2017 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom)

Power Control and Resource Allocation in TDD-OFDM Based Femtocell Networks with Interference

Mhd Tahssin Altabbaa, Taner Arsan, and Erdal Panayirci
Kadir Has University, Istanbul-Turkey
{tahsin.altabbaa, arsan, eepanay}@khas.edu.tr

***Abstract*—Femtocell technology is a promising solution for different dilemmas in cellular networks. In femtocell power control, the interference experienced by the network is divided into two main tiers according to the type of network whose signal is interfering with another network. In utilizing the functionality of a two-tier network where femtocell technology is deployed, a major challenge is in sharing the frequency resource of a macrocell. This paper proposes an enhanced dynamic algorithm bounded by two constraints to optimize the transmission powers of femtocell users in TDD-OFDM based femtocell networks, taking into consideration rate enhancement of femtocell mobile stations. We compare our algorithm with the macrocell guard system, which allows femtocells to occupy only the subchannels unoccupied by the macrocell.**

I. INTRODUCTION

Spectrum scarcity, dead zones, and the tremendous increase of mobile telephony subscribers have been forcing mobile operators to enhance their network operations. Installing additional Macro Base Stations (MBSs) with limited coverage can solve the aforementioned problems, except the fact that such a solution has a high cost. Femtocell Base Station (FBS) is a less expensive base station that users can set up in their indoor area in order to get better capacity and coverage. Due to the lack of spectrum, Femtocells (FCs) and Macrocells (MCs) share the same frequency band which leads to enormous interference, for which conventional power control techniques are not sufficient. In femtocell networks, a well-planned power control scheme can solve the interference issue and maintain the Quality of Service (QoS) in the two-tier networks.

Many related proposals for femtocell rate enhancement and interference management under uplink/downlink power optimization have been made. In [1] and [2] a Fractional Frequency Reuse (FFR) deployment is considered. The power control scheme proposed by [1] involves calculations of base stations' positions and the proposed algorithm assigns the frequency band to FBSs and MBS according to the threshold of the Signal to Interference plus Noise Ratio (SINR) of their geographical partition. In [2], the authors propose a power control mechanism for downlink communication with a sectorized antenna and a network model based on two different frequency sets. Using the information of SINR of FBSs, the algorithm obtains the updated transmitting powers, where a handover mechanism is deployed among the frequency sets. The results show that with a higher femtocell density, a better outage probability is obtained compared to omnidirectional-based cells. Authors of [3] devised a relationship between the transmitting powers and SINR. Based on an adequate SINR, a low complexity optimization-based algorithm determines the proper uplink/downlink powers. An optimization-based solution bounded by constraints that use Bit Error Rate (BER) and packet time delay for rate and power control is developed in [4]. The study proposed in [5] shows a contribution of Femto Mobile Stations (FMSs) and neighbouring FBSs for downlink power control and rate enhancement. An uplink power control mechanism concerning the interference alleviation arriving at the MBS coming from the FC side is addressed in [6], where the authors propose a Time Division Duplexing-Orthogonal Frequency Division Multiplexing (TDD-OFDM) communication model. In [7], two approaches are discussed including static and stochastic networks. The authors propose an algorithm for uplink power optimization and a Stackelberg game based solution for relaying the data of macrocell users to the best femtocell user candidate in the presence of a severe communication environment. In [8], coalitional game based resource allocation for the uplink communication is proposed, where the optimization constraints not only alleviate the interference but also preserve a minimum data rate fulfillment for the femtocell users. In [9], a Stackerlberg equilibrium based uplink power control technique is presented, where an optimal interference pricing is obtained through the Lagrange optimization method.

