# User Classifying-based Hybrid Spectrum Allocation in Two-tier OFDMA Femtocell Networks

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*Abstract*—**This paper addresses the cross-tier interference issue in two-tier OFDMA femtocell networks using hybrid spectrum allocation. Firstly, we propose a classification method for users. The macro users are classified into several categories based on their geographic location, and femto users are classified according to the categories of macro users. Then, based on such user classifications, a hybrid spectrum allocation (HSA) scheme is proposed. HSA employs a dynamic orthogonal spectrum allocation for macro user categories according to the number of MUEs in two-tier networks, and fractional spectrum reuse for femto user categories based on their different communication environments. Simulation results show that the proposed scheme can improve outage and throughput performance of macro users with less impact on femto users.**

***Keywords-OFDMA femtocell; hybrid spectrum allocation; interference mitigation; two-tier***

## I. INTRODUCTION

With the increasing demand for high data-rate wireless services for the indoor users, femtocell arises at the historic moment. It is consumer installed wireless data access point in building, which operates on the licensed frequency bands, and it is connected to broadband Internet backhaul. The low cost and low power femto access point (FAP) or so-called home Base Station (BS) can provide capacity gain, better quality of service (QoS) for the indoor users and reduced battery consumption of handset [1].

However, the introduction of femtocell in the topology of conventional macro cellular networks brings some challenges to the interference management [2]. One of the key problem is the cross-tier interference in two-tier networks with co-channel deployment. The probability of macro users (MUEs) located in the vicinity of femtocell increases greatly due to the high-density deployment of femtocell. Therefore, the interference between femtocells and macrocells are more serious. In order to cope with interference issues, orthogonal frequency division multiple access (OFDMA) femtocell is a more promising solution than code division multiple access (CDMA), mainly due to its robustness to multipath and channel variations in both frequency and time domains for the avoidance of interference[3].

At present, many various approaches are applied to deal with cross-tier interference in two-tier networks, including shared spectrum usage, orthogonal spectrum usage [4], power control, opportunistic spectrum access and spatial antenna techniques [5]. Our works focus on the spectrum allocation method. Traditional spectrum allocation methods have been in static in nature, with the spectrum assigned to a user being fixed regardless of instantaneous changes in two-tier networks. Tae-Hwan Kim et al. [6] proposed a frequency reuse mechanism with pilot sensing to select frequency bands for femtocells among frequency bands of macrocell networks. This method can reduce cross-tier interference and improve the network throughput. A hybrid spectrum sharing scheme is applied in [7]. In this scheme, the femtocells are classified to inner and outer femtocells, and the inner femtocells use orthogonal spectrum with macrocell, while the outer femtocells use shared spectrum with macrocell. And in [8] the system spectrum is divided into several frequency bands. Accordingly, the coverage area of macrocell is divided into inner and outer area, with the outer area being further sub-divided into multiple sectors. The neighboring areas use the same spectrum while the non-adjacent areas use the different spectrum.

The methods mentioned above all assign spectrum in static way. However, assigning spectrum to users in static way can lead to inefficient spectrum utilization. In order to ensure better utilization of local available spectrum, a dynamic frequency reuse scheme is provided in [9], where spectrum can be dynamically allocated to users based on their particular geographic location.

In this paper, we propose a novel user classifying-based hybrid spectrum allocation method. From user's perspective, firstly, macro users are classified into several categories based on their geographic location, and femto users are classified according to the categories of macro users. Then a hybrid spectrum allocation scheme is proposed based on user classifications, including orthogonal spectrum allocation for macro user categories, and fractional spectrum reuse for femto user categories. Our method can reduce cross-tier interference as well as improve the throughput of two-tier networks.

The remainder of this paper is organized as follows. The system model adopted is described in Section II. Hybrid spectrum allocation algorithm is presented in Section III. Simulation results and their interpretation are provided in Section IV, followed by concluding remarks in Section V.

