

Improving Capacity and Energy Efficiency of Femtocell Based Cellular Network Through Cell Biasing

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Abstract—Future of cellular networks lies in heterogeneity. Heterogeneous cellular networks are characterized by overlay of low power nodes such as microcells, picocells, and femtocells along with traditional macrocell base stations. These nodes help operators to improve system capacity in cost effective manner while making the environment greener by reducing the carbon footprint. Research has shown that femtocells can be an effective solution to handle the increasing demands for indoor mobile traffic. However, low utilization of femtocell resources limits the gain obtained from their large scale deployment. Also, random placement of femtocells accumulate additional interference to macrocell users. In this paper, we introduce the concept of cell biasing for femtocells to improve user association and resource utilization. Our work analyses the effects of cell biasing on femtocell based cellular network and provides improvement in capacity and energy efficiency of the network through frequency reuse and subchannel power control. The obtained analytical results are verified through simulation.

Index Terms—Cellular network, femtocell, cell biasing, interference, energy efficiency, performance evaluation.

I. INTRODUCTION

With advances in cellular and Internet technologies, users now expect ubiquitous connectivity on their mobile devices. This has resulted in an exponential growth of mobile data traffic in the last couple of years. Global Mobile Data Traffic Forecast expects an increase in mobile data traffic by 18-fold between 2011 and 2016 [1]. In order to meet these demands, cellular operators are shifting to next generation cellular networks such as LTE-A/WiMax and are deploying additional infrastructure such as microcells, picocells, relays and hotspots. Deployment of these nodes help improve performance of the network in terms of coverage and capacity due to reduced transmit-receive distance between communicating nodes and spatial reuse of available spectrum. This, however, requires careful network planning as well as high capital and operational expenditure. Moreover, even with the availability of higher bandwidth, and efficient modulation and coding techniques in 3G/4G networks, operators are still facing the problem of handling the growth in demand for mobile data. Recent studies show that indoor mobile users account for more than 70% of the overall mobile traffic [2]. Femtocells offer a promising solution to offload indoor users from macrocells in a cost-effective manner.

A Femtocell or a Femto Access Point (FAP) is a low-cost, low-power cellular base station installed inside homes/offices

which provides improved cellular coverage to the users in its vicinity [3]. Since placement locations of femtocells are random, traditional network planning techniques fail to circumvent the interference introduced by them to primary macrocell and neighbouring femtocell users. The best way to eliminate interference in this scenario is to use orthogonal subchannels between macrocell and femtocell users. However, this diminishes the available spectrum for users in both tiers. Another approach is to allow femtocells to control their transmit power to minimize interference. Lowering transmit power affects femtocell coverage and limits user association and resource utilization in them. It has been observed that resource utilization for femtocell in current deployment is as low as 30% [4], [5]. In order to improve resource utilization in femtocells, better techniques are needed to offload macrocell users to femtocells. Offloading also helps to free up expensive macrocell resources, thereby saving energy.

In order to analyse and improve coverage and resource utilization in small cells, various solutions have been proposed in the literature. Heuristic based approach for load balancing among femtocells via inter-femtocell coordination, while maintaining fairness, is discussed in [6]. Use of transmission power control is the preferred technique for range extension and load balancing. [7] and [8] demonstrate that fractional transmission power control provides improved performance to cell edge users. Work in [9] adjusts femtocell transmission power by a decentralized algorithm so as to balance user load among collocated femtocells.

Another promising technique is the concept of cell biasing. In an heterogeneous network, cell biasing attempts to offload users from macrocells to smaller overlaid cells. The cell selection/handover criteria is modified by adding a positive Range Expansion Bias (REB) to signal received from small cell base stations. By using REB, the users that were previously associated with macro base station are now pushed to the nearby small cells even though they receive better signal from macrocell. The authors of [10] derived a closed form expression to calculate REB for both uplink and downlink for picocells while mitigating inter-cell interference. Performance analysis of heterogeneous network for different small cell densities, REB values, and resource partitioning strategies have been discussed extensively in [11]. Recently, the concept of cell biasing for femtocells has been introduced in [12]. To analyse energy efficiency and throughput performance of such

a network, further in-depth investigations are needed.

To the best of our knowledge, there exists no work that analyses the performance of femtocell network when cell biasing is applied. Cell biasing has been used in the literature in order to improve resource utilization of operator deployed small cells (picocells and relays) by modifying handover criteria [13], [14]. Motivation behind using biasing over power control for user offloading lies in the inherent low power transmission capabilities of femtocells. Regulations limit the amount of power control that can be applied to femtocells and hence the amount of offloading that can be achieved. Also, the interference incurred to neighbouring users limits the gain obtained from power control. On the other hand, biasing balances out users in different tiers without altering the transmission power.

