An Enhanced Spectrum Resource Allocation Algorithm for Femtocells

Linjing Zhao, Guangrui Huo
State Key Laboratory of ISN
Broadband Wireless Communications Laboratory
Xidian University, Xi'an, China
Email: ljzhao@mail.xidian.edu.cn, huojiaguang@163.com

Kang G. Shin
Department of Electrical Engineering
and Computer Science
University of Michigan-Ann Arbor
Email: kgshin@eecs.umich.edu

***Abstract*—Efficient spectrum resource allocation in wireless networks is important for improving the system throughput and guaranteeing the user-percieved Quality-of-Service (QoS). In this paper, we propose an enhanced algorithm for spectrum resource allocation in femtocells. First, the bandwidth of each user is determined by the user's demand and the channel state. Second, graph theory is enhanced and used to improve spectrum efficiency. Our simulation results show that the proposed algorithm improves the system throughput significantly and also guarantees the fairness toward the users.**

***Index Terms*—Resource management, femtocell, graph theory, throughput, fairness**

I. Introduction

In recent years, with the rapid development and application of wireless communication technologies, the number of wireless subscribers and commercial demands are increasing exponentially. Two-thirds of voice service and 70% of data traffic are reported to take place indoor [1]. So, femto base stations (FBSs) inside buildings within a macrocell are deployed as an cost-effective means to provide mobile (indoor) users high data rates via better channel quality. Moreover, FBSs are able to offload their macro base station (MBS) and enhance the overall system capacity by spatial reuse of frequency.

However, the FBSs that use the same frequency band will cause significant interference, thus degrading system throughput, because the coverage areas of densely-deployed femtocells usually overlap. How to reduce the interference is, therefore, an important issue that needs to be addressed. Dynamic spectrum allocation is an effective way to reduce interference among FBSs and improve the system capacity.

Several researchers have discussed spectrum resource allocation in femtocells. For example, the authors of [2], [6] considered the fairness in serving users, and [2] used min-max algorithm for spectrum resource allocation, ensuring fairness between FBSs and reducing complexity by grouping FBSs to reuse spectrum resource. This algorithm tries to meet the need of each FBS without considering the overall system performance, thus resulting non-optimal system throughput. The authors of [5] proposed a resource management solution by categorizing clients. The authors of [3], [4], [7] proposed graph theory coloring algorithms to dynamically allocate spectrum resource to improve the spectrum efficiency. However, they didn't consider the users' rate demand, thus assigning some FBSs requiring higher rates an insufficient amount of resource, while assigning some other FBSs requiring lower rates more resource than needed.

In order to improve the system throughput and, at the same time, guarantee the fairness in serving users in LTE femto cell systems, we propose an enhanced resource allocation algorithm for femtocells based on the users' rate demand. We achieve this by the adoption of an improved graph theory coloring algorithm to reuse spectrum resource. We can then make dynamic spectrum allocation among femtocells. The advantages over existing works are two-fold.

1) The user's rate demand is considered for dynamic spectrum allocation. That is, the amount of spectrum allocated to each user reflects his demand, thus guaranteeing fairness.
2) The improved graph theory coloring algorithm is adopted to determine how to reuse spectrum resource among the femtocells, thus improving the system throughput.

II. System Model

A. Multiple femtocells in a macrocell

Suppose there are K FBSs within a macrocell as shown in Fig. 1 and each femtocell k serves M_k users. Let $R_{k,i}$ be the rate demand by the i-th user in the k-th femtocell. There is a centralized management entity to control the spectrum resource allocation to femtocells. In this paper, we focus on spectrum resource allocation in the downlink of LTE. One resource block (RB) is the minimum unit that can be allocated, and includes 12 subcarriers. Femtocells not interfering with each other can reuse the same RBs to improve spectrum-efficiency, while some others seriously interfering with each other cannot. In order to determine how the femtocells reuse RBs, we must first find the neighbors of a femtocell, A, that seriously interfere with A, and then allocate them different RBs from those assigned to A to avoid interference. This is detailed next.

