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Distributed Resource Partitioning Scheme for Intercell Interference in Multicellular Networks

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Abstract

In multicellular wireless networks, intercell interference limits system performance, especially cell edge user performance. One promising approach to solve this problem is the intercell interference coordination (ICIC) scheme. In this paper, we propose a new ICIC scheme based on a resource partitioning approach to enhance cell edge user performance in a wireless multicellular system. The most important feature of the proposed scheme is that the algorithm is performed at each base station in a distributed manner and therefore minimizes the required information exchange between neighboring base stations. The proposed scheme has benefits in a practical environment where the traffic load distribution is not uniform among base stations and the backhaul capacity between the base stations is limited.

Key Words: Cell Edge Performance, Intercell Interference Coordination, Orthogonal Frequency Division Multiple Access, Resource Partitioning.

I. INTRODUCTION

A traditional cell covers an area with a radius of up to several kilometers. However, due to the growing demand for higher data rates, this cell radius is becoming much smaller to enable increases in system capacity and provide higher spatial reuse. However, a denser cellular deployment can cause severe intercell interference among neighboring cells that use the same frequency band. To address this problem, researchers have focused their attention on an intercell interference coordination (ICIC) scheme.

The key purpose of the ICIC scheme is to differentiate the transmission power level of each frequency subband depending on user location. Users at the edge of a cell are allocated frequency subbands with a higher transmission power level that is orthogonal for the neighboring cells, while users at the center of the cell can be served on low-power frequency subbands since they have better signal power and reduced interference from neighboring cells.

Three types of ICIC schemes have been presented in previous studies [1]. The first is static ICIC, which is also known as fractional frequency reuse (FFR) [2, 3]. This scheme has a fixed cell center and cell edge subbands, and the resource partitioning does not change. The second scheme is called dynamic ICIC [4, 5]. This scheme instantly adapts its subband partitioning to network conditions. It does not require prior frequency planning, but it does demand a huge amount of information exchange between neighboring cells. The third scheme is known as semi-static ICIC [6, 7]. It operates at a centralized node in a centralized manner and entails a lot of information exchange. In this paper, a resource-partitioning algorithm categorized into a semi-static ICIC is proposed. The key feature of the proposed scheme is that it does not need a centralized node and operates in a distributed manner. It also reduces in-

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formation exchange between adjacent cells.

The rest of this paper is organized as follows. Section II presents the system model for the design of the proposed algorithm. Section III proposes a distributed resource-partitioning algorithm. Section IV provides the numerical simulation results, and the paper is concluded in Section V.

II. SYSTEM MODEL

In this study, we considered the orthogonal frequency division multiple access (OFDMA) downlink transmission in multicellular networks. Each base station (BS) and user was equipped with an omnidirectional single antenna located at the center of the cell, and each user was connected to a single BS (the terms 'BS' and 'cell' are used interchangeably throughout this paper). We assumed that BSs can exchange information with surrounding BSs through a wired backhaul connection. In this paper, we use the following notations: the set of users connected to BS-i is denoted as $\Gamma_i = \{1,\dots,m_i,\dots M_i\}$; the set of surrounding BSs of BS-i is denoted as $\Omega_i = \{1,\dots,n_i,\dots,N_i\}$; and the set of users served by BS-i and receiving interference from BS-j is denoted as $\Gamma_{i,j} = \{1,\dots,m_{i,j},\dots,M_{i,j}\}$. Based on a conventional FFR ICIC scheme, we considered a network deployment consisting of a cell and 1-tier neighboring cells, as shown in Fig. 1. Here the whole system bandwidth is denoted as B. There are three types of cells that have cell edge subbands: B_α, B_β, and B_γ. An occupied cell edge subband is denoted by R_α, R_β, and R_γ. We defined two cell states: underloaded and overloaded. In the former, B_x is larger than R_x, where x denotes cell type. The latter is the contrary cell state.

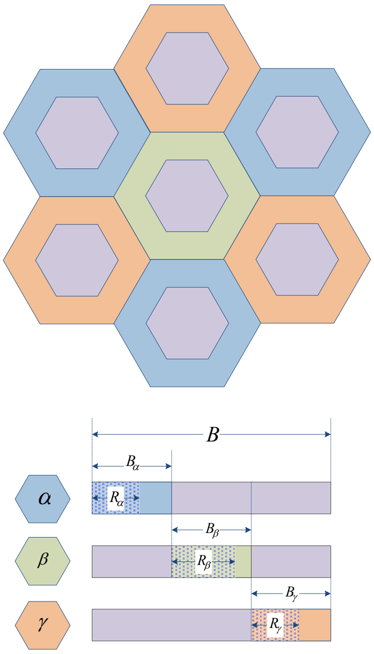


Fig. 1. System model and frequency partitioning.

