Optimal Resource Allocation for Macro Cell-edge User in Heterogeneous Macro-Femto Network

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1 Introduction

Femtocell [1] has gained great attention in industry due to the benefits for high data rate provision, low power consumption in indoor environment. However, these benefits are greatly limited by the challenges of interference between macrocell and femtocell. In this paper, we emphatically analyse the resource allocation for macro cell-edge users which location is far away from Macro Base Station (MBS) but near Femtocell Base Station (FBS). We develop a distributed optimal resource allocation scheme to maximize the capacity of these macro cell-edge users. In this scheme, the macro cell-edge user is allowed to use the unoccupied femtocell resources without affect the QoS of the original users in FBS. Firstly, the subchannels are allocated with the assumption of equal power distribution. Then optimal power allocation is performed to maximize the total transmission rate of all the macro cell-edge users based on the Lagrange optimal algorithm. Simulation results demonstrate our proposed scheme can effectively allocate power and frequency resource to these user devices, and achieve higher transmission rate than equal power allocation.

2 System Model

In this system, we consider one MBS with K Macro Users (UEs) that are uniformly located in its coverage area. Meanwhile, there are several FBSs randomly deployed around these MUEs. The system model is shown in Fig.1. We assume that time is slotted and focus on the channel allocation problem across these macro cell-edge users for a given time slot. It is reasonable to assume that the channel conditions do not change over the duration of a time slot. In the certain time interval, the FBS sends the number and the ID of its unoccupied subchannel to the MBS through the backhaul internet connection between them. And the MBS can broadcast these subchannels to its cell-edge user devices. Then these users can selectively join the FBS without exceed the resource constraint of the FBS. The original users of an FBS are defined as Primary Users (PFUEs), and the newly joining cell-edge MUE is known as Secondary Users (SFUEs). If the channel is occupied by PFUE, then SFUE can only transmit information in the channel with power constraint in order to guarantee the QoS requirement of PFUE.

Assume there are N unoccupied channels in nearby femtocells which can be used by the macro cell-edge user devices to improve its transmission rate. The object of this paper is to maximize the transmission rate of cell-edge MUEs by allocating them with optimal unoccupied FBS subchannels, which means the macro cell-edge user is allowed to join the FBS temporally. Then these users will use the orthogonal subchannel with the original FUEs and the transmission rate can be formulated as below:

$$R_k = B_c(\sum_{k=1}^{K}\sum_{n=1}^{N}\theta_{k,n}\log_2(1+\frac{p^{F,n}g^{F,n}}{\sigma^2})) \tag{1}$$

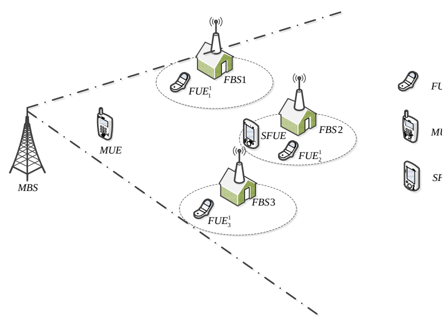

Fig. 1. System Model.

Here, we introduce a fairness index which is defined as below. It is used to ensure that each macro cell-edge user is able to achieve its capacity requirement.

$$\eta = \frac{(\sum_{k=1}^{K} R_k)^2}{K\sum_{k=1}^{K}(R_k)^2} \tag{2}$$

Then the optimization problem we considered can be formulated as follow:

$$\begin{aligned} &\max B_c(\sum_{k=1}^{K}\sum_{n=1}^{N}\theta_{k,n}\log_2(1+\frac{p_k^{F,n}g_k^{F,n}}{\sigma^2})) \\ \text{subject to}\quad & R_1 : R_2 : \cdots R_k = \eta_1 : \eta_2 : \cdots \eta_k \\ & \sum_{n=1}^{N} p_k^{F,n} \le P_{total},\quad p_k^{F,n}{}_{\ge 0} \quad for\ \ all\ k,n \\ & \theta_{k,n} = \{0,1\},\qquad \sum_{k=1}^{K}\theta_{k,n} = 1\ \ for\ \ all\ k,n \end{aligned} \tag{3}$$

Where B_c is the constant bandwidth which is assigned to each SFUE. $p_k^{F,n}$ is the transmission power of FBS for MUE k in n^{th} subchannel. $g_k^{F,n}$ is the interference channel link gain from the FBS to MUE k , and σ^2 is the noise variance. Here, we consider the transmission channel model which includes the distance-dependent path loss, log-normal shadowing, and channel variations due to frequency selection fading [2].

$$g = h^2 10^{(-L(d))/10} \tag{4}$$

Where h is an exponential random variable with unit mean and variance. $L(d)$ is the distance-dependent path loss (in dB).

$\theta_{k,n}$ is defined to indicate the subchannel allocation status of the i^{th} MUE. If $\theta_{k,n} = 1$, the k^{th} MUE is allowed to use the n^{th} subchannel. Otherwise, if $\theta_{k,n} = 0$, the k^{th} MUE is rejected by the n^{th} subchannel. The first constraint ensures the transmission rate of each macro cell-edge user device. Assume the transmission power in each subchannel is constraint. With the knowledge of the total unoccupied channels, the total power constraint can be known and we define it as P_{total} here. The third constraint shows that each subchannel can only be used by one macro cell-edge user.

3 Adaptive Resource Allocation

The objective of optimization problem we proposed in last section is a mix integer programming problem. We use low-complexity suboptimal algorithm to solve this problem [3]. The algorithm concludes two steps, suboptimal subchannel association and suboptimal power allocation.