Our work examines cell biasing in femtocells and focuses on evaluating performance of a femtocell network in terms of capacity and energy efficiency, when cell biasing is applied. An REB value is obtained which attempts to offload a desired fraction of users to femtocells. The newly offloaded users experience poor channel quality due to high interference from macrocell. To mitigate this cross-tier interference, we propose an algorithm that optimally reuses macrocell subchannels in femtocell downlink providing improved system throughput and energy efficiency. Insight on blocking probability of the system is also provided.

The rest of the paper is organized as follows. Section II discusses the system model for two tier heterogeneous cellular network along with spectrum allocation technique, energy consumption analysis, channel model and user association. We formulate our problem in section III and discuss the approach to analyse user association through cell biasing. In order to improve femtocell throughput, we also present a technique to effectively reuse macrocell subchannels for femtocell users. Section IV presents the simulation scenario and obtained results. The work is concluded in section V, with directions for future research.

II. SYSTEM MODEL

Our network model consists of a Macrocell Base Station (MBS) providing coverage in a hexagonal region of radius R_c and area $|H|$. User Equipments (UEs) and Femto Access Points (FAPs) are distributed in $|H|$ as Homogeneous Spatial Poisson Point Process (SPPP) with intensity Λ_{ue} and Λ_{fap} , respectively. Hence, mean number of UEs and FAPs can be obtained as $N_{ue} = \Lambda_{ue} * |H|$ and $N_{fap} = \Lambda_{fap} * |H|$, respectively. All FAPs are assumed to be in “Open Access” and hence can serve any UE within their range.

A. Spectrum Allocation

The total available spectrum is assumed to be divided into F orthogonal frequency subchannels, each with a bandwidth of W Hz. Unless explicitly stated otherwise, it is assumed that all subchannels within a tier are assigned equal transmit power; $P_{tx,m}$ for each macrocell subchannel and $P_{tx,f}$ for each femtocell subchannel. In order to evaluate the performance

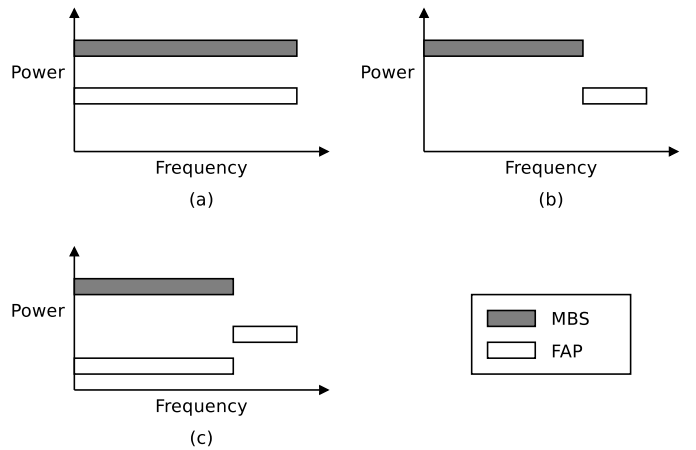


Fig. 1. Spectrum Allocation Between Macrocell and Femtocell

of our approach, we consider three different schemes for spectrum and power allocation.

- Reuse 1: Both MBS and FAPs use all available downlink subchannels for their UEs without any interference coordination technique. So, all F subchannels are allocated to MBS as well as to each FAP. This gives rise to high intra and cross-tier interference (Fig. 1(a)).
- Reuse α : FAPs operate in spectrum orthogonal to the spectrum used by MBS. In this case, available F subchannels are partitioned as $F_m = (1 - \alpha)F$ subchannels for MBS and $F_f = \alpha F$ subchannels for each FAP. Such an allocation mitigates cross-tier interference, but there still exists intra-tier interference among FAPs (Fig. 1(b)).
- Our approach: In addition to orthogonal spectrum splitting between FAPs and MBS, FAPs reuse F_m macrocell subchannels with power control for K strongest femto UEs (Fig. 1(c)) [15], [16]. This helps us to improve FAP throughput and reduce MBS energy consumption by user offloading. We name this technique as Optimal Subchannel Power Allocation (OSPA).

