International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-5 Issue-3, February 2016

Analysis of Spectral Efficiency in OFDMA Fem to Cell Networks

Swapna P. S, Susan R. J, Sakuntala S. Pillai

Abstract—Orthogonal Frequency Division Multiple Access (OFDMA) is a promising multiple access technique for next generation wireless communication such as WiMAX, LTE, IMT-A etc because of its high spectral efficiency and inherent robustness against frequency selective fading. Recently fem to cell has been proposed for indoor coverage extension and to reduce traffic within macrocells. Fem to cells are deployed in an ad-hoc manner by different consumers in the same frequency band, causing interference with each other. To fully realize the potential of these networks, it is necessary to allocate resources to them in such a way that interference is mitigated. This work aims to improve the performance of uplink OFDMA fem to cell networks by joint subchannel and power allocation. Joint subchannel and power allocation using Hungarian and water filling algorithm performs better than the existing fem to cell resource allocation algorithms with respect to spectral efficiency.

Index Terms— Orthogonal Frequency Division Multiple Access (OFDMA); femtocell; resource allocation; subchannel allocation; power allocation.

I. INTRODUCTION

Orthogonal Frequency Division Multiple Access (OFDMA) is a promising multiple access technique for forth generation and beyond wireless communications such as WiMAX, LTE, IMT-A because of its high spectral efficiency and inherent robustness against frequency selective fading. In OFDMA, the time and frequency resources are allocated in orthogonal manner to each user. Recently fem to cell has been proposed to improve indoor coverage and to reduce traffic within macro cells [1]. Fem to cells are miniature version of macro cellbase stations designed to provide cellular communication in places where the received signal power from a macro cellbase station is low to support active users. That is, they are used to give connectivity where broadband wired networks are locally available. In these networks, customers are connected to the mobile operator's networks through Digital subscriber lines (DSL). Fem to cells can be efficiently intialized in the existing macro cellnetwork in an Ad-hoc manner and both shares same frequency band. Therefore there will be interference between the macro cells and femtocells. Interference problem between the fem to cell and macro cellshould be avoided to improve the performance of the network.

Manuscript published on 28 February 2016.
***** Correspondence Author (s)
Swapna P. S, Department of Electronics and Communication Engineering, Mar Baselios College of Engineering and Technology, Trivandrum, India.
Susan R. J, Department of Electronics and Communication Engineering, College of Engineering and Technology, Trivandrum, India.
Sakuntala S. Pillai, Department of Electronics and Communication Engineering, Mar Baselios College of Engineering and Technology, Trivandrum, India.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

To successfully deploy Fem to cells in a macro cellnetwork, it is required to solve many problems such as resource allocation and synchronization [2]. In the existing literature, different resource allocation techniques for OFDMA fem to cell networks have been introduced [3]-[9]. In [3], a practical frequency planning method, which is self organizing and fully distributed interference avoidance method based on component carrier level is proposed. The authors in [4] propose a technique where, users in the network achieve equal fairness and larger system efficiency by proper allocation of resources when data is transmitted through the network. R. Chang et al. in [5] propose a fixed Fractional Frequency Reuse (FFR) technique, where a cell is divided into several concentric regions, and assign smaller reuse factor to inner region and bigger reuse factor to outer region. According to the dynamic cell load variations, the spectrum allocation cannot be adjusted dynamically because it is predetermined. Authors in [6] 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 [7] propose a location based resource allocation solution for leveraging maximal spatial reuse from femtocell. In dynamic subchannel allocation position of fem to cell and macro celluser is used, which avoid the allocation to users with larger marginal utility. Macro celldivision is used for this type of allocation. For power allocation, Hojoong Kwon and Byeong Gi lee in [8] propose a game theory technique that has long 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. Some mild conditions, performance of Nash equilibrium is very poor. In this paper, an attempt is made for the joint subchannel and power allocation for OFDMA fem to cell networks considering spectral efficiency of fem to cell network. 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.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

