Analysis of Spectral Efficiency in Downlink OFDMA Femtocell Networks

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ABSTRACT: Orthogonal Frequency Division Multiple Access (OFDMA) has been selected as the multiple access technique to meet the growth of cellular subscribers and the need for faster and more reliable data services. The fundamental in OFDMA femtocell network is the interference management. When femtocell is deployed in the existing macrocell network, there will be a chance of interference between the femtocells and macrocells. Therefore a joint subchannel and power allocation method is proposed that reduces interference. The performance of OFDMA femtocell network depends on spectral efficiency. The major focus of this paper is to study the effect of spectral efficiency on network performance.

KEYWORDS: Orthogonal Frequency Division Multiple Access (OFDMA), Femtocell, Resource Allocation, Subchannel Allocation, Power Allocation.

I.INTRODUCTION

Fourth generation and beyond cellular networks need high quality and high data rate communication. In recent years femtocell has been proposed as a solution for this. Femtocells are the miniature versions of the standard macrocell and both use the same frequency band of the spectrum. Femtocells help to improve capacity and coverage of these networks by sharing traffic loads from macrocells. Since some users are offloaded to femtocells macrocell reliability can be increased. There are mainly two kinds of interference that will occur when femtocell is deployed in the existing macrocell network. When two femtocells uses same frequency band co tier interference will occur. Cross tier occurs between femtocells and macrocell. To improve the performance of these networks interference must be avoided. For that different resource allocation strategies are used. By using OFDMA (orthogonal Frequency Division Multiple Access) in these networks, ISI (Inter Symbol Interference) can be reduced. Since orthogonal subcarriers are used. In order to improve the spectral efficiency of OFDMA Femtocell networks in the downlink, joint subchannel and power allocation is introduced.

In the existing literatures, A joint resource and power in a self organized network using a potential game is proposed in [1]. But the analysis is carried out in terms of throughput of the macrocell and femtocell networks. Authors in [2] propose an approach, where each cell manages its own subchannels (ie, self organization) to mitigate cross and co-layer interference. A Distributed Dynamic Frequency Planning (D-DFP) algorithm is used for subchannel allocation. Authors in [3] propose a utility-based signal to interference and noise ratio (SINR) that reduces the cross-tier interference in a femtocell network. However, they do not cater to the co-tier interference component, which is also termed as the bottle neck in performance enhancement for the shared channel environment. The authors in [4] propose a heuristic approach for resource allocation and power control for femtocell networks. However, the assumption of the study is that the information is thoroughly exchanged among the players for performance improvement which is not practical in the real environment. A novel detective Q-learning is employed in [5] for self-organized resource allocation in femtocell networks. However, it takes time to learn the learning mechanism for the optimal strategies, which makes it unsuitable for the real cases. The authors in [6] propose a joint subchannel and power allocation for the downlink of femtocell networks. Specifically, they have exploited the convex optimization and iterative approach for performance improvement of the network. However, they have only considered the throughput of the system.

The authors in [7] present a novel Stackelberg game for the resource allocation problem within the context of femtocell networks. In the game, the macro base station (MBS) which is the leader selects the resources for meeting the demand of its users followed by the allocation of followers with the concern to maximizing the throughput. They take the spectrum sharing into account while assuming the fixed power. However, the joint allocating task significantly improves the performance. All these works consider the throughput enhancement of the network without taking into consideration the spectral efficiency.

For power allocation, Hojoong Kwon and Byeong Gi lee in [8] propose a game theory technique that has been exploited in microeconomics to deal with competition among selfish, intelligent decision makers. It can be used to solve many optimization problems such as CDMA power control, cognitive radio and OFDMA resource allocation. Using this technique, total power consumption can be reduced. For better allocation of power, combination of game theory and water filling is used. Authors in [9] propose a technique where, joint allocation of resource blocks and transmit powers is investigated for the downlink transmission of OFDMA femtocells. When a best adaptive strategy is applied, the formulated exact potential game converges to Nash equilibrium.

