On Placement and Dynamic Power Control of Femtocells in LTE HetNets

Vanlin Sathya, Arun Ramamurthy and Bheemarjuna Reddy Tamma

Department of Computer Science and Engineering
Indian Institute of Technology Hyderabad, India
Email: [cs11p1003, me11b005, tbr]@iith.ac.in

***Abstract*—Femto cells a.k.a. Low Power Nodes (LPNs) are used to improve indoor data rates as well as to reduce traffic load on macro Base Stations (BSs) in LTE cellular networks. These LPNs are deployed inside office buildings and residential apartment complexes to provide high data rates for indoor Users. With high SINR (Signal-to-Interference plus Noise Ratio) the users experience good throughput, but the SINR decreases significantly because of interference and obstacles such as building walls present in the communication path. So, efficient placement of Femtos in buildings while considering Macro-Femto interference is very crucial for attaining desirable SINR. At the same time, minimizing the power leakage in order to improve the signal strength of outdoor users in high interference zone (HIZone) around the building area is important. In our work, we have considered obstacles (walls, floors) and interference between Macro and Femto BSs. To be fair to both indoor and outdoor users, we designed an efficient placement and power control SON (Self organizing Network) algorithm which optimally places Femtos and dynamically adjusts the transmission power of Femtos based on the occupancy of Macro users in the HIZone. To do this, we solve two Mixed Integer Programming (MIP) methods namely: Minimize number of Femtos (MinNF) method which guarantees threshold SINR ($SINR_{Th}$) -2dB for all indoor users and optimal Femto power (OptFP) allocation method which guarantees $SINR_{Th}$ (- 4 dB) for indoor users with the Macro users SINR degradation as lesser than 2dB. In MinNF method, optimal placement achieves 16% improvement over center placement of Femtos in terms of SINR for three floor apartment building.**

I. Introduction

Owing to a surge in the usage of smart phones and tablets, there is an increase in demand for spectrum and in data traffic. 3GPP tries, thus, to increase the data rates by deploying more LTE Macro base stations (BSs) in urban areas. Though the mobile operators are able to boost the data rates for outdoor users by using higher frequency bands, they are unable to increase the data rates for indoor users. It is difficult for high frequency ($\lambda = c/f$) electromagnetic signals to penetrate through walls and floors. The indoor users, hence, suffer with low signal strength. To demonstrate the aforementioned problem, we consider a single-floor building with a single Macro BS placed at a distance of 350 m [1] from it. By taking into account path losses due to walls and floors, we measured the distance upto which the signal from Macro can penetrate into the building. Fig. 1 shows the radio environmental map (REM) signal to noise ratio (SNR) for floor 1, where Z is the SNR value. Owing to the walls inside the building, the signal attenuates as the distance increases. Thus, the users inside the building receive -8 and -9 dB but the users outside the building receive 4, 2, 0 and -1 dB. As per recent statistics from Cisco and Hauwai [2], 70 % of the traffic comes from indoor environment. Hence, it becomes important for the mobile operators to boost data rates of indoor users. One solution is to deploy a large number of low power nodes (LPN) like Picos and Femtos under one umbrella Macro BS coverage. This increases the spectrum efficiency and allows spatial reuse of the same spectrum. LPNs can be installed by end users and in enterprise scenarios. But, random placement of Femtos inside the building can lead to co-tier interference, if the operator tries to reuse the same spectrum and hence, decreases the system performance. In order to increase the spectrum efficiency for indoor users, the placement of Femtos must be optimized. Optimal placement of Femtos ensures good signal strength/throughput. However, placing Femtos inside a building leads to power leakage at the edges/corners of the building. This degrades the signal performance of outdoor/Macro users in high interference zone (HIZone) around the building area because both Macros and Femtos typically operate on the same frequency. Setting the Femto transmission at optimal/low power could solve this problem. But in a real-world scenario, the Macro users may not always be there in the surroundings of the building, such as at nights. Thus, Femtos need not always transmit at low power as indoor enterprise users could benefit from the maximum transmission power of Femtos. Our goal is to address this problem and come up with a solution which dynamically adjusts transmit power based on the occupancy of Macro users around the building.

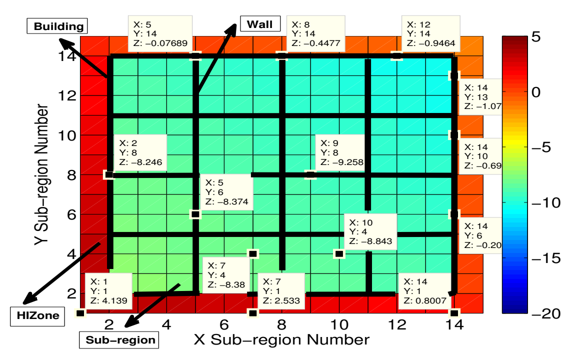

Fig. 1. REM of sub-regions in and around building for Single Macro scenario.

