DOWNLINK PERFORMANCE IMPROVEMENT OF MACRO BASE STATIONS IN HETEROGENEOUS NETWORKS

Fahim Gohar Awan, Noor Muhammad Sheikh, Asima Kiran

Faculty of Electrical Engineering, UET, Lahore, Pakistan

ABSTRACT — *This paper analyzes the technical issues of a complicated interference scenario and apply beamforming with cooperative base-stations on a femto-cell assisted cellular system describing an indoor environment and various potentials we have to improve the transmission performance both in terms of spectral efficiency and energy efficiency for cell edged users in a hexagonal cellular system. Results are validated carrying out dynamic system level simulations. A multi fold improvement is presented in terms of LTE network throughput and quality of telecommunication services. For outdoor users, the proposed scheme delivers enhanced throughput at macro base stations and serves considerably an increased number of users in a dense urban environment.*

Index Terms — Femtocell, Beamforming, cooperative Base stations, interference, LTE

. INTRODUCTION

Signal attenuation caused by building outer walls makes it hard to obtain the ubiquitously craved strong indoor signal. Even if it passes through them, its signal power is lost lowering its capacity, due to which femtocell, a low transmission power licensed access point is connected to indoor users which is connected to the core network to attain higher spectral efficiency than macrocell alone which is hosting them. Marco-cellular network is formed to provide coverage for huge and open areas including rural areas whereas femtocells are formulated for congested urban areas having some kind higher degree of difficulty of signal penetration. A base station (BS) must be programmed in such a way that it must know out of an array of the resource blocks (RB) to which of them it will transmit signals in a cooperative manner. Spectrum splitting and spectrum sharing are two approaches that are recommended in literature for spectrum allocation to femtocells. Macro and femto cells are assigned orthogonal frequency bands aiming to ensure no cross tier interference but this is not a spectrally efficient approach compared to sharing spectrum where both cells use same carrier frequency consequently leading to management challenges for inter carrier interference (ICI) as well as for multiple access interference (MAI). Femtocell may be a preferred choice in big buildings and underground rush places to get rid of low signal problem. This heterogeneous system will be more efficient regarding frequency spectrum and bandwidth if we use beamforming for the coordination of femto-BS & macro-BS.

To achieve higher data rates multicellular processing with distributed and cooperative BSs can be employed [1]. Since each femto cell possesses a fix orientation, to implements such a system, it is a mandatory requirement to manage radio resource and intercell fairness. Macro and femto cells coordination has been achieved by bypassing the macro cells and paging all femto cells with same tracking area code [2]. Compared to opportunistic beamforming in increasing the spectral efficiency and throughput, organized beam hopping performs well [3] but its complexity is high.

Transmission band is limited when macrocell and femtocell do not interfere with each other at all and share totally different spectrum bands. Spectral efficiency is increased when macrocell and femtocell share the complete spectrum. A cell must know in a perfect manner that when it should transmit its signals to the resources and at what frequency. In an optimized beamforming coordination system, due to different spatial positions of femto cell-BS, macro-BS can support more than one user/femto cell-BS treating femto cell-BS as a UE for the macro-BS at the same frequency by steering individual antenna beams at each user making use of techniques defined in spatial domain multiple access (SDMA). This technique is employed particularly to gain a good order increment in the overall capacity of the system.

Authors in [4 – 8] have presented and simulated the macrocell HSDPA network capacity improvement either by distributed downlink (DL) beamforming algorithms or by varying key parameters using UE’s CQI measurements or by inserting femtocells and exploiting antenna transmit diversity.

The work presented by authors so far have; simulated the distributed downlink beamforming algorithms on macro network, studied the bandwidth constraint, improved the capacity of femtocellular networks by optimizing its network parameters, proposed some interference avoidance algorithms and analyzed the antenna transmit diversity performance on femtocells. But none of them have explored the downlink macro base station performance under beamforming with cooperative base stations (BS) in a femtocellular environment. Therefore extending the useful work done by [1], [7] and [8], the authors in this paper investigate and implement the novel beamforming technique with cooperative base station. This paper therefore attempts to investigate the system level performance of various components for the complete network in details as given below. Capabilities of the proposed scheme are explored through extensive simulations carried out in Matlab environment for practical scenarios and a business model is presented for future networks.

The contribution in this paper is to explore constraints inherent to the deployment of femto-cells such as the outward appearance of dozens of femtoBSs in a specific region almost certainly amounts to the technical capacity challenges of macrocell’s BS and its performance. This becomes a complicated scenario with degraded efficiency as the famtocells randomness and un-coordination poses interference destructively. This paper primarily focuses on assessing the impact of femto-cell deployment on macro networks and addressing the various issues associated with femto-cell deployment.