In this paper, we consider a femtocell network where the FCs and MC share the same spectrum. The aim of our algorithm is to overcome the aggregated inter-tier (FMSs to MBS) and intra-tier (FMS to FMS) (discussed in [10]) interference experienced in the uplink direction of FMSs, taking into consideration the maximization of their uplink rate. Since FCs are randomly distributed along the network, we assume that the intra-tier interference can be high with dense FCs; consequently, considering this type of interference would enhance the system performance. The proposed communication technique is based on the TDD-OFDM. Using the Lagrange dual principle, power optimization on the uplink powers of FMSs at each subchannel is performed. Note that, our paper considers that each FMS has the channel state information of other mobile stations within the MC coverage. In real applications a channel estimation mechanism is applied; however, this is beyond the scope of our paper. The rest of this paper is organized as follows. The system model and problem formulation is discussed in Section II. The proposed algorithm is presented in Section III. The performance of the algorithm

978-1-5090-5049-9/17/$31.00 ©2017 IEEE

is illustrated with simulation parameters and results in Section IV. Finally, conclusions and suggestions for future work are given in Section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

Our system model considers a set of K non-overlapped FCs, each of which has one active mobile station and provides wireless coverage of a radius R_f. The FCs are randomly distributed and operate in a MBS wireless coverage of a radius R_c located in the center of the MC. Using the projection of TDD technique on OFDM technology, the designed model divides the frequency band into M different subchannels for uplink transmission whose bandwidths are equal, where both users of FC and MC share the M subchannels. Define f_m and I_m as the state of subchannel m at FMSs, that is when $f_m = 1$ the FMSs are allowed to occupy it, or not $f_m = 0$, and the interference tolerance on subchannel m, respectively. The proposed algorithm assumes that MBS has the ability to recognize the aggregated interference experienced at its side coming from the FMSs. In addition, whenever the aggregated interference at a specific subchannel m exceeds the interference tolerance I_m, the MBS $prohibits$ FMSs from using that subchannel. We assume that the MBS follows a power control mechanism with its attached Macro Mobile Station (MMS); consequently, there is no need to update the interference tolerance I_m of any OFDM subchannel. Fig. 1 shows a MC with femtocell deployment along with the inter-tier and intra-tier interferences discussed in this paper for alleviation purposes.

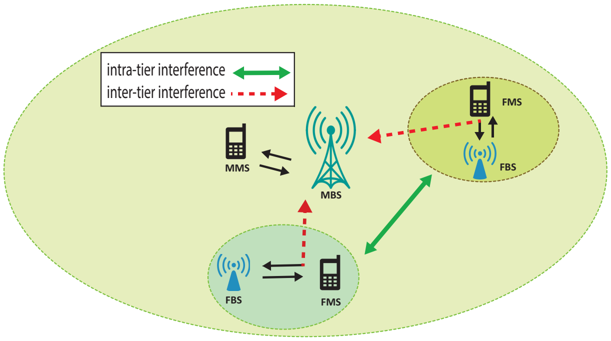

Fig. 1. Interference tiers discussed

In order to maintain the QoS of MMS communication, the transmitting powers of all FMSs must satisfy the following constraint:

$$f_m \sum_{k=1}^{K} P_k^m \; h_k^m \leqslant f_m \; I_m, \qquad (1)$$

where P_k^m represents the transmitting power of FMS $k \in K$ on subchannel $m \in M$, h_k^m represents the channel response from FMS k to MMS on subchannel m. Eq.(1) shows that the system permits FMSs to use any subchannel of M as long as the summation of the received signals coming from FMSs does not exceed a predefined threshold I_m. Define $\eta^2 = N_k^m + Q_k^m$, that represents the summation of the background noise power and the interference coming from the MMS and received at the k^{th} FMS, respectively. The k^{th} FMS can encounter a transmit information rate of,

$$R_k = \sum_{m=1}^{M} \log_2\left(1 + \frac{G\; h_{kk}^m P_k^m}{\eta^2 \; + \sum_{\substack{i=1\\ i\neq k}}^{K} h_{ki}^m \; P_i^m}\right), \qquad (2)$$

where G represents the antenna gain, h_{kk}^m indicates the channel response between FMS k and its FBS on subchannel m. h_{ki}^m and P_i^m indicate the channel response and the power of the i^{th} FMS ($i \in K$) received at FMS k on subchannel m, respectively. The summation of multiplications $h_{ki}^m \; P_i^m$ is used for the intra-tier interference alleviation purpose. Another constraint is proposed to maintain and maximize the rate of FMSs. Consequently, the optimization problem discussed above can be expressed as follows