In this work, we dynamically adjust the transmission power of Femtos by solving Mixed Integer Programming (MIP) in two steps. In the first step we (a) Minimize number of Femtos (MinNF) which guarantees certain minimum threshold SINR ($SINR_{Th}$) for each sub-region inside the building with minimum number of Femtos and in second step (b) Determine optimal Femto power (OptFP) which reduces the Femto transmission power and also maintains the minimum $SINR_{Th}$ for the outdoor and indoor users.

II. Related Work

Random placement of Femtos inside buildings can create a lot of issues like interference, frequent handovers..etc. Optimal placement of the Femtos can solve the above mentioned problems. Several optimal Femto placement approaches have been proposed, taking into account different parameters such as building dimension, walls, floors..etc. In [3] [4], a single Femto is placed in a multi room indoor environment depending on the location of the Macro BS. One drawback of these approaches is that they are not scalable for enterprise scenario. Joint Femto placement and power minimizing method proposed by the author [5] is to place the Femto optimally with fixed power in such a way that the uplink power will be minimum at any point inside the building. But the author does not consider the realistic constraints like uplink and downlink interference from Macro as well as among Femtos and also the obstructions like walls. Walls play a major role in placement of Femtos, owing to which the optimal placement may change. Operators in [6] [7] place the Femtos randomly initially. While the former moves their locations iteratively such that the overall throughput increases but requires more human resources and field testing, the latter optimizes the transmission power of random placed Femtos based on Macro interference and guarantees constant SINR for indoor users and lesser degradation for outdoor users. But here the drawback is that there is an inefficient usage of spectrum due to different reuse factor and they didn't consider walls insidec the building. The Femto count also increases due to the random placement and the Femto power gets fixed irrespective of the Macro users outside the building. In our work, we considered the factors like interference between Macro and Femtos, reuse factor one, obstruction like walls and floors and implemented a efficient placement and power control SON algorithm which dynamically increases or decreases the Femto transmit power based on Macro users pattern to boost the SINR for both indoor and outdoor users. Our algorithm also reduces the deployment cost by finding the optimal number of Femtos.

III. Proposed work

A. LTE SON and System Model

We planned to design self organization network (SON) function that dynamically adjusts the Femto power and optimizes the mobile radio access networks. In this work, we consider a LTE HetNet system comprising of Macro BSs in outdoor environment, to which the outdoor users are associated with and Femto BSs inside an enterprise office building. All these Femtos are connected to Femto-Gateway (GW) over S1 interface as shown in Fig. 2. SON features are integrated in the Femto-GW to automate the system. We have considered the case where the Femtos and Macro BSs operate on same frequencies (to enable reuse of the spectrum) and hence, experience high co-channel interference. This affects the performance in HIZone i.e, the region around the building in which the Macro users experience high interference from Femtocells and leads to degradation in performance. In this work, we propose a solution to avoid high interference in HIZone. The Table I shows the notations used in this work.

TABLE I
Glossary

Notation	Definition
S_i	Set of all inner sub-regions
S_o	Set of all outer sub-regions
w_a	1 if Femto is placed at inner sub-region a, zero otherwise
y_{ja}	1 if j^{th} inner sub-region of the building is associated with the Femto located at inner sub-region a, zero otherwise
g_{ja}	Channel gain between inner sub-regions j and a
b_j	1 if user is located at outer sub-region j, 0 otherwise
M	Set of all Macro BSs
p_a	Normalized transmit power of Femto BS a, $0 \leq p_a \leq 1$

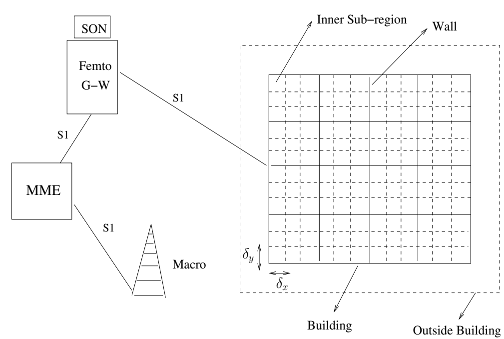

Fig. 2. LTE Femto SON Architecture.

B. Building Model

Consider the dimensions of a building to be $L \times W \times H$, where L, W and H are respectively the length, breadth and height. Let the building have g floors of equal height, where each floor is divided by walls into several rooms as shown in Fig. 2. Each room is further logically divided into smaller inner sub-regions S_i. In our example, we divide the room into (I_1,$I_2 \ldots I_{144}$) as shown in Fig. 3. Each inner sub-region is of length δ_x and width δ_y as shown in the Fig. 2. The thick lines represent the walls of the rooms and the small squares are the sub-regions. Similarly the HIZone region outside the building is represented as the outer sub-region S_o (In our example (O_1,$O_2 \ldots O_{52}$). As the size of sub-region is much smaller compared to the building size, we can safely assume that within every sub-region, the SINR value is constant. We also assume that in enterprise office environments, the amount of network traffic remains constant in any given inner sub-region which is quite true during business hours.