B. Definition of interference set and neighbors

Here we assume that all femtocells are allocated the same spectrum resource. Let $P_{k,i}$ be the received power of the

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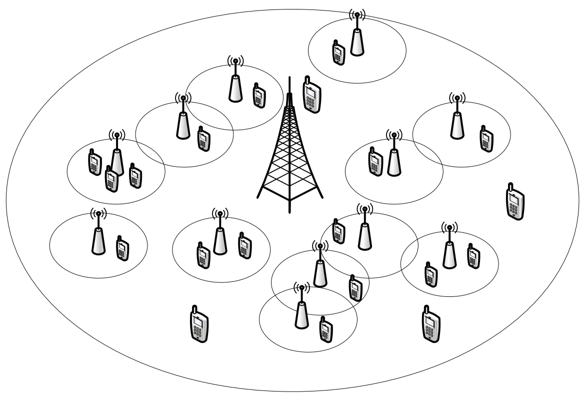

Fig. 1. System model for femtocell networks.

i-th user in the k-th femtocell, then the received signal-interference-to-noise rate (SINR) of this user can be expressed as

$$\gamma_{k,i} = \frac{P_{k,i}}{\sum_{l \in I_{k,i}} P_{l,i} + N_0}, \tag{1}$$

where $I_{k,i}$ is the set of the FBSs interfering with the i-th user, and initialized with all FBSs except the k-th FBS. That is, $I_{k,i} = \{1, 2, \ldots, k-1, k+1, \ldots, K\}$.

For a SINR threshold γ_{th}, when $\gamma_{k,i} < \gamma_{th}$, the FBS with the largest $P_{l,i}$ is chosen as a neighbor of the k-th FBS communicating with the i-th user and is removed from $I_{k,i}$. Then, we recalculate $\gamma_{k,i}$ and repeat the above process until $\gamma_{k,i} > \gamma_{th}$ holds. Finally, the set of the neighbors of the k-th FBS communicating with the i-th user is obtained as $\phi_{k,i}$ whose elements are the FBSs removed from $I_{k,i}$. The remainders in $I_{k,i}$ are the FBSs causing tolerable interference to the i-th user. The FBSs' interference to the k-th FBS $I_k = \cup I_{k,i}$.

The k-th femtocell can get its neighboring femtocell set ϕ_k by adding up all neighboring femtocell sets $\phi_{k,i}$, that is $\phi_k = \cup \phi_{k,i}$. Neighbor relationships between a femtocell and its neighboring femtocells are bidirectional. In other words, if femtocell A is femtocell B's neighbor, B is also A's neighbor. The neighbors of an arbitrary femtocell are thus found.

III. AN ENHANCED SPECTRUM RESOURCE ALLOCATION ALGORITHM

After finding the neighbors of an arbitrary femtocell, we now propose an enhanced spectrum resource allocation algorithm for femtocells. The proposed algorithm improves the system throughput as much as possible while guaranteeing fairness among users. Fig. 2 shows the flowchart of the algorithm. One can make three observations. First, according to the users' rate demand, each femtocell's RB demand is calculated to guarantee fairness. Second, an improved graph coloring algorithm is employed to assign color to each femtocell according to its RB demand to reuse colors as much as possible. Third, each femtocell is dynamically allocated the RBs that are assigned to its corresponding color to make full use of RBs and improve the system throughput.

