Cell Range Expansion and Time Partitioning for Enhanced Inter-Cell Interference Coordination in Heterogeneous Network

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Abstract

In this paper, we propose a cell selection scheme and interference management scheme in Heterogeneous Network (HetNet). The cell selection scheme is based on the SINR, and the cell expansion range can vary through the offset value. We can manage the interference between the macrocell and picocell, using ABS in the time domain. Also, a flexible ABS density is applied, to increase the spectrum efficiency. We show the simulation results of the selection scheme based on SINR with different offset values (6dB, 12dB) and the interference management scheme. Simulation results show that the proposed scheme can improve the user spectrum efficiency of the macrocell and picocell user. Eventually, the proposed scheme can improve overall user performance.

1. Introduction

Recently, mobile telecommunication service for voice communication on telecommunication networks is progressing to service for data based on wireless multimedia contents. In consequence, the data traffic demand in cellular networks today is increasing at an exponential rate.

As the point-to-point link spectral efficiency based on the macrocell is approaching its fundamental limits, further improvements in system spectral efficiency are possible, by increasing the node deployment density. However, in dense deployments today, cell splitting gains are significantly reduced, due to severe inter-cell interference.

In order to overcome these issues, HetNet has been introduced in the LTE-Advanced standardization. HetNet consists of a mix of macrocells and low-power nodes, such as picocells, femtocells, and relays, in order to bring the network closer to end users. Among the low-power nodes, the introduction of picocells is important, in order to efficiently accommodate high volume traffic in local areas, i.e. hotspots, and enhance the overall system capacity [1].

Despite the significant network performance leap expected from deploying picocells, there are numerous challenging technical problems that need to be overcome. One of these major problems is interference management between the macrocell and picocell. Cross-tier interference problems are significantly challenging in co-channel HetNet deployment. For example, the User Equipment (UE) connected to the picocell through CRE suffers severe interference from an aggressor macrocell, since the received signal power of the macrocell is higher than that of the connecting picocell for such UE, as shown in Figure 1. As a result, inter-cell interference management is critical to HetNet deployment [2].

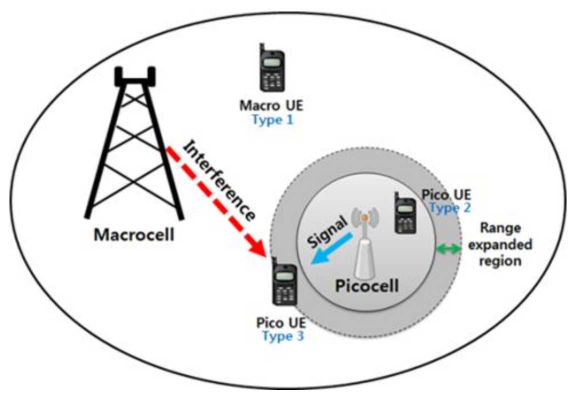

Figure 1. The dominant DL cross-tier interference scenario in HetNet

In the 3rd Generation Partnership Project (3GPP) with its REL-8/9, the interference management method did not consider the HetNet, and does not provide a suitable dominant interference scenario in HetNet. Therefore, REL-10 has introduced time-domain based interference management. The basic idea with time

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domain interference management is that an aggressor layer creates "protected" subframes for a victim layer, by reducing its transmission activity in certain subframes. To do so, the aggressor eNodeB reduces its transmission power of some downlink signals (or alternatively, mutes their transmission) during a set of low interference subframes designated as ABS, whose occurrences are known a priori at the coordinating eNodeBs. When pedestrian UEs are connected to the picocell in its range-expanded region, the macrocell uses ABS, in order to mitigate macrocell to picocell UE interference [3].

In order to obtain the offloading effect, a larger offset value for handover criteria needs to be used, such as the Reference Signal Received Power (RSRP). When a larger offset value is used, more resources need to be protected for offloaded UEs connected to picocells. Therefore, in order to obtain the best performance, the offset value for the CRE and the amount of resources need to be controlled effectively [4, 5].

In this paper, we propose a cell selection scheme based on SINR and interference management using ABS with flexible ABS ratio, to improve the spectrum efficiency in the time domain. The rest of the paper is organized as follows: in the next section, we present the system model of the HetNet environment. Section 3 describes the details of the proposed control mechanism of the cell selection techniques associated with the interference management. Then section 4 shows a performance analysis of the proposed scheme through system level simulation. Finally, section 5 concludes the paper.

2. System Model

The downlink of 3GPP LTE-Advanced networks with picocells is considered in this paper. Figure 2 shows the considered HetNet that consists of macrocells and picocells that are randomly deployed in each macrocell.

