE3 used the same RB (i.e., RB3). Beacuse FUE3 was far from MUE3, MUE3 could not sense the downlink signal between FUE3 and its serving FBS. Thus, the cross-tier interference wasmitigated. If it wasunfortunately, $R_j = \phi$, the femtocell could not have any candidate RB for FUE3. That is, no matter which RBs be used by the FUE (i.e., FUE3), other UEs will be interfered. The procedure proceeds to Step 4.

Step4: Obtained R_j from

$$R_j = M - U$$

Then, the FBS should reduce downlink transmit power. In this way, the cross-tier interference is also mitigated.

5. PERFORMANCE EVALUATION

We evaluated system performance of our proposed scheme through simulation. The major simulation parameters are listed in Table 1. We defined cell-center MUE as the MUE with distance to its serving BS less than or equal to 400 meters. Likewise, when the UE is more than 400 meters away from the BS, it is called a cell-edge MUE. The proposed scheme is compared with St FFR, So FFR, FFR-3, and No inter-cell interference coordination (ICIC) schemes. We assume that 1/2 of RBs (i.e., 24 RBs) are allocated to cell-edge MUEs in above FFR schemes.

Figure 3 showed the variation in average FUE’s throughput with varying average number of FUEs per femtocell. When the average number of FUEs every femtocell were more than 10 FUEs, some FUEs waited until some RBs were available. FFR schemes (i.e. St FFR, So FFR, and FFR-3) severely degraded the FUE’s throughput as the average number of FUEs per femtocell increasing. However, our proposed scheme has batter FUE’s throughput when the average number of FUEs per femtocell increasing.

Table 1. Simulation Parameters

Parameters	Assumption
Cell layout	7 cells, 3 sectors/cell
Macrocell radius	600 m
Femtocell radius	30 m
Number of FBS per macrocell	30
Number of MUE	16/sector
Number of FUE per femtocell	15
Dead zone	100 m
UE distribution	Uniform distribution
FBS distribution	Uniform distribution
System bandwidth	10 MHz FDD (48 PRBs)
Traffic model	Full buffer
Outdoor path loss model	$28 + 35 \cdot \log_{10}$(R), R(m)
Indoor path loss model	$38.5 + 20 \cdot \log_{10}$(R)+ L_{wall}, R(m), L_{wall}=15 dB
Thermal noise	-174 dBm/Hz
Shadowing fading variation	8 dB
MBS noise figure	2 dB
Maximum MBS Tx power	43 dBm
Maximum FBS Tx power	23 dBm

Figure 4 showed the cumulative distribution function (CDF) of FUE throughput with five different schemes. This figure showed thatour proposed scheme has batter FUE’s throughput than St FFR, So FFR, and FFR-3. The proposed scheme got the better performance of FUE throughput, because FUE could use more RBs. However, No ICIC scheme had batter throughput than our proposed scheme because FBSs could allocate all RBs without any ICIC schemes. Generally speaking, No ICIC scheme usually had the largest FUE’s throughput (i.e., because FBSs can allocate all RBs without any ICIC schemes). MUEs suffered from strong interference from femtocells, so No ICIC is not fair in a HetNet. Therefore, No ICIC was not practical in HetNets. Our proposed scheme was closed to the FUE’s throughput of No ICIC scheme. In other words, our proposed scheme had better throughput in FUE’s throughput.

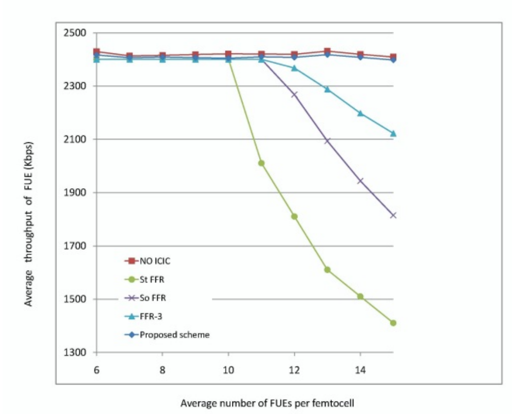

Figure 3. Average FUE throughput (Kbps)