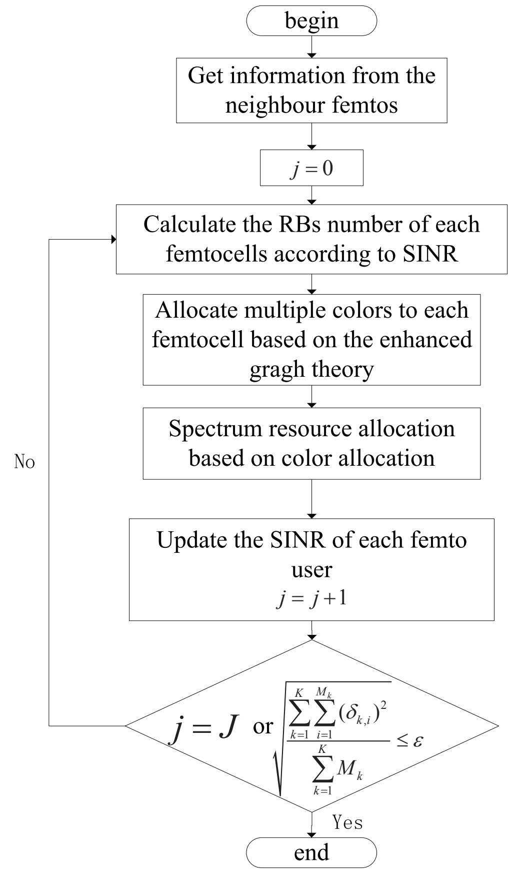

Fig. 2. Flowchart of the proposed algorithm

A. Calculation of each femtocell's RB demand

In order to avoid the situation where some FBSs requiring higher rates are assigned an insufficient amount of resource, while some FBSs requiring lower rates are assigned excessive resource, the users' rate demand should be considered and spectrum resource should be allocated accordingly to guarantee fairness. So in this section, each femtocell's RB demand is calculated to guarantee the fairness.

The obtained rate of the i-th user in the k-th femtocell by employing one RB is given as:

$$C_{k,i}^{(j)} = \begin{cases} \bar{C}_{min} = 0 & \text{for } \gamma_{k,i}^{(j)} < \gamma_{min} \\ \mu B \log_2(1 + \gamma_{k,i}^{(j)}) & \text{for } \gamma_{min} < \gamma_{k,i}^{(j)} < \gamma_{max} \\ \bar{C}_{max} & \text{for } \gamma_{k,i}^{(j)} > \gamma_{max} \end{cases}, \tag{2}$$

where j denotes that the resource allocation algorithm has been executed j times, with an initial value of 0. According to [8], μ is the attenuation factor. γ_{min} and γ_{max} are respectively the minimum and maximum thresholds for SINR. B is the bandwidth of one RB of 180KHz, and $\bar{C}_{max}$ is the user's maximum transmission rate by employing one RB. The initial received SINR of this user can be expressed as

$$\gamma_{k,i}^{(j)} = \frac{P_{k,i}}{\sum_{l \in I_{k,i}^{rem,(j)}} P_{l,i} + N_0}, \quad (3)$$

where $I_{k,i}^{rem,(j)}$ is the set of femtocells causing interference to the k-th femtocell and not including its neighboring femtocells, for they are allocated different RBs and there is no interference between them, which is different from $I_{k,i}$ in Eq. (1).

Then, the RB demand of the i-th user in the k-th femtocell is obtained by

$$N_{k,i}^{(j)} = \left\lceil \frac{R_{k,i}}{C_{k,i}^{(j)}} \right\rceil, \quad (4)$$

where $R_{k,i}$ is the required data rate of the i-th user in the k-th femtocell. The RB demand of the k-th femtocell is the sum of those of all of its users, which is calculated as $N_k^{(j)} = \sum_{i=1}^{M_k} N_{k,i}^{(j)}$.

B. Enhanced graph coloring algorithm

Based on each femtocell's RB demand calculated in subsection A, an enhanced graph coloring algorithm is proposed to assign color to each femtocell according to its RB demand in order to improve the spectrum efficiency. The traditional graph coloring algorithm assigns one fixed color or the same color to each femtocell without considering the users' demand, but the proposed enhanced graph coloring algorithm can assign different colors to femtocells according to femtocell's RB demand.

Algorithm 1 enhanced graph coloring algorithm

Initialization:

define a color pool C, containing only one color, $|C| = 1$;

Iteration:

```
for i = 1 to max_{k∈K}(N_k) do
  mark all BSs as unselected;
  repeat
    select BS_k having maximum θ of unselected BSs;
    if have assigned BS_k's colors |C_k| = N_k then
      mark BS_k as selected, select new BS having
      maximum θ of unselected BSs;
    else if |C_k| < N_k then
      find out available color(s) C_av ⊂ C that can be
      assigned to the selected BSs;
      for BS_k and C_av
      if |C_av| > 1 then
        assign a minimum color to BS_k;
      else if |C_av| = 0 then
        increase the size of C by 1, and assign the
        newly-added color to BS_k and mark BS_k selected;
      end if
    end if
  until all BSs are selected
end for
```