B. Energy Consumption

Our network consists of two different types of base stations viz. MBS and FAP. Both of them differ significantly in terms of offered load and energy consumption. An MBS supports much larger number of users over longer distance compared to a femtocell. Energy consumption of MBS is usually taken to be load dependent with some fixed “Zero Load” consumption. For FAPs, transmit power and number of users served is quite low, hence their energy consumption is assumed to be independent of offered load and taken to be constant [17].

The total energy consumption of MBS can be calculated using the following formula [18],

$$E_{MBS} = E_0 + N_{sector} * \left(\frac{T_m}{SPA} + P_{SP} \right) \quad (1)$$

where E_0 is fixed “Zero Load” energy consumption accounting for battery backup, power supply, and cooling loss. N_{sector} , SPA , P_{SP} represent number of sectors, power amplifier efficiency and signal processing overhead, respectively. Here T_m is total input power to transmitting antenna obtained

by summing up transmit power ($P_{tx,m}$) of all the subchannels in use.

For evaluation, we consider Energy Consumption Rating (ECR) as energy efficiency performance metric which is energy consumption normalized to capacity (Watts/Mbps) [19].

$$ECR = \frac{\text{Energy Consumption}}{\text{Effective System Capacity}} \quad (2)$$

C. Channel Model and Variable Bit-rate Transmission

Considering OFDMA and round robin scheduling of subchannels for UEs, all subchannels within a tier can be considered to have identical characteristics over long term. Rayleigh flat fading subchannels are assumed. For co-channel femtocell deployment (Reuse 1), the instantaneous downlink (DL) SINR of UE when connected to MBS m at subchannel j is given by,

$$\Gamma_{j,m} = \frac{P_{tx,m} G_j^m}{1 + \sum_{l=1}^{N_{fap}} P_{tx,f} H_j^{F(l)}} \quad (3)$$

Similarly, the instantaneous DL SINR of UE when connected to k^{th} FAP, $F(k)$, at subchannel j is given by,

$$\Gamma_{j,F(k)} = \frac{P_{tx,f} G_j^{F(k)}}{1 + \sum_{l=1, l \neq k}^{N_{fap}} P_{tx,f} H_j^{F(l)} + P_{tx,m} H_j^m} \quad (4)$$

where G_j^k (H_j^k) is the effective signal (interference) gain to UE from base station k over subchannel j . This accounts for path loss, antenna gain and Gaussian noise. When considering orthogonal subchannel assignment (Reuse α) between MBS and FAPs, the summation term in the denominator of Equation (3) and $P_{tx,m} H_j^m$ in Equation (4) will disappear.

Based on DL SINR received at each UE, its serving base station assigns an instantaneous bitrate as obtained by Shannon Hartley theorem [20].

D. User Association and Cell Biasing

In order to evaluate capacity and energy consumption of the system, we need to analyse the number of users in each tier and how this user association changes with biasing. Biasing is a concept of actively pushing users into a smaller cell like femtocell by modifying cell selection/handover criteria in order to improve user association in them [21].

Normally UEs, at the time of cell selection/handover get associated with the base station (BS) having highest Reference Signal Received Power (RSRP) [13]. So, the i^{th} UE will select the k^{th} BS as its serving BS if,

$$CellID_i = \arg \max_k (RSRP_k) \quad (5)$$

With cell biasing, a Range Expansion Bias (REB) of β_k dB is added to DL received power of the k^{th} BS before selection of serving BS. Then,

$$CellID_i = \arg \max_k (RSRP_k + \beta_k) \quad (6)$$

Taking β_k equal to 0 for MBS and some positive value for FAPs causes UEs to more frequently select femtocell as their serving BS even when they can get better SINR from MBS.

III. OPTIMIZATION PROBLEM FORMULATION

Our problem focuses on making operation of cellular network more energy efficient. There are two ways by which we can improve ECR. One is to decrease energy consumption of the system without significantly affecting the system capacity, and the other is to increase system capacity without appreciable change in the total energy consumption.

Our approach makes use of both techniques to improve energy efficiency. Introduction of biasing in UEs allows us to offload macrocell users to femtocells (lowering MBS energy consumption) and improving resource utilization for FAPs (improving system capacity). So, our main problem splits into two sub-problems:

- Analysing the effect of cell biasing on UE association, system capacity and energy consumption.
- Optimizing capacity and energy efficiency of the network through efficient frequency reuse and power allocation.