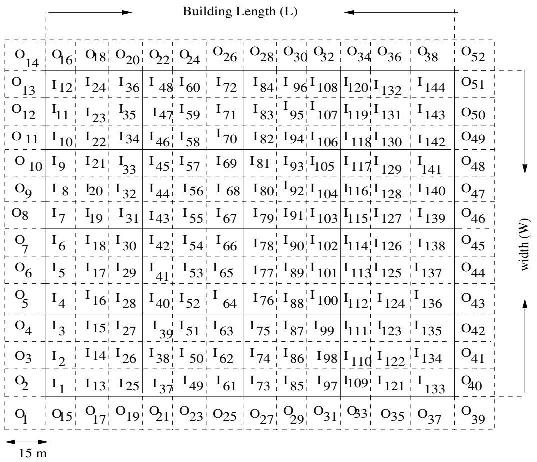

Fig. 3. Bird-eye view of floor area inside and outside the building.

C. Channel Model

The path loss model (PLM) from the Macro BS (MBS) to an inner sub-region user (ISU) and outer sub-region user (OSU) is given by:

$$PLM = 40\log_{10}\frac{d}{1000} + 30\log_{10} f + 49 + n\sigma \quad (1)$$

where, d is the distance of the sub-region of ISU/OSU from MBS in meters, n is the number of walls in between MBS and ISU, f is the center frequency of MBS, k is the number of floors and σ is the penetration loss. The PLM from Femto to ISU/OSU is given by [7]:

$$PLM = 37 + 30\log_{10} d + 18.3k^{\frac{(k+2)}{(k+1)-0.46}} + n\sigma \quad (2)$$

In our setup we assumed that the antenna gain for Macro and Femtos are 20 dBi and 2 dBi and we calculate the channel gain between users and various BSs using the PLM and antenna gain.

D. Proposed Efficient Placement and Power Control Algorithm

In our work, we propose an efficient placement and power control SON algorithm which dynamically adjusts the power of Femtos by employing two optimization methods:- MinNF and OptFP. In the MinNF method, we estimate the minimum number of Femtos required for placement, so as to provide a $SINR_{Th}$ to every inner sub-region (-2dB). Here, we assume that the Femtos transmit at maximum power owing to which SINR degradation for macro users in HIZone is high. In the OptFP method, using the solution of the MinNF optimization problem as the input setup their Femto power is optimally chosen to make sure that the difference in the SINR for Macro users before and after placement is less then 2 dB. And also a $SINR_{Th}$ value (-4 dB) is maintained for every inner sub-region. The Femto power changes dynamically (using SON module) depending upon the user pattern in the outer sub-regions S_o.

Minimize the number of Femtos (MinNF): In MinNF method, assuming that there are no Macro users in the surroundings of the building. The aim is to boost the Avg SINR for all the indoor users with a minimum number of Femtos and maintain a minimum $SINR_{Th}$ in all inner sub-regions. To boost the data rate for indoor users, the Femtos transmitting at the peak power, are placed optimally inside the building without any coverage holes. MinNF method has been described below.

(a) Problem Formulation For MinNF: The objectives of the MinNF are mentioned below:

- Minimize number of Femtos, NF_{min}, needed for maintaining threshold SINR in each inner sub-region of the building.
- Determine the optimal locations for placement of NF_{min} Femtos inside the building
- Identify the Femto in NF_{min} to which the indoor users in any given sub-region have to be associated with

In order to provide a good SINR to indoor users, every Femto operates at its peak transmit power (P_{max}). So, the goal is to minimize the total number of Femtos deployed, expressed by Eqn (3).

$$min \sum_{a \in S_i} w_a \quad (3)$$

Assuming that a sub-region corresponds to an indoor user, it is allowed to associate with only one Femto BS (refer Eqn (4)) inside the building.

$$\sum_{a \in S_i} y_{ja} = 1 \qquad \forall j \in S_i \quad (4)$$

$$y_{ja} - w_a \leq 0 \qquad \forall j, a \in S_i \quad (5)$$

These constraints ensure that every inner sub-region is connected to one and only one Femto BS.

The formulation of the MIP MinNF, guarantees certain minimum $SINR_{Th}$ for all users, within every sub-region of the building. The L.H.S of the Eqn (6) is the SINR value of the signal received by a particular inner sub-region j from the Femto located at sub-region a. To ensure good coverage, the SINR of inner sub-regions must be maintained above the predefined threshold λ, given by:

$$\frac{Inf * (1 - y_{ja}) + g_{ja} P_{max} w_a}{N_o + \sum_{b \in S_i \setminus a} g_{jb} P_{max} w_b + \sum_{e \in M} g'_{je} P_{Macro}} \geq \lambda \quad \forall j, a \in S_i \quad (6)$$

