Issues in Femtocell Deployment in Broadband OFDMA Networks : 3GPP–LTE a case study

Suvra Sekhar Das[1,2], Prabhu Chandhar[1], Soumen Mitra[1], Priyangshu Ghosh[1]
[1]G.S.Sanyal School of Telecommunications, Indian Institute of Technology Kharagpur, India.
[2]Dept. of Electronics & Electrical Communication Engineering, Indian Institute of Technology Kharagpur, India.

Abstract—**Fourth Generation and beyond broadband wireless mobile networks, specifically 3^{rd} Generation Partnership Project (3GPP)-Long Term Evolution (LTE) and beyond are considering issues related to the deployment of femtocells. Femtocells have the potential to improve Area Spectral Efficiency (ASE) several folds. However, interference is added to the system due to large number of uncontrolled, user-deployed femtocells. Hence improvement of overall system throughput becomes limited. In this paper, downlink coexistence between macro/micro cells and co-channel femtocells in Orthogonal Frequency Division Multiple Access (OFDMA)– Frequency Division Duplex (FDD) system based single frequency network is investigated. The impact of density, load and transmit power variation of the femtocells on the performance of macro/micro cell and femtocell users as well as the effect of macro/micro cell load on femtocell performance is presented. Guidelines for femtocell deployment with the objectives of maximizing sum–cell–throughput and maximizing number of active femtocells are derived. Methods of centralized control as well mixed centralized and distributed control of femtocell radio parameters to meet the above objectives are presented. The analysis is done with International Telecommunication Union (ITU) specified channel models using system level simulator.**

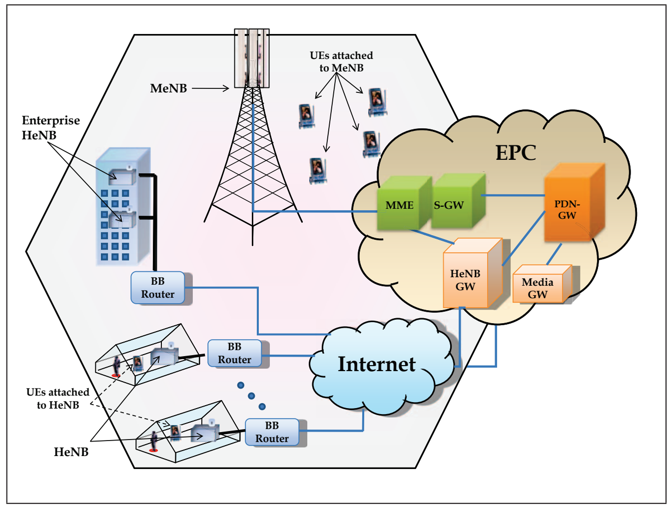

Fig. 1: Femtocell Network Control Architecture

I. Introduction

In conventional cellular networks, indoor users experience low Signal to Interference plus Noise Ratio (SINR) due to high penetration loss of radio signals thus leading to low throughput. However, it is found that most high bit rate demand is from indoor users [1]. Further, poor throughput is also experienced by users at cell edge due to high pathloss and heavy co-channel interference from neighbouring base stations in Orthogonal Frequency Division Multiple Access (OFDMA)- Single Frequency Network (SFN). To improve the situation link budget needs to be improved. A fundamental parameter is the desired received signal strength. Femtocell is one of the important approaches to address this issue. The concept of femtocell is to use very low power base station placed indoor, which uses the same Radio Interface Technology (RIT), in order to provide access to a cell of few meter radius. Femtocell, Home eNodeB (HeNB), Femto evolved NodeB (eNB), Femto Base Station indicate the same entity and are used interchangeably in this work. The femtocell connects to the core network of the telecom operator through a high data rate backhaul connectivity, which can be either X-DSL , fiber, etc as shown in Figure 1.

Advantage of deploying femtocells at home is that the same User Equipment (UE) can be used for high data rate indoor connectivity as well as outdoor connection, whereas if Wireless Local Area Network (WLAN) and Wireless Metropolitan Area Network (WMAN) combination is used, then the UE would need two hardwares to support this. Call handover is also difficult in such hybrid setup.

It is desired that when a user is indoor, calls are handled by the femtocells and channels from the macro/micro base station are freed. Thus Area Spectral Efficiency (ASE) is increased by offloading traffic from macro/micro base station to femtocells. However, major issues to be considered in femtocell deployment are radio interference management, regulatory aspects, hand over, etc. related with existence of femtocells within the macro/micro cell network for successful deployment of femtocells.