II. SYSTEM MODEL AND PROBLEM FORMULATION

ll networks with M macro cells and F fem to cell is considered. In this network, users of both tiers share the spectrum consisting of N subchannels. Let U_M denote the number of macro celluser equipments and U_F be the number of fem to cell 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 macro celluser equipments and $U_F=U_f$ denote the set of fem to cell user equipments where, f={2,3,……F}. For all user equipments in the macro celland femtocell, a fixed BS association is considered. Let **N** denote the set of all accessible frequencies which consist 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 $B_m \epsilon B$. 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 macro cellis performed before fem to cell subchannel and power allocation. The subchannel allocation matrix is defined as,

$$S(m,n) = S_m^n = \begin{cases} 1, \text{ if subchannel n is assigned for UE m} \\ 0, \text{ othewise} \end{cases} \quad (1)$$

The power allocation matrix is,

$$P(m,n) = P_m^n \quad (2)$$

When fem to cell is introduced into the macro cellnetwork, there will be interference between the fem to cell users and macro cellusers which reduces the performance of OFDMA fem to cell networks. In order to mitigate interference while maintaining desired performance resource allocation is used.

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 combine Hungarian algorithm [10] for subchannel allocation and water filling for power allocation.

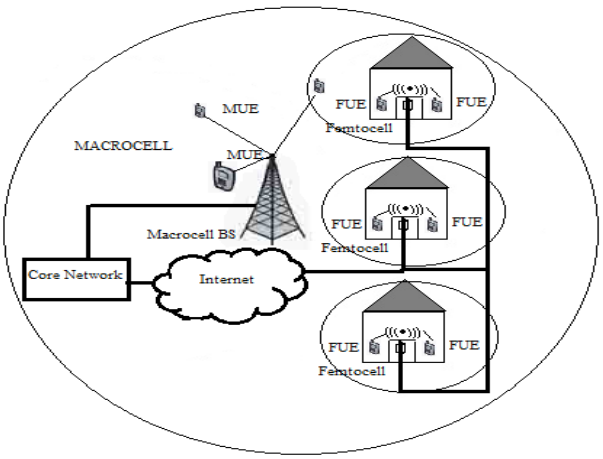

Figure 1. Network model

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. If there are m persons and m jobs to be done, the quadratic matrix

$$\begin{bmatrix} c_{00} & \cdots & c_{0m} \\ \vdots & \ddots & \vdots \\ c_{m0} & \cdots & c_{mm} \end{bmatrix}$$

denotes the cost matrix, where the element c_{ij} denotes the cost of the person i doing work j. The allocation problem is to find the exclusive assignment matrix D that minimises the sum over the costs of all jobs:

$$D = \arg\min \sum_{i=1}^{m-1} \sum_{j=1}^{m-1} D_{ij} c_{ij} \quad (3)$$

Set

$$\sum_{1=0}^{m-1} D_{ij} = 1 \qquad 0 \le j \le m-1 \quad (4)$$

$$\sum_{1=0}^{m-1} D_{ij} = 1 \qquad 0 \le i \le m-1 \quad (5)$$

The trivial solution of this problem is to check all m! possible assignments and choose the set with the lowest total cost. Hungarian algorithm reduces the exponential complexity involved in the algorithm. In this paper water filling [11] is used as the power allocation scheme. An OFDM system is represented as,

$$Y_n[m] = h_n X_n[m] + w[m] n=0,1….N-1 \quad (6)$$

Where $X_n[m]$, $Y_n[m]$ and w[m] are the input, output and noise signals in each subchannel respectively. h_n is the channel gain for each subchannel with total power constraint P_{total}. Let P_n is the transmit power in each subchannel. Using OFDM channel, maximum rate for reliable transmission is,

$$R = \sum_{n=1}^{N-1} \log\left(1 + \frac{|h_n|^2 P_n}{N_o}\right) \quad (7)$$

Where, N_0 is the power density of the noise. Therefore the power allocation can be done in such a way that it maximizes the rate in (7). Thus power allocation is the solution to the optimization problem:

$$R_N = \max_{P_0 P_{N-1}} \sum_{n=1}^{N-1} \log\left(1 + \frac{|h_n|^2 P_n}{N_o}\right) \quad (8)$$

Also,

$$P_{total} = \sum_{n=1}^{N-1} P_n \quad (9)$$

The optimization problem can be solved using Lagrangian method.

