Dynamic Downlink Resource Allocation for Wireless Networks with Inter-Cell Interference

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Abstract— The paper describes a Resource allocation in cellular networks using orthogonal frequency division multiple access (OFDMA) systems. Both center cell and edge cell users using same power, edge cell users suffer from Inter Cell Interference (ICI). Power allocation cell-edge user’s power is maximized automatically reduce the inter cell interference under the condition that desirable performance for cell-center users must be maintained. The power optimization is formulated as a Greedy Power allocation method. Simulation results indicate that our proposed scheme can achieve significantly balanced performance improvement between cell-edge and cell-center users in multi-cell networks, and goal of future wireless networks in terms of providing high performance to anyone from anywhere.

Index Terms— OFDMA, resource allocation, inter-cell interference, signal-to-interference and noise ratio, inter-cell interference coordination.

I. INTRODUCTION

NEXT generation wireless networks target ubiquitous high data rates, efficient resource (e.g., spectrum and power) usage and economical network deployment. Given the fact that radio spectrum is becoming a scarce resource in wireless Communications, the orthogonal frequency division multiple access (OFDMA) has been proposed as a state-of-the-art air interface technology to enable high spectrum efficiency and effectively combat frequency-selective fading. Due to its promising features, OFDMA is adopted in many emerging cellular systems in Inter Cell Interference and power allocation [1] and frequency reuse [2] for achieving those ambitious objectives of next generation networks.

In order to realize the flexibility on access of radio resources, OFDMA poses a new challenge for radio resource management (RRM). A good RRM scheme, including subcarrier allocation, scheduling and power control, is crucial to guarantee high system performance for OFDMA-based networks. On traditional design of RRM, most published work concentrate on the single-cell scenario where resources are allocated to deliver a local performance optimization [3]–[7]. In future wireless networks, however, denser cellular deployment with a lower frequency reuse factor is demanded. This has moved the trend to the development of RRM for multicell systems. In the multi-cell context, inter-cell interference (ICI) has become a major issue of concern since the frequency reuse-1 is agreed as the preferred frequency planning deployment for modern OFDMA-based cellular networks. Due to the same spectral usage in adjacent cells, ICI can result in severe performance degradation to users of reuse-1 OFDMA networks, particularly those at the cell edge.

Thus, developing RRM schemes with an emphasis on ICI reduction in the multicell scenario is of significant interest to recent research work [8]–[10].

The ICI-aware RRM in multi-cell OFDMA networks, in general can be formulated as a global performance optimization problem by considering the signal-to-interference-and noise ratio (SINR) instead of the signal-to-noise ratio (SNR). Unfortunately, finding the optimal solution to such a global optimization problem is extremely hard and normally not applicable in practice. This is because the problem has been known as a mixed integer programming (MIP) and proven to be NP-hard, which is computationally prohibitive to tackle [11]. Thus, in literatures this work has been analyzed from different perspectives and consequently can be separated into three categories.

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 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.

II. 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](image.png)

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 2 is 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 cell1 and 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.
The OFDM Transmitter information is Demultiplexing in serial to parallel converted and applied to the modulation in IFFT. The IFFT operation in information is converted to samples and again multiplexing operation is performed. The modulated information adding to cyclic prefix uses of interference avoidance, that information is send to transmitting in wireless medium. Again Receiver side reverse operation is performed.

III. 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.

Cell-edge users suffer from severe 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.

A. Multiple-Access Interference

The sum of interference caused by other users operating within the same cell (intra cell interference) and the interference caused at the mobile user in a cell due to reuse of same channel in the neighboring cells (inter cell interference). 

\[ I_{\text{MAI}} = I_{\text{intracell}} + I_{\text{intercell}} \]

Fig depicts intra cell and inter cell interference in hexagonal cells

\[ I_{\text{intracell}} = \left( \frac{M}{Q} \right) * E_b \]

Where M is the number of simultaneous users, Q is number of chips per time period, and E_b is the common received power level. Where \( \left( \frac{M}{Q} \right) \) is channel capacity.

a. Inter cell interference factor

The relative Inter cell interference factor is ratio of Inter cell interference and intra cell interference. That is

\[ \sigma = \frac{I_{\text{intercell}}}{I_{\text{intracell}}} \]

The value of \( \sigma \) ranges from 0.5 to 20, depending upon operating environmental conditions.

\[ I_{\text{MAI}} = (1 + \sigma) \left( \frac{M}{Q} \right) * E_b \]

Thus, the MAI is directly proportional to the channel capacity, M/Q.

b. Signal To Interference Noise Ratio (SINR)

SINR at the individual receiver is given by

\[ \text{SINR} = \frac{E_b}{N_0 + I_{\text{MAI}}} \]

CDMA cellular systems are often interference limited; that is the operating conditions are such that \( I_{\text{MAI}} > N_0 \) (typically 6 to 10dB higher).

\[ \text{SINR} = \frac{1}{1 + \sigma \left( \frac{M}{Q} \right) \left( N_0 + I_{\text{MAI}} \right)} \]

This expression shows

- Inter cell interference, \( \sigma \) It depends on the environment as well as on the handover technique
- The channel capacity, \( \left( \frac{M}{Q} \right) \). It is a design parameter that needs to be maximized in a commercial cellular system.
- The operating \( I_{\text{MAI}}/N_0 \) It related to cell size

IV. 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 $P^j_e$ and $P^j_c$ denote the total power allocated to cell edge users and cell-center users in cell j, respectively, and $P^j_e + P^j_c = P_{\text{Max}}$. Note that $P_{\text{Max}}$ is assumed to be the same for all BSs in the network.

$$P^j_e + P^j_c = P_{\text{Max}}$$

$$P^j_c = \alpha B^j_c$$

Where $B^j_c$ and $B^j_e$ denote sets of total PRBs occupied by cell-center and cell-edge users in cell j, respectively, and $\alpha$ (0<\alpha<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.

The Maximum power is allocated to cell edge user, constant power is allocated to cell center users.

V. PERFORMANCE ANALYSIS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cells</td>
<td>7</td>
</tr>
<tr>
<td>Cell radius</td>
<td>500m</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Cell-edge area ratio</td>
<td>1/3 of the total cell area</td>
</tr>
<tr>
<td>LOS path loss model</td>
<td>103.4+24.2log10(d)dB,din km</td>
</tr>
<tr>
<td>NLOS path loss model</td>
<td>131.1+42.8log10(d)dB,din km</td>
</tr>
<tr>
<td>Channel model</td>
<td>Rayleigh multipath model</td>
</tr>
</tbody>
</table>

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.

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.

Fig: 4(a)-Performance in cell edge user

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.

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.

![Fig: 4(b)-Performance in cell center user](image)

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-cell network scenarios, where full and partial ICI are experienced respectively.

VI. 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. The spectrum usage also reduced. 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.

REFERENCES