The above Eqn (6) can be linearized as,

$$Inf * (1 - y_{ja}) + g_{ja} P_{max} w_a \geq (\lambda N_o + \sum_{b \in S_i \setminus a} g_{jb} P_{max} w_b \lambda + \sum_{e \in M} g'_{je} P_{Macro} \lambda) \quad \forall j, a \in S_i \quad (7)$$

g'_{je} and g_{ja} are the channel gain from Macro and Femto calculated using Eqn (1) and Eqn (2), respectively, N_0 in Eqn (6) is the system noise and P_{Macro} is the power of the Macro. If y_{ja}=1, then w_a=1. In the above Eqn (6), Inf is a virtually infinite value (a very large value like 10^6). The reason for using $Inf * (1 - y_{ja})$ is that if $y_{ja} = 0$ then $Inf * (1 - y_{ja})$ becomes a large value and the expression can be ignored safely. Without the Virtual Infinite value, Eqn (6), ensures that all the Femtos provide a minimum $SINR_{Th}$ to a particular sub-region. But just a single Femto is necessary to give $SINR_{Th}$ for the inner sub-region. The MIP will always be infeasible if we do not use the virtual infinite value, as not all Femtos can maintain a $SINR_{Th}$ within a particular inner sub-region. Finally, the MinNF method is formulated as follows,

$$min \sum_{a \in S_i} w_a \qquad \text{s.t, (4), (5), (7).}$$

The above MinNF formulation guarantees that all the users inside the building will get a certain $SINR_{Th}$ with minimum number of Femtos. The above formulation is a good approach to boost the SINR in indoor regions when no Macro users in the surrounding of the building. But if the Macro users are present in the HIZone of the building, this method won't work as the Femtos transmit with maximum transmission power. Since Femto and Macro operate in the same spectrum, interference can occur between the Macro and Femto users and which in turn would degrade the signal strengths of the Macro users in HIZone. To overcome these shortcomings, we propose another optimization problem described below which optimally reduces the Femto transmission power.

Dynamic transmit power for each Femtos (OptFP): In this scheme, we assume that the Macro users are in the surroundings of the building and obtain the optimal NF_{min} using MinNF method. We try to guarantee minimum $SINR_{Th}$ for indoor users and reduce the SINR degradation of Macro users, by minimizing the power of the Femtos in such a way that it reduces the interference with the Macro users. A formulation of the OptFP method is described below.

(b) Problem Formulation For OptFP:

The objective of the proposed optimization scheme is to reduce the Macro users SINR degradation. By formulating this MIP, we will:

- Determine the power required by each Femto for maintaining the $SINR_{Th}$ in each of the inner sub-regions and maintain the SINR degradation at less than 2 dB in HIZone.
- Determine the Femto to which the users in any given inner sub-region have to be associated with.

The Femtos cannot operate at the highest power because if they do so, the Macro users will experience higher SINR degradation. We can safely assume that if we maximize the sum of all the transmission powers of Femtos, the transmission powers of individual Femtos will also be maximized (considering that the Femto BSs are "greedy" to keep their transmission power as high as possible) as the power values are obviously positive.

$$max \sum_{a \in S_i} p_a \tag{8}$$

$$p_a \leq w_a \qquad \forall a \in S_i \tag{9}$$

P_{max} be the maximum power of the Femto base station. The normalized power p_a value ranges from 0 to 1 and is 0 if w_a is 0. If Femto is not located at a given location a, w_a is set to 0. Once the model is solved, the actual power of Femto base station at location a is determined by $p_a * p_{max}$. Assuming that each inner sub-region corresponds to a user, any user is allowed to associate with only one Femto BS:

$$\sum_{a \in S_i} y_{ja} = 1 \qquad \forall j \in S_i \tag{10}$$

$$y_{ja} - w_a \leq 0 \qquad \forall j, a \in S_i \tag{11}$$

The two constraints mentioned above ensure that every sub-region is connected to one and only one Femto. To maintain the minimum SINR threshold for each inner sub-region is given by,

$$Inf * (1 - y_{ja}) + g_{ja} P_{max} p_a \geq (\lambda N_o + \sum_{b \in S_i \setminus a} g_{jb} P_{max} p_b \lambda + \sum_{e \in M} g'_{je} P_{Macro} \lambda) \quad \forall j, a \in S_i \tag{12}$$

Another major concern is minimizing the impact of the interference from Femtocell network on the outdoor users, who are connected to Macro BSs. To meet this requirement, we restrict the SINR degradation at each outer sub region (S_o) to be equal to or lesser than 2 dB:

$$\frac{\max_{e \in M}(g'_{je} P_{Macro}) + Inf * (1 - b_j)}{N_o + \sum_{e \in M'} g'_{je} P_{Macro} + \sum_{a \in S_i} g_{ja} P_{max} p_a} \geq \zeta_j \quad \forall j \in S_o \tag{13}$$

$$M' \equiv M \setminus arg \max_{e \in M}(g'_{je} P_{Macro}), \ \forall \ j \in S_o$$