$$L(\lambda, P_0 P_{N-1}) = \sum_{n=1}^{N-1} \log\left(1 + \frac{|h_n|^2 P_n}{N_o}\right) - \lambda \sum_{n=1}^{N-1} P_n \quad (10)$$

Where, λ is the Lagrange multiplier. The Kuhn-Tucker condition for the optimal solution is

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

$$\left.\begin{aligned}\frac{dL}{dP_n} &= 0, \text{if } P_n > 0\\ \frac{dL}{dP_n} &\le 0, \text{if } P_n = 0\end{aligned}\right\} \quad (11)$$

Power allocation can be expressed as,

$$P_n^+ = \left(\frac{1}{\lambda} - \frac{N_o}{|h_n|^2}\right)^+ \quad (12)$$

$$\sum_{n=1}^{N-1}\left(\frac{1}{\lambda} - \frac{N_o}{|h_n|^2}\right)^+ = P_{total} \quad (13)$$

If the Lagrangian multiplier λ satisfies the above condition, then (11) gives optimal solution.The inverse of the Lagrangian multiplier λ is known as the water level. 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,

$$\Gamma_m^n(S,P) = \frac{h_{Bm}^n p_m^n s_m^n}{\sum_{j\in U_{Bm}} h_{Bmj}^n p_j^n s_m^n + \eta_{Bm}^n} = \frac{P_m^n\, s_m^n}{I_m^n(S,P)} \quad (14)$$

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

$$I_m^n(S,P) \triangleq \frac{\sum_{j\in U_{Bm}} h_{Bmj}^n p_j^n s_m^n + \eta_{Bm}^n}{h_{Bm\,m}^n} \quad (15)$$

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

$$r_m^n(S,P) = \begin{cases}1, \text{if } \Gamma_m^n(S,P) < \bar{\gamma}_m^n\\ r_f, \text{if } \Gamma_m^n(S,P) \ge \bar{\gamma}_m^n\end{cases} \quad (16)$$

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

IV. SIMULATION AND RESULTS

In this section simulations of the proposed algorithm are presented. Matlab is used for the simulation. An uplink resource allocation algorithm (URA) [13] is compared with the proposed algorithm. Uplink 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 fem to cell user equipments to obtain the simulation results. The target BER E_{target} is chosen as 10^{-3} and is calculated as,

$$f^{-1}(E_{target}) = \gamma(q) \le \gamma_b(q) \quad (17)$$

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Fem to cell radius	30 m
Number of subchannels	512
Carrier frequency	2.5 GHz
Noise power	10^{-13} W
Target BER	10^{-3}

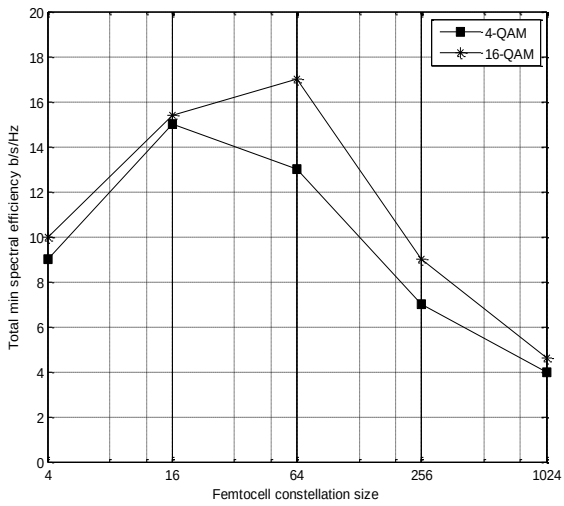

Figure 2. Total minimum spectral efficiency versus fem to cell constellation size of URA

