Frequency and Time Resource Allocation for Enhanced Interference Management in a Heterogeneous Network based on the LTE-Advanced

Sangmi Moon[1], Bora Kim[1], Saransh Malik[1], Cheolsung Kim[1], Youngil Kim[2], Kunmin Yeo[2] and Intae Hwang[1]
1) Department of Electronics and Computer Engineering,
Chonnam National University,
Gwangju, Republic of Korea,
msm0804@naver.com, bora54321@naver.com, saranshmk@gmail.com, chskim@chonnam.ac.kr and hit@chonnam.ac.kr
2) Electronics and Telecommunications Research Institute,
Daejeon, Republic of Korea,
yikim@etri.re.kr and kunmin@etri.re.kr

***Abstract*— In this paper, we propose a resource allocation scheme in the frequency and time domain, to reduce interference in the Heterogeneous Network (HetNet) scenario. In the frequency domain, the macrocell allocates frequency band by using Soft Frequency Reuse (SFR), and the picocell chooses sub-bands that are not used in the macrocell sector, to avoid interference. In addition, to allocate the limited frequency resource is difficult. Therefore, we can manage the cross-tier interference using Almost Blank Subframe (ABS) in the time domain. Simulation results show that the proposed scheme can improve Signal to Interference plus Noise Ratio (SINR), and the spectrum efficiency of macrocell and picocell users. Eventually, the proposed scheme can improve overall cell performance.**

Keywords- ABS; HetNet; Interference; Picocell; SFR

I. INTRODUCTION

Recently, small cells have been developed to gain cell subdivision, according to trends of the increase of data rate and bandwidth. Also, cells of hot zone form, such as the picocell, developed in specific areas, are becoming common for offloading explosion data traffic.

Picocells are low-power operator-installed cell towers, with the same backhaul and access features as macrocells. They are usually deployed in a centralized way, serving few users within a radio range of 300m or less, with a typical transmit power range of 23 to 30 dBm. Picocells are mainly utilized for capacity, and also for outdoor/indoor coverage infill with insufficient macro penetration (e.g. office buildings).

A network consisting of small cells, such as the low-cost, low-power picocell over the marcocell, is called a HetNet.

Interference between neighboring picocells and between picocell and macrocell occurs under the HetNet scenario. In general, the two types of interference are as follows [1]:

(a) Co-tier interference: This type of interference occurs among network elements that belong to the same tier in the network. In the case of a picocell network, co-tier interference occurs between neighboring picocells.

(b) Cross-tier interference: This type of interference occurs among network elements that belong to different tiers of the network, i.e. interference between picocells and macrocells as depicted in Figure 1. For example, when a terminal accessed picocell is located in an edge area of a picocell, access from the picocell can be disconnected, due to interference from the macrocell. This means that the picocell coverage is less than the expectation of the operators [2].

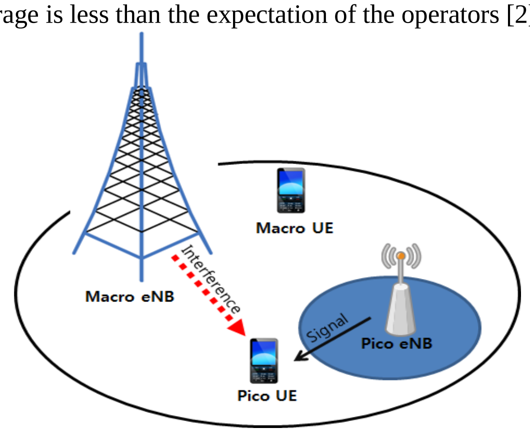

Figure 1. Cross-tier interference in HetNet.

Conventional radio resource management techniques are not suitable for HetNet. Thus, it is essential to adopt an effective and robust interference management scheme that could mitigate the co-tier interference, and reduce the cross-tier interference considerably, in order to enhance the throughput of the overall network.

In this paper, we propose not only co-tier interference management, but also cross-tier interference management for the HetNet scenario. Resource allocation is done by SFR and ABS, to manage the interference in the frequency and time domain, respectively.

The rest of the paper is organized as follows: conventional related work is explained in Section II, Section III shows the proposed scheme, and Section IV shows a performance analysis of the proposed scheme through simulation. Finally, we conclude the results in Section V.

II. CONVENTIONAL RELATED WORK

Long Term Evolution (LTE) - Advanced has developed a low-power, low-cost picocell to reduce the traffic load of the base station. However, there are many problems, such as the

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transmission rate, and transmission quality degradation due to interference between macrocell and picocell using the same frequency, in a HetNet scenario deploying picocells over the macrocell.