In order to solve the first sub-problem, we closely follow the approach of the author in [22] with few modifications to incorporate issues unique to femtocell. Assuming that UEs keep track of RSRP from different base stations in range, let $\rho = [\rho_1, \dots, \rho_{N_{ue}}]$ be the RSRPs of UEs from MBS and $\psi = [\psi_1, \dots, \psi_{N_{ue}}]$ be the RSRPs from the *strongest* FAP. We only consider the strongest FAP because UE will get handed over to only that FAP even with biasing. Let $\delta = [\delta_1, \dots, \delta_{N_{ue}}]$ be the difference between the RSRPs of MBS and the strongest FAP i.e. $\delta_i = \rho_i - \psi_i, \forall i$. So, all UEs that have δ_i less than or equal to (greater than) 0 will get higher RSRP from FAP (MBS) and hence select FAP (MBS) as its serving base station. In order to find out the total number of Femto User Equipments (FUEs), N_{fue} , we arrange the elements of δ in sorted order ($\delta_i \leq \delta_{i+1}, \forall i$),

$$N_{fue} = \arg \max_i (\delta_i), \text{ such that } \delta_i \leq 0. \quad (7)$$

The same can also be obtained through Cumulative Distribution Function (CDF) of RSRP difference which is denoted as $\mathcal{F}(x) = P(\delta_i \leq x)$,

$$N_{fue} = \mathcal{F}(0) * N_{ue}. \quad (8)$$

Figure 2 shows the curve for CDF of RSRP difference. The users to the left of vertical REB line (at $X = 0$) are FUEs while users to the right are Macro User Equipments (MUEs).

Now, consider the case when UEs add a REB of β dB to the measured RSRP from all FAPs before performing cell selection. In this case, number of FUEs can be calculated either as,

$$N_{fue} = \arg \max_i (\delta_i - \beta), \text{ such that } \delta_i - \beta \leq 0 \quad (9)$$

or by CDF of RSRP difference,

$$N_{fue} = \mathcal{F}(\beta) * N_{ue} \quad (10)$$

The dotted line in Figure 2 (at $X = \beta$) shows the effect of adding REB to measured RSRP and we can see that now more UEs are associated with FAPs. It is interesting to note that, applying REB to measured RSRP of femtocell does not affect the curve of CDF. Only the vertical line that divides the users into two sets (FUEs and MUEs) shifts to the right. As value of REB keeps increasing, more and more UEs get associated with FAPs. By using this CDF curve, the required value of REB can be easily calculated for the desired degree of offloading. So, in order to associate say $X\%$ of users to FAPs, the required value of β will be,

$$\beta = \left(\mathcal{F}^{-1}(X) \mid X = \frac{N_{fue}}{N_{ue}} \right) \quad (11)$$

Using this REB for each FAP will result in different amount of offloading among FAPs based on their location and user distribution. Practically, it is desirable to compute value of REB independently for each FAP for optimal offloading, but the complexity and overhead involved in periodically calculating REBs for each FAP is much higher due to frequent topology changes and limited backhaul connectivity. Instead, we suggest the use of same REB β for each FAP, and then improve its throughput by taking into account the parameters specific to it.

After biasing, a number of UEs get offloaded from MBS to FAPs. This in turn reduces MBS power consumption. Recently freed MBS subchannels, however, can be reassigned to other MUEs to improve throughput and reduce blocking. Consequently, FAPs now have to support more UEs and hence there will be stiff competition for its resources. In order to meet this increased demand, our approach suggests soft reuse of MBS's subchannels for FUEs while handling cross tier interference.

Once required number of users get offloaded to femtocells, we focus on improving per femtocell throughput. Let $N_{fue(i)}$ be the number of UEs associated with femtocell i and hence $N_{fue} = \sum_i N_{fue(i)}$. We divide UEs in each FAP into two mutually exclusive subsets. First subset consists of all FUEs which were associated with the AP even before REB is applied. For simplicity, we call them *inner* FUEs. Second subset consists of FUEs which get offloaded to FAP after biasing. We refer them as *outer* FUEs.