## II. SYSTEM MODEL

### A. Network Deployment

We consider the downlink operation of two-tier networks comprising $N_M$ macrocells, overlaid with $N_F$ co-channel femtocells. For each macrocell, there are three sectors and a BS locates at the center of hexagonal coverage area. MUEs are distributed uniformly in the area covered by Macro Base Stations (MBSs). The apartments are randomly inserted in each sector and the size of each apartment is 10m×10m. We assume that the deploy ratio of femtocell is $\alpha$, and the active ratio of femtocell is $\beta$. $\alpha$ and $\beta$ are in the range of 0 to 1. So the Femto Base Stations (FBSs) are distributed in these apartments according to the product of deploy ratio and active ratio. Each active FBS is coupled with a femtocell user (FUE). The transmission power of macrocell and femtocell is fixed and each femtocell adopts close subscribe group (CSG) mode. In the OFDMA system, the available system bandwidth is divided into orthogonal resource blocks (RBs).

Let $p_M$ and $p_F$ denote the transmission power of macrocell and femtocell over each subchannel, respectively. And $C$ denotes the set of subchannels. Let $N_0$ denote zero mean Additive White Gaussian Noise (AWGN) at the BS. The SINR of macro user $k$ over the $n$-th subchannel in macrocell $i$ can be written as

$$SINR_{k,n} = \frac{p_M \left|h_{ik,n}\right|^2}{\sum_{l \in N_M, l \neq i} p_M \left|h_{lk,n}\right|^2 + \sum_{j \in N_F} p_F \left|h_{jk,n}\right|^2 + N_0} \tag{1}$$

where $h_{ik,n}$, $h_{lk,n}$ and $h_{jk,n}$ respectively denote the channel frequency response from macrocell $i$, macrocell $l$ and femtocell $j$ to macro user $k$ over the $n$-th subchannel.

Similarly, the received SINR of femto user $u$ served by FBS $j$ over the $n$-th subchannel is

$$SINR_{u,n} = \frac{p_F \left|h_{ju,n}\right|^2}{\sum_{l \in N_m} p_M \left|h_{lu,n}\right|^2 + \sum_{k \in N_F, k \neq j} p_F \left|h_{ku,n}\right|^2 + N_0} \tag{2}$$

where $h_{ju,n}$, $h_{lu,n}$ and $h_{ku,n}$ denote the channel frequency response from femtocell $j$, macrocell $l$ and femtocell $k$ to femto user $u$ over the $n$-th subchannel, respectively.

### B. Path loss model

The path loss model is recommended in 3GPP TR36.921 [10], including the path loss of User Equipment (UE) to MBSs and FBSs.

1) *path loss of UE to MBSs*

a) UE is outside:

$$PL\ (dB) = 15.3 + 37.6\log_{10}R \tag{3}$$

b) UE is inside an apartment：

$$PL\ (dB) = 15.3 + 37.6\log_{10}R + L_{ow} \tag{4}$$

2) *path loss of UE to FBSs*

a) UE is outside:

$$PL\ (dB) = \max(15.3 + 37.6\log_{10}R,\ 38.46 + 20\log_{10}R) + 0.7d_{2D,indoor} + L_{ow} \tag{5}$$

b) UE is inside the same apartment as FBS

$$PL\ (dB) = 38.46 + 20\log_{10}R + 0.7d_{2D,indoor} \tag{6}$$

c) UE is inside the different apartment with FBS:

$$PL(dB) = \max(15.3 + 37.6\log_{10}R,\ 38.46 + 20\log_{10}R) + 0.7d_{2D,indoor} + L_{ow,1} + L_{ow,2} \tag{7}$$

where R and $d_{2D,\ indoor}$ are in meters. $L_{ow}$ is the penetration loss of an outdoor wall, which is 20dB. The term $d_{2D,\ indoor}$ is the distance inside the apartment (when UE is outside) or the total distance inside the two apartments (when UE is inside the different apartment with FBS). $L_{ow,1}$ and $L_{ow,2}$ are the penetration losses of outdoor walls for the two apartments.

## III. HYBRID SPECTRUM ALLOCATION ALGORITHM

The location of users varies with time in two-tier networks. When MUEs are in the vicinity of FBSs, the MUEs cannot access nearby femtocells because of the serious cross-tier interference. In order to cope with the cross-tier interference, we propose a hybrid spectrum allocation algorithm. From users' perspective, we divide users into several categories and allocate system spectrum to users based on user classification. And it is assumed that the load of each sector is proportional to the number of activated MUEs in this sector.