The feasibility of femtocells deployment in cellular network is studied by the standard development organizations like 3^{rd} Generation Partnership Project (3GPP) [2], [3]. Deployment of femtocells are considered in Long Term Evolution (LTE) networks [4]. LTE is a SFN using OFDMA in downlink and Single Carrier Frequency Division Multiple Access (SCFDMA) in uplink. In co-channel deployment of femtocells, since interference is a major challenge that has to be addressed, it is therefore necessary to analyze the performance of such systems in the light of interference in different scenarios. The objective of femtocell deployment can be diverse such as maximization of sum–cell throughput, i.e. sum throughput

978-1-4244-8327-3/11/$26.00 ©2011 IEEE

of all femtocells and the outdoor macro/micro UEs within the coverage area of the macro/micro cell, or maximizing the number of active femtocells, i.e the optimal number of femtocells allowed to operate at any instance without causing considerable co-channel interference to macro/micro UEs. The aim of this work is to investigate the different deployment scenarios for femtocells and present guidelines for the above mentioned objectives.

The impact of interference on macro/micro cell UEs depends on the power, bandwidth utilization, femtocell density, as well as the access control methods of co-channel femtocells. In open access mode, all users can be allowed to access a femtocell, and in closed access the users registered to a particular femtocell are allowed to access that femtocell [5]. A comparative study of different deployment modes such as dedicated/co-channel deployment and closed/open access for femtocell network has been presented in [6]. The impact of interference caused by femtocells on macrocell capacity and coverage for High Speed Downlink for Packet Access (HSDPA) systems and few mitigation techniques e.g. variation of data/control channel power, power zone segregation and adaptive power control are presented in [7], [8]. The macrocell offloading capacity gain due to femtocell deployments is investigated in [9]. It shows that upto 30% gain in mean throughput and about 100% gain for cell edge user throughput. However it does not give the sum throughput of the entire cell with the macro/micro eNB and deployed femto eNBs. A method of autonomous spectrum sharing between macrocell and femtocell based on user's feedback on channel conditions is presented in [10]. In [11], self optimization of OFDMA femtocells by exchanging information between the femtocells and measurement reports sent by users are presented. An adaptive power control strategy for the femtocell based on received power levels from neighbouring macro/micro users are presented in [12]. Identifying a interfering macro/micro UE for a particular femto eNB is a daunting task itself with huge amount of reliability issues associated with.

In contrast to the above mentioned works, the focus of this paper is to investigate the issues related to the femtocells in a Urban Micro (UMi) scenario where the Inter Site Distance (ISD) is only 200m. In such a close configuration of micro cell eNBs (base stations) the deployment of femtocell is expected to create high interference thereby degrading the performance of micro-cell users. The aim of this work is to investigate deployment guidelines for femtocells under such heavy interference conditions. The analysis is presented using practical channel models as given by ITU [13]. Impact of femtocell density, load and transmit power of femtocells as well as the impact of load variation in the macro/micro cells is investigated. The guidelines are prepared considering two objectives, viz. maximization of sum–cell–throughput and maximization of number of active femtocells. A centralized strategy for controlling the femtocells' radio parameters for meeting these objectives is presented in details. Finally a hybrid mode using centralized control along with distributed power control, to restrain the femtocell throughput within a limit, so as to meet the above objectives are also analyzed. The results presented further show that controlling macro/micro cell parameters also influences the overall system performance.

The rest of this paper is organized as follows. Section II illustrates the system model. In section III, results are presented. Finally conclusions are drawn in section IV.

II. System Model

In this work, closed access for femtocells is considered. The system model considered in this paper is based on the 3GPP-LTE OFDMA system. The UMi scenario with 50% indoor and 50% outdoor users is considered for the analysis [13]. The HeNB houses are dropped randomly and uniformly throughout the center cell in a non-overlapping manner. The ITU-R pathloss model and antenna pattern for UMi scenario is used for characterizing the path loss between Macro eNodeB (MeNB) and UEs, and HeNB and UEs [2]. Rayleigh and Rician fading are used for characterizing small scale channel variations. System level simulation using Monte-Carlo method is used for evaluating average cell throughput and average user throughput. Additional simulation parameters are listed in Table I.

