

An Auction Approach to Resource Allocation with Interference Coordination in LTE-A Systems^{*}

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Abstract— We propose a resource allocation scheme based on the auction algorithm that aims at minimizing inter-cell interference (ICI) in multi-carrier LTE-A systems. The prices paid for resources by cell-edge users are infrequently exchanged between adjacent cells to help deciding who needs a specific resource the most. Furthermore, the Relative Narrowband Transmit Power (RNTP) indicator that is exchanged between cells in the LTE-A system is exploited to minimize the information exchange rate. When RNTP is used, only resources that suffer interference higher than a certain threshold are considered in the price exchange mechanism. Performance evaluation results show that the proposed scheme significantly improves the cell-edge throughput. The use of RNTP not only minimizes the exchange overhead, especially in a multi-carrier scenario, but it also improves the system performance as the cell neighbors would not avoid using a resource unless they are the culprit interferers to the original cell that uses it.

Keywords- Resource allocation; auction algorithm; inter-cell interference coordination

I. INTRODUCTION

Orthogonal frequency division multiple access (OFDMA) is a promising technique for next generation wireless networks. Both Long Term Evolution (LTE), LTE-Advanced (LTE-A) and Worldwide Interoperability for Microwave Access (WiMAX) systems have adopted OFDMA as their multiple access technique for either downlink only or both uplink and downlink to achieve their high performance requirements.

In OFDMA systems, interference between the neighboring cells significantly affects the system performance, especially at the cell edge. Due to the scarcity of the frequency resources, it is not favorable to deploy frequency reuse systems with reuse factor greater than one. Instead, a reuse-1 frequency management scheme where the whole resources are used in each cell should be deployed. Although it achieves the highest peak data rate, reuse-1 scheme suffers high inter-cell interference (ICI) which results in unfavorable conditions for the users at the cell edge. Several solutions are proposed to mitigate the effect of ICI in OFDMA based wireless networks [1], inter-cell interference coordination (ICIC) is one of these solutions that aims at avoiding possible ICI occurring due to sharing of the same resource block by two users in two neighboring cells.

The ICIC problem is studied extensively in the literature [1]. Most of the existing work in this field focuses on minimizing the ICI without paying attention to the importance of certain resources to cell-edge users in different cells. If there is a resource that should not be used in two adjacent cells, existing schemes may only prevent one of them from being assigned to this resource without considering who needs it the most. In this paper, we propose an auction based ICIC scheme that aims at minimizing ICI while taking the needs and priorities of cell-edge users into account. The auction algorithm was previously proposed in [2] as an efficient solution to the symmetric assignment problem, and is shown in [3] to be a suitable solution for parallel synchronous and asynchronous implementations. A resource allocation algorithm based on the auction method for uplink OFDMA cellular networks is proposed in [4] and is shown to offer near-optimal performance. It is also shown that the scheme is well-suited to parallel and distributed implementations. In [5], the authors consider the uplink interference problem in OFDMA-based femtocell networks with partial co-channel deployment. The auction algorithm for macrocell users and femtocell users is shown to independently reduce the inter- and intra-tier interferences in the system compared to the existing methods. However, the auction algorithm in [5] does not consider cell-edge users' priorities in different cells. Instead, each cell runs the algorithm independently to minimize the ICI.

The contribution of this paper is three-fold: (1) A distributed resource allocation scheme based on auction algorithm for a multi-carrier LTE-A system is proposed where each User Equipment (UE) on each cell bids for its demand of resources from multiple carriers each sub-frame in a dynamic manner; (2) An infrequent price exchange method is proposed to minimize ICI in which each cell in the network exchanges the prices of resources with its neighbors where these prices reflect how crucial these resources are for the cell users; (3) Explicit usage of the Relative Narrowband Transmit Power (RNTP) indicator that is standardized in the LTE-A systems [6] to reduce the information exchange rate. The proposed methodology leads to two positive effects on the performance. First, it minimizes the amount of information exchange, particularly in LTE-A systems aggregating multiple carriers in which exchanging information regarding all resources causes high overhead. Second, the use of RNTP prevents releasing some allocations from neighboring cells that actually do not cause much interference, so it restricts the coordination on the resources that

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suffer from high ICI. We show that the proposed scheme produces significant gains in the cell-edge throughput as compared with systems without pricing exchange.