$$U = \max \sum_{k=1}^{K} o_k \; R_k \qquad (3)$$

subject to

$$\sum_{m=1}^{M} P_k^m \; \leqslant \; P_k^{MAX}, \qquad (4)$$

where $o_k = 1/K$ is the normalized rate weight among FMSs, and P_k^{MAX} denotes the maximum transmitting power that a FMS is allowed to use for transmitting on a subchannel m. Substituting Eq.(2) into Eq.(3), the objective function (U) can be written as

$$U = \sum_{k=1}^{K} o_k \sum_{m=1}^{M} \log_2\left(1 + \frac{G\; h_{kk}^m \; P_k^m}{\eta^2 \; + \sum_{\substack{i=1\\ i\neq k}}^{K} h_{ki}^m \; P_i^m}\right) > 0. \qquad (5)$$

The objective function in (5) is found to be convex when a gradient test is applied to it with respect to P_k^m. Consequently, we propose our algorithm based on the Lagranigan duality principle [11] to solve the optimization problem in the next section.

III. RATE ENHANCEMENT AND POWER CONTROL ALGORITHM

In this section, we introduce our power control algorithm. According to [11], we can project the constraints (1) and (4) into Lagrange duality via the dual vectors $\boldsymbol{\mu} = [\mu_1 \; \mu_2 \; .. \; \mu_M]^T$ and $\boldsymbol{\lambda} = [\lambda_1 \; \lambda_2 \; .. \; \lambda_K]^T$. Consequently, the Lagrangian function can be obtained as follows

$$\begin{aligned} L(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) &= \sum_{m=1}^{M} \sum_{k=1}^{K} o_k \sum_{m=1}^{M} \log_2(1 + \frac{G h_{kk}^m P_k^m}{\eta^2 + \sum_{\substack{i=1\\ i\neq k}}^{K} h_{ki}^m P_i^m}) \\ &+ \sum_{k=1}^{K} \lambda_k (P_k^{MAX} - \sum_{m=1}^{M} P_k^m) + \sum_{m=1}^{M} \mu_m f_m (I_m - \sum_{k=1}^{K} P_k^m h_k^m) \end{aligned}$$

$$= \sum_{m=1}^{M} \Big\{ \sum_{k=1}^{K} o_k \log_2(1 + \frac{G h_{kk}^m P_k^m}{\eta^2 + \sum_{\substack{i=1 \\ i \neq k}}^{K} h_{ki}^m \ P_i^m}) - \sum_{k=1}^{K} \lambda_k P_k^m$$
$$+ \mu_m \ f_m \ (I_m \ - \ \sum_{k=1}^{K} \ P_k^m \ h_k^m) \Big\} \ + \ \sum_{k=1}^{K} \ \lambda_k \ P_k^{MAX},$$

where **P** = $[P_1^1 P_1^2 \ .. \ P_1^M P_2^1 P_2^2 \ .. \ P_K^{M-1} P_K^M]^T$ is the power allocation vector of the transmitting power of each FMS k on each subchannel m.

$$\Leftrightarrow \ L(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = \sum_{m=1}^{M} \ L_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) \ + \ \sum_{k=1}^{K} \ \lambda_k \ P_k^{MAX}, \quad (6)$$

where

$$L_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = \sum_{k=1}^{K} \ o_k \ \log_2(1 + \frac{G \ h_{kk}^m P_k^m}{\eta^2 \ + \sum_{\substack{i=1 \\ i \neq k}}^{K} h_{ki}^m \ P_i^m})$$
$$- \ \sum_{k=1}^{K} \ \lambda_k \ P_k^m + \mu_m \ f_m \ (I_m \ - \ \sum_{k=1}^{K} \ P_k^m \ h_k^m). \quad (7)$$