TABLE I: Simulation Parameters

Parameter	Value
Cell Layout	19 Cells, 3 Sectors , Wrap Around
Scenario	UMi
ISD	200m
Bandwidth	10MHz
Channel Model	as specified in ITU M-2135
Carrier Frequency	2.5GHz
MeNB transmit power	41dBm
Maximum HeNB transmit power	20dBm
MeNB antenna height	20m
Number of Tx and Rx antennas	1×2
MeNB antenna gain (boresight)	17dB
HeNB antenna gain	0dB
Thermal noise level	-174dBm/Hz
Receiver noise figure	7dB
UE speed	3Kmph
Minimum separation	MeNB – macro/microUE : 20m. MeNB and HeNB : 20m. HeNB – femto UE : 1m. Inter HeNBs : 20m
Shadow fading σ (dB)	4 for outdoor users 7 for indoor users
Shadowing correlation between sectors	0.5

$\mathrm{N_F}$ number of Femto eNBs are deployed in a macrocell network with $\mathrm{N_{eNB}}$ number of MeNBs. The network also has $\mathrm{N_{u_m}}$ number of active macro/micro users and $\mathrm{N_{u_{f,m}}}$ number of femto users in m^{th} macrocell at any instance. The antenna configuration is taken as 1x2 Maximal Ratio Combining (MRC) and hence the average SINR at the femto UE ($\mathrm{u_f}$) or macro/micro UE ($\mathrm{u_m}$) on subcarrier k is calculated as,

$$\gamma_{\mathrm{k}} = \frac{\mathrm{P}^{(0)}_{\mathrm{T,k}}\mathrm{P}^{(0)}_{\mathrm{g}}\mathrm{G}^{(0)}_{(\theta,\phi)}[|\mathrm{h}^{(0)}_{\mathrm{k},1}|^2 + |\mathrm{h}^{(0)}_{\mathrm{k},2}|^2]^2}{\mathrm{P}^{\mathrm{M}}_{\mathrm{I,k}} + \mathrm{P}^{\mathrm{F}}_{\mathrm{I,k}} + [|\mathrm{h}^{(0)}_{\mathrm{k},1}|^2 + |\mathrm{h}^{(0)}_{\mathrm{k},2}|^2]B_{\mathrm{k}}\mathcal{F}\mathrm{N}_0} \quad (1)$$

where $\mathrm{P}^{\mathrm{M}}_{\mathrm{I,k}}$ is the total interference power received from the neighbouring macrocells,

$$\mathrm{P}^{\mathrm{M}}_{\mathrm{I,k}} = \sum_{\mathrm{m}=1}^{\mathrm{N_{eNB}}} \mathrm{P}^{(\mathrm{m})}_{\mathrm{T,k}}\mathrm{P}^{(\mathrm{m})}_{\mathrm{g}}\mathrm{G}^{(\mathrm{m})}_{(\theta,\phi)}|(\mathrm{h}^{(\mathrm{m})}_{\mathrm{k},1}\mathrm{h}^{(0)^*}_{\mathrm{k},1}) + (\mathrm{h}^{(\mathrm{m})}_{\mathrm{k},2}\mathrm{h}^{(0)^*}_{\mathrm{k},2})|^2, \quad (2)$$

$\mathrm{P}^{\mathrm{F}}_{\mathrm{I,k}}$ is the total interference power received from the neighbouring femtocells,

$$\mathrm{P}^{\mathrm{F}}_{\mathrm{I,k}} = \sum_{\mathrm{f}=1}^{\mathrm{N_F}} \mathrm{P}^{(\mathrm{f})}_{\mathrm{T,k}}\mathrm{P}^{(\mathrm{f})}_{\mathrm{g}}\mathrm{G}^{(\mathrm{f})}_{(\theta,\phi)}|(\mathrm{h}^{(\mathrm{f})}_{\mathrm{k},1}\mathrm{h}^{(0)^*}_{\mathrm{k},1}) + (\mathrm{h}^{(\mathrm{f})}_{\mathrm{k},2}\mathrm{h}^{(0)^*}_{\mathrm{k},2})|^2, \quad (3)$$