The rest of this paper is organized as follows. In Section II we describe the system model. The problem formulation is provided in Section III. Results and performance evaluation are provided in Section IV. Finally, conclusions are drawn in Section V.

II. SYSTEM MODEL

We consider a downlink LTE-A system with N cells and L carriers operating in Frequency-Division Duplex (FDD) mode. Each cell in the system comprises an enhanced NodeB (eNB), and a number of UEs, labeled as $\mathcal{U} = \{u_1, u_2, \dots, u_U\}$ uniformly distributed in the cell area. The terms user and UE are used interchangeably throughout this paper. UEs request a constant amount of data, expressed in bytes each sub-frame of 1 millisecond. A dynamic resource allocation is performed each sub-frame in which unsatisfied demand is added to the next sub-frame's demand.

We consider a two-level power allocation scheme in which the power of a resource allocated to the edge-user, denoted as p_e , is greater than the cell-center resource power, denoted p_c . The ratio between them is called the power ratio (PR) and is defined as:

$$PR = p_e/p_c \quad (1)$$

and obviously it is greater than one. To calculate p_e and p_c we assume that both cell-edge users and cell-center users have a share factor of the total power per carrier P_T denoted as w_e and w_c , respectively, where $0 < w_e, w_c < 1$ and $w_e + w_c \leq 1$. The share factors of cell-center and cell-edge users are determined according to the ratio of each of them in the system with respect to the total number of users. Then we can state that:

$$P_T = w_e \cdot p_e + w_c \cdot p_c \quad (2)$$

and therefore for a given P_T and PR, we can get p_c by substituting p_e from (1) in (2) and vice versa.

According to the LTE-A downlink system standard, a UE reports the channel state information (CSI) of the available resources to the serving eNB in terms of an index called the Channel Quality Indicator (CQI) index [6]. This index is reported in a periodic manner and has an integer value ranging from 1 to 15, each corresponding to a certain Signal-to-Interference-plus-Noise Ratio (SINR) range. Thus, the eNB does not have the exact SINR level of a UE, but a CQI value corresponding to what a Modulation and Coding Scheme (MCS) is needed for this user to maintain a Block Error Rate (BLER) $\leq 10^{-1}$ [6].

III. PROBLEM FORMULATION

A. The Assignment Problem

We formulate the problem as a symmetric assignment problem and solve it using the auction algorithm [2]. The assignment (weighted matching) problem is a 0-1 combinatorial optimization problem that can be solved easier than other combinatorial optimization problems since its linear programming polytope is the convex hull of its integer solutions [8]. It is usually solved by either the simplex method or the Hungarian method [9]. The assignment problem is similar to the transportation problem in that both problems aim at minimizing the cost (or maximizing the benefit) of shipping of units from the supply points (objects) to the demand points (persons). However, the difference is that in the assignment problem, the number of units on each supply point and demand point equals one. That is why it is considered a one-to-one matching problem. The objective of solving the assignment problem is to find a solution with maximum total benefit. The formulation of the assignment problem is as follows:

$$\max_{\mathbf{H}} \sum_i \sum_j f_{j,i} \eta_{j,i} \quad (3)$$

subject to

$$\begin{aligned} \sum_i \eta_{j,i} &= 1, \forall j \\ \sum_j \eta_{j,i} &= 1, \forall i \\ \eta_{j,i} &\in \{0,1\}, \forall i, \forall j \end{aligned}$$

where $\eta_{j,i}$ is a 0-1 combinatorial factor that determines if the object i is assigned to the person j or not and $f_{j,i}$ is the benefit from assigning the object i to the person j .