The 3rd Generation Partnership Project (3GPP) has discussed Interference control technology in an LTE-Advanced system. 3GPP with its REL-8/9 supports Fractional Frequency Reuse (FFR) and Relative Narrowband Transmission Power (RNTP) for interference control. Both of these methods are to reduce the interference level, by adjusting the level of signal that is transmitted through a certain frequency resource. However, picocells are deployed over the existing macrocell network, and share the same frequency spectrum. Due to spectrum scarcity, to eliminate interference is limited in the frequency domain. Therefore, REL-10/11 has introduced the Cooperative Silencing scheme, using ABS in the time domain for interference control [3]. Interference management has been actively discussed in the time domain. Time-Domain Resource Partitioning was proposed [4]. This determines users protected by ABS, and then finds the optimal amount of ABS, by evaluating the overall system utility.

Also, Enhanced Dynamic Spectrum Sharing (EDSS) was proposed for interference management in the picocell. This combines the DSS with FFR for the HetNet scenario. According to the principle of DSS, and the fact that the coverage area of the macro center area (which can be efficiently controlled, by adjusting the transmitting power of the macro system) has no overlap with the coverage area of cell-edge Pico cells. The cell-edge Pico cells can use not only the whole spectrum in the macro cell uplink environment, but also the spectrum in the macro center area downlink environment, while central Pico cells can just use the spectrum in the macro cell uplink environment in TDD mode [5].

FFR allocates resource in the frequency domain for interference management. In addition, SFR is one of the solutions to reduce inter-cell interference in the Orthogonal Frequency Division Multiple Access (OFDMA) based macro system. In FFR, each cell turns off the transmission power of the subband using a Frequency Reuse Factor of 3, but in the case of SFR, this factor can increase the overall system efficiency, by transmitting with a reduced transmission power. Under this condition, cross-tier interference that occurs due to the development of the picocell can be minimized. Additionally, ABS can be applied, for interference management in the time domain. Therefore, we focus on the interference management between the macrocell and the picocell, by allocating resource in the frequency and time domains.

III. THE PROPOSED SCHEME

In this section, we propose a new scheme that allocates resource in the frequency and time domain. In the frequency domain, resource is allocated based on SFR. Additionally, resource is allocated based on ABS in the time domain.

A. Frequency Domain

We allocate the frequency band into macrocell and picocell, based on SFR for intercell interference management, as depicted in Figure 2 (a). The macrocell coverage is divided into a center zone and edge region, each of which include three sectors, denoted by C1, C2, and C3, and E1, E2, and E3. The whole frequency band is partitioned into three parts, denoted by A, B, and C.

For the macrocell, a different frequency sub-band is allocated to each macrocell sub-area, according to the SFR. A reuse factor of one is applied in the center zone, while the edge region adopts a factor of three. The entire frequency bands are used in the center zone (C1, C2 and C3), and sub-bands A, B and C are applied in the E1, E2 and E3 regions, respectively. Also, the overall system efficiency is increased, by reducing the transmission power in the center zone of the macrocell, as illustrated in Figure 2 (b).

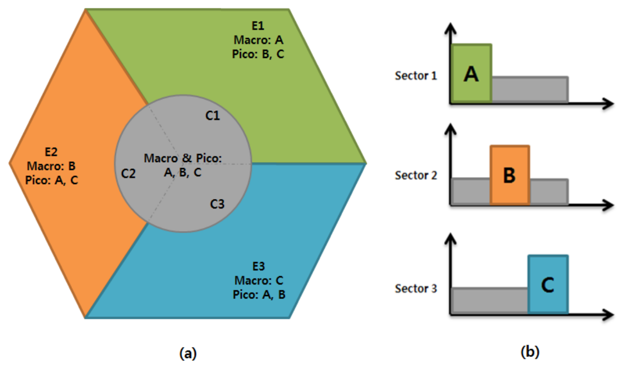

Figure 2. The proposed interference management scheme using SFR in the frequency domain: (a) frequency planning , and (b) power allocation.

Under this circumstance, the picocell chooses sub-bands that are not used in the macrocell sub-area. For example, when a picocell is located in the region E1, it uses sub-bands B and C, while the macrocell uses sub-band A. However, when a picocell is located in the center zone, it uses the entire frequency band, because when a macrocell is located in the center zone, it uses the entire frequency band.

B. Time Domain

When a picocell is located in the center zone of a macrocell, it uses the entire frequency band. The interference problem between the macrocell and picocell still exists. Therefore, we solve the cross-tier interference, by applying the ABS in the time domain.