$\mathrm{P}^{(.)}_{\mathrm{T,k}}$ is the transmit power of the macro/femto base station on subcarrier k, $\mathrm{P}^{(.)}_{\mathrm{g}}$ is the pathgain between macro/femto base station and UE, $\mathrm{G}^{(.)}_{(\theta,\phi)}$ is the antenna gain of the macro/femto base station, θ is azimuth angle between the macro/femto base station and UE, ϕ is a elevation angle between the macro/femto base station and UE, $\mathrm{h}^{(.)}_{\mathrm{k},1}$ is the small scale channel gain on link (.) for UE receiver antenna 1 and, $\mathrm{h}^{(.)}_{\mathrm{k},2}$ is the small scale channel gain on link (.) for UE receiver antenna 2, m indicates the m^{th} macro/micro base station, f indicates the f^{th} femto base station, B_{k} is subcarrier bandwidth (Hz), $\mathcal{F}$ is the receiver noise figure, N_0 is noise power spectral density (W/Hz) and $.^{(0)}$ represents the desired link.

The main objectives of femtocell deployment in a cellular network can be expressed as follows,

$$1.\quad \mathrm{maximize}\{\mathrm{C_{Tot}} = \sum_{\mathrm{u_m}\in\mathrm{U_m}} \mathrm{C_{u_m}} + \sum_{\mathrm{u_{f,m}}\in\mathrm{U_{f,m}}} \mathrm{C_{u_f}}\} \quad (4)$$

$$2.\quad \mathrm{maximize}\{\mathrm{N_{F_{atv}}}\} \quad (5)$$

where $\mathrm{U_m} = \{1_\mathrm{m}, 2_\mathrm{m}, \ldots, \mathrm{N_{u_m}}\}$ is the set of users attached to m^{th} macro/micro base station and $\mathrm{U_{f,m}} = \{1_{\mathrm{f,m}}, 2_{\mathrm{f,m}}, \ldots, \mathrm{N_{u_{f,m}}}\}$ is the set of users attached to femto base stations deployed under the coverage of m^{th} macro/micro base station, $\mathrm{N_{F_{atv}}}$ is the number of active femtocells, $\mathrm{C_{u_m}}$ is the throughput (bits/s) of the $\mathrm{u_m}^{th}$ macro/microUE as per the modified Shannon formula [14], which represents the throughput (bits/s) of the PHY layer of LTE (encapsulating the effects of forward error control code, HARQ etc.) and $\mathrm{C_{u_f}}$ is the throughput (bits/s) of the $\mathrm{u_f}^{th}$ femto UE and $\mathrm{C_{Tot}}$ is the total throughput (bits/s) of macro/micro UEs and femto UEs.

These objectives should satisfy the following constraints:-

1) $\mathrm{P}^{(\mathrm{f})}_{\mathrm{T}} \leq \mathrm{P}^{(\mathrm{f})}_{\mathrm{Tmax}}$

2) $\mathrm{P}^{(\mathrm{m})}_{\mathrm{T}} \leq \mathrm{P}^{(\mathrm{m})}_{\mathrm{Tmax}}$

3) $\mathrm{B} \leq \mathrm{B_T}$

4) $\{5\% - \text{tile-point } \mathrm{C_{u_m}}\} \geq \mathrm{C^{min}_{u_m}}$

5) $\overline{\mathrm{C_{u_f}}} \leq \mathrm{C^{th}_{u_f}}$

where $\mathrm{P}^{(\mathrm{f})}_{\mathrm{T}}$ is the transmit power of f^{th} femtocell, $\mathrm{P}^{(\mathrm{f})}_{\mathrm{Tmax}}$ is the maximum transmit power of f^{th} femtocell, $\mathrm{P}^{(\mathrm{m})}_{\mathrm{T}}$ is the transmit power of m^{th} macrocell, $\mathrm{P}^{(\mathrm{m})}_{\mathrm{Tmax}}$ is the maximum transmit power of m^{th} macrocell, B is bandwidth of operation, $\mathrm{B_T}$ is the total system bandwidth, $\mathrm{C^{min}_{u_m}}$ is the minimum required throughput for the macrocell users, $\overline{\mathrm{C_{u_f}}}$ is the mean throughput of femtocell and $\mathrm{C^{th}_{u_f}}$ is the maximum mean femto throughput.

For the above mentioned optimization problem, the degrees of freedom available are,

$$\mathrm{P}^{(\mathrm{f})}_{\mathrm{T}} = \{\mathrm{P}^{(\mathrm{f})}_{\mathrm{Tmin}}, \ldots, \mathrm{P}^{(\mathrm{f})}_{\mathrm{Tmax}}\} \quad (6)$$

$$\beta_{\mathrm{f}} = \{\beta_{\mathrm{f}min}, \ldots, \beta_{\mathrm{f}max}\} \quad (7)$$

$$\mathrm{N_{F_{atv}}} = \{1, 2, \ldots, \mathrm{N_F}\} \quad (8)$$

where β_{f} is femtocell load factor.