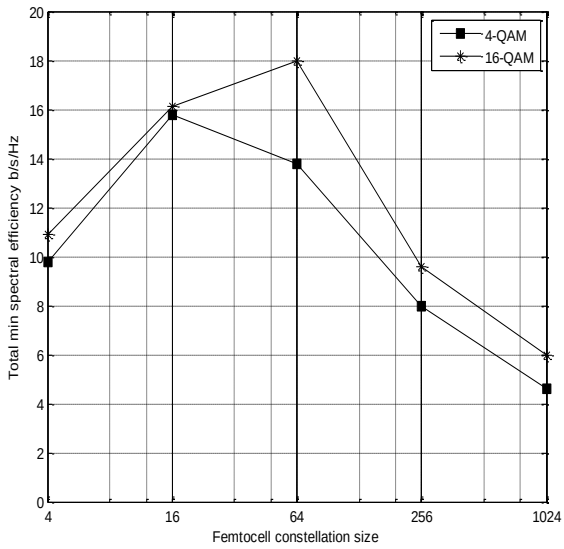

Figure 3. Total minimum spectral efficiency versus fem to cell constellation size of proposed algorithm.

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

$$\gamma_b(q) = \frac{\left[Q^{-1}\left(\frac{E_{target}}{x_q}\right)\right]^2}{y_q} \quad (18)$$

Where Q(.) denotes the Q function.

$$x_q = 2(1-1/\sqrt{q})/\log 2, \quad (19)$$

$$y_q = 3/2(q-1) \quad (20)$$

γ(q) is the signal to interference plus noise ratio(SINR) and $\gamma_b(q)$ is the target SINR. Fig. 2 and 3 show the total minimum spectral efficiency of each fem to cell versus the constellation size of QAM modulation scheme of URA algorithm and proposed algorithm. The figure shows that when the constellation size of fem to cell increases spectral efficiency increases and then decreases.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

If the constellation size of macro user equipments increases spectral efficiency decreases. That is, higher constellation sizes have higher target SINRs, which require higher transmission power and produce more interference to other users in the networks. Therefore, for higher constellation sizes 256 and 1024 the power constraint of FUEs and MUEs are more likely to be violated, which limits the number of subchannels allocated for each FUEs. For low constellation sizes, the spectral efficiency on each assigned subchannel increases when the modulation level increases. But the number of assigned subchannels for each FUE does not decrease too much.

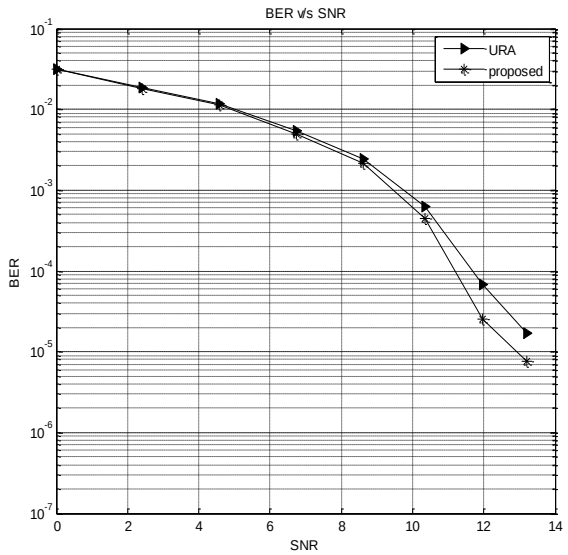

Figure 4. Comparison of BER vs SNR.

Fig. 4 shows the relation between BER and SNR of proposed algorithm and URA. Proposed algorithm using Hungarian algorithm and waterfilling algorithm gives better performance than URA algorithm. Fig. 5 shows the total minimum spectral efficiency of fem to cell versus the maximum power of each FUE with different modulation levels of MUEs of URA algorithm and proposed algorithm. The figure show that when the maximum power budget increases spectral efficiency increases and is saturated when power budget become sufficiently large. Resource allocation using Hungarian and water filling gives better spectral efficiency than URA algorithm.