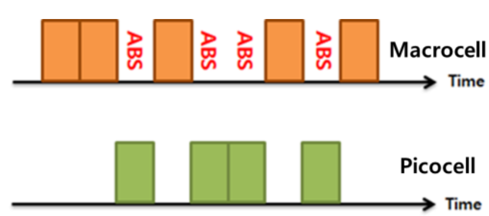

Figure 3. The proposed interference management scheme, using ABS in the time domain.

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The aggressor macrocell uses ABS, which doesn't transmit a signal during some subframe for the victim pico user, as depicted in Figure 3. Therefore, the picocell can avoid interference, by transmitting a signal during the ABS of the macrocell.

IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

A. Simulation Model and Simulation Parameters

The simulation results are based on 3GPP LTE-Advanced system level simulation parameters [6]. The overall network is composed of 7 macrocells, and picocells are randomly deployed over the macrocells. The number of picocells is 3 in one macrocell coverage. The main simulation parameters are listed in Table I.

TABLE I. SIMULATION PARAMETERS.

Parameter	Value	
	Macrocell	***Picocell***
Number of Cells	7	3/Macro
Cell Coverage	Radius 1km (ISD = 1,732m)	Radius 250m
Channel Bandwidth	10MHz	
BS Transmit Power	46dBm	30dBm
Number of Users	30	6
Size of Center zone	0.63 of macrocell coverage	
White Noise Power Density	-174 dBm/Hz	
Path Loss	L = 128.1 + 37.6logR (R in km)	L = 140.7 + 37.6logR (R in km)

B. Problem Fomulations

To demonstrate the improvement of Quality of Service (QoS) for users, it is necessary to obtain the Signal to Interference plus Noise Ratio (SINR) of these users. In our simulation, the received SINR of a macro user *m* on sub-carrier *k* can be expressed by the following definition:

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

where, $P_{M,k}$ and $P_{M',k}$ are the transmit powers of serving macrocell *M* and neighbor macrocell *M'* on sub-carrier *k*, respectively. $G_{m,M,k}$ is the channel gain between macro user *m* and serving macrocell *M* on sub-carrier *k*. Channel gains from neighboring macrocells are denoted by $G_{m,M',k}$. Similarly, $P_{P,k}$ is the transmit power of the neighboring picocell *P* on sub-carrier *k*. $G_{m,P,k}$ is the channel gain between macro user *m* and the neighboring picocell *P* on sub-carrier *k*. N_0 is the white noise power spectral density.

In the case of a picocell user, it is interfered from macrocells and the adjacent picocell. The received SINR of a pico user *p* on sub-carrier *k* can be similarly given by

$$SINR_{p,k}= \frac{P_{P,k}G_{p,P,k}}{N_0+\sum_{M'}(P_{M,k}G_{p,M,k})+\sum_P(P_{P',k}G_{p,P',k})} \quad (2)$$

where, $P_{P,k}$ and $P_{P',k}$ are the transmit powers of the serving picocell *P* and neighboring picocell *P'* on sub-carrier *k*, respectively. $G_{p,P,k}$ is the channel gain between pico user *m* and serving picocell *P* on sub-carrier *k*. The channel gains from neighboring picocells are denoted by $G_{p,P',k}$. Similarly, $P_{M,k}$ is the transmit power of neighboring macrocell M on sub-carrier *k*. $G_{p,M,k}$ is the channel gain between pico user p and neighboring macrocell *M* on sub-carrier *k*. N_0 is the white noise power spectral density.

Also, capacity of the MUE *m* in macrocell *M* and the PUE *p* in picocell *P* can be expressed by equation (3) and (4), respectively.

$$C_{m,M} = \sum_{k=0}^{N_{RB}} \frac{BW}{N_{RB}} log_2 (1 + SINR_{m,k}) \quad (3)$$

$$C_{p,P} = \sum_{k=0}^{N_{RB}} \frac{BW}{N_{RB}} log_2 (1 + SINR_{p,k}) \quad (4)$$

where, BW is the system bandwidth, and N_{RB} is the number of the resource block that assigned the user.

C. Performance Analysis of Proposed Scheme

The proposed scheme is compared with several comparison schemes, as follows. In the No ICIC(Inter-cell Interference Coordination) scheme, both macro and pico users are randomly assigned the resource in time and frequency domain. Also, SFR is the proposed scheme that assigns the resource using only SFR in the frequency domain, and ABS with SFR is the proposed scheme that assigns the resource using SFR and ABS in the frequency and time domain, respectively.

