Balancing Resource Utilization and User Level Fairness of Femtocell Networks in Presence of Users Demands

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Abstract

Femtocells have been widely employed to improve poor indoor coverage and to lessen high cost of cellular networks. However, femtocells and macrocells share similar frequency bands leading to a major challenges in allocation of time/frequency resources. Fairness among femtocells and utilization of time/frequency resources are the main purpose of previous studies. However, the balance between femtocell-level fairness and utilization has been considered in a few number of previous studies. Nevertheless, providing user level fairness and QoS requirements are other main factors in user satisfaction which have not received adequate attention so far. In this paper, a centralized resource allocation algorithm has been proposed to improve the balance between user level fairness and radio resource utilization involving users' demands for radio resources. In this algorithm, two phases are employed independently. The first phase greedily assigns resources to femtocells to increase the reused spectrum utilization according to the proposed priority. The second phase is planned to guarantee the fairness between users with respect to their required resources whenever the residual resources are not further proportional to the unmet requirements. Comparing to the conventional method, the proposed method provides more improvement in terms of utilization and fairness due to consideration of the resource demands of femtocell users.

Keywords

Femtocell, Resource Allocation, Users Demand, Fairness, Utilization.

1 Introduction

In recent years, the world has encountered a rapid growth in mobile computing. It has been predicted that the number of Internet users that access via mobile devices will grow 25-fold between 2010 and 2015 [1]. Obviously, the traditional cellular network cannot support such amount of connections through the expensive deployment of macrocells [2]. Moreover, 45% of home users and 30% of business users are not satisfied due to poor indoor coverage while 66% calls and over 90% of data services happen indoor [3]. Therefore, Femtocell Access Points (FAPs) as a new solution are employed to provide better indoor coverage for consumers and cost reduction for cellular network operators [2]. FAP is a cellular access point with short-range, low-power, low-cost, and easy plug-and-play that is installed by consumers. User Equipments (UEs) are associated with FAPs through the air interface while the FAPs are connected to the operator core network via a broadband connection such as Digital Subscriber Line (DSL). There are several mode in access of FAPs; each UE is allowed to associate with open access FAPs while only authorized UEs can be associated with closed access ones [4].

In this paper, the smallest part of time-frequency resources (OFDM symbols) that can be assigned to a UE is assumed to be one Physical Resource Block (PRB). Each PRB uses 12 subchannels during 0.5 ms of time (one time slot). Similar to LTE, it is assumed that PRBs are assigned to UEs per Transmission Time Interval (TTI) which equals to 1 ms (two time slots).

As the FAPs share the same spectrum resources with macrocells, cross-tier interference between FAP users and macrocell users is possible in addition to co-tier interference from neighboring FAPs [5]. Assuming that PRBs allocated to the macrocell are separate from PRBs considered for femtocells, this paper only considers co-tier interference. Therefore, PRBs should be appropriately assigned to FAPs to mitigate the interference level and improve the network capacity.

Interference mitigation in a femtocell network is attained using power control mechanisms, resource allocation algorithms or both of them. In power control mechanisms, each FAP adjusts the transmission power per each PRB to mitigate the interference imposed on others and also to reduce the power consumption [6-10]. However, resource allocation algorithms try to mitigate the interference level by appropriate sharing of radio resources between various FAPs.

Maximizing resource utilization is the goal of some proposed resource allocation algorithms [11-13] while fair allocation of resources between FAPs is another objective considered in some other studies [14-17]. Those fairness methods assign the same amount of resources to the FAPs regardless of the number of UEs associated with them [14-15, 17]. However as the number of UEs associated with FAPs and their resource demands are different, this assignment may not be fair in user level. Achieving fairness among UEs has recently been focused by Lu et al. [16]. There, user level fairness means that each UE of the femtocell network obtains the same amount of resources comparing to other UEs regardless of the FAP that the UE is associated with it. However, UEs have different resource demands and their work does not consider this issue. While resource demands of users have been satisfied in a few number of previous studies [18-21], however they suffer from neglecting user level fairness.

Moreover, there is a tradeoff between fairness and utilization. This tradeoff has been considered in a few number of previous studies [7, 15, 17], however those have not regarded user level fairness and user demands.

Owing to lack of attention to those important factors, i.e. user level fairness, balance between utilization and fairness, and regarding resource demands of UEs, this paper tries to meet these criteria simultaneously. So, a centralized resource allocation algorithm is proposed to improve the balance between user level fairness and resource utilization besides satisfying demands of UEs. This algorithm models the interference between femtocells by a graph, and uses a novel idea to allocate the time-frequency resources based on the above purpose.

The remainder of this paper is organized as follows: Section 2 gives an overview of the previous works. Section 3 presents the system model and problem formulation. Section 4 introduces our solutions for resource allocation in OFDMA femtocell networks and Section 5 presents the simulation results. Finally, Section 6 concludes the paper.

2 Related work

The background of resource allocation is related to cellular networks. In [22], resource allocation has been considered in multi user OFDMA cellular networks to obtain fairness and increase utilization by maximizing the number of users satisfying QoS requirements. However, since the location and on-off status of the cells are stable comparing to femtocells, resource allocation in femtocell networks is more complex than traditional cellular networks.

Several studies have investigated the interference mitigation issues in femtocell networks. Adjusting transmission power of each frequency channel has been used independently or in combination with resource allocation algorithm as a solution for interference mitigation in several studies. In [9], authors have proposed a power control mechanism that ensures a constant femtocell radius in the downlink; but in [8] three control loops are proposed to protect uplink communications by adjusting UEs' power. Similarly, a power control mechanism has been considered in [6] for the sake of interference mitigation by a learning algorithm. In [10], a distributed graph coloring algorithm is proposed to maximize the utilization, as well as, power control mechanism used to reduce the power consumption. In [7], a distributed heuristic method is proposed to combine power control mechanism and resource allocation algorithm. This resource allocation algorithm is aimed to make proportional fairness between femtocells. However, power control mechanism may be used as an optional solution besides resource allocation algorithm. It is noteworthy that power control mechanisms have not been incorporated in our paper, so we do not investigate them further.

Resource allocation algorithms have been exploited as a solution in other studies. The main goal of these researches is one of the followings: maximizing utilization, maximizing fairness (max-min fairness), or balancing between fairness and utilization (proportional fairness). In [11] and [12], authors propose a distributed heuristic algorithm to minimize the total interference and maximize the utilization. In [13], a centralized graph coloring algorithm is aimed to maximize the utilization. This algorithm converts interference graph of femtocells to a chordal graph by adding a minimal set of edges. Then, the number of resources should be assigned to nodes of chordal graph is determined to maximize the utilization.