TABLE I. BASIC AUCTION ALGORITHM

Algorithm 1: Basic Auction Algorithm

1. **Initialization:** Set $0 < \epsilon < 1/n$; start with all prices equal zero (i.e., $r_i = 0, i = 1, \dots, n$); start with all persons unhappy.
2. **Repeat**
 - a) Choose an unhappy person and calculate its maximum profit $\gamma_{j,i_j} = \max_i \{f_{j,i} - r_i\}$ and its second maximum profit $\phi_{j,i_j} = \max_{i,i \neq i_j} \{f_{j,i} - r_i\}$.
 - b) Allocate the object i_j to person j . If the object was pre-assigned to another person j' , release the object from this person and set it as unhappy.
 - c) Update the price of object i_j to be $r_{i_j} = r_{i_j} + (\gamma_{j,i_j} - \phi_{j,i_j}) + \epsilon$.
 - d) Set person j as happy.
3. **Until** all persons are happy.

B. Problem Mapping

The problem of LTE-A multi-carrier resource assignment is formulated as an assignment problem as follows:

- On each carrier, the physical resource blocks (PRBs) being assigned to users represent the problem objects. Each resource block represents a separate unit in the problem.
- Each user in the system is divided into a number of sub-users equal to the number of PRBs needed to satisfy its traffic demand. This number of PRBs is calculated by converting their demand originally in bytes using the wideband CQI values. Thus, the objects in the assignment problem will be the sub-users, in which each of them requesting only one PRB, as to maintain the one-to-one matching of the formulation. Any user in the system is assumed to be able to access the entire bandwidth, i.e. can be assigned resources from any carrier. Furthermore, a user can be allocated multiple resources from different carriers simultaneously.
- The benefit of assigning an object to a person in the problem should be chosen to reflect the main objective of the optimization problem. Since the proportional fairness (PF) metric is known to be one of the most efficient and fair scheduling metrics, we choose the benefit to be the PF metric such that higher PF metric values increase the opportunity of assigning the corresponding resources. Therefore, the benefit can be expressed as:

$$f_{j,i} = \frac{R_{i,j}}{\bar{R}_j} \quad (4)$$

where $f_{j,i}$ is the benefit of assigning PRB i to user j , $R_{i,j}$ is the instantaneous rate of user j when assigned the PRB i and $\bar{R}_j = \sum_i \bar{R}_{i,j}$ is the historical total average rate for user j in the previous allocations over the entire bandwidth, and $\bar{R}_{i,j}$ is the average rate of user j over PRB i . The instantaneous rate is calculated by the use of the transport block size (TBS) tables standardized in [7]. This is done by mapping the reported CQI index to its corresponding MCS level and then, the TBS tables are used to determine the block size of one PRB in terms of bits.

The proposed solution is inspired from the auction algorithm [10] which is an intuitive method that operates like real auctions where persons compete for their favorable objects by raising their prices through competitive bidding. We apply the auction algorithm in a distributed fashion in each cell in the system to allocate the PRBs to users. However, cells apply infrequent prices exchange that represents how important the resources allocated to its cell-edge users are. This exchange is not for all resources allocated to cell-edge users but only for resources that is highly interfered by the neighbors and hence each cell attempts to coordinate with other cells in order to decide which of them needs this resource the most. The auction algorithm and pricing exchange mechanism is explained in the following subsections.

C. Auction Algorithm

In the symmetric assignment problem [10], the objective is to match in a one-to-one basis n persons and n objects in such a way that the total benefit is maximized given a benefit $f_{j,i}$ for matching person j to object i . If the problem is an asymmetric version of the assignment problems, namely the number of persons is greater or lower than the number of objects then the problem is converted to a symmetric one by adding dummy persons or objects in order to be able to solve it. Any matching of a dummy person to an object will not be considered after solving the problem. The auction algorithm is one of the efficient solutions to the assignment problems [2]. It emulates the bidding in real auctions by performing a competitive bidding process in which persons simultaneously bid for the objects and raise their prices to win their favorable ones.