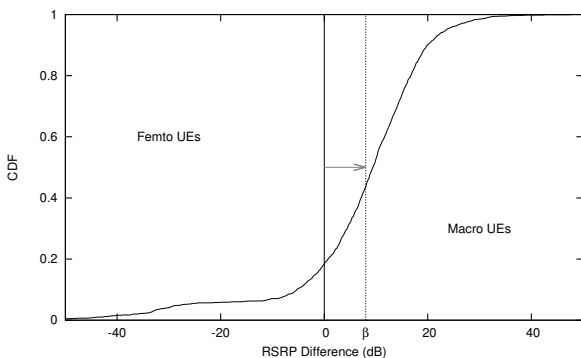


Fig. 2. CDF of Difference of RSRP

OSPA technique now allocates $F_m + F_f$ subchannels among inner and outer FUEs. We suggest the use of F_m subchannels only for inner FUEs and F_f subchannels for both inner and outer FUEs. Outer FUEs experience very low signal gain compared to inner FUEs due to larger distance and wall penetration loss. By using F_f subchannels for outer FUEs, we can improve their SINR by eliminating interference from MBS. Inner FUEs are allocated F_m reuse subchannels plus remaining F_f subchannels, if any.

OSPA first allocates F_m subchannels among inner FUEs and then adjusts subchannel transmit power by multiplying it by a power factor, Υ . This power factor adjusts transmit power in such a way that the sum interference received at MUEs over these subchannels is negligible and can be counted as noise [23], [24]. For this, we form an optimization problem which calculates power factor value for each subchannel of each FAP while maximizing femtocell throughput. We ignore the interference to neighbouring FUEs over these F_m subchannels considering high double wall penetration loss ($\simeq 20dB$). Practically, interference will occur from MBS to inner FUEs over F_m subchannels but it is negligible, and hence ignored for computational simplicity.

Finally, F_f subchannels are allocated to both inner and outer FUEs. The number of subchannels allocated to each FUE depends on underlying subchannel allocation policy. For simplicity, we consider equal number of subchannels are allocated to all FUEs. However, obtained results can be extended to incorporate any subchannel allocation policy (fair, proportionate allocation, etc.).

Let θ_k be the number of inner FUEs in $FAP(k)$. Considering flat fading subchannels, the SINR received at a UE on each assigned subchannel will be same. Hence, the sum throughput obtained for $FAP(k)$ can be represented as,

$$\begin{aligned} thpt_{FAP(k)} &= \sum_{i=1}^{\theta_k} \Re_i \log(1 + \Gamma_{j,F(k)}) \\ &+ \sum_{i=\theta_k+1}^{N_{fue(k)}} \Re_i \log(1 + \Gamma_{j,F(k)}) \\ &+ \xi_k \end{aligned} \quad (12)$$

where array $\Re = [\Re_1, \dots, \Re_{N_{fue(k)}}]$ represents the subchannel allocation vector for inner and outer FUEs. As we use equal allocation for each outer FUE, $\Re_i = F_f/N_{fue(k)}$ and for each inner FUE, $\Re_i = (F_f/N_{fue(k)} + F_m/\theta_k)$. The last term, ξ_k represents the throughput gain obtained by reusing F_m subchannels with power control. Hence,

$$\xi_k = \sum_{j=1}^{F_m} \log(1 + \Upsilon_j^k P_{tx,f} G_j^k)$$

where Υ_j^k is the power factor applied for transmission on subchannel j of $FAP(k)$.

Our objective is to maximise sum throughput of all femto-cells over these F_m subchannels while satisfying interference and maximum transmit power constraints. We formulate our optimization problem as,

$$\text{Maximize}_{\Upsilon_{j \times k}} \quad \sum_{k=1}^{N_{fap}} \xi_k$$

$$\text{Subject to,} \quad \sum_{k=1}^{N_{fap}} \Upsilon_j^k P_{tx,f} H_j^k \leq I_{max} \quad \forall j \quad (13)$$

$$\sum_{j=1}^{F_m} \Upsilon_j^k \leq F_m \quad \forall k \quad (14)$$

$$\Upsilon_j^k \geq 0 \quad \forall j, k \quad (15)$$

where $\Upsilon_{j \times k}$ is the matrix containing power factor values for each subchannel of each FAP and I_{max} is the threshold for the Gaussian noise. Equation (14) is the maximum transmit power constraint for FAPs over these F_m subchannels. When optimization is performed over these F_m subchannels, the transmit power of few subchannels are reduced (where $\Upsilon_j^k < 1$) and the residual power can be redistributed among rest of the subchannels while keeping sum transmit power constant.