Max-min fairness and proportional fairness are considered in several studies as the goal of resource allocation algorithm. In [14-15], distributed graph coloring algorithms have been proposed by constructing FAPs' interference graph. These methods assign resources to each FAP based on fairness among them. Max-min fairness and proportional fairness are exploited to obtain those goals, respectively. In [17], authors have introduced a centralized graph coloring algorithm for assigning resources to the nodes (FAPs) based on constructed interference graph. Their proposed *simulated annealing* algorithm finds Maximal Independent Set (MIS) of interference graph as long as each node belongs to an MIS. Then, some resources are assigned to each MIS based on a rule which tries to attain proportional fairness among FAPs. Convergence time of simulated annealing algorithm is a shortcoming of that research.

Owing to the fact that fairness among FAPs does not necessarily result in fairness among UEs, user level fairness has recently been addressed by Lu et al. [16]. Their proposed method for interfering model of FAPs (INT algorithm) models the problem in open access mode; but it can be used in closed access mode with minor changes. The graph coloring algorithm repeatedly picks up an MIS of UEs and assigns one resource to this set. When all of the UEs are colored, the reused resources are assigned to UEs based on the user level fairness. As their proposed algorithm tries to find the minimum number of resources required for coloring the graph, it guarantees that each UE obtains at least one resource. However, allocation of more resources to the UEs has fairly been accomplished based on the reuse of the radio resources. As a limitation, this method has not proposed any solution when the number of total resources dedicated for FAPs is higher or lower than that minimum value.

While above mentioned researches have not paid attention to the requirements of users, user requirements have been considered in some other studies. In [19], resource allocation is modeled as a game theoretical approach that each player (FAP) seeks to maximize local utility. The local utility is defined in such a way that the required rate is fairly assigned to FAPs. In [18], a distributed learning algorithm is proposed to maximize utilization besides obtaining required resources. But the main limitation of game theory and learning approaches is slow convergence with respect to dynamic nature of femtocell networks. In [20], a centralized greedy algorithm called Resource Allocation scheme of Femtocell-to-Femtocell interference (RAFF) has been proposed to guarantee the rate and delay requirements. Herein, some classes of service are defined and if QoS could not be guaranteed for a demand with respect to its class, the admission control mechanism rejects it. Then, RAFF assigns resources to requests to maximize utilization. However, maximizing utilization without considering the fairness leads to dissatisfaction of further number of users. Also, RAFF is a simple greedy algorithm that does not guarantee to meet an optimal solution of the problem. Authors of [21] have proposed an improved solution based on [20] to solve the problem. The proposed algorithm, called Interference-Aware Resource Block Assignment (IARBA), assigns resources to FAPs using a centralized graph coloring algorithm. Maximal Weight Independent Set (MWIS) has been employed to find independent set of FAPs that have maximal sum weight (weight of each FAP is sum of minimum required resources).Then, resources are assigned to each member of MWIS to maximize utilization. IARBA only considers required resources and does not exhibit any mechanism to strictly satisfy tolerable delay of UEs. As a limitation, the fact that IARBA does not fairly assign resources to UEs may cause dissatisfaction of some users.

Due to the limitations of previous studies, in this paper, we introduce a new centralized graph coloring algorithm to improve the balance between user level fairness and time-frequency resource utilization whilst meeting required resources of UEs.

3 System model and problem formulation

In this section, we first present the model of the system and then describe the optimization problem defined based on the derived model.

3.1 system model

A network consisting of a macrocell and M FAPs, $F = \{f_1, f_2, \dots, f_M\}$ is assumed. Each FAP transmits with a fixed power p without any power control. To avoid cross-tier interference between femtocells and the macrocell, the set of usable PRBs dedicated for FAPs are separated from macrocell PRBs. Denoting total number of PRBs as N, the number of PRBs dedicated for FAPs as N_f, and the number of PRBs allocated to macrocell as N_m, the following equation holds:

$$N = N_f + N_m \tag{1}$$

The set $U = \{u_1, u_2, \dots, u_K\}$ denotes UEs where each user is only associated with a femtocell or the macrocell. The $K \times M$ matrix B demonstrates that which UE is now associated with which FAP, where K is the number of UEs in the system. As shown in Equation (2), B_{ij} indicates the association of UE i to femtocell j.

$$B_{ij} = \begin{cases} 1 & \text{user } i \text{ is connected to femtocell } j \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

When a UE is not associated with any of the femtocells, it is assumed that the UE is associated to the macrocell, as shown in the following equation:

$$\sum_{j=1}^{M} B_{ij} = \begin{cases} 1 & \text{user } i \text{ is connected to a femtocell} \\ 0 & \text{user } i \text{ is connected to the macrocell} \end{cases} \tag{3}$$

The number of UEs associated with FAP j is denoted by un_j which is calculated according to Equation (4). The set $UN = \{un_1, un_2, \dots, un_M\}$ shows the number of UEs associated with each FAP.

$$un_j = \sum_{k=1}^{K} B_{kj} \tag{4}$$

The above network can be modeled as a graph $G = (V, E)$ that its vertices, V, denote FAPs, and its edges, E, indicate the potential interference relations between FAPs assuming downlink communications. Denoting the maximum channel gain between FAP k and UEs associated with FAP n as $G_{n,k}^{max}$, the minimum channel gain between FAP n and its UEs as $G_{n,n}^{min}$, and the power of the additive white Gaussian noise as σ^2, the SINR value of the user of FAP n assuming that it only receives interference from FAP k is given by $SINR_{n,k}$ which can be expressed as Equation (5). When the minimum value of $SINR_{n,k}$ and $SINR_{k,n}$ is lower than SINR threshold, Γ, it is assumed that vertex n and vertex k are interfering and there is an edge between them in G as shown in Equation (6).

$$SINR_{n,k} = \frac{p \times G_{n,n}^{min}}{p \times G_{n,k}^{max} + \sigma^2} \tag{5}$$

$$E_{nk} = E_{kn} = \begin{cases} 1 & \min(SINR_{n,k}, SINR_{k,n}) < \Gamma \\ 0 & \min(SINR_{n,k}, SINR_{k,n}) \geq \Gamma \end{cases} \tag{6}$$

In this network, the $N_f \times M$ matrix *A* represents that which PRB is allocated to which FAP. As shown in Equation (7), A_{ij} indicates the allocation of PRB i to one of the UEs associated with FAP j.

$$A_{ij} = \begin{cases} 1 & \text{PRB } i \text{ is allocated to one of } the \text{ UEs associated with FAP } j \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

Assuming the required PRBs of UE i is represented by $reqU_i$ with respect to its demand, the set $REQ\_U = \{reqU_1, reqU_2, \dots, reqU_K\}$ denotes required resources of all UEs. As shown in Equation (8), required PRBs of femtocell j is denoted by $reqF_j$ which is the sum of its UEs' requirements. So, the set $REQ\_F = \{reqF_1, reqF_2, \dots, reqF_M\}$ demonstrates the number of required PRBs for each FAP.