In this paper, an attempt is made for the joint subchannel and power allocation for OFDMA femtocell networks considering spectral efficiency for femtocell user equipments in each femtocell.
The rest of the paper is organized as follows: Section II presents the system model used for investigation and the problem formulation. Section III proposes a joint subchannel and power allocation algorithm. Section IV involves simulation and results. Finally section V concludes the paper..

II.SYSTEM MODEL

Fig. 1 shows the system model. Here, an OFDMA based two tier macrocell-femtocell networks with M macrocells and F femtocell is considered. In this network, users of both tiers share the spectrum consisting of N subchannels. Let U_M denote the number of macrocell user equipments and U_F be the number of femtocell user equipments. Both user equipments are served by the base station (BS) of the network. Let U be the total number of user equipments in the network and $U_M = U_1$ denote the set of macrocell user equipments and $U_F = U_f$ denote the set of femtocell user equipments where, f={2,3,……F}.

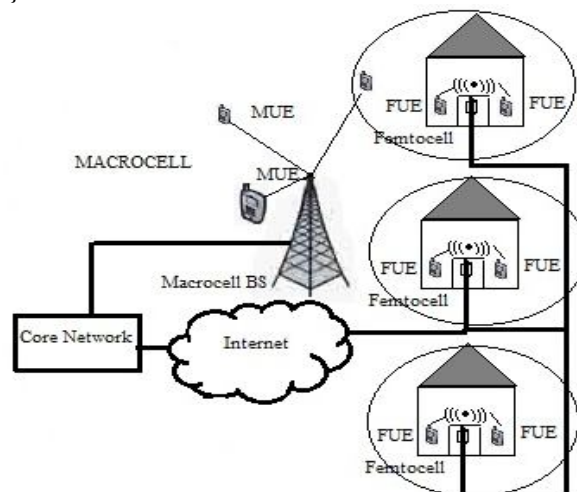Fig. 1. System model.

For all user equipments in the macrocell and femtocell, a fixed BS association is considered. Let **N** denote the set of all accessible frequencies which consists of N orthogonal subchannels. In the case of OFDMA, a particular OFDM subchannel can be used by at most one user equipment in that cell at a given time. Let the base station serving user equipment m is denoted as $B_m \in B$. To reduce the complexity of assigning subchannels into each user, the resource allocation problem is divided into subchannel allocation and power allocation. In this paper, a joint subchannel and power allocation is considered where, power allocation of macrocell is performed before femtocell subchannel and power allocation. The subchannel allocation matrix is defined as,

$$S(m,n) = S_m^n$$

$$= \begin{cases} 1, \text{ if subchannel n is assigned for UE m} \\ 0, \text{ othewise} \end{cases} \tag{1}$$

The power allocation matrix is,

$$P(m,n) = P_m^n \tag{2}$$

III. JOINT SUBCHANNEL AND POWER ALLOCATION

Resource allocation is the process of assigning different sets of subchannels, bits and power periodically to different users depending on their current channel states to satisfy specific performance criteria. In this paper, a joint subchannel and power allocation algorithm is introduced, which combines Hungarian algorithm [10] for subchannel allocation and water filling [11] for power allocation. The Hungarian method is an algorithm which finds an optimal assignment for a given cost matrix. It is a combinational optimization algorithm that solves the assignment problem in polynomial time and which anticipated later primal-dual methods. The steps involved in Hungarian algorithm are summarized as follows.

Let S denotes the subchannel allocation matrix of order N. Then following operations are carried out.
- Subtract the smallest entry in each row from all the entries of its row.
- Subtract the smallest entry in each column from all the entries of its column.
- Draw lines through appropriate rows and columns so that all the zero entries of the cost matrix are covered and the minimum number of such lines is used.
- If the number of covering lines is N, an optimal assignment of zeros is possible and is finished.
- If the number of covering lines is less than N, an optimal assignment of zeros is not yet possible. In that case proceed to next step.
- Determine the smallest entry not covered by any line. Subtract this entry from each uncovered row, and then add it to each covered column. Return to step 3.