Suppose one color represents one required RB. First, we define a color set C, $C = \{1\}$, and the k-th femto's color set C_k is initialized as a null set. Second, we assign a color to the BS. If there are not enough colors to assign to the BS, add a new color to C and increase the size of C by 1, until all the BSs are allocated RBs. After coloring the FBS, all the FBSs have several colors represented as C_k and the color set C is updated. The total number of colors N_F can be calculated as $|C|$. Also, how many times each color is used is recorded. Let the saturation θ_k be the number of the femtocells which are neighbor femtocells of the k-th femtocell and allocated different colors from the k-th femtocell. The pseudo code for this step is as shown in Algorithm 1.

C. Dynamic spectrum allocation among femtocells

After allocating a color to each femtocell, dynamic spectrum allocation among femtocells can be done. In order to make full use of RBs and improve the system throughput, RBs can be allocated according to the number of colors and how many times each color is used. That is, when the total number of RBs is smaller than that of colors, the colors used less cannot be arranged as more RBs, and vice versa.

Assume one RB is assigned to one color. First, how many times a color is used is calculated. Second, the colors are queued in descending order according to their usage count. Third, the sorted colors are successively assigned the RBs. Each femtocell is allocated the RBs assigned to its corresponding color. Assume that there are a total of N RBs. There are two cases for N as follows.

Case 1. $N \geq N_F$: sufficient spectrum resource is available. Each color can be assigned one RB, and there must be unassigned RBs. Then, we repeat this assignment until the remaining RBs are all allocated.

Case 2. $N < N_F$: spectrum resource is scarce. The colors used less will not be arranged to receive any RBs. Each femtocell is allocated the RBs arranged to its corresponding color.

D. The iteration of resource allocation

To calculate the initial received SINR of the i-th user in the k-th femtocell, we assume that each FBS will be interfered with by other FBSs in the set of I_k. After RBs are allocated, the interference set will be changed. Because some FBSs in the interference set may be allocated different RBs with the k-th FBS, there will not be any interference between them. This FBS should be removed from the interference set I_k. Thus, the SINR will also change. If the updated SINR increases after the resource is allocated, then the user may be allocated fewer RBs to achieve the required rate, and vice versa. Hence, the interference set and SINR should be updated, and the resource allocation should be executed again. Therefore, iteration is introduced in order to make full use of the spectrum resource.

Let j be the number of iterations and initialized as 0. After allocation of RBs, j is increased by 1, the interference set is updated and each user's SINR is recalculated. If $j = J$

or $\sqrt{\sum_{k=1}^{K}\sum_{i=1}^{M_k}{\delta_{k,i}}^2/\sum_{k=1}^{K}M_k} \le \varepsilon$ is satisfied, the algorithm terminates. Otherwise, return to subsection II. J represents the maxmum number of iterations. $\delta_{k,i}$ is the difference between the two SINRs derived in the j-th and $(j+1)$-th cycle. ε is a pre-defined threshold.

The proposed enhanced spectrum resource allocation algorithm can be summarized as following steps.

Step 1 Calculate each femtocell's RB demand and initialize $j = 0$.

Step 2 Assign color to each femtocell according to its RB demand with the enhanced graph coloring algorithm.

Step 3 Allocate RBs to each femtocell according to its assigned colors with the dynamic spectrum allocation algorithm.

Step 4 Recalculate each user's SINR and increase j by 1. Determine whether the condition $j = J$ or $\sqrt{\sum_{k=1}^{K}\sum_{i=1}^{M_k}{\delta_{k,i}}^2/\sum_{k=1}^{K}M_k} \le \varepsilon$ is satisfied. If it is satisfied, the algorithm terminates. Otherwise, return to step 2.

The proposed enhanced spectrum resource allocation algorithm is performed according to the users' rate demand, and uses the enhanced graph coloring algorithm to reuse spectrum as much as possible and use dynamic spectrum allocation to improve the system throughput. Therefore, the system throughput increases and at the same time, the fairness is guaranteed.