$$reqF_j = \sum_{i=1}^{K} (B_{ij} \times reqU_i) \tag{8}$$

3.2 problem formulation

As the set of usable PRBs dedicated for the FAPs are separated from macrocell PRBs (according to Equation (1)), the presence of macrocell users are not important and it is assumed that all of *K* UEs are associated with femtocells. In the resource allocation problem, each FAP acquires some PRBs. Assuming that FAPs can obtain the same gain from each PRB, the quota allocated to FAP i (namely rf_i) is described as the total number of PRBs allocated to FAP i, as shown in the following Equation:

$$rf_i = \sum_{k=1}^{N_f} A_{ki} \tag{9}$$

Since each FAP tries to fairly share the PRBs between its UEs, the average number of PRBs allocated to *j*th UE associated with *i*th FAP is calculated according to Equation (10).

$$\overline{ru_j} = \frac{rf_i}{reqF_i} \times reqU_j \tag{10}$$

The resource allocation is the problem of optimally allocating PRBs to the FAPs. Therefore, the PRB assignment (matrix *A*) should be attained in such a way that both the user level fairness and the resource utilization of the system are maximized. The user level fairness shown in Equation (11) is defined as max-min fairness. The equation implies that the minimum number of assigned PRBs with respect to the user demand should be maximized among UEs. On the Other hand, maximizing the utilization of PRBs is expressed in Equation (12). This equation aims to maximize the total reuse (namely *TR*) obtained from allocation of PRBs which is the total number of times that each PRB has been utilized through the femtocell network.

$$\max_{A} \min_{1 \leq i \leq K} \frac{\overline{ru_i}}{reqU_i} \tag{11}$$

$$\max_{A} \left(TR = \frac{\sum_{i=1}^{K} \overline{ru_i}}{N_f}\right) \tag{12}$$

Since there is a tradeoff between fairness (Equation (11)) and utilization (Equation (12)), maximizing both of them is not possible independently. Therefore, maximizing the balance between user level fairness and resource utilization is regarded. This balance is motivated from the idea in [23] and defined as multiplication of fairness and utilization which is shown in Equation (13). In this equation, the first term of multiplication demonstrates the utilization (Equation 12) while the second term represents the fairness level which has been formulated as Jain index [24] with respect to the user requirements (Equation 14).

$$\max_{A} TR \times JF \tag{13}$$

$$JF = \frac{(\sum_{i=1}^{K} x_i)^2}{K.\sum_{i=1}^{K} x_i^2} \quad where\ x_i = \frac{\overline{ru}_i}{reqU_i} \tag{14}$$

Moreover, to avoid the interference between neighboring FAPs, the same PRBs are not assigned to the UEs associated with the interfering FAPs, as shown in Equation (15). Also, the ratio of PRBs assigned to each FAP should not be greater than the sum of its UEs' demands, as shown in Equation (16). In fact there is no guarantee for users' demands to be completely satisfied.

$$\forall (\mathrm{i}, \mathrm{j}, \mathrm{k}) \in \{1,2,, \dots, M\}\colon E_{ik} \times \left(A_{ji} \times A_{jk}\right) = 0 \tag{15}$$

$$\forall i \in \{1,2,, \dots, M\}\colon 0 \le rf_i \le reqF_i \tag{16}$$

Therefore, resource allocation problem can be represented as the optimization problem of Equation (13) regarding Equations (15-16) as constraints. Similar to optimization problems defined in previous works such as [16], the proposed optimization problems is NP-hard. Therefore, a centralized heuristic algorithm is proposed to achieve its near optimal solutions as will be discussed in the next section.

4 Proposed method

Considering the graph *G* introduced in Section 3.1, the resource allocation problem can be modeled as a graph multi coloring problem [25], where each node (FAP) should be assigned some colors (some PRBs with respect to its UEs' demands). The flow chart of our proposed algorithm, which solves the graph multi coloring problem in reasonable time, has been demonstrated in Figure 1. The algorithm is performed by a central entity called Femtocell Management System (FMS), which is assumed to be available in network backhaul regarding 3GPP specifications [26]. Some previous works have also considered this entity in their method [20-21, 27-28].

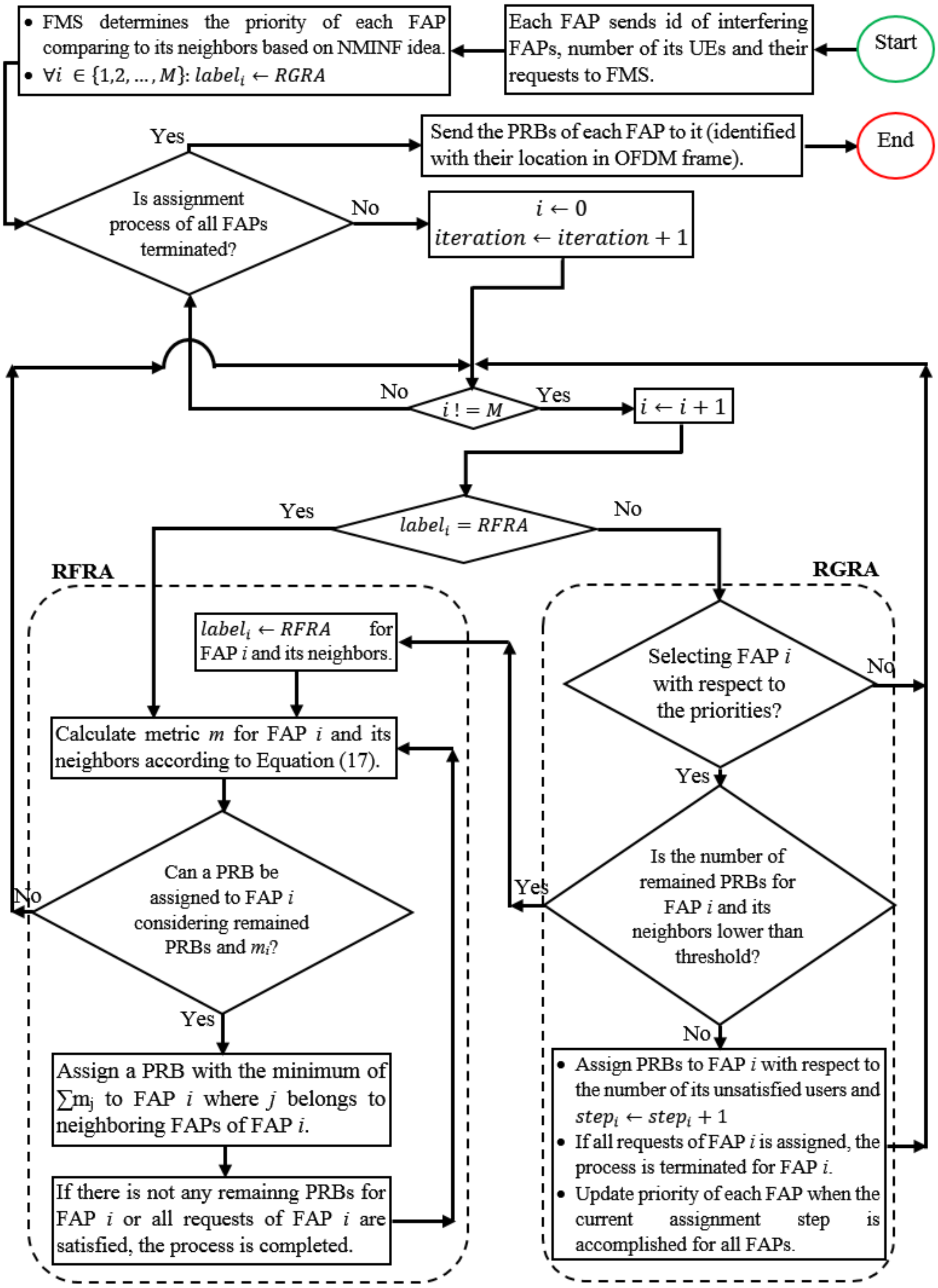


Fig. 1. Flowchart of the proposed method.