In this paper water filling [11] is used as the power allocation scheme.

When subchannels and power are allocated to different users in an OFDMA femtocell network, is to be ensured that there is balance between user's fair performance and user's QoS performance. Once the subchannel allocation is obtained, the power allocation for each user can be determined, which aims at maximizing the total capacity and does not affect the users fair performance. So the power allocation plays an important role in the resource allocation of OFDMA femtocell networks.

The total capacity is the sum of the capacity of each subcarriers in the OFDM system, the capacity can be defined as:

$$C = \frac{B}{N} \sum_{n=1}^{N} \log(1 + \frac{\alpha_n^2 P_n}{BN_0 / N}) \tag{3}$$

TABLE I. NOTATION

Notation	Description
N	Number of subchannels
B	System bandwidth
α_n	Gain of subcarrier n
P_n	Transmitted power
N_0	Noise power

Then with the total power constraint, shannon capacity problem can be formulated as:

$$C = \max \frac{B}{N} \sum_{n=1}^{N} \log(1 + \frac{\alpha_n^2 P_n}{BN_0 / N}) \tag{4}$$

Subject to:

$$P_T = \sum_{n=1}^{N} P_n \leq P \qquad (5)$$

$$\sum_{n=1}^{N} P_n \geq 0 \qquad \forall n \qquad (6)$$

The basic principle in the water filling algorithm is to allocate power to subcarriers that experience higher channel gain, while allocating little or no power to the subcarriers having low channel gain.

According to (4) Lagrange function can be defined using Lagrange multiplier. The allocated power can be formulated as follows:

$$P_n = \left[\frac{1}{\beta} - \frac{1}{T_n} \right]^+ \qquad (7)$$

Where, β is the water level. To get better performance iterative water filling can be used. But the computational complexity will be higher.

Let S denote the subchannel allocation matrix and P denote the power allocation matrix, then SINR achieved at the base station B_m due to the transmission of UE m over subchannel n can be represented as,

$$\Gamma_m^n (S, P) = \frac{h_{Bm}^n P_m^n s_m^n}{\sum_{j \notin U_{Bm}} h_{Bmj}^n p_j^n s_m^n + \eta_{Bm}^n} \qquad (8)$$

$$= \frac{P_m^n s_m^n}{I_m^n (S, P)} \qquad (9)$$

Where, $I_m^n (S, P)$ is the effective interference of user equipment (UE) m on subchannel n. $I_m^n (S, P)$ is ,

$$I_m^n (S, P) \triangleq \frac{\sum_{j \notin U_{Bm}} h_{Bmj}^n p_j^n s_m^n + \eta_{Bm}^n}{h_{Bm\,m}^n} \qquad (10)$$

The spectral efficiency of Femto User Equipment (FUE) m on one subchannel can be defined as,

$$r_m^n (S, P) = \begin{cases} 1, \text{if } \Gamma_m^n (S, P) < \bar{\gamma}_m^n \\ r_{f,} \text{if } \Gamma_m^n (S, P) \geq \bar{\gamma}_m^n \end{cases} \qquad (11)$$

Where $r_f = \left(\frac{1}{N} \right) \log_2 q_f$, and q_f is the constellation size of FUEs in all femtocells.

In the downlink structure the power constraint is less complicated than in the uplink. For downlink resource allocation, MUEs calculates the transmission power values on the corresponding subchannels from the estimated effective interference on their allocated subchannels. Then the updated transmission power values of each MUEs is send to the macro base station. The transmission power values of all subchannels are updated by the macro base station.