The above Eqn (13) can be linearised as,

$$\max_{e \in M}(g'_{je} P_{Macro}) + Inf * (1 - b_j) \geq (\zeta_j N_o + \sum_{e \in M'} g'_{je} P_{Macro} \zeta_j + \sum_{a \in S_i} g_{ja} P_{max} p_a \zeta_j) \quad \forall j \in S_o \tag{14}$$

ζ_j is the minimum $SINR_{Th}$ at outer sub-region j. After the deployment of Femto, the precomputed ζ_j would be 2dB lesser than the original SINR. Note that outer sub region j is assumed to be attached to Macro BS $\text{argmax}_{e \in M}(g'_{je} P_{Macro})$. The reason for using $Inf*(1-b_j)$ is that if $b_j = 0$ then $Inf*(1-b_j)$ becomes a large value and the expression can be ignored safely. Without the Virtual Infinite value, Eqn (13), ensures that the outer sub-region which doesn't have any macro user will also have a threshold SINR, which is a waste of resources. Finally, the OptFP method is formulated as follows,

$$max \sum_{a \in S_i} p_a \qquad \text{s.t, (9), (10), (11), (12), (14).}$$

The above OptFP formulation guarantees a certain minimum $SINR_{Th}$ for indoor users and less degradation for Macro users. This method is good when Macro users are present in the outer sub-regions but it could be a waste of resources because the indoor users could benefit from the peak power of Femtos but they are actually receiving reduced power, even when no macro user is present outside the building. To overcome the above drawback, the OptFP method is solved whenever a Macro user is present within 15m range outside the building (HIZone), the users SINR degradation is under 2dB.

SON Module in Our Work:

A practical way to implement the proposed algorithm would be to use the SON module dynamically such that whenever a Macro user is nearby, the Femto will reduce its transmission power and increase the transmission power when there is no Macro user nearby. Now the question that arises is, what are the parameters that should be given as input to the SON module in Femto-GW?. The following paragraph strives to answer this question.

Fairness to Indoor and Outdoor Users: Our efficient placement and power control SON algorithm is fair to both indoor and outdoor users. There are some factors which we consider to dynamically adjust the Femto transmission power when a Macro users is nearby. We can get the mobility information of the Macro users from MME. Based on the velocity of the user, we can estimate user's movement in the outdoor sub-regions. Similarly, we can get the exact position of the outdoor users from position reference signal (PRS) stored by the Macro BS. Also, we can get the current scheduling information (i.e., whether the user was allocated any resource block for transmission (both uplink and downlink), given by the Macro BS). Three main parameters (user mobility, PRS and scheduling information) are given as inputs to Femto-GW by Macro BS and MME as shown in Fig. 2. From these parameters, Femto-GW can estimate the occupancy pattern of users in the outer sub-regions. Each occupancy pattern will contain a different combination of users in outer sub-regions (for eg: (O_1,O_2), (O_6,O_7), (O_2,O_3), (O_6,O_7,O_2,O_3)...etc). The total possible combination for outdoor sub-region pattern is given by,

$$n_{c_0} + n_{c_1} + n_{c_2} + ...+ n_{c_n} = 2^n$$

where, n is the total number of outer sub-regions. n_{c_0} $\Rightarrow$ represents no Macro users present in any of the outer sub-regions, n_{c_1} $\Rightarrow$ represents only one outer sub-region is occupied by Macro users, n_{c_2} $\Rightarrow$ represents two outer sub-region are occupied by Macro users, n_{c_n} $\Rightarrow$ All outer sub-regions are occupied by Macro users, 2^n $\Rightarrow$ Total combination of users in all outer sub-regions. If our pattern is n_{c_0}, we will simply apply MinNF method i.e no Macro users in outer sub-region (refer Algorithm 1). Otherwise, we will apply OptFP method. Initially, the position of each outdoor user in the sub-region pattern is given as input to the GAMS tool [8]. This tool (having a low running time) provides the optimal power of the Femtos. Then, Femto-GW will decide which side of the Femto should reduce or increase its transmission power (in worst case it might be all the Femtos). This, in turn, will boost the signal strength for both indoor and outdoor user devices and this power values of that pattern is stored in a database. The process is repeated for most of possible occupancy pattern of users in the outdoor sub regions and the data patterns are stored. If, in future an old occupancy pattern matches, instead of running the GAMS tool, we fetch the power values from the database. Otherwise, it is given as an input to the GAMS tool. The new resultant output data pattern may also be stored.

Algorithm 1 Efficient Placement and Power Control SON

Initialization:

- Let S_i and S_o be the set of all inner and outer sub-regions, respectively.

{ Minimize count of Femtos, find the optimal co-ordinates and transmit with maximum power. }

$min \sum_{a \in S_i} w_a$ st, Eqn (4), (5) and (7);

while true **do** { Dynamic Femto power allocation. }

- $S_u \subset S_o$ where S_u is the set of outer sub-regions with Macro users.