### A. Classification of macro and femto users

The classification methods of macro and femto users are described in this section. Firstly, the MUEs can be divided into two categories based on the geographic location of MUEs, including indoor MUEs and outdoor MUEs. Then, the outdoor MUEs are sub-divided into the near outdoor MUEs and the far outdoor MUEs according to the fading value from a MUE to a FBS. The method is setting a fading threshold $F_{thr}$, if the fading value is greater than $F_{thr}$, this MUE is far outdoor MUE of the FBS. Otherwise, the MUE is near outdoor MUE of the FBS. Consequently, macro users are divided into three categories, which are indoor MUEs, near outdoor MUEs and far outdoor MUEs.

For each macrocell, we assume that there are $M$ macro users in each sector and $K$ femtocells located in the area covered by the MBS. Let $\Phi_1=\{a_i|i=1,2,\ldots,M\}$ denote the set of indoor MUEs in a sector, the subscript $i$ indicates the $i$-th MUE in this sector. $\Phi_2=\{b_{ij}|i=1,2,\ldots,M;\ j=1,2,\ldots,K\}$ denotes near outdoor MUEs in the sector, where $b_{ij}$ indicates MUE $i$ is the near outdoor MUE of FBS $j$ and the fading value between the two is smaller than $F_{thr}$. The set of far outdoor MUEs is denoted by $\Phi_3=\{c_{it}|i=1,2,\ldots,M;\ t=1,2,\ldots,K\}$, where $c_{it}$ indicates MUE $i$ is the far outdoor MUE of FBS $t$ and the fading value between the two is greater than $Fthr$. Moreover, $a_i$, $b_{ij}$ and $c_{it}$ are equal to 0 or 1. The value of 1 means $a_i$, $b_{ij}$, $c_{it}$ are in the corresponding set and the value of zero means not in.

The communication environments of FUEs are disparate because of the random character of MUEs' location.

According to the existence of MUEs around the apartment, which has an active FBS, and the categories of MUEs, we can divide the FUEs into several categories described below.

Let $\Psi_i$ ($i$=1,2,3,4) denote which category the FUE belongs to and the subscripts indicate the category. Hence, FUEs can be summarized as follows:

(1)$\Psi_1$: there are MUEs in the same apartment with the FUE and the vicinity of this apartment exists near outdoor MUEs.

(2)$\Psi_2$: there are MUEs in the same apartment with the FUE and near outdoor MUEs is inexistence around this apartment.

(3)$\Psi_3$: the apartment only has a FUE, but there are near outdoor MUEs around this apartment.

(4)$\Psi_4$: the apartment only has a FUE and no near outdoor MUEs around this apartment.

## B. *Spectrum allocation of MUEs*

Firstly, we calculate the number of indoor MUEs, near outdoor MUEs and far outdoor MUEs in a sector, respectively. Then, the system spectrum is allocated to MUEs based on the proportion of the number of each category MUEs to the total number of MUEs in this sector. We define the frequency sets of each category MUEs are $F_{indoor}$, $F_{near}$ and $F_{far}$, respectively. The subscripts denote which category the MUEs belong to. Therefore, we can calculate $F_{indoor}$, $F_{near}$ and $F_{far}$ as follows.

$$F_{indoor} = \lfloor (N_{indoor} / (N_{indoor} + N_{near} + N_{far})) * N_{RB} \rfloor \tag{8}$$

$$F_{near} = \lfloor (N_{near} / (N_{indoor} + N_{near} + N_{far})) * N_{RB} \rfloor \tag{9}$$

$$F_{far} = \lfloor (N_{far} / (N_{indoor} + N_{near} + N_{far})) * N_{RB} \rfloor \tag{10}$$

where $N_{indoor}$, $N_{near}$ and $N_{far}$ are the number of indoor MUEs, near outdoor MUEs and far outdoor MUEs in a sector, respectively. $N_{RB}$ is the total number of resource blocks. The symbol "$\lfloor X \rfloor$" means the largest integer which is smaller than X.

Finally, the MUE are scheduled using the rule that each category MUE only selects resource blocks in its corresponding frequency set.