Consequently, the Lagrangian dual optimization formulation can then be expressed as

$$D(\boldsymbol{\lambda}, \boldsymbol{\mu}) = \max_{\mathbf{P} \ \geq \ 0} \ L(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}). \quad (8)$$

Equations (6) and (7) show that, a M independent Lagrangian optimization functions can be formulated for solving the dual optimization in Eq.(8). Consequently, the optimization problem can be expressed as,

$$\max_{\mathbf{P} \geq \ 0} \ L_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}), \qquad m = 1, 2, ..., M. \quad (9)$$

The gradient of $L_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu})$ obtained above with respect to P_k^m can be expressed as

$$L'_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = \frac{1}{\ln(2)} \ \frac{o_k \ G \ h_{kk}^m}{\eta^2 \ + \sum_{\substack{i=1 \\ i \neq k}}^{K} h_{ki}^m \ P_i^m \ + \ G \ h_{kk}^m \ P_k^m}$$
$$- \ \lambda_k \ - \ \mu_m \ f_m \ h_k^m. \quad (10)$$

We set Eq.(10) to zero and solve for P_k^m as follows

$$P_k^m = \frac{o_k}{\zeta_k^m} - \frac{\eta^2}{G \ h_{kk}^m} - \frac{\sum_{\substack{i=1 \\ i \neq k}}^{K} h_{ki}^m \ P_i^m}{G \ h_{kk}^m}, \quad (11)$$

where, $\zeta_k^m \ = \ \ln(2)(\lambda_k \ + \ \mu_m f_m h_k^m)$. According to [12], Eq.(11) can be expressed as

$$P_k^m = \frac{1}{h_{kk}^m} \bigg(\theta_k^m - \frac{\sum_{\substack{i=1 \\ i \neq k}}^{K} h_{ki}^m \ P_i^m}{G} \bigg), \ k = 1, 2, ..., K, \quad (12)$$

where

$$\theta_k^m = \frac{o_k \ h_{kk}^m}{\zeta_k^m} - \frac{\eta^2}{G}.$$

The linear equation obtained in (12) can be expressed in the following matrix form

$$\begin{pmatrix} 1 & \frac{h_{2,2}^m}{G \ h_{1,1}^m} & \cdots & \frac{h_{K,K}^m}{G \ h_{1,1}^m} \\ \frac{h_{1,1}^m}{G \ h_{2,2}^m} & 1 & \cdots & \frac{h_{K,K}^m}{G \ h_{2,2}^m} \\ \vdots & \ddots & \cdots & \vdots \\ \frac{h_{1,1}^m}{G \ h_{K,K}^m} & \frac{h_{2,2}^m}{G \ h_{K,K}^m} & \frac{h_{K-1,K-1}^m}{G \ h_{K,K}^m} & 1 \end{pmatrix} \begin{pmatrix} p_1^{*m} \\ p_2^{*m} \\ \vdots \\ p_K^{*m} \end{pmatrix} = \begin{pmatrix} c_1 \\ c_2 \\ \vdots \\ c_K \end{pmatrix}$$

$$\Longleftrightarrow \ A \mathbf{p}_k^{*m} = \mathbf{c}_k, \quad (13)$$

where

$$c_k^m = \frac{\theta_k^m}{h_{kk}^m}.$$

The equilibrium power levels of the M subchannels of the k^{th} FMS are obtained uniquely from Eq.(13) and given by

$$P_k^{*m}(t) = \frac{1}{h_{kk}^m} \frac{G}{G-1} \bigg(\theta_k^m - \frac{1}{G+K-1} \sum_{i \neq \ k}^{K} \theta_i^m \bigg), \quad (14)$$

where

$$\theta_i^m = \frac{o_i \ h_{ii}^m}{\zeta_i^m} - \frac{\eta^2}{G},$$

h_{ii}^m represents the channel response between FMS i and its FBS on subchannel m, o_i = o_k, and $\zeta_i^m \ = \ \ln(2)(\lambda_i \ + \ \mu_m f_m h_i^m)$. Then the transmitting power of the k^{th} FMS on subchannel m can be updated as follows,