The relevant techniques and state of the art employed are discussed in the next section in detail. In the remainder of paper, Section II presents modeling and analysis of the proposed technique. Section III describes a pragmatic case study for to validate the assertions followed by conclusions.

I. MODELING & ANALYSIS

This section presents the assumed simulation spatial model that using beamforming coordination calculates the LTE-A network throughput at all levels within a specific topology of cell after integrating femto and macrocells. For link quality estimation the key parameters are shadow fading and path loss maps. Whereas the key performance indicator is chosen to be average throughput based on signal to interference and noise ratio (SINR) maps. We considered a scenario of dense buildings at cell edges and a specific arrangement of UEs served by femtocells. Intercell fairness are supported for cooperation in allocating resource among femtocells maintaining the same cell capacity and complexity and making traffic load based power allocations. We further assume a cooperative DL system of N cells having full reuse intercell resources and orthogonal intracell communication. A free of interference and dedicated communication link between BS's is considered capable of information sharing cooperatively between them. Mathematically we can express as$y_n = h_{n,n}x_n + \sum_{k\epsilon I(n)} h_{n,k}x_n + \mathrm{w}_n \,, \quad n = 1, \dots, N$ (1)
where y_n is the nth mobile station (MS) received signal and x_n is the nth base station transmitted signal. $\{w_n\}$ are i.i.d. Gaussian noise variables, with mean=0 and variance σ^2. For cell n $I(n)$ is the set of indexes of the adjacent cells. $h_{n,k}$ is the path gain from BS k to MS n. A MIMO system is formed if we enable BS cooperation among the N BSs and N MSs, then beamforming can be carried out via a linear precoder T ϵ $R^{N\times N}$. Fairness across mobiles can be provided if SINR characterizes the performance of each MS. The worst SINR optimization problem, subject to a sum power constraint, can be stated as

$$\max_{\boldsymbol{T}} \min_{n} SINR_n \,, \qquad s.t. \ \|\boldsymbol{T}\|^2 \le P_t \,. \qquad (2)$$

This is a generalized consideration of weighted SINR, reflecting different priorities amongst the MS's.

The proposed method is designed to solve the problem for a cellular system with a large number of base stations. Mathematical models and framework is developed and extended to enable simulation of this complex system using appropriate simulation tools. These models are designed to strike a right balance between mathematical tractability and realism in terms of capturing all key physical phenomena affecting the problem (base station cooperation and convergence of message passing). More detailed mathematical models will hinder the tractability of the solutions and possibility of realistically simulating and testing the performance of the system. To verify the convergence of algorithm and quantify the improvement from the state of the art methods, we use extensive system level simulations.

The simulation environment has been created in accordance with the LTE-Advanced. The layer mapping is done according to [9,10].

In case all the base stations cooperate among each other as a group which is listed at the core network. An UE connected with a femtoBS enables transmission and all other remaining femtoBSs and macroBS out of the group aid this transmission. These BSs simultaneously put a null in the direction of the UEs connected with macroBS thereby effectively improving the femtocell performance to the extent that the principle interference is originated from the macroBS.

Table 1 defines the network parameters configured for both the base layer and its overlaying layer. To define the outdoor-to-indoor and indoor-to-outdoor links environment, an additional penetration loss by concrete wall of 20 dB is modeled. SINR for each subcarrier n and each user is calculated. On a subcarrier *n* the capacity of the user *i* is given by

$$C_{i,n} = \Delta f . log_2\left(1 + \alpha SINR_{i,n}\right), \qquad (3)$$

Where α is the constant for target Bit Error Rate. To meet the conditions of interference avoidance among neighboring