III. RESOURCE PARTITIONING SCHEME

1. User Classification

To apply ICIC schemes, users need to be classified as either cell center or cell edge users. To do this, we used reference signal received power (RSRP) in a long-term evolution (LTE) system because it can be measured from both a serving BS and neighboring BSs. We denoted RSRP at user-m from serving BS-i as P_i^m and RSRP at user-m connected to BS-i from neighboring BS-j as $P_{i,j}^m$.

Using the RSRP values, we defined the interference factor (IF). The IF from neighbor BS-j at user-m connected to serving BS-i can be defined as

$$I_{i,j}^m = \frac{P_{i,j}^m}{P_i^m}, m \in \Gamma_i, j \in \Omega_i. \tag{1}$$

The IF at user-m connected to serving BS-i is defined as

$$I_i^m = \sum_{j \in \Omega_i} I_{i,j}^m = \sum_{j \in \Omega_i} \frac{P_{i,j}^m}{P_i^m}, m \in \Gamma_i. \tag{2}$$

Using the above IF and a predefined threshold value (IF_{th}), we performed a user classification. The set of cell center users connected to the serving BS-i can be denoted as

$$\Gamma_i^c = \{\Gamma_i \mid I_i^m < IF_{th}, m \in \Gamma_i\}. \tag{3}$$

In the same way, the set of cell edge users connected to the serving BS-i is denoted as

$$\Gamma_i^e = \{\Gamma_i \mid I_i^m \geq IF_{th}, m \in \Gamma_i\}. \tag{4}$$

For the proposed algorithm, we needed to subdivide the set of cell edge users. Therefore, we defined the set of cell edge users connected to serving BS-i and interfering from neighboring BS-j as

$$\Gamma_{i,j}^e = \{\Gamma_i^e \mid I_{i,j}^m \geq IF_{th}, m \in \Gamma_i, j \in \Omega_i\}. \tag{5}$$

2. Coupling Factor

In general, user distributions among cells are not homogeneous. There may be overloaded or underloaded cells. Moreover, within a cell, there may be uneven distributions of users in the cell center and cell edge regions. In such cases, the impact of the interference between adjacent BSs is dependent on the distributions of users and the traffic load. Here, we present a new metric that can measure the impact of interference from neighboring BSs. To do this, we define the coupling metric (CM) and coupling factor (CF), which is a combination of the IF defined above and the user's traffic load. If L_i^m is the traffic load of user-m, then the CM of the BS-i from the neighboring BS-j is defined as

$$CM_{i,j} = \sum_{m \in \Gamma_{i,j}^e} I_{i,j}^m L_i^m. \tag{6}$$

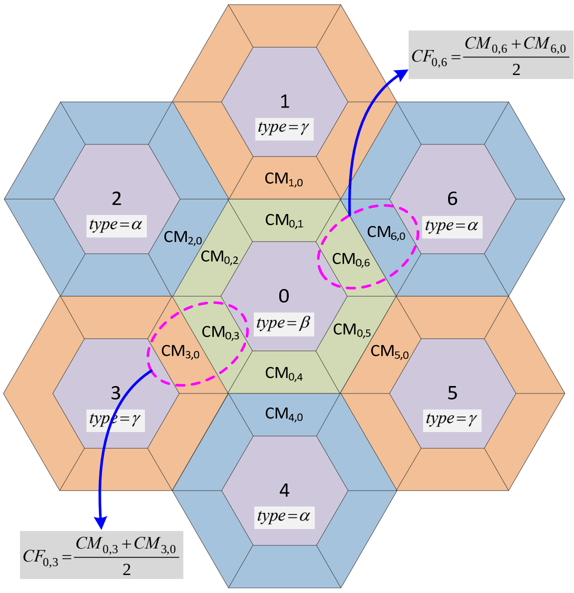


Fig. 2. Coupling metric (CM) and coupling factor (CF) calculation.

The CF is defined as the average value of the CM between two BSs:

$$CF_{i,j} = mean\{CM_{i,j},\ CM_{j,i}\}. \tag{7}$$

The CF means that adjacent cells interfere with each other via two factors, power from other cells and users' own traffic from serving cells. In a seven-cell deployment, the CM and CF can be calculated as shown in Fig. 2.