## C. *Spectrum allocation and reuse of FUEs*

The spectrum reuse can increase the system capacity. When the distance between two users is far enough, the interference signal does not affect the reception of the desired signal, and they can use the same spectrum. We assume a FUE can reuse the spectrum which is used by far outdoor MUEs of the FBS and the FBS is in the same apartment with this FUE.

The FUEs have been divided into four categories according to the communication environment of each FUE as mentioned above. And the rule of FUEs selecting available spectrum is described as follows.

The FUE in the same apartment with a FBS can use the spectrum used by a category of MUEs which does not exist around this FBS. For example, users $\Psi_1$ can use resource blocks in frequency set $F_{far}$, sharing spectrum with the far outdoor MUEs. Similarly, users $\Psi_2$ can use RBs in frequency sets $F_{far}$ and $F_{near}$, users $\Psi_3$ can use RBs in frequency sets $F_{indoor}$ and $F_{far}$, users $\Psi_4$ can select RBs in frequency set $F_{indoor}$, $F_{far}$ and $F_{near}$, that is the whole system spectrum. So we can obtain the formulas:

$$f_1 = F_{far} \tag{11}$$

$$f_2 = F_{far} \cup F_{near} \tag{12}$$

$$f_3 = F_{far} \cup F_{indoor} \tag{13}$$

$$f_4 = F_{far} \cup F_{near} \cup F_{indoor} \tag{14}$$

where $f_i$ ($i$=1,2,3,4) indicates the available frequency set of FUEs. A Spectrum partitioning example for our proposed scheme is shown in Fig.1. $F_{far}$ , $F_{near}$ and $F_{indoor}$ denote the available spectrum for far outdoor MUEs, near outdoor MUEs and indoor MUEs, respectively. Meanwhile, $F_{far}$ can be reused by all FUEs, $F_{near}$ can be reused by $\Psi_2$,$\Psi_4$ and $F_{indoor}$ can be reused by $\Psi_3$, $\Psi_4$.

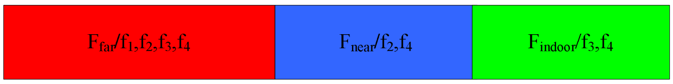


Figure 1. Spectrum partitioning example for our proposed scheme

## D. *Algorithm procedure*

The number of UEs varies with time in two-tier networks due to the dynamic nature of network. So the amount of spectrum allocated to a category users with time, varies in accordance with the MUE density in each sector. So we set a time threshold $T_{thr}$, once the time exceeds the threshold, the number of activated MUEs and the number of each category MUE are updated in each sector. $F_{indoor}$, $F_{far}$, $F_{near}$ and $f_i$ ($i$=1,2,3,4) are also updated immediately. The hybrid spectrum allocation algorithm procedure is presented in Table I.

TABLE I. ALGORITHM PROCEDURE

**Algorithm :** Hybrid Spectrum Allocation Algorithm

```
begin
  for tindex ∈ N_TTI
    while (tindex%T_thr=0)
      for each sector
        Initialization: Φ1, Φ2, Φ3, N_indoor, N_far, N_near
        Calculate Φ1, Φ2 and Φ3 based on F_thr;
        Calculate N_indoor=|Φ1|;
        for i ∈ M do
          for t, j ∈ K do
            if (c_it=1and b_ij=0) N_far+1;
            if (sum(b_ij)>=1) N_near+1;
      for each sector
        Calculate F_indoor, F_near, F_far according to
            (8)(9)(10), respectively
        Calculate f1, f2, f3, f4 according to
            (11)(12)(13)(14), respectively
```

## IV. SIMULATION RESULTS

In this section we analyse the performance of our spectrum allocation scheme by computer simulation. The common simulation parameters are summarized in Table II. Two contrasting schemes are provided in this section. (1) Full Spectrum Reuse (FSR) scheme, which is the MUEs and the FUEs sharing the whole system spectrum. (2) Orthogonal Spectrum Allocation (OSA) algorithm, dividing the total system spectrum into two orthogonal parts (7MHz and 3MHz), the MUEs use 7MHz and the FUEs use 3MHz. There is no inter-information sharing.