$$P_k^m(t+1) = [\ P_k^m(t) \ + \ \sigma \ L'_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) \ ] \ ^+, \quad (15)$$

where $[x]^+ \ = \ max \ (0, \ x)$ and σ is chosen to be small to ensure the convergence of the updated power. In order to determine the unknown Lagrangian dual vectors $\boldsymbol{\lambda}$ and $\boldsymbol{\mu}$, the convex optimization in (8) can be converted into a dual optimization problem, as follows [6] [11],

$$\min_{\lambda, \mu \ \geq \ 0} \ D(\boldsymbol{\lambda}, \boldsymbol{\mu}). \quad (16)$$

Substituting Eq.(14) into Eq.(6), and taking the derivatives with respect to λ_k and μ_m we can obtain

$$\omega_k(\boldsymbol{\lambda}_k) = \sum_{m=1}^{M} \bigg\{ \bigg(\frac{o_k}{\ln(2)} \frac{G h_{kk}^m}{\eta^2 + \sum_{\substack{i=1 \\ i \neq k}}^{K} h_{ki}^m \ P_i^m + G h_{kk}^m P_k^{*m}}$$
$$\bigtriangledown_{P_k^{*m}}(\lambda_k) \bigg) - P_k^{*m} + (\mu_m f_m h_k^m - \lambda_k) \bigtriangledown_{P_k^{*m}}(\lambda_k) \bigg\} + P_k^{MAX}, \quad (17)$$

$$\varpi_m(\boldsymbol{\mu}_m) = \sum_{k}^{K} \frac{o_k}{\ln(2)} \frac{G h_{kk}^m \bigtriangledown_{P_k^{*m}} (\mu_m)}{\eta^2 + \sum_{\substack{i=1 \\ i \neq k}}^{K} h_{ki}^m P_i^m + G h_{kk}^m P_k^{*m}}$$
$$- \sum_{k=1}^{K} \lambda_k \bigtriangledown_{P_k^{*m}} (\mu_m \ ) + f_m(I_m - \sum_{k=1}^{K} P_k^{*m} h_k^m)$$
$$- \mu_m f_m h_k^m \bigtriangledown_{P_k^{*m}} (\mu_m). \quad (18)$$

where, $\bigtriangledown_{P_k^{*m}}(\mu_m)$ and $\bigtriangledown_{P_k^{*m}}(\lambda_k)$ are the derivatives of P_k^{*m} in (14) with respect to μ_m and λ_k, respectively; as follows

$$\bigtriangledown_{P_k^{*m}}(\boldsymbol{\lambda}_k) = \frac{1}{h_{kk}^m} \frac{G}{G-1} \frac{- \ln(2) \ o_k}{(\zeta_k^m)^2} \quad (19)$$

$$\bigtriangledown_{P_k^{*m}} (\boldsymbol{\mu}_m) = \frac{G}{(G-1) h_{kk}^m} \{ \frac{- \ln(2) \ o_k f_m h_k^m}{(\zeta_k^m)^2}$$
$$+ \frac{1}{G+K-1} \sum_{i \neq \ k}^{K} \frac{\ln(2) f_m h_i^m o_i}{(\zeta_k^m)^2} \}. \quad (20)$$

Consequently, the dual variable λ_k and μ_m can be updated using (17) and (18), respectively as follows

$$\lambda_k(t+1) = [\ \lambda_k(t)\ -\ \Gamma(t)\ \omega_k(\lambda_k)\ ]^{+}, \tag{21}$$

$$\mu_m(t+1) = [\ \mu_m(t)\ -\ \Gamma(t)\ \varpi_m(\mu_m)\ ]^{+}, \tag{22}$$

where, $\Gamma(t)$ is the convergence step and should be set as follows [6],

$$\lim_{t\to\infty} \Gamma(t) = 0,$$

where,

$$\sum_{t=1}^{\infty} \Gamma(t) = \infty.$$

Eq.(21) and Eq.(22) are calculated by the FMS and MBS, respectively. Consequently, FMSs update their transmitting power price $\lambda_k(t+1)$ according to the updated $\mu_m(t+1)$ value announced by the MBS.