The control mechanism for femtocell deployment in a macro/micro cellular network can be classified as follows:-

A. Centralized Control

The central HeNB controller located in Core Network (CN) sends information to HeNBs on maximum allowable transmit power and maximum allowable load based on the overall cell statistics.

B. Distributed Control

The femtocell decides its transmit power according to local received interference power.

C. Hybrid Control

The central HeNB controller sends upper limit on allowable transmit power, bandwidth and throughput for the femtocells. Then each femtocell dynamically adjusts the power and load over and above the allowed limit within a certain margin to meet the rate requirement. Then the central controller may also inform the management entity in the CN to adjust the active number of UEs and load in the macro/micro cell depending upon the objectives (a) maximizing sum–cell–throughput, (b) maximizing number of active femtocells.

III. Results and Discussion

In this work, full load as well as fractional load condition for macrocell is considered. Under fractional load condition, the percentage of bandwidth utilization in macrocell is less than 100%. This is meaningful because some percentage of macro/micro cell traffic is offloaded to the femtocells. Further it is interesting to note that, many Physical Resource Blocks (PRBs) are left vacant during dynamic scheduling of Voice over IP (VoIP) even at full capacity [15]. This is due to Physical Downlink Control Channel (PDCCH) limitation. In UMi Scenario, under 100% macro/micro load condition, maximum 85 users are served by a macrocell with mean throughput of 128 Kbps. The corresponding 5% outage throughput is 23.5 Kbps. This is considered as $\mathrm{C^{min}_{u_m}}$ for further analysis.

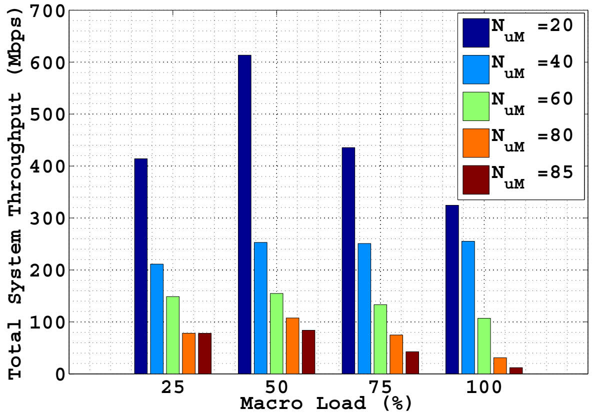

Fig. 2: Total system capacity evaluation for various macro/micro load conditions with constraint: $C_{u_m} \geq 23.5$ Kbps and objective 1: $\text{maximize}\{C_{Tot}\}$

TABLE II: Operating guidelines of femtocell for various combination of macro/micro load (β_m) and number of active macro/micro users (N_{u_m}) and corresponding maximum allowable number of active femtocells ($N_{F_{atv}}$), femto load (β_f), femtocell transmit power ($P_T^{(f)}$) while $\text{maximize}\{C_{Tot}\}$ subject to constraint: $C_{u_m} \geq 23.5$ Kbps

N_{u_m}	20	40	60	80	85
		$\beta_m = 25\%$			
$max\{N_{F_{atv}}\}$	15	10	10	10	10
$max\{\beta_f\}$ (%)	80	60	20	20	20
$max\{P_T^{(f)}\}$(dBm)	2	2	5	11	5
$max\{C_{Tot}\}$(Mbps)	414	211	148	78	78
$\overline{C_{u_m}}$(Kbps)	245	137	95	75	71
$\overline{C_{u_f}}$(Mbps)	27	21	7.15	7.22	7.18
		$\beta_m = 50\%$			
$max\{N_{F_{atv}}\}$	25	10	10	20	15
$max\{\beta_f\}$ (%)	100	60	40	20	20
$max\{P_T^{(f)}\}$(dBm)	2	2	2	2	2
$max\{C_{Tot}\}$(Mbps)	613	253	155	108	84
$\overline{C_{u_m}}$(Kbps)	389	218	150	118	112
$\overline{C_{u_f}}$(Mbps)	24.22	24.43	15.58	4.91	4.96
		$\beta_m = 75\%$			
$max\{N_{F_{atv}}\}$	25	25	20	20	10
$max\{\beta_f\}$ (%)	100	60	40	20	20
$max\{P_T^{(f)}\}$(dBm)	2	2	2	2	2
$max\{C_{Tot}\}$(Mbps)	435	251	133	75	43
$\overline{C_{u_m}}$(Kbps)	456	237	171	135	131
$\overline{C_{u_f}}$(Mbps)	17	9.66	6.14	3.2	3.14
		$\beta_m = 100\%$			
$max\{N_{F_{atv}}\}$	20	20	10	10	-
$max\{\beta_f\}$ (%)	100	100	80	20	-
$max\{P_T^{(f)}\}$(dBm)	5	2	2	2	-
$max\{C_{Tot}\}$(Mbps)	324	255	107	31	-
$\overline{C_{u_m}}$(Kbps)	363	220	169	135	-
$\overline{C_{u_f}}$(Mbps)	15.86	12.32	9.68	2.03	-