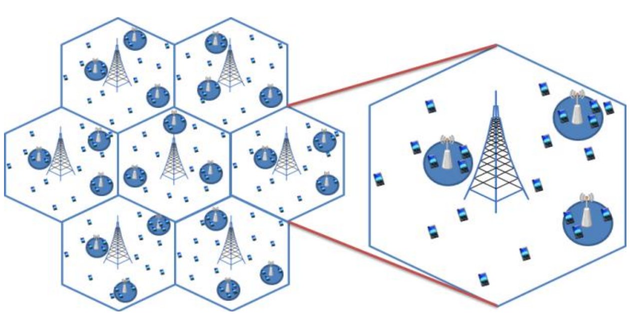

Figure 2. A Heterogeneous Network consisting of macrocells and picocells

In LTE-Advanced System, both macrocells and picocells are OFDMA systems operating in the same frequency band. Therefore, the received SINR of a macro UE (MUE) 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. The 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 gains 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.

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

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

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

3. Cell Selection and Interference Management

3.1. Cell Selection Scheme

In order to obtain accurate channel quality for cell selection, the average received SINR is the best criterion. Therefore, in the paper, the average SINR in the ABS for picocell and non-ABS for macrocell is used for SINR-based cell selection, as shown in Figure 3. In order to obtain the offload effect from macrocells to picocells, an additional offset value, α_{SINR}, is introduced, and the UE selects the cell index based on the following criteria.

$$i_{SINR} = argmax_{0 \le i \le N_P} SINR_i' \quad (5)$$

$$\begin{cases} SINR_i' = SINR_{Non-ABS}, & Macrocell: i = 0 \\ SINR_i' = SINR_{ABS} + \alpha_{SINR}, & Picocell: 1 \le i \le N_P \end{cases}$$

where, i and N_P represent the cell index and number of picocells, respectively. i_{SINR} and $SINR_i'$ represent the selected cell index based on the SINR-based criteria, and the SINR value of the i^{th} cell to be used for cell selection, respectively. Also, $SINR_{Non-ABS}$ and $SINR_{ABS}$ represent the average SINR for the i^{th} cell to which the ABS is not applied, and the average SINR for the i^{th} cell to which the ABS is applied, respectively.

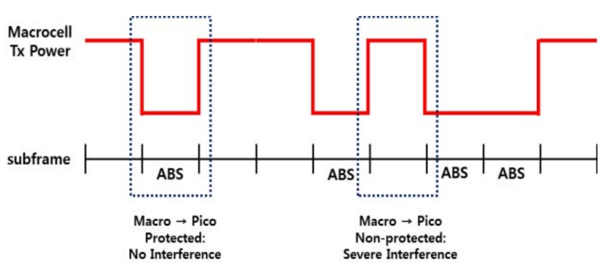

Figure 3. Measurement resources for cell selection

3.2. Interference Management using ABS

When range extension techniques are employed, the coverage area of picocells will extend, and the number of PUEs will increase. However, the PUEs that are associated with CRE will suffer noticeable interference from the macrocell. Therefore, we employ time-domain resource partitioning for interference management.

Before partitioned resource in the time domain is assigned, we divide UEs into three types, as illustrated in Figure 1:

- Type 1 UE: UE that arrives inside of the macrocell coverage
- Type 2 UE: UE that arrives inside of the picocell coverage
- Type 3 UE: UE that arrives inside of the cell range expanded region

The macrocell only needs to stop transmission for a specific time resource that is referred to as ABS, to protect the UEs connected to the picocells with CRE. Picocell sends data to the type 3 UE connected to the picoell using ABS, as illustrated in Figure 4, since the interference from the picocells is not a problem in HetNet.

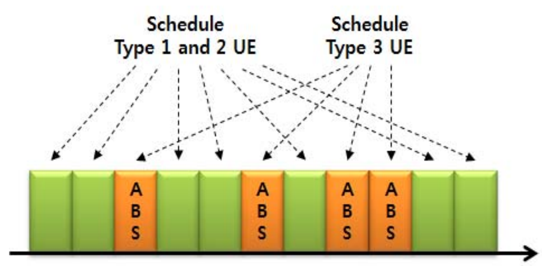

Figure 4. The proposed interference management scheme, using ABS in the time domain

Also, when many picocells exist within the macrocell area, high ABS density provides better performance. However, when there are no picocells in the adjacent macrocell, applying the ABS can cause high performance degradation of the macrocell. Therefore, it is important to consider the density of ABS that should be scheduled. In this paper, the ABS density, which is defined as (6) according to the ratio of the MUEs and PUEs, is obtained.

$$\beta = \frac{Number\ of\ Type\ 3\ UEs}{Number\ of\ Type\ 1\ and\ 2\ UEs} \quad (6)$$

The picocells send data to the Type 3 PUE using ABS, and to the Type 2 PUE using non-ABS that is used in the macrocell. Therefore, system efficiency can be maximized by the use of different ABS density.