The auction algorithm mainly consists of two phases: the bidding phase, in which persons bid for objects and the assignment phase in which objects are assigned to the highest bidder. It terminates when all persons become *happy* with their assignment. The person is considered happy for being within a positive scalar ϵ from the *optimal*. The optimal assignment is the one at which the person profit (profit is benefit minus price) from the assignment is maximum, i.e. $f_{j,i} - r_i$ is maximum for all i , where r_i is the current price of object i which is initialized to zero and updated as described in algorithm 1. The update of r_i attempts to make the difference between the best and the second best object to a bidder as the price that this bidder can afford to win the best object. Hence the person j is defined as happy with object i if:

$$f_{j,i_j} - r_{i_j} \geq \max_i \{f_{j,i} - r_i\} - \epsilon \quad (5)$$

The basic auction algorithm is explained in Table I.

D. Price Exchange Mechanism

In the proposed solution, the auction algorithm is applied separately on each cell to allocate PRBs to users. By using the two level power allocation scheme described in Section II, and without coordination between neighboring cells, the auction algorithm may allocate the same resource to two edge users in two adjacent cells, and hence high ICI values is expected on both of them. Although the resource allocation already considers the PF metric that is a function of the reported CQI index (and hence the SINR level) this CQI value cannot be a direct indication to the source of this interference, so it does not guarantee minimizing ICI by preventing allocations to adjacent cell-edge users.

To overcome this problem, we propose a price exchange mechanism that helps adjacent cells to determine which resource to use to serve edge-users and which to leave for other cells that could have a more pressing need for it. The proposed scheme exploits the auction algorithm mechanism in which the price paid by a user represents the difference between the maximum and the second maximum profit and hence it can be used as an indication of how important that resource is for this user. Since users compete for a resource by raising its price until one of them gets it, the latest price indicates how important this resource is for the winning user. The idea is to exploit this to determine the most eligible cell-edge user for a resource. This is done by allowing cells to exchange the latest prices of the cell-edge resources after an allocation and then, in the next sub-frames, they will modify their edge-users' bids to these resources by scaling them to higher or lower values, and therefore increase or decrease their opportunity to win certain resources. Subsequently, when a cell-edge user submits a regular bid then the cell will scale this bid to increase/decrease its possibility of winning this resource. We further define the factors of scaling the bid to higher and lower values to be s_h and s_l , respectively. The proposed scheme is performed according to the following steps:

- 1- Each cell reports to its neighbors the prices paid by its cell-edge users for their associated resources in an infrequent manner (e.g. each 10 sub-frames), so that if another cell finds that the price of a resource in a neighbor cell is higher, then it should try to minimize the probability of assigning this resource to its edge-users by scaling their bids in the next sub-frames to lower values by a factor s_l . To guarantee that the first cell will benefit from this resource that is released for it, when it finds that its price is greater than that of the second cell, it will scale the bids of its edge-users on this resource to higher values by a factor s_h to benefit from this released resource in the following sub-frames.
- 2- Since the interference seen by a certain cell on different PRBs varies due to the different propagation conditions on different frequencies, not each resource allocated to its cell-edge users suffers from high ICI values, and hence asking the other cells to release it will cause degradation in those cells without benefiting the first cell. For this reason, the scheme exploits the Relative Narrowband Transmit Power (RNTP) indicator that is exchanged by the neighboring cells in LTE systems. The RNTP is reported once per PRB in the downlink[6], indicating if the received interference power on that PRB with respect to the intended received signal power will be greater than a given threshold. Thus, neighboring cells can anticipate which resources would suffer more severe interference and take the right scheduling decisions rather than relying on the UEs' CQI reports only. In our scheme, each cell reports only the prices of the PRBs allocated to its edge-users if these PRBs suffer from high interference. These PRBs are defined as the interfering PRBs, other PRBs are defined as the non-interfering PRBs. In this case, the cell reports the RNTP value as standardized in LTE and indicates the price of this resource on the last allocation.
- 3- After the cell receives prices from the neighboring cells, it forms a matrix called the Price Exchange Matrix (PEM). The cell uses the PEM to modify the bids of cell-edge users before each allocation as described in step 1. It keeps the PEM to use in the subsequent sub-frames until cells prices are updated again (note that the exchange of pricing is totally asynchronous). Figure 1 shows an illustrative example of the PEM in a three-cell pricing exchange example with arbitrary price values. The example shows only the first three PRBs and is observed from the first cell's point of view. This table is assumed to be formed using the latest prices of the PRBs at the last sub-frame before the exchange. As shown, the cell 1 has the highest price for the first PRB so it should scale cell-edge users' bids to this resource to higher values (it is expected that cell 2 and cell 3 will scale their UEs bids to lower values to decrease the probability of assigning this PRB to their cell-edge users). For the second PRB, cell 2 has the highest price, so cell 1 and cell 3 should scale cell-edge users' bids to lower values to release it to cell 2. For the third PRB, no other cell is interested in the resource and suffering high ICI from it, so no scaling will occur and we call this PRB a non-interfering PRB, whereas other PRB's such as PRB1 and PRB2 are called interfering PRBs.