Each FAP sends *ID* of its interfering FAPs, number of UEs, and their requests to FMS, so it constructs graph *G*, set *UN* and set *REQ_U*. It is also assumed that FMS knows N_f. Therefore, it calculates the priority of each FAP comparing to its neighbors based on our proposed idea, namely Neighbors of Maximum Interfering Node First (NMINF). In fact, this idea means that the neighbors of the FAP with more Interference Level (IL) have higher priority than others. The IL of each FAP is computed as the number of UEs associated with that FAP plus the number of UEs associated to its neighbors. It is noteworthy that firstly attending the FAPs with higher IL increases the total number of PRBs that are required to satisfying requirements of all FAPs. Therefore, the rationale behind the NMINF is to firstly attending the neighbors of such FAPs. As a result, the neighbors of such FAPs are assigned higher priority than others to better reuse the PRBs among FAPs leading to increase of the utilization of the system, as defined in Equation (12).

Figure 2 demonstrates an example to clarify the NMINF idea. In this figure, a femtocell network is assumed that contains 6 interfering FAPs with their UEs. Each UE needs some PRBs as illustrated in the figure, e.g. the UE1 associated to FAP1 requires 2 PRBs. Using NMINF idea, IL of each FAP is computed and finally resources are assigned to FAPs in order of their IL as illustrated in Figure 2. Results of NMINF have also been compared to the results of MIS idea exploited in some previous studies such as [16], [17]. In each iteration of MIS, maximum non-interfering FAPs are selected, and number of PRBs required by their UEs is assigned to them. This example shows that the NMINF idea needs fewer PRBs to satisfy all UEs' demands comparing to MIS since neighbors of the FAP with more IL (FAP 3) have been attended before. So, PRBs are reused between neighbors of FAP 3 and as a result, the number of total required PRBs has been reduced.

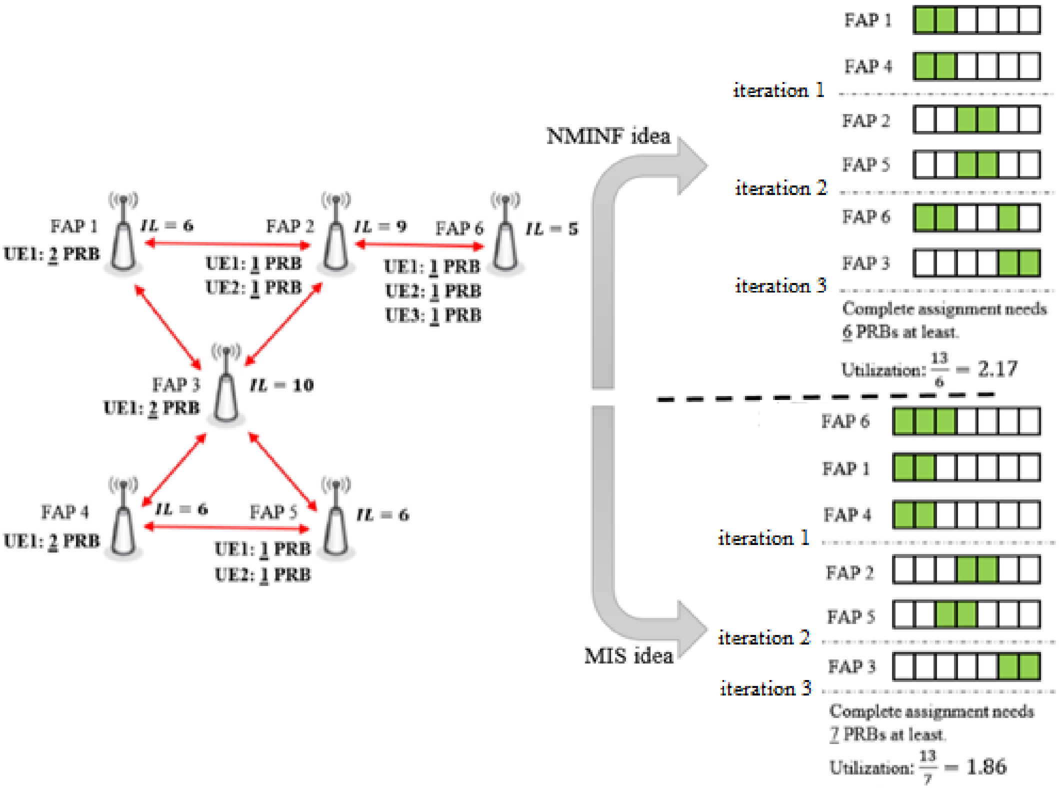


Fig. 2. Comparing assignments of NMINF and MIS ideas in a sample femtocell network.

After stating the priorities of FAPs, two main loops are executed. Outer loop checks whether the allocation task has been completed for all FAPs, while inner loop performs some PRBs assignment to FAPs during an iteration. This assignment process starts with Request based Greedy Resource Allocation (RGRA) phase for each FAP, but it may be continued with Request based Fair Resource Allocation (RFRA) phase whenever the resources of the FAP and its neighbors are not sufficient for greedy PRB grabbing. Therefore, entering to RFRA phase is checked at the beginning of the inner loop.

RGRA phase works according to the NMINF based priority. Therefore, for each FAP, the algorithm performs the RGRA phase if its neighboring FAPs with higher priority are in higher step, and the neighboring FAPs with lower priority are in the same step. Since RGRA assigns PRBs to FAP *i* with respect to the number of its unsatisfied UEs, the remaining PRBs for FAP *i* and the remaining PRBs of its neighbors may be lower than their unsatisfied UEs, consequently next assignment would be unfair. In this case, the assignment process for FAP i and its neighbors is switched to RFRA phase to fairly assign the remaining PRBs to them as will be discussed later. However, if the assignment do not switch to RFRA phase, PRBs are assigned to FAP i with respect to the number of its unsatisfied users and the assignment step of FAP i is increased by one. Each UE is satisfied when all of its requested PRBs are assigned according to its demand. Consequently, as some UEs of each FAP may be satisfied after each step, IL of some FAPs and their neighbors may be reduced. Therefore, priority of each FAP is updated when the current assignment step has been accomplished for all FAPs.

