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Optimal Resource Allocation for Wireless Networks with Inter-Cell Interference

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Abstract: The paper describes a Resource allocation is an important issue in orthogonal frequency division multiple access (OFDMA) systems. For multicell systems, the interference across different cells makes the optimization of resource allocation difficult. While inter cell interference (ICI) for the downlink of multi-cell systems in general and orthogonal frequency division multiple access networks, the uplink has received less attention. Inter-cell interference coordination (ICIC) schemes can be viewed as a scheduling strategy used to limit the inter-cell interference such that cell-edge users in different cells preferably are scheduled on complementary parts of the spectrum when needed. The common theme of ICIC avoidance schemes is to apply restrictions to the usage of downlink resources such time/frequency and/or transmit power resources. Such coordination of restrictions will provide an opportunity to limit the interference generation in the area of the cellular network. Accordingly, Signal to Interference and Noise Ratio (SINR) can be improved at the receivers in the coverage area, which will provide capability for increased (cell-edge) data-rates over the coverage area, or increased coverage for given data-rates.

Keywords: OFDMA, resource allocation, inter-cell interference, signal-to-interference and noise ratio, inter-cell interference coordination.

I. INTRODUCTION

The multiuser Orthogonal Frequency Division Multiplexing (OFDM) is a very promising transmission technique for broadband wireless networks. The orthogonality characteristic among the subcarriers is another very important feature of OFDM technique, since it combats intra-cell interference inside a cell. anyway, in a multicell environment inter-cell interference exists and plays an important role for the outcome performance of the network. To be more specific, interference in OFDM-based systems arises when the same frequency resources are used in near another cell. For example, when two users in different cells, use the same frequency block instantaneous, then the Signal to Interference and Noise Ratio (SINR) associated with these blocks can drop to a very low value, resulting in a bad resource utilization and lower performance.

In order to face up this problem, 3GPP is find out under the *Long Term Evolution (*LTE), ICI techniques. Three methods are currently being considered, ICI randomization, ICI cancellation and ICIC.

The first method aims at randomizing the interfering signal and thus allowing interference suppression at the mobile terminal either by applying (pseudo) random scrambling after channel coding/interleaving or using different kinds of frequency hopping.

The second method based on interference suppression which can be achieved by spatial suppression using multiple antennas at the mobile terminal.

The last method aims at applying conditions to the downlink resource management in a coordinated way between cells. These conditions can be either on the available resources of the resource manager or can be in the form of restrictions on the transmit power that can be applied to certain radio resources. Such conditions in a cell will provide the possibility for improvement in SINR, and continuously to the cell edge throughput and coverage. Inter-cell Interference Co-ordination (ICIC) requires also communication between different network nodes in order to set and reconfigure these conditions. Two cases are considered, the static one where reconfiguration of the conditions is done on a time scale corresponding to days and the semi-static where the time scale is much smaller and corresponds to seconds.

The impact of inter-cell interference is more obvious for the cell-edge users, which are more sensitive due to the already bad channel gains with their serving base stations. This results in poor receptions at the cell edge in the downlink direction. Limited reception at the cell edge is an issue of great importance for the wireless operators who want to provide full coverage inside their service area and guarantee a certain Quality of Service (QoS) to their subscribers independently of their positions inside a cell. the recent discussions in the LTE project about inter-cell interference mitigation techniques shows the strong interest and will of the wireless industry to study and overcome this

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problem. The scope of this thesis is to examine how users can share the available radio resources, in terms of bandwidth and power allocation, in order to suppress inter-cell interference and enhance cell-edge throughput and spectrum efficiency.

The performance of the proposed schemes is analyzed comprehensively in a multi-cell network. The schemes are also evaluated under different scenarios with respect to uneven user distribution and various traffic loads. Extensive simulations demonstrate that the proposed schemes can provide significant performance improvement for both cell-edge and cell-center users compared with existing schemes. It is also shown that substantial fairness can be further addressed by the proposed schemes in terms of achieving balanced performance between cell-edge and cell-center users in the network.

SYSTEM MODEL

A multi-cell OFDMA-based downlink network is considered in this project. One example of the network layout with seven hexagonal cells is displayed in Fig: 1, where a BS equipped with an omnidirectional antenna is placed at the center of each cell to serve users who are randomly distributed within the cell. In OFDMA systems, the frequency resource is divided into subcarriers while the time resource is divided into time slots. The smallest radio resource unit that can be allocated to transport data in each transmission time is termed as traffic bearer in general. The PRB is a group of subcarriers that can be coherently allocated to users in a given time. For consistency, thus, from now on we will use the term PRB to As specified in the LTE standard, the traffic bearer is defined as a physical resource block (PRB), which consists of twelve consecutive subcarriers in the frequency domain and one slot duration (0.5 msec) in the time domain represent the single unit of radio resource for allocation in the OFDMA-based network. In addition, the following fundamental assumptions are made throughout the remainder of this paper.