In the suboptimal subchannel association scheme, we assume that FBS distributes equal transmission power in each subchannel for SFUE which wants to join its area. Different subchannel will generate different channel gain for different UE. With equal transmission power, to maximize its transmission rate, the macro cell-edge user device will choose the subchannel with highest channel gain. We define Ω_k as the set of subchannel which is associated with cell-edge MUE k .

Algorithm 1: Iterative algorithm for subchannel allocation of macro cell-edge user devices

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Initialize $\Omega_k = \varnothing$ for $k = 1, 2 \cdots, K$ and $Q = \{1, 2, \cdots, N\}$

For each subchannel do

  Compute $g_k^{F,n}$ according to (3)

  If $g_k^{F,n} > g_k^{F,j}$ for all $j \in Q, j \neq n$

    $\Omega_k = \Omega_k \cup \{n\}$

    $Q = Q - \{n\}$

  End

end

Based on the above subchannel allocation, the optimization problem can be rewritten as below. Compared with (3), we simplified B_c , as B_c is a constant value which has no affection to the optimization problem. And Ω_k is the set of unoccupied subchannel which is assigned to the macro cell-edge user.

$$\begin{aligned} & \max\left(\sum_{k=1}^{K}\sum_{n\in\Omega_k}\log_2\left(1+\frac{p_k^{F,n}g_k^{F,n}}{\sigma^2}\right)\right) \\ \text{s.t. } & R_1 : R_2 : \cdots R_k = \eta_1 : \eta_2 : \cdots \eta_k \\ & \sum_{n=1}^{N} p_k^{F,n} \le P_{total},\quad p_k^{F,n}{}_{\ge 0} \quad for\ \ all\ k,n \\ & \Omega_1 \cup \Omega_2 \cup \cdots \Omega_k = N \end{aligned} \tag{5}$$

Next, we will present the Lagrange's dual algorithm for the optimize power allocation problem in the case of instantaneous constraint. The Lagrangian of the optimization problem is defined as:

$$\begin{aligned} \mathcal{L}(\{p_k^{F,n}\},\{\lambda_k\},\{\mu\}) = & \sum_{k=1}^{K}\sum_{n\in\Omega_k}\log_2\left(1+\frac{p_k^{F,n}g_k^{F,n}}{\sigma^2}\right) \\ & +\lambda_k\sum_{k=2}^{K}\left(\sum_{n\in\Omega_1}\log_2\left(1+\frac{p_1^{F,n}g_1^{F,n}}{\sigma^2}\right)-\sum_{n\in\Omega_k}\log_2\left(1+\frac{p_k^{F,n}g_k^{F,n}}{\sigma^2}\right)\right) \\ & +\mu\left(\sum_{k=1}^{K}\sum_{n=1}^{N}p_k^{F,n}-P_{total}\right) \end{aligned} \tag{6}$$

Where λ_k are the Lagrange multipliers for the transmission rate constraint and μ are the Lagrange multipliers for the transmit power constraint. For fixed λ_k , maximization of (6) can be decomposed into K independent subproblems. The suboptimal power allocation is reached iteratively according to the calculation of (6).

4 Simulation Resluts

In this section, to evaluate the proposed scheme we set a simulation platform in which the total bandwidth is 10MHz and the number of unoccupied femtocell subchannels is 64. The transmission radius of macrocell and femtocell are 300m and 20m, respectively. The macro cell-edge user devices are randomly located in the macrocell coverage area. Of course, the distance between these UEs and FBS is much closer than their distance to MBS. To make it simplify, we assume $\eta_1 : \eta_2 : \cdots \eta_k = 1:1:\cdots:1$, which means each macro cell-edge user has the same capacity constraint. We compare our result with the normal equal power control transmission. That is, these unoccupied subchannels and power are equally allocated to all the macro cell-edge user devices.

From Fig.2, it can be easily seen the total transmission rate of the macro cell-edge users is improved using our proposed method. The resource is optimally assigned for each user. And the total capacity of these users is increased. The fluctuation of the blue bar is caused by the location of different user and the channel gain in each subchannel.

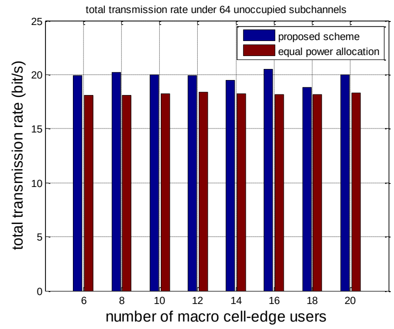

Fig. 2. Transmission Rate versus Number of Macro Cell-edge Users.

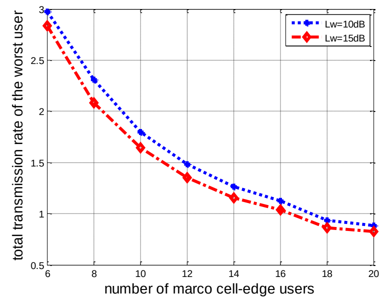

Fig. 3. Capacity versus number of UE with different $L_{..}$.

Fig.3 illustrates the total capacity of cell-edge UEs versus the number of UE under different wall loss. It is clear that when the wall loss increases, the pathloss will increase. Then the throughputs of the entire cell-edge UEs will decrease.

5 Conclusion

In this paper, an adaptive resource allocation scheme is proposed to maximize the total transmission rate of macro cell-edge UE while considering the rate fairness between different user devices. In this framework, the macro cell-edge user device which experiences lower SINR is allowed to use the resource of nearby femtocell without cause interference to the original FUE in the femtocell. A two-step procedure is taken to achieve the maximal transmission rate, i.e. subchannel allocation and power allocation. The simulation result shows the optimal algorithm achieve higher capacity compared with the equal power allocation from MBS. In the future, we would like to study the total transmission rate with different rate fairness requirement.

References

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