TABLE I
CONFIGURATION PARAMETERS FOR MACRO & FEMTO CELLS

Parameter	Value
Frequency	2.0 GHz
Bandwidth	20 MHz
Number of available RBs	100
Thermal noise density	-174 dBm/Hz
Receiver noise figure	9 dB [11]
nTX × nRX antennas	Scenario dependent
TX mode	i) SISO,ii) SISO with femto, iii) Codebook based Beamforming
Simulation length	100 TTIs
Inter eNodeB distance	500m
Minimum Coupling Loss	70 dB [11]
Macroscopic pathloss	40*(1-4e-3* Dhb)* $\log_{10}$(R)-18*$\log_{10}$(Dhb)+21*$\log_{10}$(f)+80dB, [11] (TS 25942 urban)
Shadow fading	lognormal, space-correlated [12], μ = 0; σ = 10 (dB)
Shadow fading correlation	Inter-site: 0.5, Intra-site: 1 [11]
eNodeB T_X power	46 dBm [11]
Microscale fading	Ext. PedB uncorrelated, time-correlated [13][14]
Number of UEs	10 UEs/sector
UE speed	5 KM/h
BS Antenna pattern	$A(\theta) = -\min[12(\theta/70^0)^2, 20dB], -180 \le \theta \le 180.$
BS antenna gain	15 DBi [11]
Scheduler	max TP
Subcarrier averaging algorithm	MIESM
Uplink delay	3 TTIs
RB_bandwidth	180 KHz
Length of a TTI (subframe)	1 mSec
Maximum number of codewords per TTI	2
Number of eNodeB rings	01 (07 BS, 21 Sectors)
Additional Penetration Loss	Deep Indoor (23dB)
Traffic type	Full buffer
Cell Layout	Hexagonal grid, sectors/eNodeB, hexagonal sectors
Penetration Loss for Indoor wall	20dB
Femtocell	
Frequency	2.0 GHz
Bandwidth	20 MHz
FemtoCell radius	10m
Minimum Coupling Loss	70 dB [11]
HeNodeB T_X power	21 dBm
Maximum Number of UEs/Cell	4
UE speed	5 KM/h
BS Antenna pattern	$A(\theta) = -\min[12(\theta/70^0)^2, 20dB], -180 \le \theta \le 180.$
FemtoBS antenna gain	5 DBi
Penetration Loss for Indoor wall	20dB
Cell Layout	Circular, 1sectors/HeNodeB

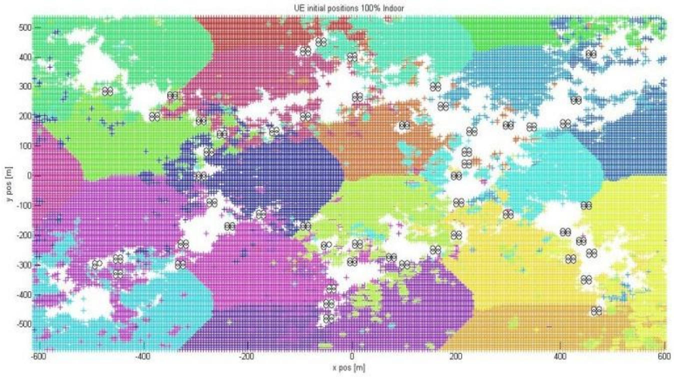

Fig. 1. Shadow fading map with 100% indoor users

blocks, a perfect time and frequency synchronization is assumed. The average throughput is the temporal data acknowledged over its unit interval.

$$Throughput = Acknowledged\ data\ (bits)/Time\ (s), \quad (4)$$

For user j the aggregate throughput is calculated using the achieved SINR/resource block γ_i^j as

$$T^j = \sum_{i \epsilon R^j} W_{RB}\ log_2\left(1 + \gamma_i^j\right), \quad (5)$$

Where for user j γ_i^j represents SINR achieved by the ith RB, R^j is the set of RBs and W_{RB} is the fixed bandwidth for a unit RB.

II. SIMULATION RESULTS

For the network defined in the previous section, sector wise throughput is calculated after estimating the SINR for the three different scenarios of configuration. Simulations are executed in an environment crated as testbed in MATLAB. Both environments, the macro and the overlay femtocell are formulated according to [15] and [7]. For cell edged users, compensations are required for losses like pathloss, intra cell and inter cell interferences. Signals penetrating the walls of the buildings further add up to these losses and make the environment worse when high bandwidth applications are run by indoor users.

Data collected at network central core indicates that out of total traffic the contribution of indoor users is around 70% [7], [8], [16], [17]. Femtocells become active part of the network as an UE(s) enter the coverage indoor. Figure 1 explain the graphical positioning of poor indoor coverage at cell edges and need for compensation like femtocell.

Simulation Results: The proposed technique is subjected to simulation run to analyze its performance. A case study is considered with three different scenarios. Network throughput is considered as a performance indicator and indoor traffic as a variable. After realizing the scarcity of the signal in standalone network, an overlay network is used as its compensation. The scenarios are (1) Macro layer only (7-macrocells), (2) Macrocells + Femtocells in co-channel operation hybrid access mode (for 210 UEs) and (3) Similar to 2 but with BF and Cooperative BS.