Pattern p; { Occupancy of Macro users in S_o as given by S_u}

if database.contains(S_u) **then**

Retrieve power values from database;

else { With the additional information of optimally placed Femto, we optimize the power of Femtos. }

$max \sum_{a \in S_i} p_a$ st, Eqn (9), (10), (11), (12) and (14);

{ Let the tuple Soln = (P_1,P_2...$P_{NF_{min}}$) be a solution to the above MIP. Where, P_1,P_2...$P_{NF_{min}}$ are the power value of Femtos. }

database.add(p,Soln); { Store the patterns in database. }

end if

delay t_o; { Vary depends on pattern }

end while

IV. Experimental Setup and Numerical Results

The system model described in Section III is simulated using MATLAB and the simulation parameters are given in Table II. We have considered a single floor building and the shortest distance between building and Macro is 350 m (diagonally from the center of inner sub-region I_1). Femtos are allowed to be placed only to the ceiling of the building and the minimum number of Femtos with their optimal co-ordinates and corresponding sub-region indices are obtained by solving MinNF MIP problem using GAMS CPLEX solver [8], which utilizes branch and bound framework for solving MIP based optimization problems. The output (optimal co-ordinates of Femtos) of GAMS solver is then given as the input to MATLAB based system model. In the following, we analyze two extreme scenarios: without Macro users and with Macro users in HIZone.

TABLE II
Simulation Parameters

Parameters	Values
Building dimensions	48 m × 48 m × 3 m
Number of Rooms	16
Room dimensions	12m × 12m × 3m
Number of inner Sub-region	144
Number of outer Sub-region	52
Inner Sub-region dimension	4 m × 4m × 3m
Number of Floor	One
Floor and Wall loss	8 and 10 dB
Femto Power	20 dBm (0.1w)
Macro Power	46 dBm
Macro BS Height	30 m

No Macro Users in HIZone:

The MinNF method provides the optimal NF_{min} for four Femtos with corresponding sub-region indices and they are placed inside the building at those sub-regions I_{30}, I_{71}, I_{98}, I_{129} (refer Fig. 3 for numbering of sub-regions) as shown in Fig. 4. At this instant there are no Macro users present in HIZone within a distance of 15 meters. Hence all Femtos placed at the

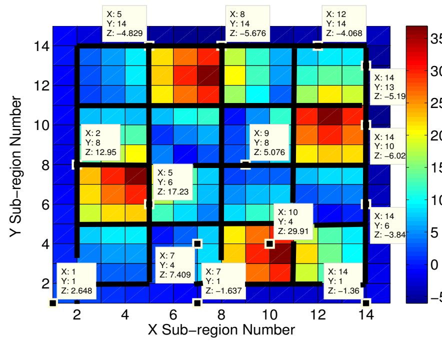

Fig. 4. REM across sub-regions for MinNF

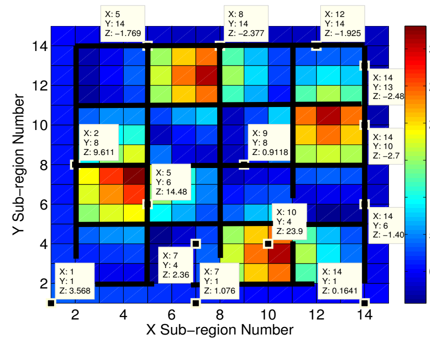

Fig. 5. REM across sub-regions for OptFP

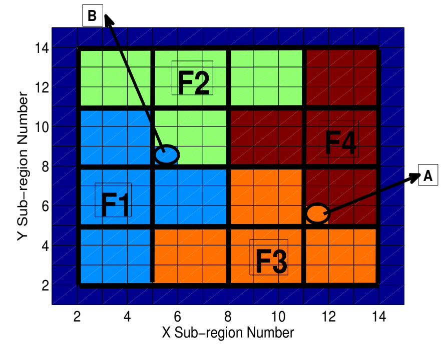

Fig. 6. Femtos sub-region association for MinNF

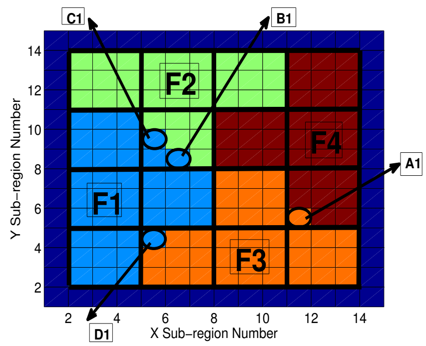

Fig. 7. Femtos sub-region association for OptFP

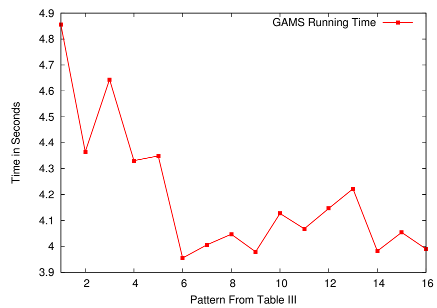

Fig. 8. GAMS Running Time.