RFRA phase is aimed to fairly allocate the remaining PRBs from previous phase one by one. First when the lable of a FAP is switched to RFRA phase, this phase also should be considered for neghboring FAPs if they have not already been labeled for this phase. It leads to propagation of this phase to other FAPs. Then, according to Equation (17), the metric *m* is calculated for FAP *i* and its neighbors. Higher value of metric m_i specifies more neediness and criticality of FAP *i* comparing to its neighboring FAPs. This metric depends on three terms which is recognized with parentheses: 1) number of remained (unsatisfied) request, 2) number of remaining assignable PRBs, and 3) number of assigned (satisfied) request.

$$m_i = \frac{(reqF_i - rf_i)}{(number\_of\_assignable\_\mathrm{PRBs}_i) + (rf_i)} \tag{17}$$

Metric *m* is aimed to properly manage the FAP priority with respect to the fairness requirement. This metric attends to achieve near optimal solution. When PRB *k* is assigned to FAP *i*, the first and the second term of m_i decrease, however the third term increases and consequently m_i decreases. On the other hand, the metric of neighboring FAPs increases (because of decrease in second term) if they also have PRB *k* in their set of assignable PRBs.

After calculating metric *m*, for each assignable PRB *k*, if FAP *i* has a metric greater than the metric of its neighboring FAPs having PRB *k* in their set of assignable PRBs, PRB *k* is qualified for being assigned to FAP *i* and is inserted to candidate PRBs list. If candidate PRBs list is not empty, PRB *k* is selected from the list and assigned to FAP *i* based on the criterion that aggregate metric of the neighboring FAPs that have PRB *k* in their assignable PRBs, gets minimum. This results to selecting the PRB with minimum criticality regarding neediness of neighboring FAPs. If there is not any remaining PRBs for FAP *i* or all resource requests of UEs of FAP *i* have been satisfied, its assignment process is completed. Whenever the assignment process of all FAPs are terminated, FMS informs each FAP about the PRBs allocated to it.

5 Numerical Results

In this section, the proposed algorithm is evaluated in an OFDMA based simulated network. System parameters and simulation assumptions are shown in Table 1. Regarding Equation (1), the PRBs dedicated to FAPs are separated from macrocell PRBs to avoid the cross-tier interference and so macrocell and its UEs have been ignored in simulations. The whole frequency band is assumed to be 5 MHz that makes 50 PRBs available in each TTI. The fraction of PRBs allocated to femtocell network is variable for each scenario and has not been specified in Table 1.

Table 1. System parameters and simulation assumptions.

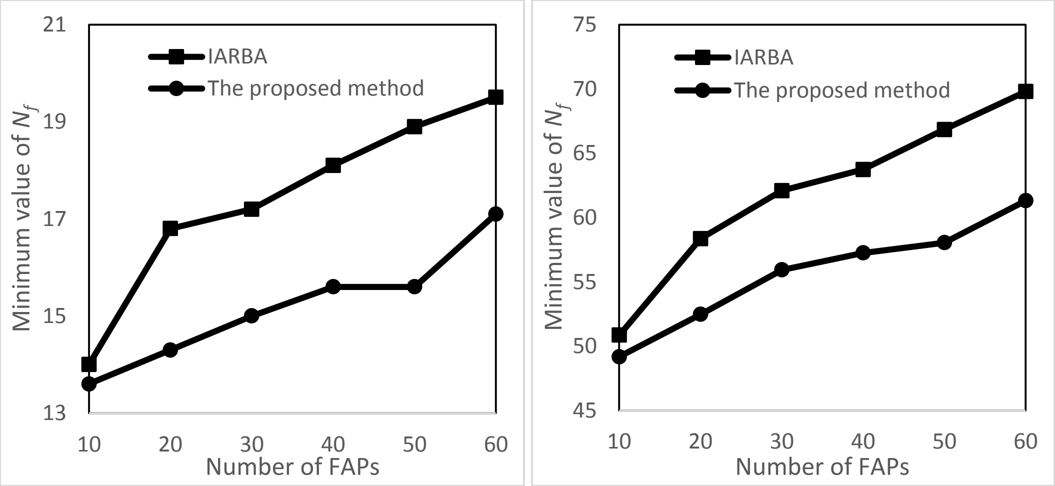
Parameters	Setting
Carrier frequency	2 GHz
FAP power	13 dBm
Path loss	$20\log_{10}(\mathrm{d}) + 38.46$
Noise power	9 dB
Bandwidth	5 MHz (50 available PRBs in each TTI)
Modulation	64 QAM
Apartment size	$10\mathrm{m} \times 10\mathrm{m}$
FAP layout	Grid model
Number of FAPs	$\{10,20,30,40,50,60\}$
Number of UEs associated with each FAP	$\{1,2,3,4,5\}$
Number of required PRBs by each UE	$\{1,2,3,4,5,6\}$
UE location in each apartment	Uniform random distribution
FAP location in each apartment	Center of apartment

In each simulation scenario, FAPs are assumed to be arranged in a grid model and are located in the center of a $10\mathrm{m} \times 10\mathrm{m}$ apartment. The number of FAPs is assumed to be between 10 and 60 depending on each scenario. The path loss is determined by $20\log_{10}(\mathrm{d}) + 38.46$ at distance d meters from transmitter [29]. The number of UEs associated with each FAP is assumed to be between 1 and 5 and UEs are randomly located in apartments based on uniform distribution. Each UE demands for a random number of PRBs between 1 and 6 according to uniform distribution. Each UE sends its report about the neighboring FAPs to its serving FAP. Considering the received reports, each FAP identifies its neighboring FAPs based on the mean interference level from the other FAPs (according to Equations (6-7)) and reports it to the FMS to build the interference graph G. Moreover, each FAP sends the number of UEs and their required PRBs to FMS, too. Whenever there is a modification in interference graph or attributes of FAPs (e.g. number of UEs or their demands), the FMS repeats the algorithm again to obtain up to date allocations based on recently modified state and the results will be applied after the next coming TTI.

5.1 simulation results

Our Simulation results are compared to the centralized IARBA algorithm introduced in [21]. As discussed earlier, a centralized MWIS algorithm has been employed in [21] to maximize the radio resource utilization besides considering UEs demands. The simulations are performed on 100 random scenarios and the average of simulation results is reported.

The first evaluated criterion is minimum number of PRBs required for satisfying demands versus the number of FAPs as shown in Figure 3. Figure 3 compares the minimum value of N_f using each method in two different scenarios. In Figure 3 (a), we compare the minimum required PRBs to allocate just 1 PRB to each UE (the case without resource demand of UEs). However, in Figure 3 (b) minimum number of required PRBs for satisfaction of UEs' demands has been represented versus the number of FAPs (in this experiment, it is assumed that 100 PRBs are available regarding 10MHz bandwidth). This figure shows that the proposed method requires smaller number of PRBs than IARBA method to cover the user demands which is a measure of its superiority.



(a) (b)

Figure. 3. Minimum value of N_f in allocating (a) 1 PRB to each UE and (b) all demands of UEs versus the number of FAPs.