To solve this problem, we propose a centralized algorithm which determines the power factor values for each subchannel of each FAP. We assume that the centralized algorithm has instantaneous information about all the gains (signal and interference) either through FAP backhaul or by uplink signal estimation. To solve the above problem, we make use of Lagrange's dual method [25], [26],

$$\begin{aligned} \mathcal{L}(\Upsilon_j^k, \{\mu_j\}, \{\lambda_k\}) &= \sum_{k=1}^{N_{fap}} \sum_{j=1}^{F_m} \log(1 + \Upsilon_j^k P_{tx,f} G_j^k) \\ &\quad - \sum_{j=1}^{F_m} \mu_j \left(\sum_{k=1}^{N_{fap}} \Upsilon_j^k P_{tx,f} H_j^k - I_{max} \right) \\ &\quad - \sum_{k=1}^{N_{fap}} \lambda_k \left(\sum_{j=1}^{F_m} \Upsilon_j^k - F_m \right) \end{aligned} \quad (16)$$

where μ_j 's and λ_k 's are non-negative Lagrange multipliers for noise and transmit power constraints.

Keeping λ_k fixed, we can divide the problem into F_m independent sub-problems, one for each subchannel as,

$$\begin{aligned} \max_{\Upsilon_j^k} \quad & \sum_{k=1}^{N_{fap}} \log(1 + \Upsilon_j^k P_{tx,f} G_j^k) \\ & - \mu_j \left(\sum_{k=1}^{N_{fap}} \Upsilon_j^k P_{tx,f} H_j^k - I_{max} \right) \\ & - \sum_{k=1}^{N_{fap}} \lambda_k (\Upsilon_j^k - F_m) \quad \forall j \end{aligned} \quad (17)$$

Algorithm 1 Power Factor Calculation

Initialize $\lambda_1, t = 1$

repeat

for all subchannel **do**

 Compute $\mathbf{S} = \sum_{k=1}^{N_{fap}} \max \left(0, \frac{1}{\lambda_k} - \frac{1}{P_{tx,f} G_j^k} \right) P_{tx,f} H_j^k$

if $\mathbf{S} < I_{max}$ **then**

 Set $\mu_j = 0$

else

 Find μ_j that satisfies Equation (19) with equality.

end if

 Calculate $\Upsilon_n^m, \forall n, m$ using Equation (18).

end for

Update $\lambda_{t+1} = \lambda_t - \Delta \left(F_m - \sum_{i=1}^m \Upsilon_i^k \right)$

if $\lambda_{t+1} < 0$ **then**

 Set $\lambda_{t+1} = 0$, and stop

end if

until $(\lambda_{k+1} - \lambda_k)^2 \leq \varepsilon$

Note : Here, λ_t is a column vector of size k at iteration t , Δ is the step size, and ε is a positive small number to define convergence.

In order to maximize the above Lagrangian, derivative of Equation (17) with respect to Υ_j^k is taken. Considering the non-negative power constraint in Equation (15), we have,

$$\Upsilon_j^k = \max(0, Q(\mu_j)) \quad (18)$$

where

$$Q(\mu_j) \equiv \left(\frac{1}{\mu_j P_{tx,f} H_j^k + \lambda_k} - \frac{1}{P_{tx,f} G_j^k} \right).$$

Substituting Υ_j^k in Equation (13) gives us,

$$\sum_{k=1}^{N_{fap}} \max(0, Q(\mu_j)) P_{tx,f} H_j^k \leq I_{max} \quad (19)$$

For fixed λ_k , we can see that $Q(\mu_j)$ is a decreasing function of μ_j which obtains maximum value when $\mu_j = 0$. If LHS in Equation (19) is smaller than RHS, we can set μ_j equals to zero. If not, the value of μ_j can be easily calculated using bisection method as discussed in [23], [27].

The centralized algorithm (Algorithm 1) repeats the above process until μ_j is found within desired accuracy while updating λ_k using subgradient algorithm. Once all μ_j 's are determined, power factor values are calculated. Using Equations (18) and (19) for each subchannel, the centralized algorithm constructs a matrix $\Upsilon_{j \times k}$ containing power factor values for each FAP's subchannel. Finally, these values are communicated to FAPs in order to perform appropriate power control as to mitigate interference to MUEs.

IV. SIMULATION RESULTS

Our simulation scenario consists of a single large macrocell overlaid with low power FAPs. Both UEs and FAPs are distributed using homogeneous SPPP in the covered region. We run the simulation considering full buffer traffic model i.e., UEs always have some data to send. Femtocells are assumed to be in *Always-ON* state unless there are no UEs under its coverage. Snapshots are taken at discrete time intervals. Based on statistics of subchannels used by UEs, values of power factor are calculated. The noise threshold, I_{max} , is taken to be 1% of femtocell subchannel transmit power ($0.01 * P_{tx,f}$). All values are obtained for 95% confidence interval averaged over 30 iterations. The simulation parameters are given in Table I.