IV. SIMULATION PARAMETERS AND RESULTS

The performance of the algorithm is investigated in this section. Our results project an environment with active FCs, considering aggregated inter-tier and intra-tier interferences. In addition, we compare our proposed algorithm with the guard system technique, where our proposed guard system model follows our algorithm, except it prohibits the FMSs from using the active subchannels occupied by MMS. A flow chart of the proposed algorithm is shown in Fig. 2, and the parameters chosen for simulation are given in Table-I.

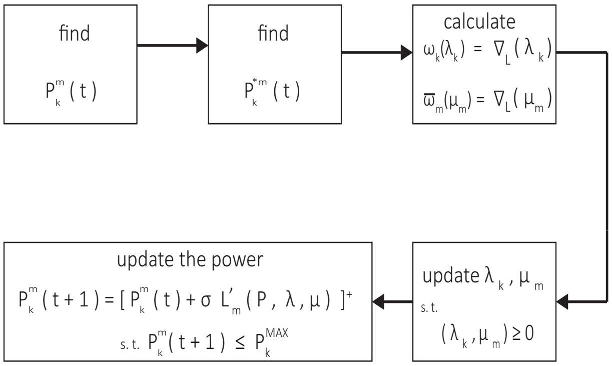

Fig. 2. Proposed Approach

γ = 2 x 10^{-4} is defined as the loss factor that depends on antenna gain, where the antenna gain G is considered to be equal to G=100, and $\sigma = 10^{-2}$ is chosen to be small enough to guarantee the convergence of the power update in Eq.(15). Define d_{kk} and d_k as the distance between FMS k and its FBS, and the distance between FMS k and the MMS, respectively. Consequently, $h^m_{kk} = \gamma\ d_{kk}^{-\alpha_2}$ and $h^m_k = \gamma d_k^{-\alpha_1}$ represent the channel response between the k^{th} FMS and its FBS and the channel response between FMS k and MMS, on subchannel m, respectively. $\alpha_1 = 4$ and $\alpha_2 = 3$, represent the path loss exponents of outdoor and indoor communication.

Fig.3 illustrates the rate convergence of FMSs for our proposed algorithm in terms of iterations. As presented, the optimal results of the rates of FMSs are achieved after the seventh iteration. In addition, the figure shows that all FMSs are achieving a decent rate and no FMS is experiencing transmitting blockage.

Parameter	**Value**
MC Radius, R_c	$500m$
FC Radius, R_f	$20m$
Number of subchannels, M	20
MMS maximum transmitting power, P_M	7 Watts
FMS maximum transmitting power, P_k^{MAX}	10 mWatts
Interference tolerance per subchannel, I_m	3x10^{-14} Watts
Noise power per subchannel, N_k^m	5x10^{-15} Watts