Figure 5 showed the CDF of MUE throughput with different schemes. This figure showed that our proposed scheme has batter MUE’s throughputthan No ICIC, St FFR, and So FFR. In FFR-3, large throughput of MUEs was observed due to throughput with different schemes. Our proposed scheme had the largest total throughput. The throughput of FFR-3 was smaller than No ICIC due to limited spectrum allocation of femtocell. When RBs were exhausted in the femtocell, the FBS did not allocate other RBs that would not caused strong interference to neighbor MUEs. However, the throughput of No ICIC is smaller than our proposed scheme because MUEs suffer from strong interference from neighbor femtocell.

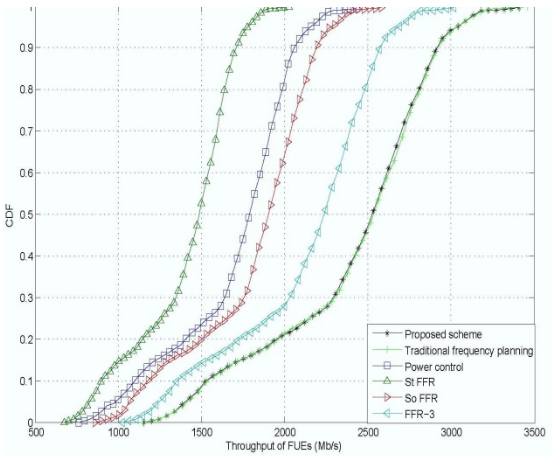

Figure 4. CDF of FUE throughput (Kbps)

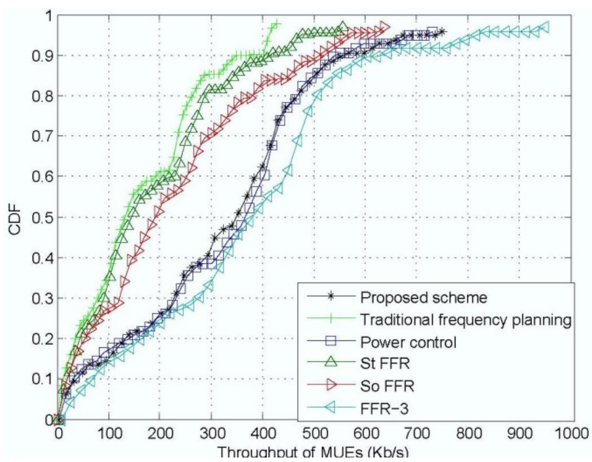

Figure 5. CDF of MUE throughput (Kbps)

Table 2 shows that total throughput with different schemes. Ourproposed scheme has the largest total throughputin this table. The throughput of FFR-3 was smallerthan No ICIC due to limited spectrum allocation of femtocell. When RBs were exhausted32in the femtocell, the FBS did not allocate other RBs that would not caused strong interference to neighbor MUEs. However, the throughput of No ICIC is smaller thanour proposed scheme because MUEs suffered fromserious interference from neighboring femtocell.

Table 2. Total Throughput

Scheme	Total UE throughput (Mbps)
St FFR	642.57
So FFR	828.68
FFR-3	972.28
No ICIC	1091.49
Proposed scheme	1094.93

6. CONCLUSION

In this paper, we proposed a novel scheme for downlink ICIC in LTE-advanced networks. To alleviate interference, we used cognitive radio techniques to sense radio environment and adjust RB allocation. In our proposed scheme, we sacrificed a little MUE's throughput (i.e., 4.8%) for femtocell. For a femtocell, the more RBs could be used. The FUE's throughput was thus improved (i.e., 13.1%). Simulation results showed that our proposed scheme can achieve better total throughput compared with other ICIC schemes.

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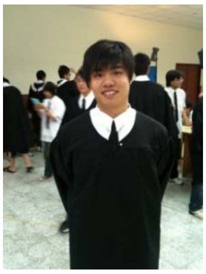

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