3. Cell Edge Subbands

Considering the system model in Fig. 1 and an inhomogeneity in user distribution, in the underloaded state, the cell in an overloaded state needs more cell edge subband from neighboring cells. By assuming that cell 0 in Fig. 2 is in an overloaded state and its neighboring cells are in underloaded state, we can explain the procedure to obtain the available cell edge subband at cell 0. Let $\bar{R}_i^x$ be the unused cell edge subband of cell i in cell type x. The available cell edge subband obtained from cell type α in cell 0 can then be represented as

$$\bar{R}^\alpha = \bar{R}_2^\alpha \cap \bar{R}_4^\alpha \cap \bar{R}_6^\alpha . \tag{8}$$

In the same way, the available cell edge subband obtained from cell type γ in cell 0 can be represented as

$$\bar{R}^\gamma = \bar{R}_1^\gamma \cap \bar{R}_3^\gamma \cap \bar{R}_5^\gamma . \tag{9}$$

The resulting cell edge subband of cell 0 is a summation of the available cell edge subband from cell type α and from cell type γ. If W_i^x is the available cell edge subband of cell i in cell type x, then we can denote the available cell edge subband of cell 0 as

$$W_0^\beta = \bar{R}^\alpha \cup \bar{R}^\gamma . \tag{10}$$

According to this description, $\bar{R}^x$ is determined by the smallest unused cell edge subband among cell type x. This means that the inhomogeneity of user distribution among cells of the same type causes low resource utilization. To alleviate this problem, we can introduce the CF threshold value to obtain more available cell edge subband. A large CF value between two cells means that the cells are tightly coupled with interference. We therefore propose a scheme that the cells with CF values smaller than the threshold value are omitted in the calculation process of (10). Let Ω_i^x and Λ_i^x denote a set of neighboring cells of cell i with cell type x and the set of neighboring cells of cell i with a CF value below the threshold value. We can then obtain the following expressions:

$$\Omega_i^x = \{\Omega_i \mid cell\,type = x\}, \tag{11}$$

$$\Lambda_i^x = \{\Omega_i^x \mid CF_{i,j} < CF_{th},\, j \in \Omega_i\}. \tag{12}$$

Using (11) and (12), we can denote the available cell edge subband obtained from cell type x considering the CF threshold value as follows:

$$\bar{R}^x = \bigcap_{j \in (\Omega_i^x - \Lambda_i^x)} \bar{R}_j^x , \tag{13}$$

which is the relaxed expression of (8) or (9). In addition, (10) can be rewritten in more general expression as

$$W_i^y = \bigcup_{y \neq x} \bar{R}^x . \tag{14}$$

A lower CF threshold value means that resource conflicts in the cell edge subband are not allowed; thus, the interference between neighboring cells is decreased at the cost of resource utilization. In contrast, a higher CF threshold value implies a higher probability of resource overlapping between neighboring cells for high resource utilization.

4. Cell Scheduling

Although all the cells in a network can calculate the available cell edge subband, they cannot use those resources at the same time. This therefore leads to the problem of determining which cell should use the available cell edge subband. To resolve this dilemma, we propose the following resource allocation scheme, which we refer to as a cell-scheduling scheme.

Let V_i be the volume of transmitted user data through the available cell edge subband of cell i during the previous unit time period. We define the utility function for the cell i with cell type x as

$$U_i = \frac{W_i^x}{V_i}. \tag{15}$$

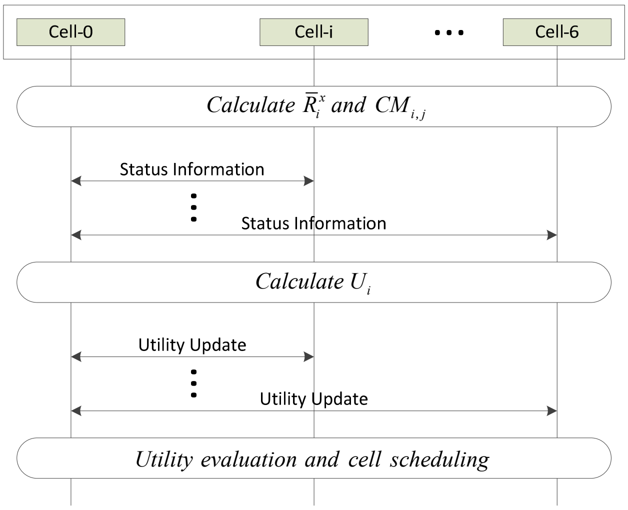


Fig. 3. Information exchange procedures.