From detailed system level simulations the combination of control parameters: femtocell transmit power ($P_T^{(f)}$), femto load (β_f) and number of active femtocells ($N_{F_{atv}}$) that maximizes the total system throughput (C_{Tot}) under fractional load condition in macrocell is presented in Table II. The corresponding C_{Tot} is given in Figure 2. Similarly values for control parameters for maximizing number of active femtocells are given in Table III and corresponding $N_{F_{atv}}$ is given in Figure 3.

For the simulation, 25%, 50%, 75% & 100% macro/micro load (β_m) conditions are considered. The femtocell transmit power is varied from 2dBm to 20dBm in steps of 3dB in each case. The value of femto load is considered from 0% to 100% with a step of 20% for each scenario. The number of active femtocells is varied from 5 to 25 with a step of 5 in each situation. The number of macro/micro users is varied through 20, 40, 60, 80 and 85.

A. Maximization of sum–cell–throughput

It can be seen from the Table II that for a given macro/micro load say β_m=25% and given number of macro/micro users say N_{u_m}=40, that the combination of maximum allowable number of active femtocells ($N_{F_{atv}}$), femto load (β_f), femtocell transmit power ($P_T^{(f)}$) are 10, 60% and 2dBm respectively which attains the maximum C_{Tot} of 211Mbps. Any other combination of these control parameters yields C_{Tot} which is less than 211Mbps. Under the given macro/micro load of 25% the centralized controller may inform the macro/micro cell management entity to reduce the number of users from 40 to 20 in order to maximize the C_{Tot} to 414Mbps. Corresponding values for these set of parameters can be read from the table. It can be seen from the Figure 2 that the maximum C_{Tot} that can be attained is 613Mbps. This can be achieved when the macro/micro cell load is 50% with 20 number of macro/micro cell users and 25 active femtocells with 100% load and transmitting at 2dBm power level. It can be seen in general C_{Tot} is maximized by decreasing number of macrocell users which in turn means offloading macro/micro cell traffic to femtocells. On the other hand, it is found the 50% macro/micro cell loading is optimum for obtaining maximum C_{Tot}. It is also observed that, the effect of increasing femto load have more impact on maximization of C_{Tot} than effect of increasing transmit power of femtocell. It is observed that in most situations, 2dBm to 5dBm power is sufficient for the femtocells to operate. It is seen that up to 44 fold increase in ASE is achievable by using co-channel femtocells in a UMi Scenario.

B. Maximization of number of active femtocells

For a given macro/micro load say β_m=25% and given number of macro/micro users say N_{u_m}=40, it can be seen that upto 25 active femtocells can be supported, provided that the femtocells transmit at 5dBm power with 20% load, thereby achieving C_{Tot} of 184Mbps. Whereas in comparison to the previous result, it can be observed that the 150% increase in the number of active femtocells can be achieved against a penalty of 12.8% reduction in the C_{Tot}. From the Table III it can be observed that in many cases, with 60 macro/micro users 25 femtocells are supportable which is stark contrast with the previous results.