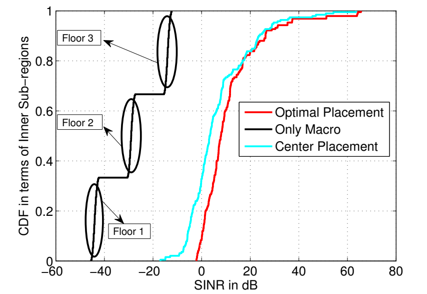

Fig. 9. Indoor SINR Variation in Three Floor Building.

TABLE III
OPTIMAL FEMTO TRANSMISSION POWER

S.NO	Pattern in Outer Sub-regions	$I_{30}(W)$	$I_{71}(W)$	$I_{98}(W)$	$I_{129}(W)$
1	West:(O_1,$O_2 \ldots O_{14}$)	0.038	0.1	0.1	0.1
2	North:(O_{14},$O_{16} \ldots O_{52}$)	0.1	0.0211	0.1	0.1
3	South:(O_1,O_{15},$O_{17}..O_{39}$)	0.1	0.1	0.0229	0.1
4	East:(O_{39},$O_{40} \ldots O_{52}$)	0.1	0.1	0.1	0.0223
5	All Sides of Building	0.036	0.021	0.027	0.022
6	O_{18},O_{20}	0.1	0.0344	0.1	0.1
7	O_{24},O_{26}	0.1	0.0211	0.1	0.1
8	O_6,O_7	0.0380	0.1	0.1	0.1
9	O_2,O_3	0.0675	0.1	0.1	0.1
10	O_1,O_2	0.0828	0.1	0.1	0.1
11	O_6,O_7, O_2,O_3	0.0380	0.1	0.1	0.1
12	O_{29},O_{31}	0.1	0.1	0.0229	0.1
13	O_{21},O_{23}	0.1	0.1	0.0432	0.1
14	O_{29},O_{31}, O_{21},O_{23}	0.1	0.1	0.0229	0.1
15	O_{18},O_{20},O_{23},O_{24},O_{26}	0.1	0.0212	0.0432	0.1
16	O_{47},O_{48}, O_{49}	0.1	0.1	0.1	0.0223
17	No Macro users	0.1	0.1	0.1	0.1

corner of the building transmit with their peak power (0.1w) as shown in Table III (S.NO 17). So the users inside the building get good SINR. The Fig. 4 shows the SINR values for all users inside the building. For example, in the sub-region I_{98}, the users get SINR value of 29.9 dB as the Femto (F3) is very close to it. Similarly, the sub-regions I_6, I_{29}, I_{79}, I_{51} inside the building have relatively good SINR values 12.9, 17.2, 5.0, 7.4 dB, respectively. But if we observe only Macro scenario where there are no Femtos inside the building like in Fig. 1, the sub-regions I_6, I_{29}, I_{79}, I_{51} inside the building have relatively less SNR values of -8.2, -8.3, -9.2, -8.3 dB, respectively due to poor indoor signal strength.

As a result of Femtos, the users present inside the building get a maximum SINR upto 35 dB (as shown in SINR graph of Fig. 4). But in this case, if some Macro user enters the outer sub-region (for eg. O_{48}), they will get an SINR as low as -6.0 dB. This is a consequence of the Femtos being closer to the corners of the building and hence, there being a high power leakage (interference) in HIZone. Similarly O_{51}, O_{36}, O_{28}, O_{20}, O_1, O_{25}, O_{37}, O_{44} outer sub-regions also have respectively low SINR values as -5.1, -4.0, -5.6, -4.8, 2.6, -1.6, -1.3, -3.8 dB. But if we observe only Macro scenario in Fig. 1, the sub-regions O_{51}, O_{36}, O_{28}, O_{20}, O_1, O_{25}, O_{37}, O_{44} outside the building have relatively good SNR values -1.0, -0.09, -0.4, -0.07, 4.1, 2.6, 0.8, -0.2 dB, respectively due to no interference.

In Fig. 6, the Femtos (F1, F2, F3, F4) are transmitting at peak power. User's in the inner sub-regions of the building, respectively, can thus connect a certain Femto. But, the Femtos are not placed in a manner that the sub-regions spanned by their transmission are uniform. So the users in some sub-regions in the neighboring rooms also can connect to another Femto based on the factors like the distance from the Femto and number of obstructing walls. For example, although the transmission power of Femto F1 (I_{30}) crosses more number of walls than Femto F2 (I_{71}) to the sub-region I_{43}, its distance from the sub-region (represented by B) is lesser. So, the sub-region I_{43} gets connected to the Femto F1. Similarly, the Femto located in I_{98} (F3) is closer to the sub-region I_{112} (represented by A). Hence, the sub-region I_{112} gets connected to Femto F3.