Fig.2 depicts a snapshot of femtocell deployment example in macrocell networks. For each macrocell, 75 femtocells and 90 macro users are distributed uniformly in the area covered by the macro Base Stations. A 25 femtocell deployment example in a sector of a macrocell area is presented in Fig.3.

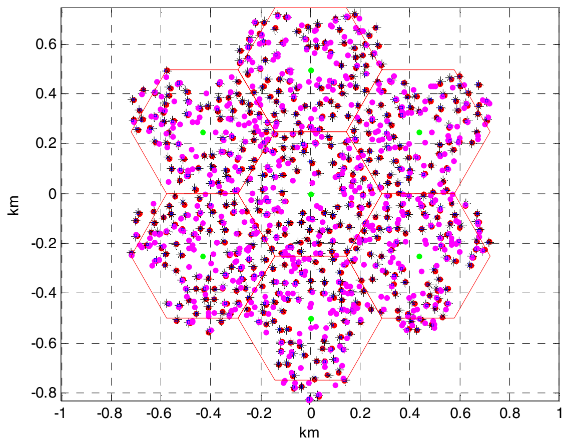


Figure 2. Snapshot of 525 femtocells and 630 MUEs located in macrocell area

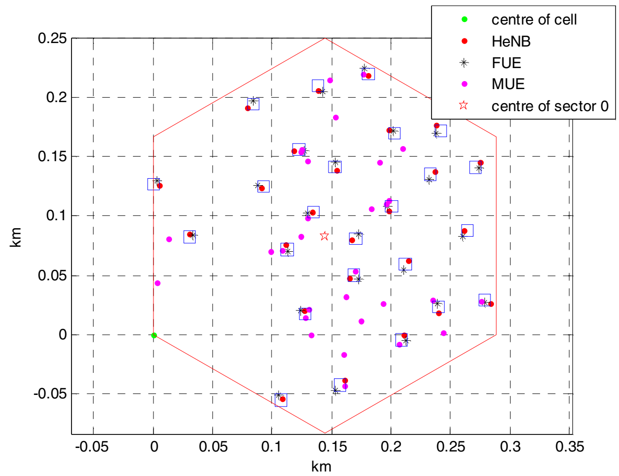


Figure 3. Snapshot showing 25 femtocells and 30 MUEs located in a sector

Fig.4 and Fig.5 show the SINR performance of macro and femto users with different resource allocation schemes. In Fig.4, it is clearly observed that, compared with the other two schemes, our proposed scheme can improve macro user SINR conditions as a result of the higher priority of macro users and the reduction of cross-tier interference. The reduction of outage probability for macro users (when their SINR are lower than -6 dB) is from 4.48% to 0.7% with OSA, and 0.4% with our proposed scheme.

However, as shown in Fig.5, the SINR improvement of macro users has an influence on the SINR degradation of femto users. Compared with FSR, our scheme can improve femto user SINR conditions. The SINR curve of OSA is better than our proposed scheme because of the cross-tier interference exists in our proposed scheme. The outage probability of femto users is very low, so the outage of femto users can be neglected.

TABLE II. SIMULATION PARAMETERS

| | |
|---|---|
| Macrocell Layout | 7 cell,3 sectors per cell |
| Inter-cell distance | 500m |
| Carrier Frequency | CF=2.0GHz,BW=10MHz |
| Shadowing standard deviation | 8dB |
| Numbers of femtocells per apartment | 1 |
| Size of per apartment | 10m×10m |
| FUE number per femtocells | 1 |
| Transmission power of MBS | 46dBm |
| Transmission power of FBS | 20dBm |
| Probability of MUE being indoors | 35% |
| MUE number per sector | 30 |
| Minimum target SINR | -6dB |
| Fading threshold | 120dB |