1) Performance Analysis of SINR

Figure 4 shows the Cumulative Distribution Function (CDF) of macro user SINR. In the case of the proposed scheme applying only SFR, co-tier interference between the macrocells is reduced. Also, cross-tier interference between the macrocell and picocell is reduced, because users of picocell located in the macrocell edge use a sub-carrier that is not used by a macrocell in that area. Therefore, the reduction of interference of the cell edge brings improved SINR performance.

The picocell transmits signal with low power. So, a macrocell is less affected by interference. If the center of the macrocell is applied with ABS as well as SFR, the proposed ABS with SFR scheme brings only a slight performance improvement over the scheme applied with only SFR, because the user of the picocell located in the center uses ABS time, which is not used by a macrocell in that area. Otherwise, the sub-carriers are randomly assigned to the macro and pico users. If the same sub-carrier can be used by an edge user in a different cell, co-tier interference occurs. Also, cross-tier interference between the macro user and pico users occurs, when the same sub-carrier can be used by the macro user and pico users who are very close to each other.

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Therefore, the No ICIC scheme does not bring SINR performance improvement, because not only co-tier interference, but also cross-tier interference is higher than the proposed scheme.

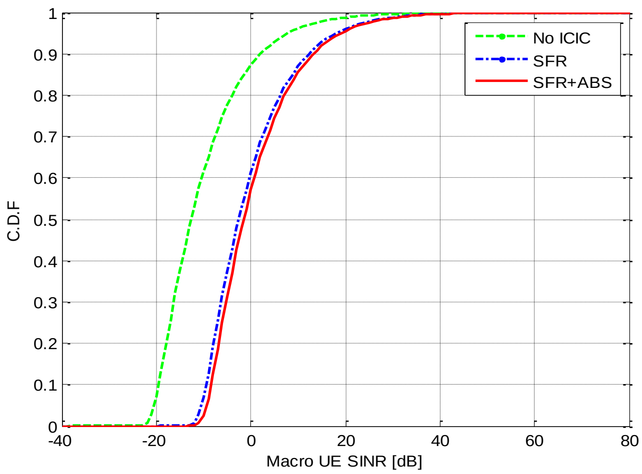

Figure 4. CDF of the Macro User SINR.

Figure 5 shows the CDF of the pico user SINR. It can be seen that the SINR performance of the pico user is similar to the SINR performance of the macro user, and is improved in the following order: No ICIC, SFR, and ABS with SFR.

But, the proposed ABS with SFR scheme brings significant performance improvement, compared with the macro user. The reason can be found from Section III. For SFR, performance of the cell edge is improved. Also, with the reduction of cross-tier interference from the macrocell using ABS, SINR performance is improved correspondingly in the center area.

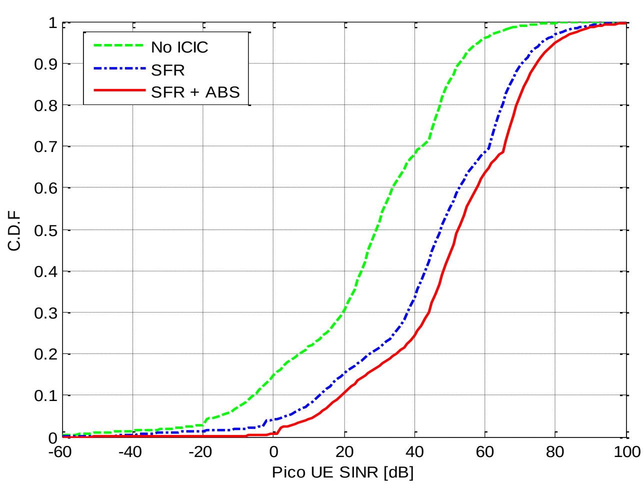

Figure 5. CDF of the Pico User SINR.

Figure 6 shows the CDF of the total user combined macro user and pico user. Simulation results show that the proposed scheme improves the total user SINR.

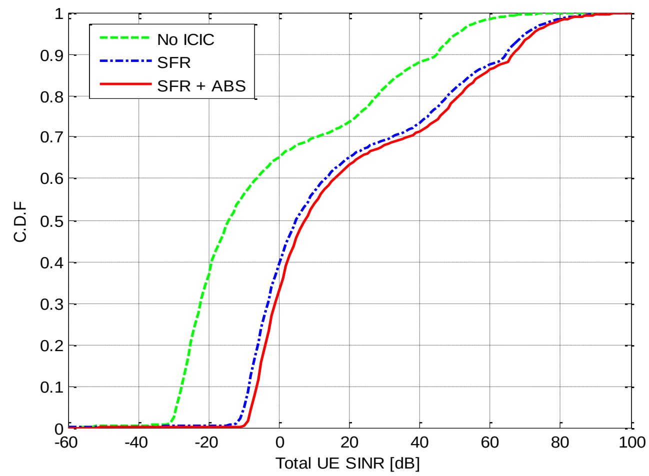

Figure 6. CDF of the Total User SINR.