The auction algorithm for the resource allocation problem after applying the prices exchange mechanism is explained in Table II. The algorithm is repeated each sub-frame and each cell exchanges with its neighbors the final prices of the interfering PRBs allocated to its edge users each predetermined number of sub-frames. Cells update the PEM accordingly before proceeding to the next sub-frame.

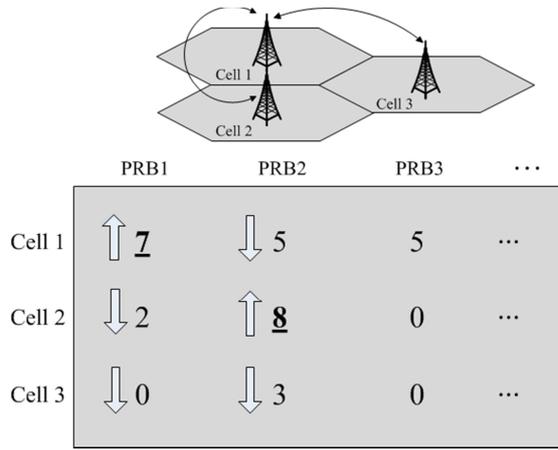


Figure 1. An example for the Price Exchange Matrix (PEM), for each PRB, the cell with the highest price increases cell-edge UEs' bids whereas other cells decrease them.

TABLE II. PROPOSED ALGORITHM

Algorithm 2: Auction Algorithm for resource allocation with prices exchange

1. **Initialization:** Set $\epsilon > 0$, $s_l < 1$, $s_h > 1$; start with all prices equal zero (i.e., $r_i = 0, i = 1, \dots, n$); start with all sub-users unhappy; start with the latest PEM version.
2. **Repeat**
 - a) Choose an unhappy sub-user, if it is located in the cell edge, scale its bids to the interfering PRBs by the scaling factors s_l or s_h according to the price values in the PEM.
 - b) Calculate its maximum profit $\gamma_{j,i_j} = \max_i \{f_{j,i} - r_i\}$ and its second maximum profit $\phi_{j,\bar{i}_j} = \max_{i,i \neq i_j} \{f_{j,i} - r_i\}$.
 - c) Allocate the PRB i_j to sub-user j . If the PRB was pre-assigned to another sub-user j' , release the PRB from this sub-user and set it as unhappy.
 - d) Update the price of PRB i_j to be $r_{i_j} = r_{i_j} + (\gamma_{j,i_j} - \phi_{j,\bar{i}_j}) + \epsilon$.
 - e) Set sub-user j as happy.
3. **Until** all sub-users are happy.
4. Update the PEM if there is a price exchange in the current sub-frame.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed scheme. We use the WINNER phase II C2 channel model as specified in [11]. We consider a multi-cell multi-carrier scenario, in which we perform the dynamic resource allocation process on the scheduled cells concurrently on each sub-frame. The main parameters used in the simulations are summarized in Table III. The cells layout is depicted in Figure 2 where scheduling takes part in all cells in the layout, however, throughput is calculated only in the three interior cells whereas the cells in the outer tier are simulated only to guarantee realistic interference on the interior cells.

Each cell contains 10 UEs distributed randomly in the cell area. Without loss of generality, we assume that 20-30% of UEs are located in the cell-edge whereas the rest are in the cell-center. A UE is considered as a cell-edge user if its distance from the center is more than 80% of the cell radius. The traffic demand for the users is generated in terms of a constant bit rate (CBR) application. A constant rate of 40 Mbps is offered in each cell.