For the deployed scenarios with 60 FAPs, the user level fairness (Equation 14), PRB utilization (Equation 12), and multiplication of fairness and utilization ($TR \times JF$) have been plotted versus the value of N_f for both the proposed method and IARBA as shown in Figures 4 to 6. Figure 4 shows that the proposed method provides better fairness index comparing to IARBA especially whenever the number of available resources (N_f) is limited. Although IARBA is aimed to maximize PRB utilization, however its utilization is also considerably lower than the proposed method especially whenever the number of available resources is fewer. Moreover as shown in Figure 6, the proposed method provides better balance between fairness and utilization comparing to IARBA.

According to these figures, increasing N_f leads to more unused PRBs and so the PRB utilization is decreased. However, UEs' demands are more satisfied and consequently the user level fairness is increased. Therefore, multiplication of fairness and utilization represents a convex curve.

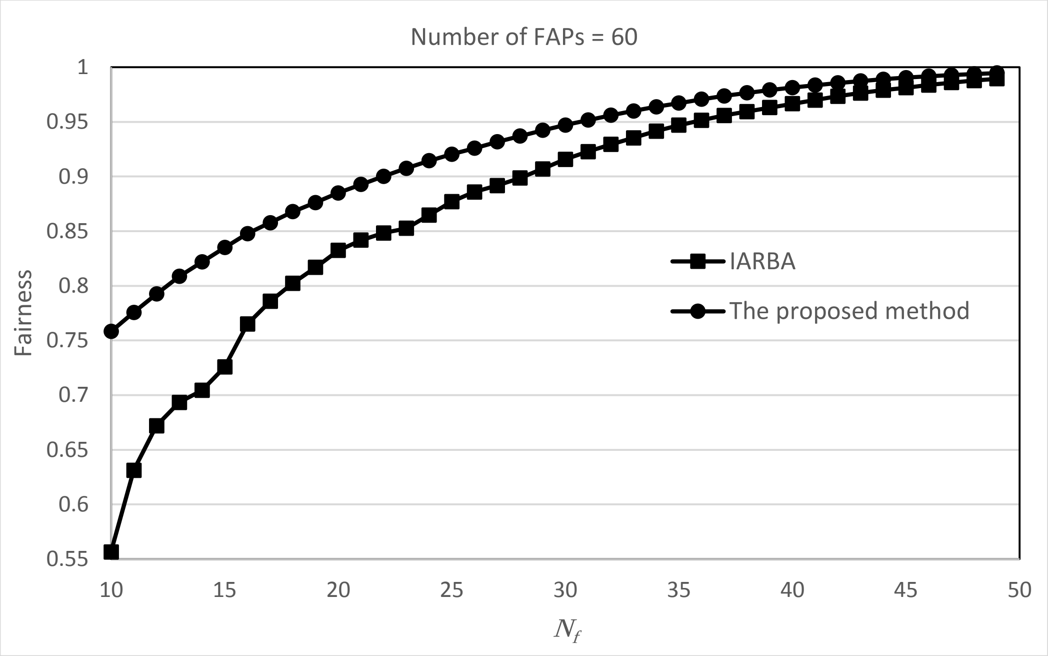


Fig. 4. Comparison of user level fairness versus N_f.

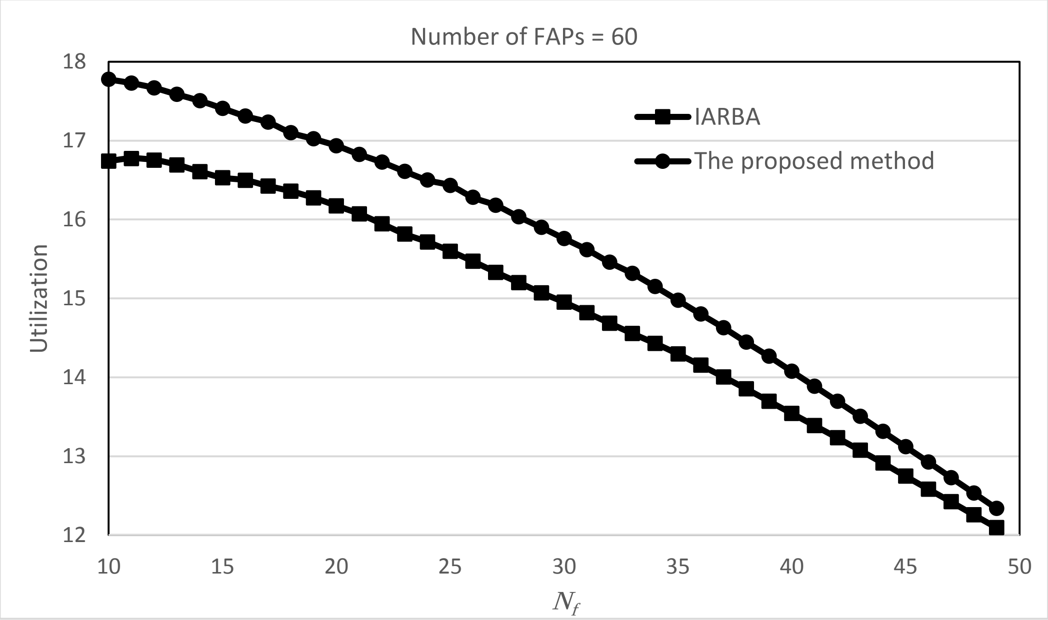


Fig. 5. Comparison of PRB utilization versus N_f.