2) Performance Analysis of the Spectrum Efficiency

We also evaluated the proposed scheme in terms of spectrum efficiency. Figure 7 and Figure 8 show the CDF of the macro user and pico user spectrum efficiency, respectively, and Figure 9 shows the total user spectrum efficiency.

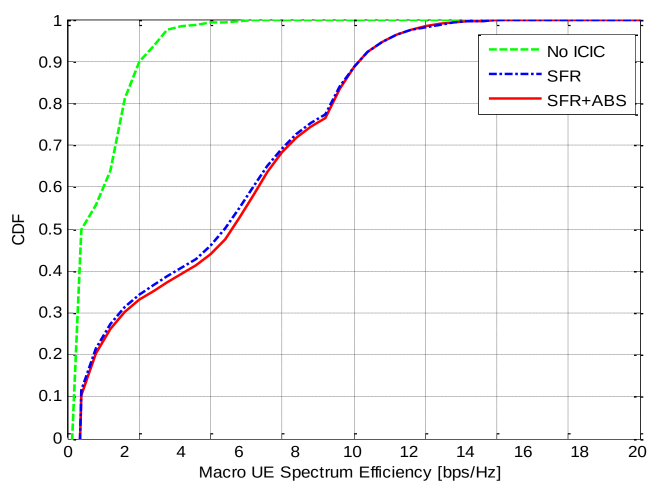

Figure 7. CDF of the Macro User Spectrum Efficiency.

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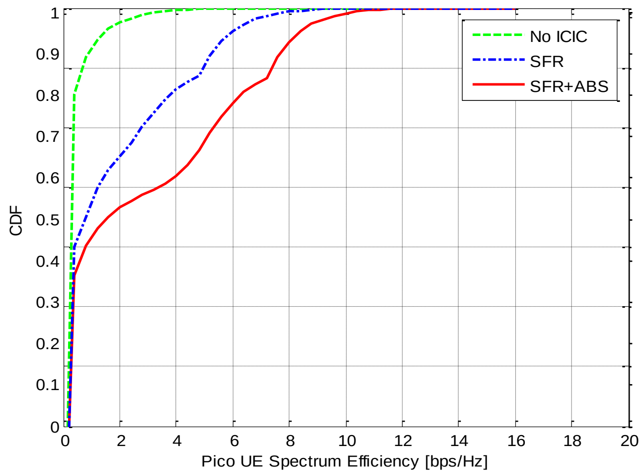

Figure 8. CDF of the Pico User Spectrum Efficiency.

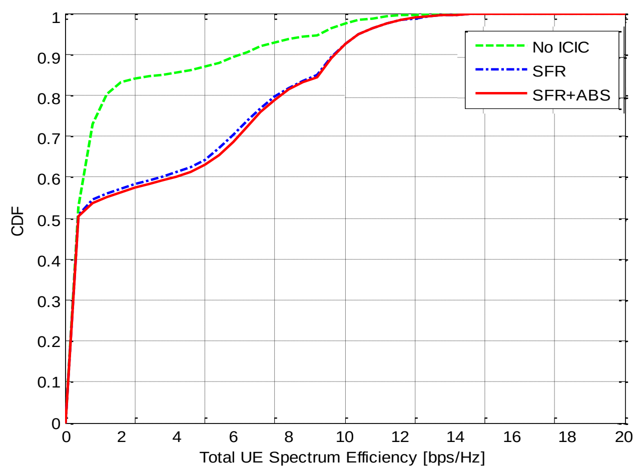

Figure 9. CDF of the Total User Spectrum Efficiency.

It can be seen that the spectrum efficiency is improved in the following order: No ICIC, SFR, and ABS with SFR.

V. CONCLUSIONS

We propose an interference management scheme for the HetNet scenario with coexisting macrocell and picocell, by allocating resource in the frequency and time domains. In the frequency domain, under the macrocell allocating frequency band by the SFR, the picocell chooses sub-bands that are not used in the macrocell sector, to avoid interference. In addition, to allocate the limited frequency resource is difficult. Therefore, we can manage the cross-tier interference, using ABS in the time domain. Simulation results demonstrate that the proposed scheme can improve the performance, in terms of SINR and spectrum efficiency.

We expect that the proposed scheme configures a more efficient cellular environment based on LTE-Advanced, due to the improvement of performance. Also, this improve the overall cell performance in the HetNet scenario, for the next generation wireless communication environment.

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