To evaluate the performance of the proposed scheme, we compare it against the following schemes:

- A regular auction based scheme with *no exchange* between cells.
- An auction scheme with *full price exchange* in which all prices of resources allocated to edge users are exchanged. Therefore, the RNTP is not used.
- SFR-1 scheme: a soft-frequency-reuse (SFR) scheme that is used in [13] in which it allows for each 3 neighboring cells, cell-center users to access the whole bandwidth with lower power levels whereas one third of each carrier is assigned to edge users with higher power levels such that the resources used in the edge of three neighboring cells are orthogonal.
- SFR-2 scheme [13]: It is similar to SFR-1 scheme but cell-center users cannot access the entire bandwidth but only the two thirds of each carrier that is not assigned to cell-edge users. This guarantees that one third of resources are completely dedicated to cell-edge users.

The two SFR schemes explained above can be used as a benchmark to compare with since the second one achieves highest cell-edge throughput, this comes at the expense of highest degradation of the average throughput, since cell-center users are forced to

TABLE III. SIMULATION PARAMETERS

| Parameter | Value/description |
|--------------------------------|--|
| Layout scenario | Hexagonal grid with 3 interior cells, and 9 outer cells. Typical urban scenario [11] |
| Shadowing | Log-normal [11] |
| Carriers Bandwidth | Three aggregated carriers, 10 MHz each |
| Site-to-site distance | 500 m |
| Max. BS Tx power/CC | 46 dBm |
| Number of PRBs per CC | 50 PRB, each containing 12 subcarriers |
| Sub-frame duration | 1 ms |
| Simulation time | 1000 sub-frames |
| FFT size | 1024 |
| Antenna configuration | 1*1 |
| Traffic model | CBR (40 Mbps/cell) |
| Number of users | 10 users per cell |
| Thermal noise spectral density | -174 dBm/Hz |
| CQI reporting resolution | 3 PRBs/sub-band |

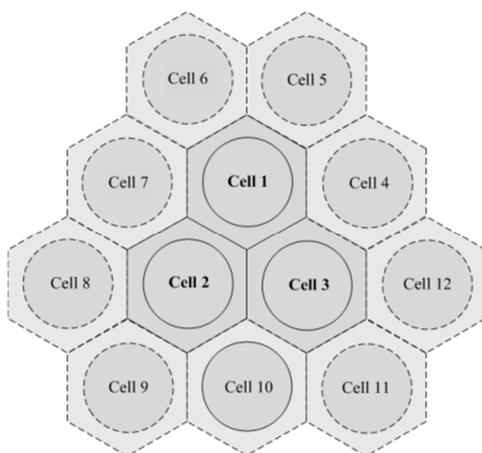


Figure 2. Cells layout

use only a predefined two thirds of resources. On the other hand, the first SFR scheme allows cell-center to access all resources including cell-edge portion, hence it provides the best average throughput but with relatively low improvement to the cell-edge. In both schemes, the local partitioning arrangement is applied (in which the partitioning is applied on each carrier separately) since it is shown in [13] that it performs better than a global partitioning when all users are capable of connecting to multiple carriers.

In the first experiment, we set the exchange rate to be once each 10 sub-frames. This means that the exchanged prices are used to form the PEM and this matrix is kept for use during a period of 10 sub-frames. We choose the scaling factors s_l and s_h to be 0.1 and 5, respectively. Further, we choose the RNTP threshold to be 1 so that the PRB is considered interfered when the Reference Signal Received Power (RSRP) of the interfering cells $RSRP_i$ is approximately 25% higher than the RSRP from the serving cell $RSRP_s$ (i.e. $RSRP_i / RSRP_s = 1 \text{ dB} \approx 1.25$). We also assume that the cell calculates the RSRP as expressed by its worst cell-edge user.