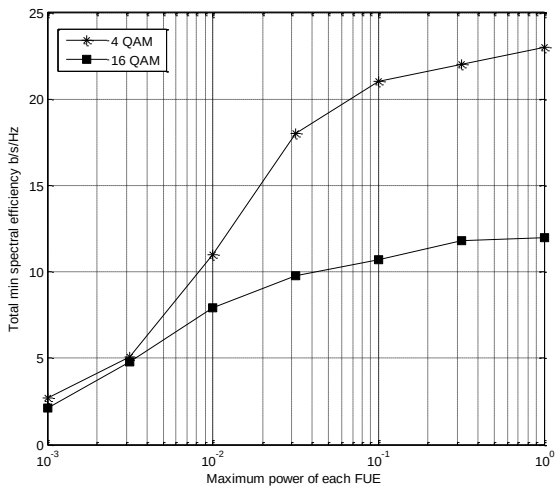

Figure 5. Total minimum spectral efficiency of proposed algorithm

V. Conclusion

Fourth generation cellular networks uses OFDMA as the multiple access techinique. For indoor coverage and traffic reduction Fem to cells are introduced. They are deployed in the existing macro cellnetworks and use the same frequency bands of macro cells which creates interference between the Fem to cells and macrocells. In order to improve the performance of these networks resources must be properly allocated. The joint subchannel and power allocation technique improve the performance of OFDMA fem to cell networks by increasing the spectral efficiency of these networks. By joint subchannel and power allocation, interference between the neighboring users can be reduced. This will increases the spectral efficiency and performance of OFDMA fem to cell networks.

References

1. Taeyoung Lee, Hyuntai Kim, Jinhyun Park, and Jitae Shin, " An Efficient Resource Allocation in OFDMA Fem to cell Networks", IEEE 72nd Vehicular Technology Conference Fall (VTC 2010-Fall), 2010.
2. G. Li and H. Liu, "Downlink radio resource allocation for multi-cell OFDMA system," IEEE Trans. Wireless Commun., vol. 5, no. 12, pp. 3451–3459, Dec. 2006.
3. L. Garcia, K. Pedersen, and P. Mogensen, "Autonomous component carrier selection: Interference management in local area environments for lte-advanced," IEEE Communications Magazine., 2009.
4. R. Madan, J. Borran, A. Sampath, N. Bhushan, A. Khandekar, and T. Ji, "Cell association and interference coordination in heterogeneous LTE-A cellular networks," IEEE Journal on Selected Areas in Communications., 2010.
5. R. Chang, Z. Tao, and C.-C. Zhang, J.and Kuo, "A graph approach to dynamic fractional frequency reuse (ffr) in multi-cell ofdma networks," in IEEE ICC, 2009.
6. David Lopez, Akos Ladanyi, Alpar Juttner and Jie Zhang, "OFDMA femtocells: A Self Organizing approach for frequency assignment" IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications, 2009.
7. K. Sundaresan, S. Rangarajan, " Efficient Resource Management in OFDMA Femto Cells," Proceedings of the tenth ACM international symposium on Mobile ad hoc networking and computing, May. 2009.
8. Hojoong Kwon and Byeong Gi Lee," Distributed Resource Allocation through Noncooperative Game Approach in Multi-cell OFDMA Systems," IEEE conference publications,2006.
9. L. Giupponi and C. Ibars, "Distributed interference control in OFDMAbased femtocells," in Proc. 2010 IEEE Int. Symp. on Personal, Indoor and Mobile Radio Commun., pp. 1201–1206.
10. Stephen Schedler and volker Kuhn, "Resource allocation for the multiple access relay channels and OFDMA," EURASIP Journal on Advances in Signal Processing 2013.
11. Qilin Qi, Andrew Minturn, and Yaoqing (Lamar) Yang, "An Efficient Water-Filling Algorithm for Power Allocation in OFDM-Based Cognitive Radio Systems", 2012 International Conference on Systems and Informatics (ICSAI 2012).
12. R. Jain, A. Durresi, and G. Babic, "Throughput fairness index: Anexplanation," ATM Forum Document Number: ATM Forum/990045, Feb. 1999.
13. Vu Nguyen Ha and Long Bao Le, "Fair resource Allocation for OFDMA Fem to cell Networks with Macro cellProtection", IEEE Transactions On Vehicular Technology, Vol. 63, No. 3, March 2014.
14. Prabhu Chandhar, Suvra Sekhar Das," Analysis of Area Spectral Efficiency for Co-Channel Deployed Macrocell-Fem to cell OFDMA Networks", wireless communications symposium IEEE ICC, 2013.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.