TABLE I. Simulation Parameters

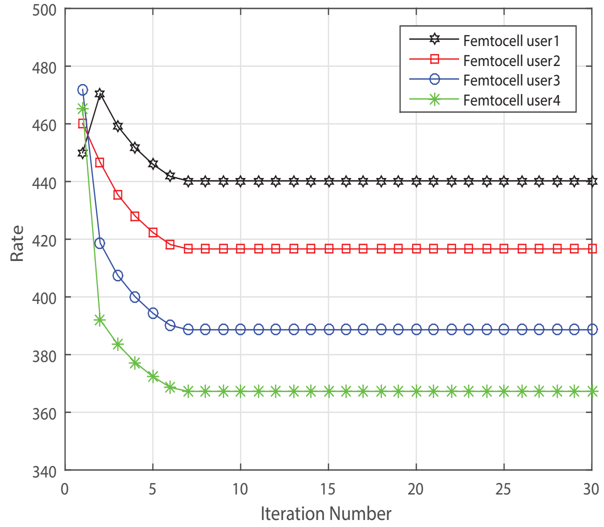

Fig. 3. Rate Convergence Process for K = 4

Fig.4 presents the effect of the interference tolerance on the total rate of our system when $K = 4$, while a better system rate can be achieved when a higher interference tolerance exists. In this figure, the system total rate stops increasing after a certain interference threshold due to the maximum power constraints. In Fig.5 the impact of outdoor path loss exponent on the rate of the system is presented. The proposed guard system shows a lower total rate gain than our algorithm. In addition, much power will be consumed by FMSs in the presence of guard model and a lower gain will be achieved, whereas the gain accomplished by our proposed model is considerably high in the presence of a higher transmitting power threshold. Fig.6 shows the total rate of FMSs drawn by our proposed algorithm as the number of FCs increases. As presented, the proposed algorithm gives much better rate than the guard system, due to its ability of subchannel sharing.

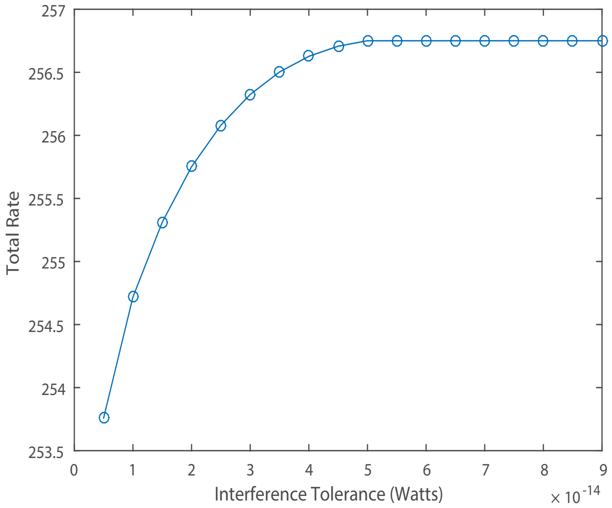

Fig. 4. Total rate as a function of interference tolerance

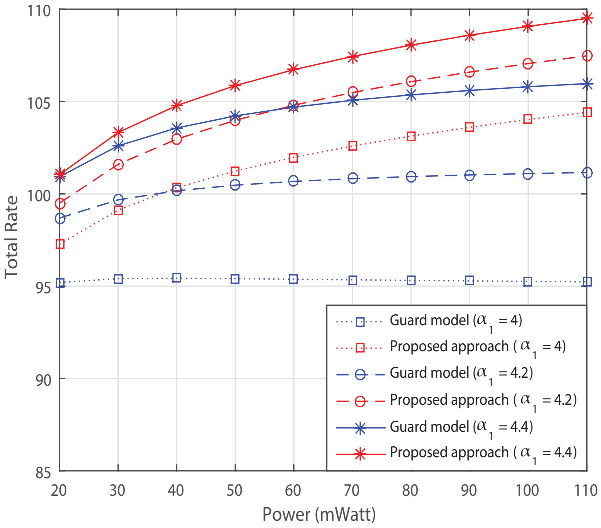

Fig. 5. Total rate as a function of path loss exponent

V. CONCLUSIONS AND FUTURE WORK

The proposed solution in this paper addresses a power control optimization approach that is concerned with the rate of femtocell users and interference mitigation through Lagrangian dual method. The algorithm preserves the communication in a two-tier environment, taking into account the aggregated interference received from all FMSs on each communication subchannel. The results show that in a sparsely distributed femtocell model where the spectrum is shared among the two tiers, the algorithm addresses a decent rate at each femto mobile station and achieves a better total rate than the proposed guard system. In addition, the system model and proposed approach can be extended into a realistic environment that involves dense mobile stations in both tiers taking into consideration the CSI estimation by the FMSs.