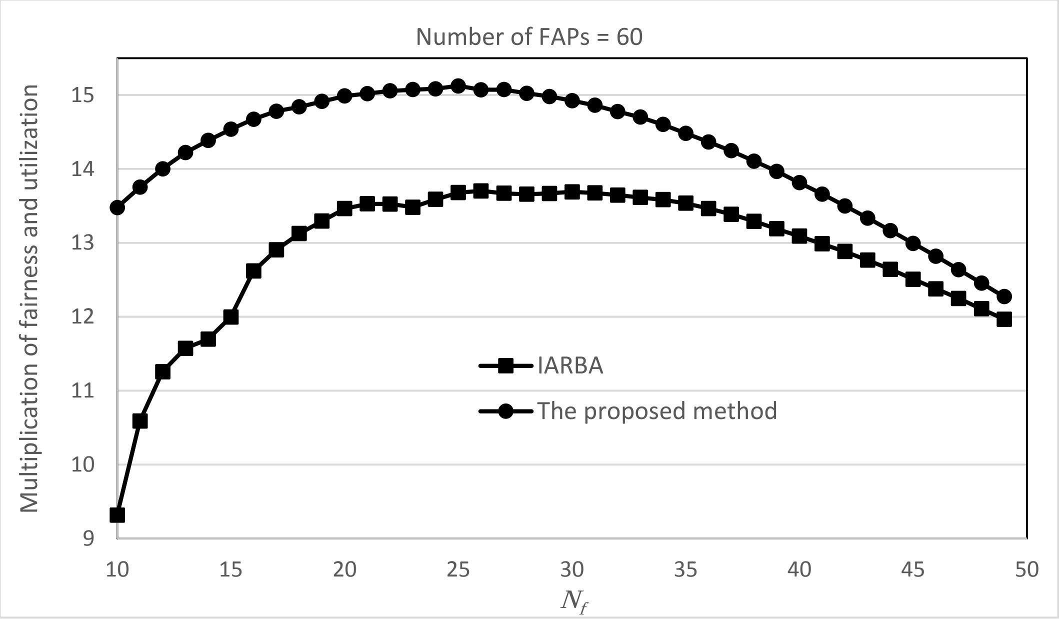
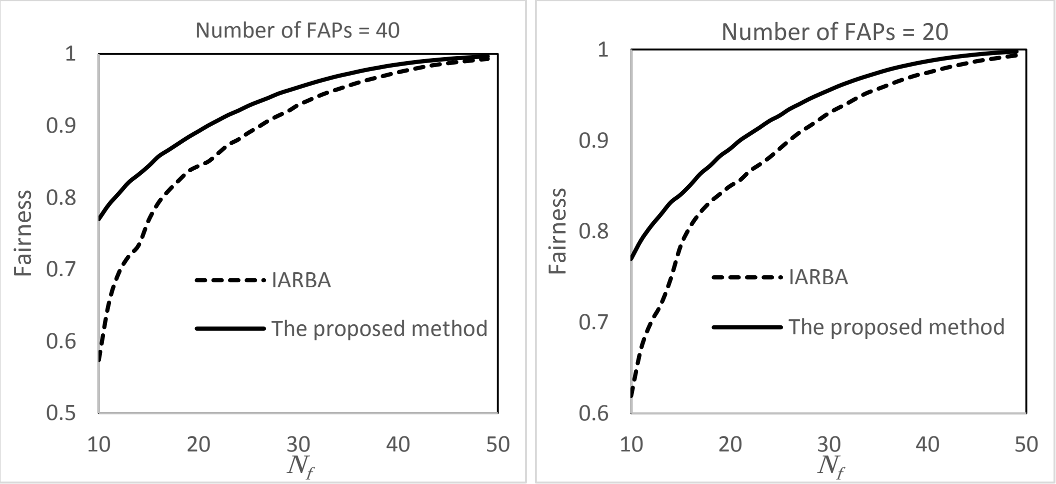


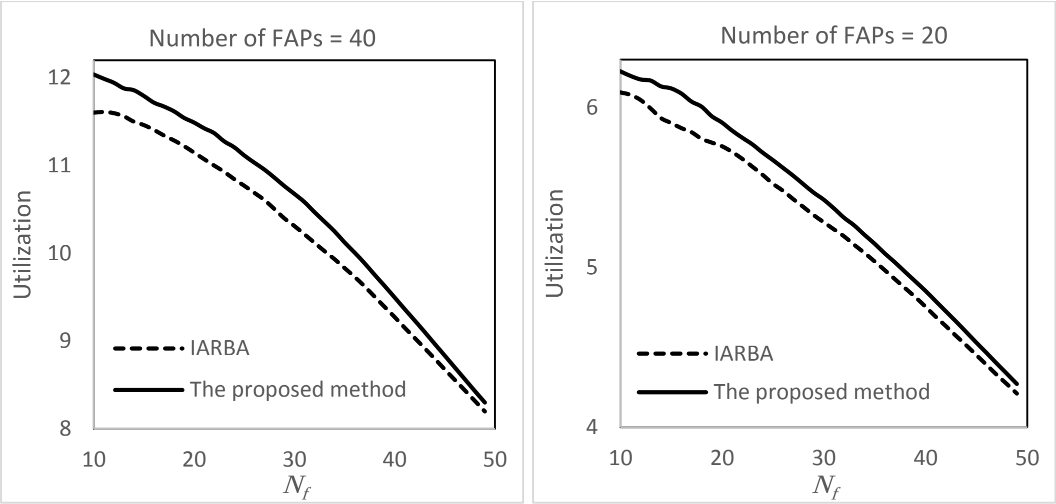
Fig. 6. Comparison of multiplication of fairness and utilization versus N_f.

Similarly Figures 7 to 9 are results of scenarios with 20 and 40 FAPs. In these figures, the proposed method and IARBA are compared in terms of user level fairness, PRB utilization, and multiplication of fairness and utilization versus the value of N_f. These figures confirm the superiority of the proposed method comparing to IARBA method too.



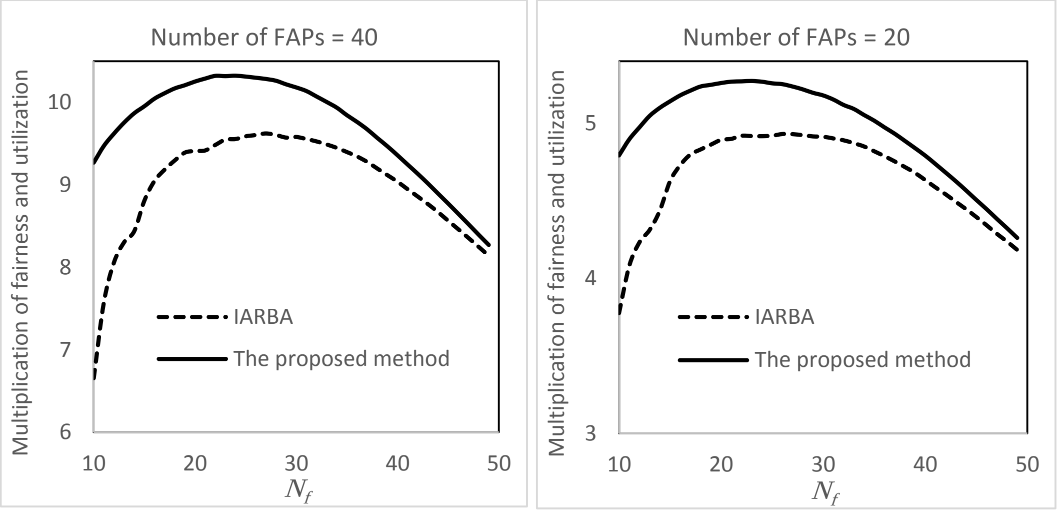
(a) (b)

Fig. 7. Comparison of user level fairness versus N_f with (a) 40 FAPs, (b) 20 FAPs.



(a) (b)

Fig. 8. Comparison of PRB utilization versus N_f with (a) 40 FAPs, (b) 20 FAPs.



(a) (b)

Fig. 9. Comparison of multiplication of fairness and utilization versus N_f with (a) 40 FAPs, (b) 20 FAPs.

In [21], the Authors compare IARBA to their previous RAFF method introduced in [20]. The simulation results in [21] show that the IARBA method acquire 11% more utilization than RAFF method. Therefore, higher utilization of the proposed method can also be concluded comparing to RAFF method.