C. Hybrid control

In one of the scenarios with N_{u_m}=85, β_m=100% where femtocells are not allowed to transmit, application of hy-

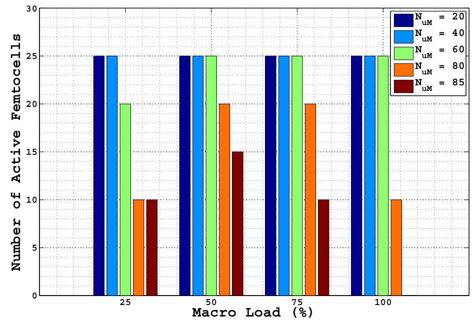

Fig. 3: Optimum number of supportable active femtocells for various macro/micro load (β_{m}) conditions with constraint: $\mathrm{C}_{\mathrm{u_m}} \geq 23.5$ Kbps and objective 1: $\mathrm{maximize}\{\mathrm{C}_{\mathrm{Tot}}\}$ & objective 2: $\mathrm{maximize}\{\mathrm{N}_{\mathrm{F_{atv}}}\}$

TABLE III: Operating guidelines of femtocell for various combination of macro/micro load (β_{m}) and number of active macro/micro users ($\mathrm{N}_{\mathrm{u_m}}$) and corresponding maximum allowable number of active femtocells ($\mathrm{N}_{\mathrm{F_{atv}}}$), femto load ($\beta_{\mathrm{f}}$), femtocell transmit power ($\mathrm{P}_{\mathrm{T}}^{(\mathrm{f})}$) while $\mathrm{maximize}\{\mathrm{C}_{\mathrm{Tot}}\}$ & $\mathrm{maximize}\{\mathrm{N}_{\mathrm{F_{atv}}}\}$ subject to constraint: $\mathrm{C}_{\mathrm{u_m}} \geq 23.5$ Kbps

$\mathrm{N}_{\mathrm{u_m}}$	20	40	60	80	85
		$\beta_{\mathrm{m}} = 25\%$			
$max\{\mathrm{N}_{\mathrm{F_{atv}}}\}$	25	25	20	10	10
$max\{\beta_{\mathrm{f}}\}$ (%)	40	20	20	20	20
$max\{\mathrm{P}_{\mathrm{T}}^{(\mathrm{f})}\}$(dBm)	5	5	5	11	5
$max\{\mathrm{C}_{\mathrm{Tot}}\}$(Mbps)	362	184	149	78	78
$\overline{\mathrm{C}_{\mathrm{u_m}}}$(Kbps)	245	137	95	75	71
$\overline{\mathrm{C}_{\mathrm{u_f}}}$(Mbps)	14.27	7.15	7.15	7.22	7.18
		$\beta_{\mathrm{m}} = 50\%$			
$max\{\mathrm{N}_{\mathrm{F_{atv}}}\}$	25	25	25	20	15
$max\{\beta_{\mathrm{f}}\}$ (%)	100	40	20	20	20
$max\{\mathrm{P}_{\mathrm{T}}^{(\mathrm{f})}\}$(dBm)	2	2	5	2	2
$max\{\mathrm{C}_{\mathrm{Tot}}\}$(Mbps)	613	244	152	108	84
$\overline{\mathrm{C}_{\mathrm{u_m}}}$(Kbps)	389	212	147	118	112
$\overline{\mathrm{C}_{\mathrm{u_f}}}$(Mbps)	24.22	9.42	5.73	4.91	4.96
		$\beta_{\mathrm{m}} = 75\%$			
$max\{\mathrm{N}_{\mathrm{F_{atv}}}\}$	25	25	25	20	10
$max\{\beta_{\mathrm{f}}\}$ (%)	100	60	20	20	10
$max\{\mathrm{P}_{\mathrm{T}}^{(\mathrm{f})}\}$(dBm)	2	2	5	2	2
$max\{\mathrm{C}_{\mathrm{Tot}}\}$(Mbps)	435	251	118	75	43
$\overline{\mathrm{C}_{\mathrm{u_m}}}$(Kbps)	456	237	171	135	131
$\overline{\mathrm{C}_{\mathrm{u_f}}}$(Mbps)	17	9.66	6.14	3.2	3.14
		$\beta_{\mathrm{m}} = 100\%$			
$max\{\mathrm{N}_{\mathrm{F_{atv}}}\}$	25	25	25	10	-
$max\{\beta_{\mathrm{f}}\}$ (%)	100	60	20	20	-
$max\{\mathrm{P}_{\mathrm{T}}^{(\mathrm{f})}\}$(dBm)	2	2	5	2	-
$max\{\mathrm{C}_{\mathrm{Tot}}\}$(Mbps)	307	198	87.17	31	-
$\overline{\mathrm{C}_{\mathrm{u_m}}}$(Kbps)	420	233	154	135	-
$\overline{\mathrm{C}_{\mathrm{u_f}}}$(Mbps)	12	7.54	3.12	2.03	-

brid control method shows nearly 19% improvement in 5% macro/micro cell throughput is observed. In hybrid control method, we have considered dual constraints $\mathrm{C}_{\mathrm{u_m}} \geq 23.5$ Kbps and $\overline{\mathrm{C}_{\mathrm{u_f}}} \leq 5$ Mbps.