All the cells in the network calculate their own utility value as described above and compare it with the utility values of the adjacent cells. If its own utility value is the highest one, then the cell uses the available cell edge subband in the next time period. From the utility function (15) and expressions (11) and (12), we can describe the selected cell index k with the cell scheduling scheme as follows:

$$k^* = \arg \max_{k \in \{i\} \cup (\Omega_i^x - \Lambda_i^x)} U_k. \qquad (16)$$

5. Information Exchange between Cells

The proposed algorithm described above needs to share information among the 1-tier cells. To do this, we assume that all the 1-tier cells are connected through a high-speed wired link, such as an X2 interface, in an LTE system. To calculate the CF value between two cells, the cells need to share their CM and unused cell edge subband ($\bar{R}_i^x$) with each other. The calculated utility values also need to be shared within all the 1-tier cells. Therefore, this information exchange consists of two stages (shown in Fig. 3).

From the viewpoint of information exchange, each cell only needs to share information with the adjacent cells surrounding it. This means that each cell can simply decide to use the available cell edge subband in a distributed manner with a two-stage information exchange process.

IV. NUMERICAL RESULTS

1. Simulation Setup

To simulate this scenario, we considered a system of 19 hexagonal cells, each with a radius of 1,000 m. Table 1 shows the parameters used in the simulation. We used the central cell technique developed by [8]; that is, the simulation results were collected only in the central cells of the simulated multicell layout for a more accurate evaluation. To conduct a performance comparison using the proposed algorithm, we used the Reuse-1 and static FFR as the reference schemes. The Reuse-1 scheme randomly assigns physical resource blocks (PRB) to different users with equal power and bandwidths irrespective of their category. For a static FFR scheme, we fixed the cell edge subbands at each cell and allocated the cell edge users to these subbands with higher priority. In contrast to the proposed scheme, there was no overlapping or conflict of the cell edge subbands between adjacent cells.

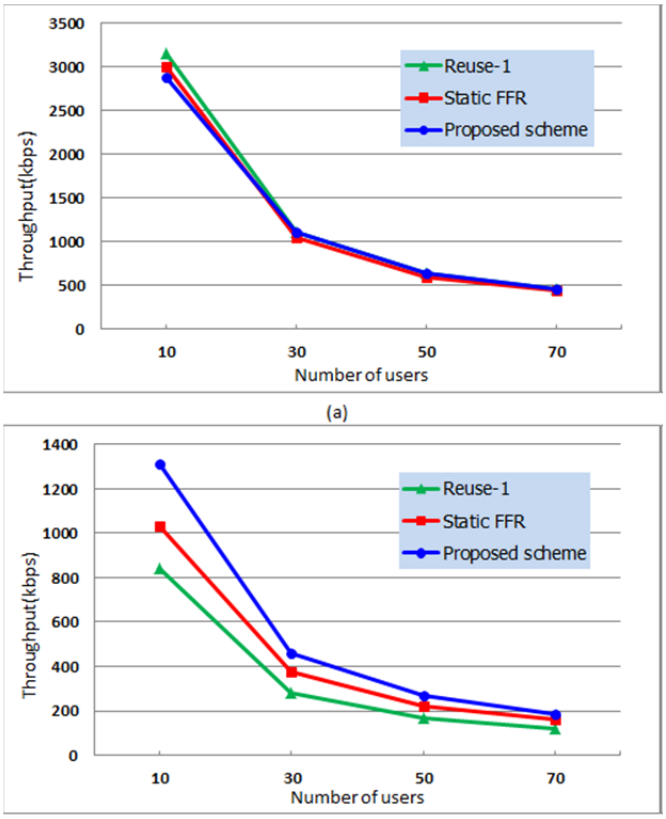
Table 1. Simulation parameters

Parameter	Value
Number of cells	19
Uniform users	10, 30, 50, 70
Non-uniform users	30, [20,40], [10,50], [5,55]
Cell radius (m)	1,000
Total bandwidth (MHz)	10
Carrier frequency (GHz)	2
Number of subchannels	16
Number of cell center subcarriers	$(\alpha,\beta,\gamma) = (10,10,11)$
Number of cell edge subcarriers	$(\alpha,\beta,\gamma) = (5,5,6)$
Path loss	$16.62 + 37.6 * \log_{10}(d)$
Total transmit power (dBm)	43
Cell edge/center power ratio	3
Thermal noise density (dBm/Hz)	-174
Traffic model	Full buffer model
Scheduling scheme	Proportional fair