1. In each cell, users are classified as either cell center or cell-edge users depending on their current geographic locations and straight-line distances to the serving BS. The boundary that separates the cell center and cell edge region, as shown in Fig: 1 can be adjusted as a design parameter. The geographic location information can be reported to the BS by users periodically via the uplink control channels.

2. In every transmission time interval (TTI), each BS has to make a decision on PRB assignment to its served users. The duration of TTI is equal to one time slot of the PRB. We also assume that BSs can have perfect knowledge of channel state information updated periodically via feedback channels for every TTI.

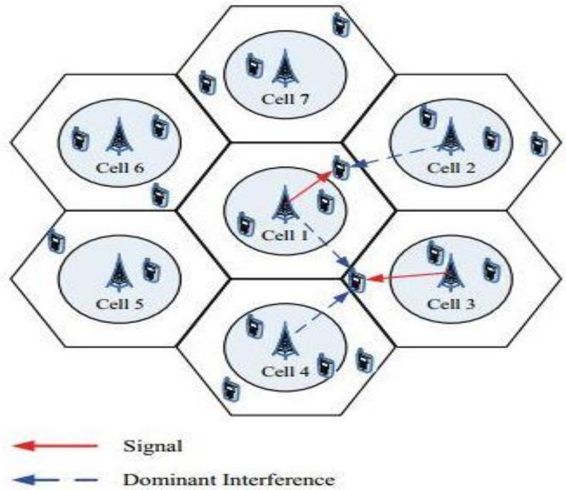

Fig: 1 An Example of LTE Network with inter cell interference

3. The transmission power is allowed to be independently allocated on each active PRB that has been assigned to users in the network. Hence, dynamic or fixed power allocation can be performed depending on different given schemes. The sum of the overall allocated power in each cell cannot exceed the maximum transmission power of the BS. We assume that all BSs in the network are given the same maximum transmission power.

4. To any cell, only interference from its adjacent Cells are regarded as the effective ICI. In particular, to any cell-edge user there is a dominate interference that usually comes from its closest adjacent cell (i.e., in Fig: 1 cell 2is considered as the dominant interfering cell to the cell-edge user in cell 1). In addition, cell-edge users may have at most two dominant interfering cells when they are located at the corner of serving cells and thus have nearly equal distances with both neighboring cells (i.e., in Fig:1 both cell1and cell4 are dominant interfering cells for the cell-edge user in cell 3). Note that this assumption has been invoked by many prior authors in literature and particularly verified.

II. PROBLEM FORMULATION

Optimization goal is to maximize the overall throughput of cell-edge users while maintaining the required throughput for cell-center users. As a result, a balanced performance improvement between cell edge and cell-center users is expected to be achieved in the multi-cell systems. The reason behind this is that cell-center users usually do not suffer from heavy ICI and relatively high performance is easy to be obtained for these users even in a network without optimization, whereas cell-edge users' performance is much more vulnerable to ICI and their performance improvement has to strongly rely on optimization schemes.

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Cell-edge users suffer from several interference due to the shorter distances to the adjacent BSs.

1. Users within the same cell are mutually connected.
2. For any cell-edge user, the connection is only pair wise established with other cell-edge users of its dominant interfering cells.

III. POWER ALLOCATION APPROACH

The radio resource allocation, the power allocation is decided individually in each cell and subsequently performed by BSs in a distributed manner. Therefore, a distributed power allocation approach is proposed in this section with an emphasis on performance optimization for cell-edge users

a. Total Power Distribution

The overall transmission power of each cell into two parts: total power for cell-edge users and cell-center users. Let P_E^j and P_C^j denote the total power allocated to cell edge users and cell-center users in cell j, respectively, and $P_E^j + P_C^j = P_{Max}$. Note that Pmax is assumed to be the same for all BSs in the network.

$$P_E^j + P_C^j = P_{Max}$$

$$\frac{P_C^j}{P_E^j} = \alpha \frac{|B_C^j|}{|B_E^j|}$$

Where B_C^j and B_E^j denote sets of total PRBs occupied by cell-center and cell-edge users in cell j, respectively, and α (0<α<1) is a proportional factor indicating that a higher weight is given to cell-edge users for power allocation

b. Power Allocation for Cell-center Users

The objective is to conditionally maximize the performance of cell-edge users and there is no optimization for cell-center users, though protection of their performance is stated as an important constraint. Thus, we simply determine the power allocation to cell-center users by evenly distributing the total power for cell-center users among their used PRBs in each cell.

c. Power Allocation for Cell-edge Users

Given the fixed PRB allocation and power allocation of cell center users, the original optimization problem becomes a convex function of power of cell-edge users and can be decomposed into parallel sub-problems, where the optimal power allocation to cell-edge users is solved locally by each BS of the network. Where only mutual interference between cell-edge and cell-center users is taken into account.