TABLE I
SIMULATION PARAMETERS

Parameter	Value	
Bandwidth	10 MHz	
No. of Subchannels	256	
MBS Transmit Power	46 dBm	
FAP Transmit Power	30 dBm	
Wall Loss	10 dB	
Macrocell Radius	600 m	
Femtocell Radius	15 m	
Reuse Factor (α)	0.2	
Gaussian Noise Figure	-174 dBm/Hz	
Femtocell Power Consumption	10 Watts	
Zero-Load MBS Power Consumption (N_0)	500 Watts	
Number of Sectors (N_{sector})	1	
Range Expansion Bias (REB)	{0, 2, 4, 6, 8}	
Path Loss Coefficient	Macrocell	2.5
	Femtocell	3.5
Antenna Gain	Macrocell	14 dB
	Femtocell	7 dB
	User Equipment	0 dB

We analyse the throughput and energy consumption of both MBS and FAPs in order to evaluate energy efficiency of the system. Simulations are performed for three different spectrum and power allocation schemes viz. Reuse 1, Reuse α , and OSPA. For each technique, random allocation of F_m subchannels among MUEs is done, while satisfying minimum bitrate constraints. Additionally for OSPA, we adapt subchannel transmit power in order to maximize femtocell throughput.

Our work, OSPA, is independent of the subchannel allocation policy used after spectrum partitioning between MBS and FAPs, and can work with any allocation policy such as equal, proportionate, and fair allocation. It helps improve femtocell throughput irrespective of the underlying policy in use.

Figure 3 depicts the CDF of throughput for MUEs. As we can see, CDF improves for Reuse α compared to Reuse 1. This results from reduced co-channels interference from femtocell to MUEs due to orthogonal spectrum reuse. Similar improvement is also observed for OSPA technique. Key observation is that, the curve of OSPA and Reuse α closely overlap with each other. This shows that, after performing power control over F_m subchannels, the effect of co-channels interference is nullified at MUEs.

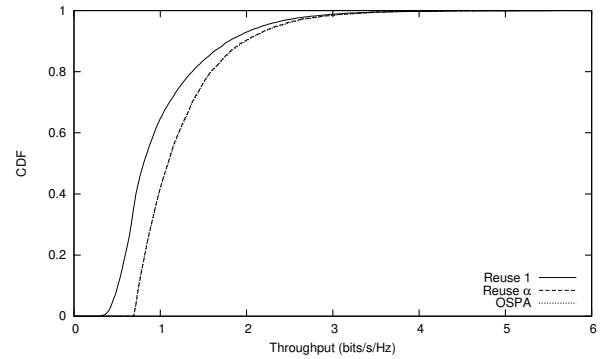


Fig. 3. CDF of MUE Throughput, REB = 4 dB

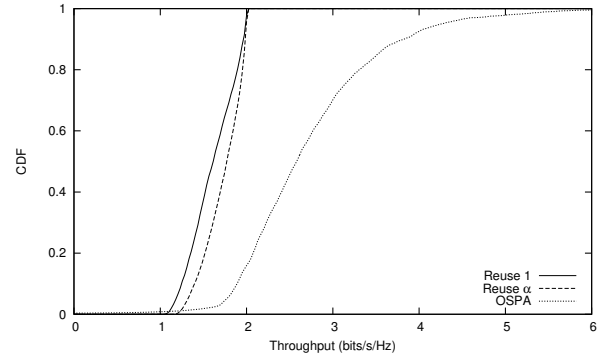


Fig. 4. CDF of FUE Throughput, REB = 4 dB

Figure 4 illustrates the CDF of throughput for FUEs. It can be seen that there is slight improvement in throughput of FUEs for Reuse α compared to Reuse 1. This is the result of reduced co-channel interference from MBS to FUEs. However, availability of fewer subchannels for FUEs diminish the total system capacity drastically as can be seen in Figure 5. Finally, OSPA technique shows significant improvement over Reuse 1 and Reuse α schemes. This improvement is obtained due to optimal power distribution over F_m subchannels. Acquired results show that values of power factors for these subchannels vary from 0.27 to as high as 3.2. We also observe that throughput improvement for the top 20% FUEs is significantly high in OSPA, as the subchannels assigned to those users are not used by any MUE and hence FAPs use maximum available transmit power for them to maximize throughput.