Macro Users in HIZone: When a Macro user enters an HIZone, the Macro BS provides users Mobility, PRS and scheduling information to Femto-GW from which we can decide if some Macro user is present in an HIZone. At this instance the Macro users are present at all sides of the building, and thus all the Femtos at the corners I_{30}, I_{71}, I_{98}, I_{129} of the building have to reduce their transmission power values optimally to 0.036, 0.021, 0.027, 0.022 W as shown in (Table III S.NO 5). Now, if we observe Fig.5 the users in the outer sub-regions O_{48}, O_{51}, O_{36}, O_{28}, O_{20}, O_{1}, O_{25}, O_{37}, O_{44} have their respective SINR values as -2.7, -2.48, -1.9, -2.3, -1.7, 3.5, 1.0, 0.1, -1.0 dB. This shows a better improvement in SINR values when compared to the method of maximum transmission power Femto as in Fig. 4.

As a result of this, the users inside the building get lesser SINR 35 dB to 30 dB as can be observed in the graphs of Fig. 4 and 5. The minimum $SINR_{Th}$ (-4 dB) is maintained in all sub-regions inside the building. The inner sub-region I_{98}, I_{6}, I_{29}, I_{79}, I_{51} inside the building have the respective SINR values of 23.9, 9.6 14.4, 0.9, 2.3 dB, hence showing a slight degradation of SINR values when compared to maximum transmission power Femto. Owing to that, the pattern of serving area of a Femto changes slightly when compared to maximum transmission power Femto connection, as shown in Fig. 7. This is because when the transmission power of Femtos is reduced, some of the sub-regions can't maintain the minimum $SINR_{Th}$. Hence, a mobile device (user) trying to get connected to a certain Femto might now connect to a neighboring Femto in such a manner that minimum $SINR_{Th}$ is maintained. As shown in Fig. 7, the encircled regions B1, C1, D1 are the sub-regions where the threshold SINR value cannot be maintained by Femtos F2 and F3, so the users in those sub-regions will get connected to the neighboring Femto F1 to maintain a $SINR_{Th}$. Although, the delay t_o is large in algorithm 1 because for most of the combinations of Macro occupancy pattern, the power values remain the same (for eg. Table III SNO 8,11), the Femto transmission power need not always be constant.

If the Macro users are present only in the West side (O_1,$O_2 \ldots O_{14}$) of the building then the Femto placed in I_{30} (F1) will optimally reduce its power to 0.038 w (Table III S.NO 1). Similarly, for the Macro users only in the North , South and East are shown in Table III (S.NO 2,3,4). But, as mentioned before, the reduction in the Femto transmit power need not always be constant on any given side of the building and will vary depending upon the sub-regions on that given side. If we observe the West side pattern (S.NO 6,7,8 from Table III) of the Macro users in the outer sub-region, the transmission power of the Femto F1 (I_{30}) keeps on decreasing because the outer sub-regions (pattern) (O_6, O_7) is very close to the Femto F1 as compared to the pattern (O_2,O_3) and (O_1,O_2). All the patterns and their results in Table III are stored in the database of the Femto-GW and whenever, the pattern matches, the corresponding solution is retrieved from the database. Otherwise GAMS tool is run again. The Network operator must install the GAMS solver in the Femto-GW, which resides on operator side. The running time of GAMS tool is less than 5 seconds as shown in Fig. 8. It would thus take even lesser time, on a machine in a Femto-GW (which has high computing resources).

Whenever the Femto power is dynamically increased (if there is no Macro user outside the building and close by to it), it is advantageous to an indoor user and whenever the Femto power is dynamically decreased it is advantageous to a macro user situated in HIZone. Also, when a Macro user is present, it will save more energy in terms of Femtos by reducing its power and improve the performance of the Macro user. Largely, this solution aims at ensuring good SINR to both indoor and outdoor users. If we observe all the outer sub-region in both Fig. 1 and Fig. 5, the SINR degradation for Macro users is under 2 dB.

Performance Evaluation in Apartment Building: To study the performance of proposed algorithm, we consider the same simulation parameters in Table II in a three-floor building. We assumed that no Macro users are present in HIZone. In the case that indoor users connect to a Macro only and do not have Femto facilty, we observed three steps in Fig. 9 of the CDF curve (lower curve: Floor 1, Middle curve: Floor 2, Upper curve: Floor 3). The reason for the increase in SNR with the increase in the height of the floor is that the Macro signals get stronger with increasing height. Even with this relative improvement in the signal strengths, communication is not possible for indoor users. In order to maintain a good SINR for indoor users, we placed the Femtos first in an optimal fashion and then a centrally-placed manner and compared its performance. As it is a No Macro Users scenario, all Femtos can emit at peak power in optimal placement. An optimal NF_{min} (10), obtained as a solution for the MinNF method, are required to be placed in indoor sub-regions to maintain the $SINR_{Th}$ of -2dB as shown in Fig. 9. Now, we centrally placed the same count of Femtos. We observed 16% improvement in SINR values in optimally placed over the centrally placed Femtos scenario.

V. Conclusions and Future Work

In this paper, we designed an efficient Femto placement and power control algorithm which dynamically adjusts its transmission power and ensures fair SINR allocation to indoor and outdoor users. We plan to implement the above algorithm in a real time test bed and observe its performance.

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