The cell-edge performance and the average performance of the proposed scheme for different power ratios are provided in Figure 3 and Figure 4, respectively, as compared against the schemes explained above. It is shown that the proposed scheme achieves significant gains in terms of cell-edge throughput as compared to the scheme without prices exchange. Both of them are also better than the SFR-1 scheme in terms of cell-edge UE throughput. However, SFR-2 scheme achieves the highest cell-edge throughput, but as explained above, this comes at the expense of achieving the worst average performance as shown in Figure 4. While SFR-1 on the contrary achieves the best average throughput, the proposed scheme is shown to achieve lower average performance but much better than SFR-2.

It is worth mentioning that the performance of the scheme with full-price exchange is lower than the proposed scheme that uses the RNTP. Although it may be thought that the exchange of information about higher number of resources will always lead to better performance, the results show the opposite. That is because exchanging prices of resources that are in fact not suffering from high interference may result in the whole set of neighboring cells trying not to allocate these resources to their edge users whereas their allocation may not be harmful to the cell that reported the prices. Moreover, a great advantage of the RNTP is that it significantly reduces the amount of data exchange needed since only a subset of the cell-edge resources will be considered in the coordination process. In a multi-carrier scenario, the amount of information exchange is a critical factor given the high number of PRBs used in the system.

In Figure 5, the same comparison is made with the geometric average of the UE throughput against the average cell-edge UE throughput. We use the geometric average of rates as in [12], expressed as:

$$\hat{R} = \left(\prod_{j=1}^U \bar{R}_j \right)^{\frac{1}{U}} = \exp \left(\frac{1}{U} \sum_{j=1}^U \ln(\bar{R}_j) \right) \quad (6)$$

since it is a good measure of system rate utility defined as sum of the log the users rate (the geometric average is then the exponent of the utility). The experiment is conducted while varying the power ratio from 4 to 10 with a step of two. The proposed scheme is simulated with two exchange rates of 5 and 10 sub-frames.

It is shown that for a given geometric average throughput, the proposed scheme achieves considerable gains in terms of cell-edge throughput than the schemes of no exchange and full exchange. Increasing the rate of exchanging prices increases the gains achieved by using the proposed scheme at the expense of increasing the information exchange overhead. Again, SFR-2 achieves the highest cell-edge throughput but with the lowest geometric average throughput.

It can be concluded that the RNTP is a good measure of the need to coordinate the allocation of a certain resource with neighbors. Using it along with auction prices exchange can lead to further improvement of the cell-edge throughput with lower decrease in the average throughput. This is unlike the static SFR schemes that rely on dedicating a portion of the resources to cell-edge users to improve their throughput, thus it sacrifices much of the cell-center throughput and hence the average throughput.

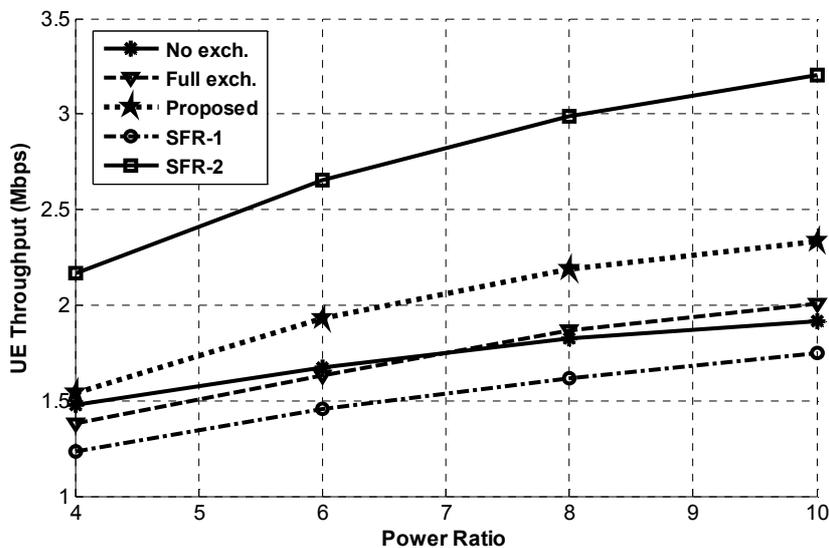


Figure 3. Average cell-edge UE throughput performance of the proposed scheme compared with other schemes for different power ratios