Figure 5 shows the effect of biasing on system capacity. Here, system capacity considers the combined throughput of MBS and all FAPs. In all three cases (Reuse 1, Reuse α , OSPA), system capacity increases with increasing REB value. This is due to the fact that, with increasing REB, more users come under FAPs coverage and hence have access to more number of subchannels. While for fixed REB, Reuse α deteriorates system capacity compared to Reuse 1 despite having better SINRs for users. Availability of only a fraction of bandwidth to users in each tier limits the throughput for Reuse α technique. Here, maximum system capacity is obtained for OSPA technique due to the optimization performed by centralised algorithm over F_m subchannels.

Figure 6 makes it is clear that OSPA is optimal in terms

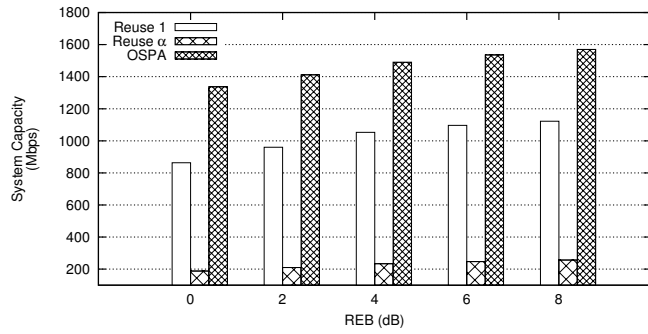


Fig. 5. System Capacity vs. REB

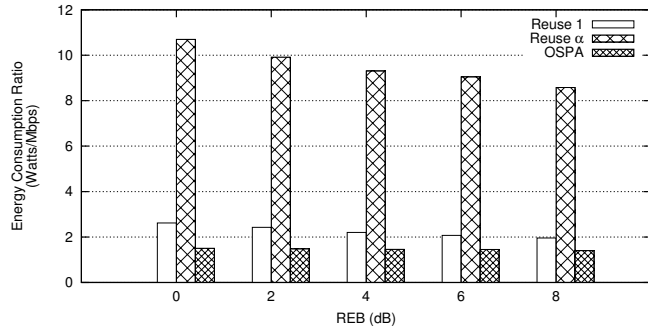


Fig. 6. Energy Consumption Ratio vs. REB

of energy efficiency too. For all REB values, OSPA has the least ECR value compared to Reuse 1 and Reuse α . This is a direct consequence of throughput optimization for FUEs and reduction in MBS energy consumption. Also, as REB increases, more users get offloaded from MBS and get associated with FAPs. This further reduces MBS energy consumption, lowering ECR.

Finally, the blocking probability of the system is represented in Figure 7. As expected, Reuse 1 has least blocking due to availability of higher number of subchannels in each tier, and high blocking is observed for Reuse α due to fewer subchannels in each tier. Negligible improvement is observed for OSPA compared to Reuse α because a few overloaded FAPs can now support additional users. For all cases (Reuse 1, Reuse α , OSPA), as REB increases, more MUEs get offloaded and blocking probability eventually declines to zero.

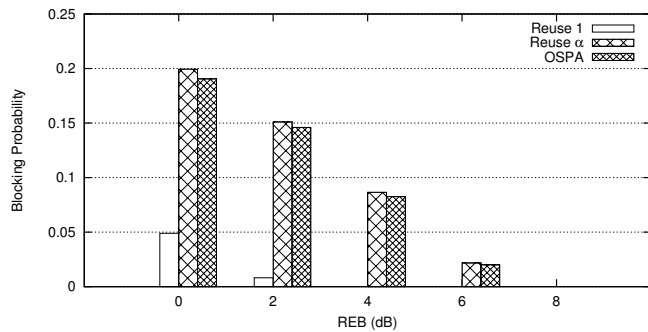


Fig. 7. Blocking Probability vs. REB

V. CONCLUSION

In this paper, we have introduced the concept of cell biasing for femtocells. Biasing allows us to offload users from MBS to FAPs without making any changes to transmit power. Our work has improved system capacity and energy efficiency of two-tier femtocell network through frequency reuse and power control over femtocell subchannels. Simulation results have verified the improvement in system capacity and energy efficiency without affecting macro users' signal quality. Our suggested OSPA technique achieves the best performance by optimal power control over macrocell reuse subchannels while satisfying maximum power and Gaussian noise constraints. We have also provided an insight on blocking probability of the system.

Future work can include developing a closed form expression for obtaining range expansion bias while incorporating macrocell and inter-femtocell interference. Also, the possibility of distributed algorithm considering stochastic geometry of users and femto access points can also be explored.

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