V. RESULT AND DISCUSSION

In this section simulation results of the proposed algorithm are presented. Simulation tool used is the Matlab. A downlink resource allocation algorithm (DRA) [13] is compared with the proposed algorithm. Downlink resource allocation algorithm uses Hungarian algorithm for subchannel allocation and Foschini Miljanic power updation algorithm for power allocation. In this paper, joint Hungarian and water filling is used for subchannel allocation and power allocation. Five modulation schemes (8, 16, 64, 256 and 1024) are used for femtocell user equipments to obtain the simulation results. The target BER E_{target} is chosen as 10^{-3} and is calculated as,

$$f^{-1}(E_{target}) = \gamma(q) \leq \gamma_b(q) \qquad (12)$$

Where q is the constellation size of QAM-modulation scheme and $\gamma_b(q)$ is,

$$\gamma_b(q) = \frac{\left[Q^{-1}\left(\frac{E_{target}}{x_q}\right)\right]^2}{y_q} \tag{13}$$

Where Q(.) denotes the Q function and $x_q=2(1-1/\sqrt{q})/\log 2$, $y_q=3/2(q-1)$. $\gamma(q)$ is the signal to interference and noise ratio(SINR) and $\gamma_b(q)$ is the target SINR.

Fig. 2 shows the total minimum spectral efficiency with femtocell constellation size for different values of macrocell constellation sizes of downlink resource allocation (DRA) algorithm. The figure shows that, for higher constellation sizes spectral efficiency[14] of OFDMA femtocell network will be higher.
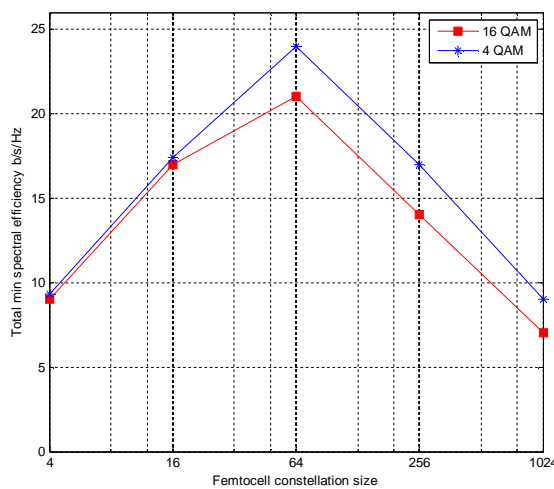

Fig. 2. Total minimum spectral efficiency of DRA.

Fig. 3 shows the total minimum spectral efficiency with femtocell constellation size for different values of macrocell constellation sizes of proposed algorithm. Comparing Fig. 2 and 3, the proposed algorithm gives better spectral efficiency than the URA algorithm. Therefore downlink resource allocation of OFDMA femtocell networks using proposed method gives better performance than the DRA algorithm.
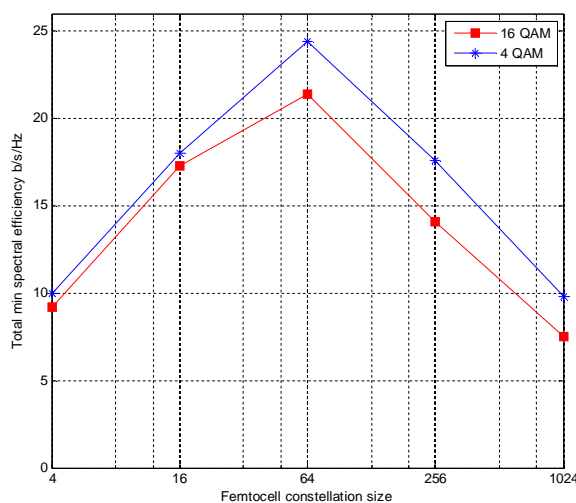

Fig. 3. Total minimum spectral efficiency of proposed algorithm.

VI.CONCLUSION

In this work, downlink resource allocation for OFDMA femtocell network was conducted and the effect of spectral efficiency on system performance was analyzed. Analysis shows that proposed algorithm involving joint subchannel and power allocation using Hungarian algorithm and waterfilling algorithm gives better spectral efficiency than the downlink resource allocation algorithm. Also the proposed algorithm gives better network performance. Results show that spectral efficiency depends on both femtocell and macrocell constellation size. Lower the macrocell constellation size better will be the spectral efficiency. When the femtocell constellation size is increased, initially spectral efficiency increases after that it gradually decreases.

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