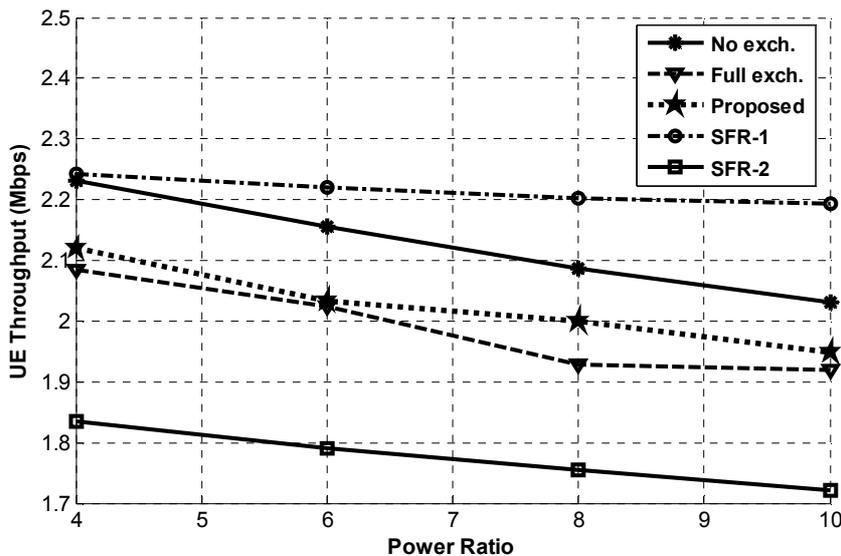


Figure 4. Average UE throughput performance of the proposed scheme compared with other schemes for different power ratios

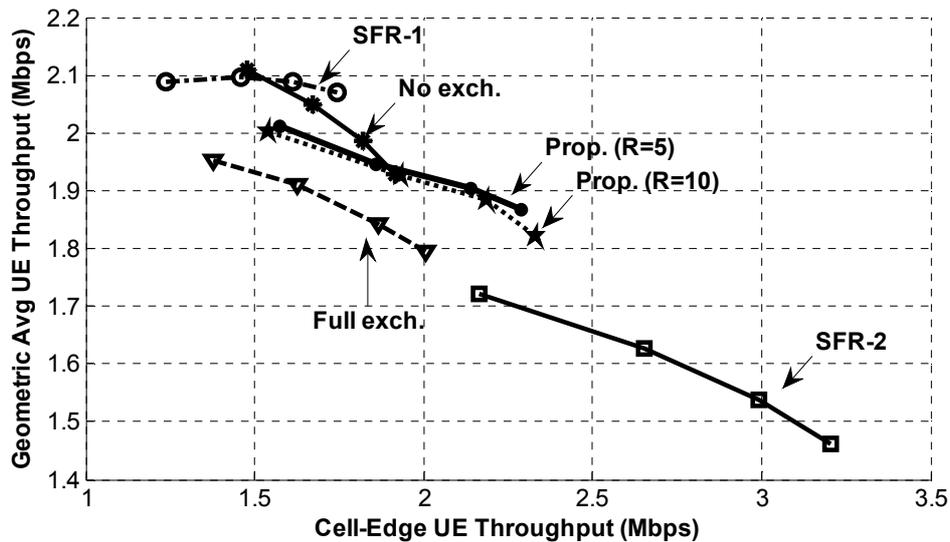


Figure 5. Geometric average throughput against cell-edge throughput for the proposed scheme for two different exchange periods(R=5 and R=10) compared to other schemes

V. CONCLUSIONS

In this paper, a novel resource allocation scheme in LTE-A downlink system based on auction algorithm is proposed. The problem is formulated as an assignment problem and a pricing exchange mechanism is proposed that is shown to reduce the inter-cell interference (ICI) significantly. Furthermore, the Relative Narrowband Transmit Power (RNTP) indicator is exploited to exchange only the prices of the resources that suffer high levels of interference to consider them only in the coordination process. It is shown that the proposed scheme significantly improves the cell-edge throughput at different exchange frequencies. Frequent exchange rates are shown to provide better performance, however, infrequent exchange rates also improve the cell-edge performance.

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