IV. Simulation Results

We conducted in-depth simulations to evaluate the performance of the proposed algorithm. Some simulation parameters are listed in Table I. The total number of RBs $N = 50$. The path loss of a user to an FBS is determined by the formulas $PL = 127 + 30\lg d$. The simulation scenario is shown in Fig. 3, where a red dot represents an FBS and a blue square with the side length of 10m represents an apartment where an FBS is placed. We evaluate the performance by throughput

TABLE I
SIMULATION PARAMETER

Parameters	Value
Number of cells	72
Number of users in each cell	1-5
The maximum transmission power of a BS(dBm)	20
Transmission power on one RB of a BS(dBm)	0
Coverage radius of a BS(m)	20
μ	0.6
γ_{min}(dBm)	-10
γ_{max}(dBm)	22
$\bar{c}_{max}$(Mbps)	0.792

and fairness of the system and compare the proposed algorithm with the graph-based algorithm [4] and the FCRA algorithm based on MinMax [2]. The throughput of the system is defined as the total rates all users achieved. Let $SINR_{k,i}^m$ be the received SINR of the i-th user in the k-th femtocell when

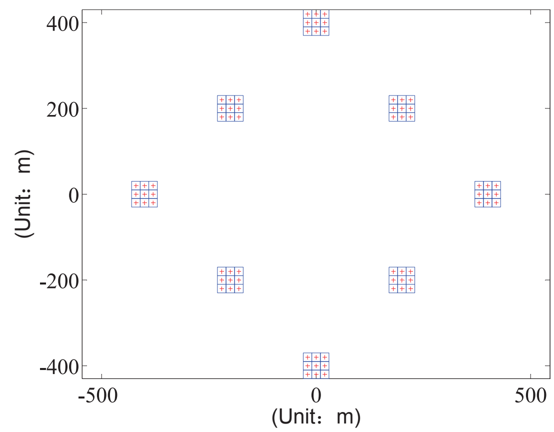

Fig. 3. Simulation scenarios

allocated RB m. The rate $C_{k,i}^m$ achieved by this user with RB m can be expressed as

$$C_{k,i}^m = \begin{cases} \bar{C}_{min} = 0 & \text{for } \gamma_{k,i}^m < \gamma_{min} \\ \mu B \log_2(1+\gamma_{k,i}^m) & \text{for } \gamma_{min} < \gamma_{k,i}^m < \gamma_{max} \\ \bar{C}_{max} & \text{for } \gamma_{k,i}^m > \gamma_{max} \end{cases}. \quad (5)$$

Then, the rate obtained by the i-th user in the k-th femtocell allocated the RBs set $m_{k,i}$ can be calculated as

$$Th_{k,i} = \begin{cases} \sum_{m\in m_{k,i}} C_{k,i}^m & \text{for } \sum_{m\in m_{k,i}} C_{k,i}^m < R_{k,i} \\ R_{k,i} & \text{for } \sum_{m\in m_{k,i}} C_{k,i}^m \ge R_{k,i} \end{cases}. \quad (6)$$

The rate achieved by the k-th femtocell Th_k is equal to $\sum_{i=1}^{M_k} Th_{k,i}$. Then, the throughput of the system can be obtained by $\sum_{k=1}^{K} Th_k$. The evaluation of the system fairness can be evaluated by the fairness indicator $\sum {s_k}^2/(K\sum {s_k}^2)$, where s_k is the ratio of the obtained rate to the required rate of a femtocell and $s_k = Th_k/R_k$, R_k is the total required data rate of the k-th femtocell and $R_k = \sum_{i=1}^{M_k} R_{k,i}$. Obviously, the closer to 1 the indicator is, the fairer the system is.

As shown in Figs. 4 and 5, the system performance is evaluated by the throughput and the fairness indicator with different iteration times. It can be concluded that the performance is improved with the increase of the iteration index and converges after three iterations.

Compared to the other two algorithms, as shown in Figs. 6 and 7, the fairness indicators of these three algorithms decrease and the system throughput of the algorithms increase when the users' average rate demand increases. It is obvious that the proposed algorithm makes a tradeoff between fairness and the throughput. Considering the users' demand, the new algorithm gets a better performance in fairness than the graph-based allocation algorithm. By introducing the enhanced graph theory, the new algorithm achieves a higher throughput than the FCRA algorithm. Therefore, when both fairness and throughput are considered, the proposed algorithm yields better results.