Performance Evaluation: Results generated by the standalone network as a testbed are summarized in this section. Which are then compared with the network performance gains after overlying with scenario 2 and 3 as described in table 2. Scenario 1 describes the base layout of simulation. On executing the simulation run for cell edged indoor user completely, there is 55% performance degradation in throughput [18], [19]. Since femtocell was configured to accommodate 4 UEs only, therefore for all configured UEs, 53 would be the optimum required number of femtocells. Although this requirement is dependent on the indoor assigned load by relevant macro station. Once calculated, this number is kept constant for the scenarios 2 and 3 for a comparative statement at each increment of load step.

Figure 2 depicts the various network components in terms of their average throughputs performance compared to the base line existing macrocellular system shown in black solid line. Curves for scenario-2 are shown in green, brown and blue lines where the contribution of femtoBS is a linear function of indoor load and macroBS performs better than without femtocells. The overall network has considerable gain of the order of 10 over existing macro network defined in scenario-1. Similarly curves for scenario-3 are shown in mustard, sky blue and purple lines where the contribution of femtoBS is a function of indoor load following same pattern as in previous case but with larger gap and macroBS performs far better than without femtocells. The overall network in this case has considerable gain of the order of 18 over existing macro network defined in scenario-1 and 1.8 folds compared to scenario-2. This indoor improvement is mainly due to shorter transmit-receive distance within femtocell and better interference management due to cooperation of BSs. Throughput performance curve of macroBS with SISO-femto is almost identical but slightly higher than the original network for the reason that now the resources freed by femtoUEs are available to take care of the rest of the UEs connected to it, macroBS with BF on the other hand obtains much better performance due to its underlying technology. For larger indoor load macroBS with BF nearly follows the same trend as for the other two curves. This is for the reason that now most of the users are engaged with femtocells and the freed resources are in abundance to accommodate lesser number of UEs connected with macroBS than it was originally designed for. In other words, it provides the maximum throughput for a range of UEs connected to it. When all UEs are indoor, throughput performance curve of macroBS with SISO crosses SISO only curve for larger number of femtocells deployed indoor that underperforms the macroBS being inefficient to the large number of its freed resources because there are not enough degrees of freedom and all the resources undermines network performance. For mid-range indoor users, there is 2.17 and 5.9 fold improvement in the macroBS compared to scenario-1 and 3 respectively. Similarly there is 1.9 fold improvement in scenario-3 compared to scenario-2 although

TABLE II: PERFORMANCE COMPARISON

	Scenario 1	Scenario 2	Scenario 3
Network Throughput	55% Degradation	10 fold improvement	18 fold improvement (1.8 times Sc-2)
MacroBS Throughput (30-80)% Gbps	0.733	1.597 (2.17 times)	4.322 (5.89 times) (2.7 times Sc-2)
Range of UEs served	-	++	+++

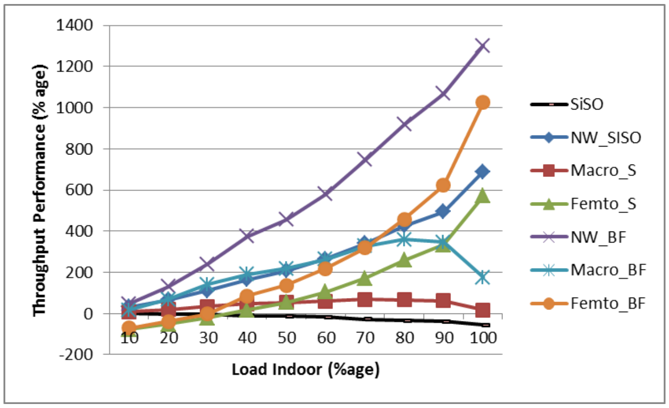

Fig. 2. Throughput Performance (% age)

both function on the same femto-layer but with different underlay technologies. Additionally macroBS in scenario-3 can accommodate another 20% users compared to 2^{nd} scenario.

III. CONCLUSION

In this paper we have presented cooperative base stations beamforming technique on cellular network assisted withfemto-cell. By enhancing the spectral efficiency we have shown a marked improvement in quality of service and throughput performance. We have described a framework to enable femtocells coordination on top of macrocells layer. The system level simulation results are validated for its efficiency, complexity and applicability. Under slow fading environment created in Matlab, Performance gains of 18 fold network throughput are achieved. Peak throughput requirements are met for macroBS for a range of outdoor users as well. The results clearly indicates that femtocells can be deployed at large scale of in a dense urban environment and may serve as a basis for a realistic future business model to meet higher bandwidth requirement at higher data rates for indoor applications and devices.

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