4. Simulation Results and Performance Analysis

4.1. 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 1.

Also, we show the simulation results of the selection scheme based on SINR with different offset values (6dB, 12dB) and the interference management scheme. In the time domain, ABS is applied for interference management. But, in the frequency domain, interference management is not applied, for simulation simplicity. In other words, the sub-carriers are randomly assigned to the MUE and PUE.

Table 1 Simulation Parameters

Parameter	Value	
	Macrocell	***Picocell***
Number of Cells	7	
Cell Coverage	Radius 1km (ISD = 1,732m)	Radius 250m
Channel Bandwidth	10MHz	
BS Transmit Power	46dBm	30dBm
Size of Center zone	0.63 of macrocell coverage	
White Noise Power Density	-174 dBm/Hz	
Path Loss	L = 128.1 + 7.6logR (R in km)	L = 140.7 + 37.6logR (R in km)

4.2. Performance Analysis of Proposed Scheme

In order to measure the performance gain, the following performance metric is defined. User spectrum efficiency is the user throughput per 1Hz for one user, expressed as bps/Hz/user. Also, the proposed scheme is compared with a baseline that has 0dB offset value, and fixed ABS density.

Figure 5 shows the Cumulative Distribution Function (CDF) of the user spectrum efficiency with 6dB offset value. The Type 3 UEs connected to the picocell through Cell Range Expansion (CRE) suffer strong interference from the macrocell. This problem can be solved from the proposed interference management scheme, using ABS. Therefore, there is a significant improvement on the PUE, compared with the baseline. Otherwise, MUEs have low spectrum efficiency, because MUEs suffer strong interference from the picocell. But, there are some improvements on the MUE spectrum efficiency. Therefore, the proposed scheme improves the performance of the total user combined MUE and PUE.

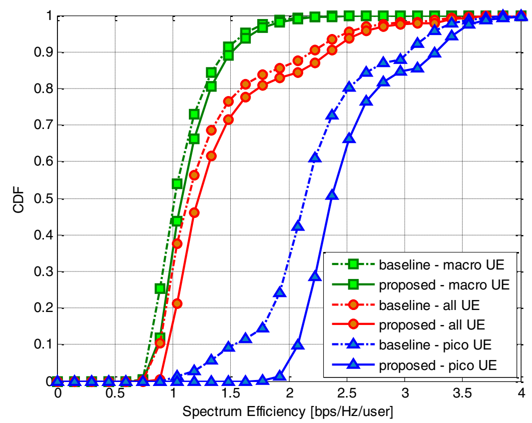

Figure 5. CDF of user spectrum efficiency (α_{SINR} = 6dB)

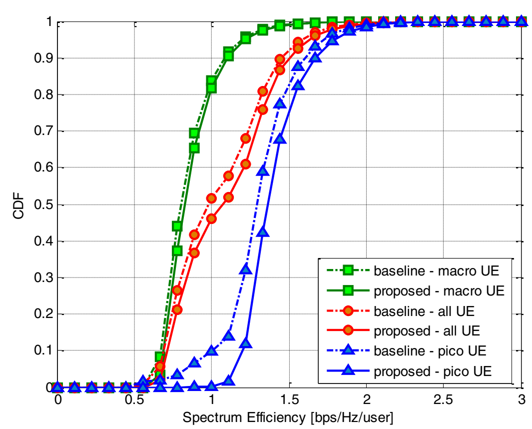

Figure 6: CDF of user spectrum efficiency (α_{SINR} = 12dB)

Also, we show the simulation results of the selection scheme based on SINR with different offset values (6dB, 12dB) and the interference management scheme. In the time domain, ABS is applied for interference management. But, in the frequency domain, interference management is not applied, for simulation simplicity. In other words, the sub-carriers are randomly assigned to the MUE and PUE.

Figure 6 shows the CDF of user spectrum efficiency with a 12dB offset value. It can be seen that the performance of PUE is similar to the performance with 6dB offset value, and is improved. But, the proposed scheme brings a slight performance improvement, because ABS density is increased according to the increase of type 3 UE, and then resources in the time domain are reduced for MUE.

5. Conclusions

We propose a cell selection and interference management scheme for the HetNet scenario with coexisting macro cell and picocell, based on LTE-Advanced downlink. The cell selection scheme is based on the SINR, and the cell expansion range can vary through the offset value. In addition, we can manage the interference between the macrocell and picocell, using ABS in the time domain. Also, a flexible ABS density is applied, to increase the spectrum efficiency.

Simulation results demonstrate that the proposed scheme can improve the performance in terms of spectrum efficiency. Therefore, we expect that the proposed scheme configures a more efficient cellular environment based on LTE-Advanced, due to the improvement of performance. Also, it can improve the overall cell performance in the HetNet scenario, for the next generation wireless communication environment.

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