IV. PERFORMANCE ANALYSIS

TABLE I
MAIN SIMULATION PARAMETERS

Parameter	Value
Number of cells	7
Cell radius	500m
Bandwidth	5 MHz
Carrier frequency	2 GHz
Cell-edge area ratio	1/3of the total cell area
Total number of PRBs	24
Frequency spacing of a PRB	180 kHz
Total transmission power per cell	43 dBm
LOS path loss model	103.4+24.2log10(d)dB,d in km
NLOS path loss model	131.1+42.8log10(d)dB,din km
Channel model	Rayleigh multipath model
Thermal noise	-174 dBm/Hz

Fig: 2(a) the average throughput achieved by the proposed scheme for both cell-edge and cell-center users in the reference cell. Here the values of modulator are chosen as [64-QAM] and the number of the users in each cell is 10.

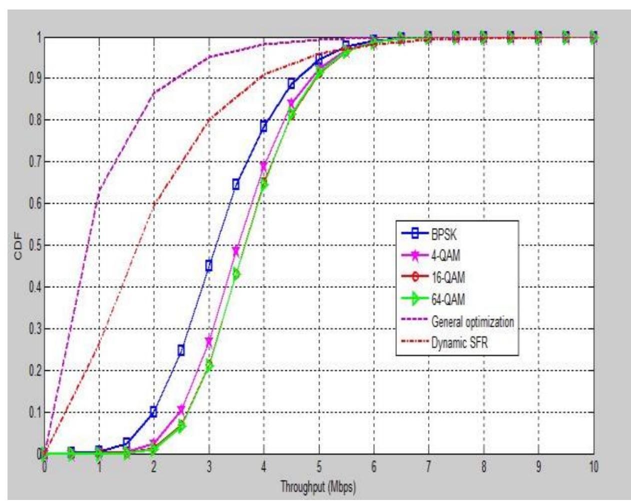

Fig: 2(a)-Performance in cell edge user

The performance of the proposed scheme with different values of the modulator and various numbers of users per cell are evaluated. Therefore, we fix the SINR threshold value as 16 dB in the following proposed schemes, though it may not result in the exact performance balance when other modulators are used.

The cumulative distribution functions (CDF) of throughputs achieved by the different schemes for cell-edge and cell-center users of the reference cell in the network with 10 users per cell, respectively.

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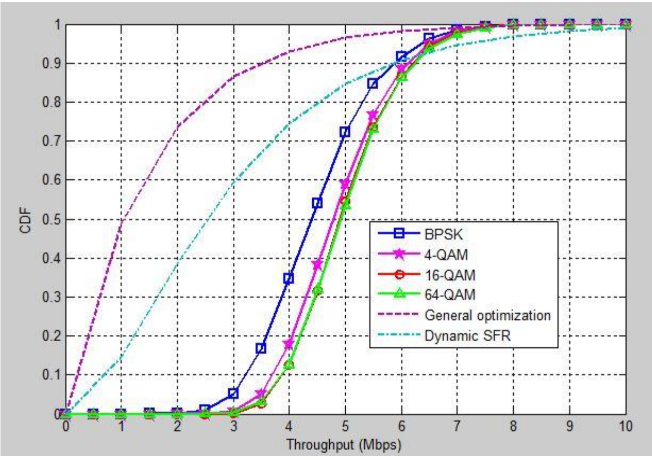

Fig: 2(b)-Performance in cell center user

In addition to the aforementioned benchmark schemes for comparison, we investigate performance of the proposed scheme with various values of the modulator. Fig: 2(b) shows that our proposed schemes can achieve significant improvement for cell-edge users over the reference schemes, where the general optimization scheme surprisingly performs worst. On the other hand, the general optimization scheme maximizes the performance of cell-center users and greatly outperforms other schemes. It is because that the general optimization scheme targets overall performance maximization and thereby allocates resources (PRBs and power) dominantly to users with good channel conditions, e.g., cell-center users. Nevertheless, Fig: 2(b) also reveals that our schemes can successfully maintain high performance for cell-center users, i.e., 50% cell-center users can achieve throughput over 3 Mbps and nearly all of them can achieve throughput over 2 Mbps compared to 80% by the general optimization scheme and 60% by the dynamic SFR scheme reaching the target of 2 Mbps, respectively. Among the proposed schemes, in addition, [64-QAM] indicates high modulator given to cell-edge users for resource allocation and thereby yields the best performance to cell-edge users while lowest for cell center users. In contrast, [16-QAM] achieves the best performance for cell-center users and lowest for cell edge users.

However, it is noticed that the performance achieved by all the schemes for the overall network surpasses that of the reference cell. This is because, with the exception of the reference cell, each cell of the considered 7-cell network is only partially surrounded by neighboring cells and thus suffers from less ICI than the reference cell does.

Therefore, the performance improvement of our proposed schemes has been comprehensively evaluated by the single cell and 7-cellnetwork scenarios, where full and partial ICI are experienced respectively.

V. SUMMARY AND CONCLUSION

The optimal solution is obtained by the proposed scheme can achieve significant performance improvement for cell-edge users and desirable performance for cell-center users compared with the reference schemes. Also the consistent improvement is verified by performance evaluation on various user densities in the network. Therefore, the proposed resource allocation scheme can yield balanced performance between cell-edge and cell-center users, which allows for future wireless networks to deliver consistent high performance to any user from anywhere.

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