There are two types of user distributions, uniform and non-uniform. In a uniform distribution, each cell has the same number of users that are uniformly distributed within the cell. In a non-uniform distribution, the number of users varies from 10 to 70. ICIC schemes generally use a resource-partitioning method to enhance the cell edge performance at the cost of average user throughput. The goal of our scheme was to improve the cell edge user throughput with a minimal degradation of the average user throughput. We therefore evaluated both the average user throughput and the cell edge user throughput.

2. Simulation Results

Fig. 4 shows the average user throughput versus the number of users per cell and the cell edge user throughput versus the number of users per cell in a uniform user distribution. It can be noted that the proposed scheme significantly improves the cell edge user throughput (50% to 60% more than the Reuse-1 scheme) and only slightly degrades the average user throughput (less than 10% compared with Reuse-1). As the number of users



(a)

(b)

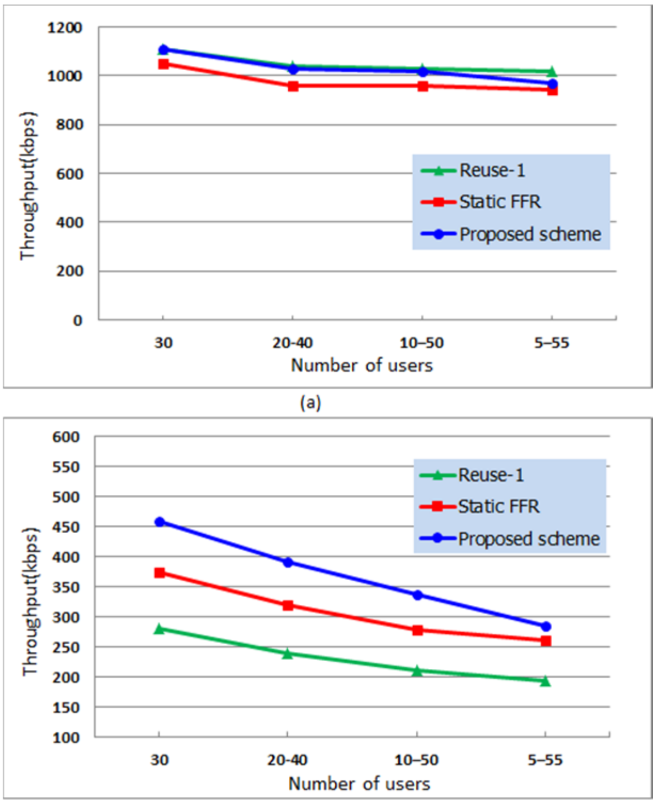
Fig. 4. (a) Average user throughput and (b) cell edge user throughput for uniform user distribution. FFR=fractional frequency reuse.

increases, the amount of unused subband in neighboring cells decreases and the performance of the three schemes becomes more similar as shown in Fig. 4(b).

Fig. 5 shows the average user throughput versus the number of users per cell and the cell edge user throughput versus the number of users per cell in a non-uniform user distribution. In this scenario, we maintained the average number of users per cell as 30. As the inhomogeneity of user distribution increases, all performance metrics decrease. However, our proposed scheme has the highest cell edge user performance regardless of user distribution.

V. CONCLUSION

In this paper, we have proposed a new resource-partitioning scheme with ICIC for multicellular networks. The proposed scheme enables improved cell edge throughput performance with only a slight degradation in average user throughput performance compared with the Reuse-1 and static FFR schemes. Our proposed scheme is based on the utilization of the cell edge subband from adjacent cells in an underloaded state. To further improve the performance of the cell edge user throughput and to increase resource utilization, we have presented the idea of using a CF between adjacent cells as it leads to a performance trade-off between the cell edge and cell center zones. The key feature of the proposed scheme is that it is performed at each base station in a fully distributed manner and that there is no need for a central functional entity. Each cell solves its own resource allocation problem with minimal information exchange between adjacent cells. The simulation results show the effectiveness of our scheme under various scenarios.



(a)

(b)

Fig. 5. (a) Average user throughput and (b) cell edge user throughput for non-uniform user distribution. FFR=fractional frequency reuse.

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