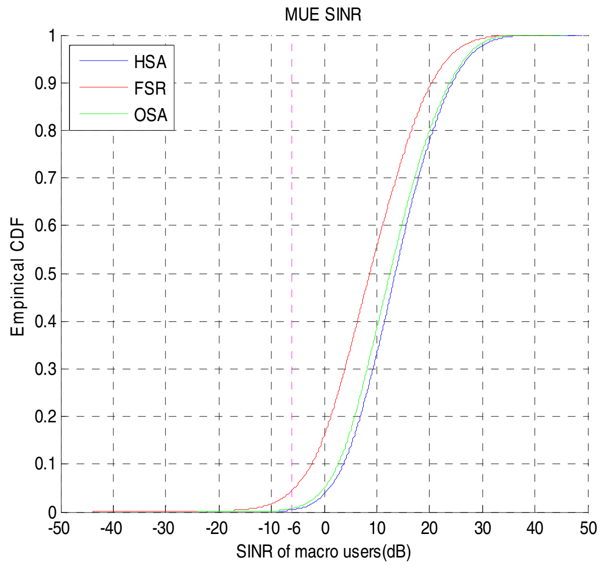


Figure 4. SINR distribution of macro users with different schemes

The average throughput of macro and femto users is provided in Fig.6. Compared with FSR and OSA, our scheme can improve throughput of macro users, increasing from 5.9477 Mbps with OSA to 6.0667 Mbps with FSR, and 9.7886 Mbps with our proposed scheme. Meanwhile, it results in some throughput degradation of femto users, decreasing from 20.08 Mbps with FSR to 10.789 Mbps with our scheme, and 6.3516 Mbps with OSA. The interference between femtocells also has impact on the throughput degradation of femto users.

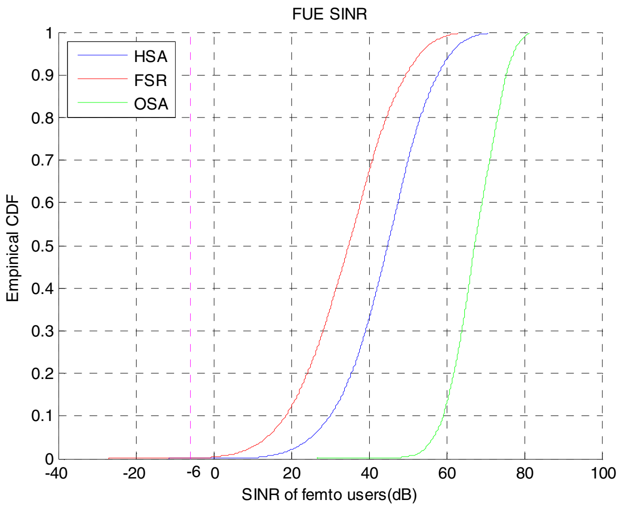

Figure 5. SINR distribution of femto users with different schemes

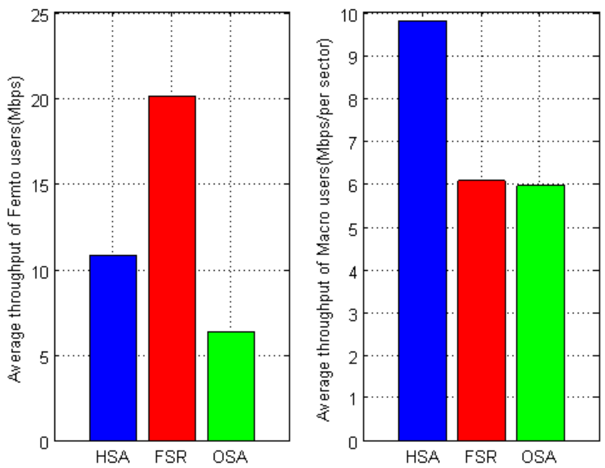

Figure 6. Average throughput of femto and macro users with different schemes

## V. CONCLUSIONS

In this paper, we have proposed a novel spectrum allocation scheme based on user classifications in two-tier OFDMA networks to mitigate cross-tier interference. Using dynamic spectrum allocation scheme for macro users and spectrum reuse for femto users based on their communication environments. Simulation results show that our proposed method could achieve higher throughput of macro users and the SINR of macro users are also improved. We also obtained a good tradeoff between SINR and average throughput for femto users.

It can be concluded that the spectrum allocation scheme proposed in this paper is outperform the other compared schemes. Our future works will be focus on how to alleviate the interference between femtocells based on the other methods, such as Cognitive Radio (CR) technology, power control and adaptive beamforming.

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