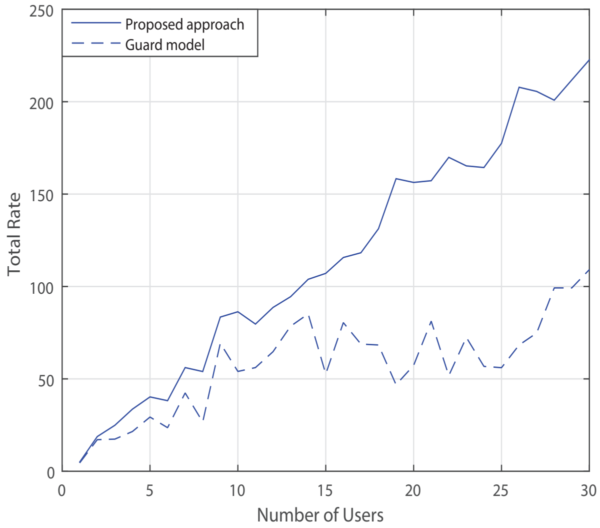

Fig. 6. Total rate as a function of FMSs number

REFERENCES

[1] R. Ullah, N. Fisal, H. Safdar, Z. Khalid, W. Maqbool, "Fractional Frequency Reuse for Irregular Geometry Based Heterogeneous Cellular Networks," in *2015 5th National Symposium on Information Technology: Towards New Smart World (NSITNSW)*, 2015, pp. 1 - 6.

[2] T. Lotfollahzadeh, S. Kabiri, H. Kalbkhani, M. G. Shayesteh, "Femtocell base station clustering and logistic smooth transition autoregressive-based predicted signal-to-interference-plus-noise ratio for performance improvement of two-tier macro/femtocell networks," in *IET Signal Processing*, 2016, vol. 10, issue. 1 pp. 1 - 11.

[3] M. Monemi, M. Rasti, E. Hossain, "Low-complexity SINR feasibility checking and joint power and admission control in prioritized multitier cellular networks," *IEEE Transactions on Wireless Communications*, 2016, vol. 15, pp. 2421 - 2434.

[4] G. Lu, L. Zhixin, M. Kai, Y. Yuan, "Robust power control for QoS guarantee in two-tier femtocell networks," in *2016 35th Chinese Control Conference (CCC)*, pp. 8397 - 8401, 2016.

[5] X. Zhou, G. Wang, G. Feng, S. Qin, Y. Guo, "Dynamic power control for maximizing system throughput in enterprise femtocell networks," in *2016 International Conference on Networking and Network Applications (NaNA)* 2016, pp. 184 - 189.

[6] J. Zhang, Z. Zhang, K. Wu, A. Huang, "Optimal distributed subchannel, rate, and power allocation algorithm in OFDM-based two-tier femtocell networks," *2010 IEEE 71st Vehicular Technology Conference*, pp. 1 - 5, 2010.

[7] T. LeAnh, N. H. Tran, S. M. A. Kazmi, T. Z. Oo, C. S. Hong, "Joint pricing and power allocation for uplink macrocell and femtocell cooperation," in *2015 International Conference on Information Networking (ICOIN)*, pp. 171 - 176, 2015.

[8] T. LeAnh,N. H. Tran, C. S. Hong, "Distributed power and channel allocation for cognitive femtocell network using a coalitional game approach," *2016 International Conference on Big Data and Smart Computing (BigComp)*, 2016, pp. 251 - 256.

[9] M. Lashgari, B. Maham, H. Kebriaei, W. Saad, "Distributed power allocation and interference mitigation in two-tier femtocell Networks: A Game-Theoretic Approach," in *2015 International Wireless Communications and Mobile Computing Conference (IWCMC)*, 2015, pp. 55 - 60.

[10] J. H. Yun, "Intra and inter-cell resource management in full-duplex heterogeneous cellular networks," *IEEE Transactions on Mobile Computing*, 2016, vol. 15, pp. 392 - 405.

[11] S. Boyd and L. Bandenberghe, "Convex optimization," Cambridge University Press, March 2004.

[12] T. Alpcan, T. Basar, R. Srikant, and E. Altman, "CDMA uplink power control as a non-cooperative game," in *Wireless Networks*, vol. 8, pp. 659 - 670, 2002.