5.2 complexity analysis

In this section, we analyze the time complexity of the proposed method and compare it to IARBA method of [21]. In the proposed method, firstly priority of each FAP is determined based on NMINF idea as discussed in section 4. The pseudo code of calculating priorities is shown in Table 2. It is clear that the time complexity of applying this algorithm for all FAPs is of order $O(M\Delta^2)$ in the worst case, where Δ is the maximum degree of nodes in interference graph G.

Table 2. Pseudo code of calculated priorities based on NMINF idea.

```
1- Calculate the Interference Level of Neighbors List ($ILNL$):
    $ILNL_i = [IL_{j:\forall j \in Neighbors_i}]$ sorted in descending order
2- Compare members of $ILNL_i$ to member of $ILNL_j$, $\forall j \in Neighbors_i$ one by one as follows:
    $\begin{cases} ILNL_i[k] = ILNL_j[k]: & \text{continue with next } k \\ ILNL_i[k] > ILNL_j[k]: & \text{add } j \text{ to priority list of node } i \ (P_i) \\ ILNL_i[k] < ILNL_j[k]: & \text{add } i \text{ to priority list of node } j \ (P_j) \end{cases}$
```

Next, two main loops are executed and in inner loop, the algorithm enters either the RGRA or RFRA phases for each FAP. The time consuming part of RGRA phase is related to assigning unused PRBs to a FAP (the first item inside the third box of RGRA phase shown in Figure 1) that the pseudo code of this process is shown in Table 3. Obviously, the time complexity is of order $O(N_f \Delta N_f)$ in the worst case. In RGRA, priority of each FAP is updated when the current assignment step is accomplished for all FAPs (the third item inside the third box of RGRA phase shown in Figure 1) which is not repeated per each execution round of RGRA phase. Therefore, we will consider its time complexity in next paragraph in conjunction with other parts of the algorithm with respect to the number of total executions of the outer loop.

Table 3. Pseudo code of assigning unused PRBs in RGRA phase.

```
for PRB p from 1 to $N_f$ do
    if (Assigning one PRB to each unsatisfied user of FAP i has not been completed yet) AND
        ($p \notin$ assigned PRBs of FAP $i$ AND $p \notin$ assigned PRBs of FAP $j_{\forall j \in Neighbors_i}$) then
            add p to assigned PRBs of FAP i
    end if
end for
```

The time consuming part of RFRA phase is related to assigning a PRB with the minimum of aggregate metric (the forth box of RFRA phase shown in Figure 1) that the pseudo code of this part has been shown in Table 4. Obviously, the time complexity is of order $O(N_f \Delta N_f)$ in the worst case. Therefore, the time complexity of one execution round of RGRA/RFRA phases is of order $O(\Delta N_f^2)$ and is equivalent for both phases.

Table 4. Pseudo code of assigning a PRB with the minimum of aggregate metric in RFRA phase.

```
$\min_{k \in \, candidate \ PRBs \ list \ for \ FAP \ i} \sum_{k \in \, assignable \ PRBs \ for \ FAP \ j} metric_{j:\forall j \in Neighbors_i}$
```

After entering the resource allocation process per each FAP, the RGRA phase is executed only once while RFRA loop may be repeated some times. The number of times that both the RGRA and the RFRA phases are executed depends on input parameters and is not straightly measurable. To overcome this difficulty, the total execution rounds of RFRA loop plus RGRA phase has been estimated by counting them in some simulations with varying settings. Simulation results show that total number of those executions is a function of both M and N_f and is of order $O(MN_f)$ in the worst case. Therefore, the time complexity of the outer loop is in $O(MN_f \times \Delta N_f^2)$ in the worst case. Moreover, the number of times that the priority of FAPs are updated in RGRA is not straightly measurable too. However, similar experimental analysis has shown that number of executions is a linear function of both M and N_f and is of order $O(MN_f)$ in the worst case. Therefore, the time complexity of priority updates is of order $O(MN_f \times M\Delta^2)$ in the worst case.

Therefore, the proposed algorithm has a complexity of $O(M\Delta^2) + O(M^2\Delta^2 N_f) + O(M\Delta N_f^3)$ in the worst case. Since N_f is a constant value, it can be ignored in complexity comparisons and thus complexity is of order $O(M\Delta^2) + O(M^2\Delta^2) + O(M\Delta)$. So, the time complexity of the proposed method is of order $O(M^2\Delta^2)$ in the worst case. In a dense graph that each FAP is interfering to most FAPs, Δ value is near to M; and as a result the complexity is of order $O(M^4)$. However, if each FAP is interfering to a few others (which is conventional), Δ value is negligible comparing to M and thus the complexity is of order $O(M^2)$. In conventional femtocell networks, each FAP is usually interfering to a few nearby FAPs and so Δ value would be small and negligible comparing to M.

Table 5 compares the time complexity of the proposed resource allocation algorithm to IARBA. The IARBA algorithm [21] employs an MWIS discovery method with time complexity of $O(M^2)$. The MWIS is executed Δ times in the worst case and so the time complexity of IARBA is of order $O(M^2\Delta)$. Therefore, the time complexity of IARBA is between $O(M^2)$ and $O(M^3)$ with respect to Δ regarding density of femtocell network. The results show that the time complexity of proposed method is almost equal to IARBA method in conventional scenarios of femtocell networks.

Table 5. Time complexity comparison of the resource allocation algorithms.

	Complexity (worst case)		
method	**general**	$\Delta \ll \boldsymbol{M}$	$\Delta \approx \boldsymbol{M}$
IARBA [21]	$O(M^2\Delta)$	$O(M^2)$	$O(M^3)$
The proposed method	$O(M^2\Delta^2)$	$O(M^2)$	$O(M^4)$

6 Conclusion

In this paper, a novel method has been proposed to allocate PRBs to FAPs in OFDMA based femtocell networks. This method is aimed to improve the balance between the user level fairness and the radio resource utilization as well as satisfying the resource requirements of UEs. So the femtocell network was modeled as an interference graph in which each FAP needs some PRBs regarding to their UEs requests and an algorithm was proposed which employs two independent phases of the resource allocation on that graph. In the first phase, the priorities of FAPs are determined based on an idea called NMINF in order to improve the reuse factor and consequently the resource utilization. However, the second phase, called RFRA, is applied based on a fair prioritizing metric to improve user level fairness, whenever the number of remaining PRBs is not sufficient with respect to the resource requirements of unsatisfied users. The proposed method is compared to a conventional method in terms of user level fairness, PRB utilization and multiplication of fairness and utilization in addition to the minimum number of required PRBs to satisfy the demands of all UEs. The simulation results show that the proposed method has better performance than the conventional method in terms of the above measures. Time complexity analysis of two methods shows that the proposed method is almost similar to the compared one in conventional deployment of femtocell networks. As the proposed algorithm is based on the information gathered from the neighboring FAPs and their neighbors, a distributed algorithm based on this idea is considered for the future research. Moreover, extending the proposed method to attend the tolerable delay of UEs is an issue to be regarded in our future works.

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