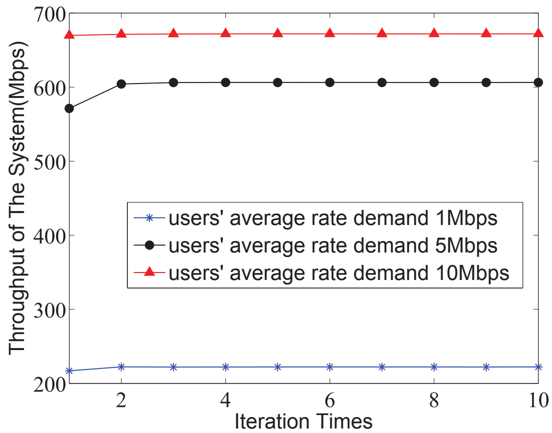

Fig. 4. Throughput during the RB allocation process with different users' rate demand

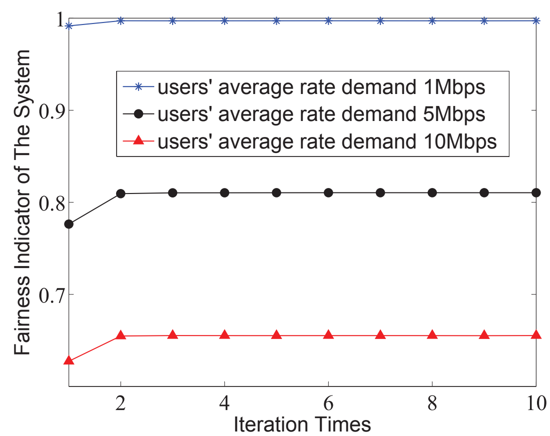

Fig. 5. Fairness during the RB allocation process with different users' rate demand

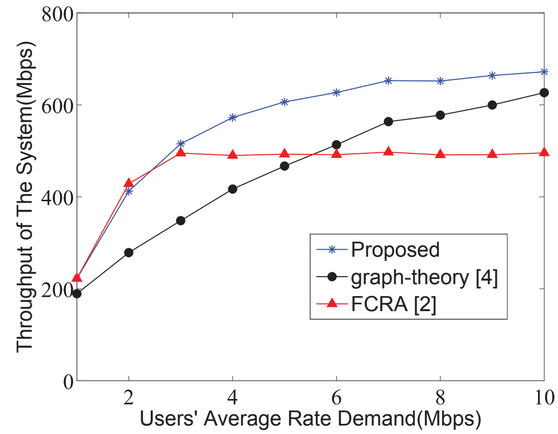

Fig. 6. Throughput comparison with other algorithms with different users'rate demand

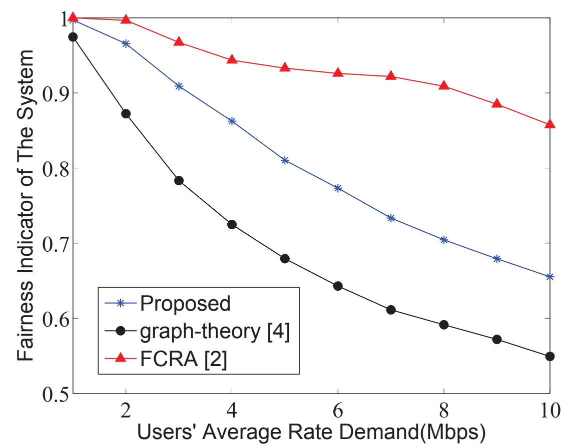

Fig. 7. Fairness comparison with other algorithms with different users'rate demand

V. Conclusion

In this paper, an enhanced spectrum resource allocation algorithm for femtocells is proposed. Spectrum efficiency is improved by an enhanced graph coloring algorithm and the user fairness is also considered because the allocation is determined by the users' demand. Our simulation results have demonstrated that the new algorithm improves the system throughput while guaranteeing the user fairness.

Acknowledgement

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