IV. Conclusion

Investigation of co-channel deployment of femtocell, in UMi scenario as per ITU channel model is presented in this work. Two objective functions viz. maximization of sum–cell–throughput and maximization of active number of femtocells are studied. Clear guidelines to attain these objectives by choosing appropriate femtocell transmit power, femto load, number of active femtocells for combinations of macro/micro cell users and macro/micro cell load are presented in details. It is found that offloading macro/micro cell traffic to femtocells helps in increasing sum–cell–throughput significantly. It is seen that up to 44 times increase in area spectral efficiency can be achieved by using co-channel femtocells in a UMi Scenario following the methods described in this work. A hybrid control strategy is also investigated which increases the 5% macro/micro user throughput by 19%. Further it is found that, 2dBm to 5dBm of femto transmit power is sufficient to attain both the objective functions mentioned above.

References

[1] V. Chandrasekhar, J. Andrews, and A. Gatherer, "Femtocell networks: a survey," *IEEE Communications Magazine*, vol. 46, no. 9, pp. 59–67, september 2008.

[2] 3GPP, "Further advancements for e-utra physical layer aspects," Tech. Rep. TR.36.814 v2.0.10, 30-Mar 2010.

[3] "3g home nodeb study item technical report," 3GPP, Tech. Rep. TR.25.820 v8.2.0, 15-Sep 2008.

[4] D. Knisely, T. Yoshizawa, and F. Favichia, "Standardization of femtocells in 3gpp," *IEEE Communications Magazine*, vol. 47, no. 9, pp. 68–75, september 2009.

[5] G. de la Roche, A. Valcarce, D. Lopez-Perez, and J. Zhang, "Access control mechanisms for femtocells," *IEEE Communications Magazine*, vol. 48, no. 1, pp. 33–39, january 2010.

[6] H. Mahmoud and I. Guvenc, "A comparative study of different deployment modes for femtocell networks," in *IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications, 2009*, 13-16 september 2009, pp. 1–5.

[7] N. Arulselvan, V. Ramachandran, S. Kalyanasundaram, and G. Han, "Distributed power control mechanisms for hsdpa femtocells," in *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, april 2009, pp. 1–5.

[8] M. Yavuz, F. Meshkati, S. Nanda, A. Pokhariyal, N. Johnson, B. Raghothaman, and A. Richardson, "Interference management and performance analysis of umts/hspa+ femtocells," *IEEE Communications Magazine*, vol. 47, no. 9, pp. 102–109, september 2009.

[9] H. Claussen and D. Calin, "Macrocell offloading benefits in joint macro- and femtocell deployments," in *Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on*, 13-16 2009, pp. 350–354.

[10] M. Andrews, V. Capdevielle, A. Feki, and P. Gupta, "Autonomous spectrum sharing for mixed lte femto and macro cells deployments," mar. 2010, pp. 1–5.

[11] D. Lopez-Perez, A. Ladanyi, A. Juttner, and J. Zhang, "Ofdma femtocells: A self-organizing approach for frequency assignment," sep. 2009, pp. 2202–2207.

[12] Morita, M. and Matsunaga, Y. and Hamabe, K., "Adaptive Power Level Setting of Femtocell Base Stations for Mitigating Interference with Macrocells," in *Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd*, vol. , no. , sept. 2010, pp. 1–5.

[13] "Guidelines for evaluation of radio interface technologies for imt-advanced," ITU, Tech. Rep. M2135.

[14] P. Mogensen, W. Na, I. Kovacs, F. Frederiksen, A. Pokhariyal, K. Pedersen, T. Kolding, K. Hugl, and M. Kuusela, "Lte capacity compared to the shannon bound," in *Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th*, april 2007, pp. 1234–1238.

[15] Y. Fan, P. Lunden, M. Kuusela, and M. Valkama, "Efficient semi-persistent scheduling for voip on eutra downlink," in *Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th*, 2008, pp. 1–5.