Optimal Placement of Femto Base Stations in Enterprise Femtocell Networks

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***Abstract*—Femto cells a.k.a. Low Power Nodes (LPNs) are deployed to improve indoor data rates as well as reduce traffic load on macro Base Stations (BSs) in 4G/LTE cellular networks. Indoor UEs getting high SNR (Signal-to-Noise Ratio) can experience good throughput, but SNR decreases at faster rate due to obstacles, present along the communication path. Hence, efficient placement of Femtos in enterprise buildings is crucial to attain desirable SNR for indoor users. We consider obstacles and shadowing effects by walls and include them in the system model. We develop a Linear Programming Problem (LPP) model by converting convex constraints into linear ones and solve it using GAMS tool, to place Femtos optimally inside the building. Our extensive experimentation proves the optimal placement of Femtos achieves 14.41% and 35.95% increase in SNR of indoor UEs over random and center placement strategies, respectively.**

I. Introduction

With the increased penetration of smartphones and tablets in modern times, there is a huge demand for power and data rates. Long Term Evolution (LTE) promises to deliver higher data rates in outdoor environments. But indoor users still suffer from lower data rates owing to poor coverage and path loss due to obstacles. According to Cisco and Huawei [1], 70% of traffic in cellular networks comes from indoor User Equipments (UEs). Hence, there is a dire need of high data rates which are on par with outdoor environments for the indoor UEs. To achieve this, deployment of Low Power Nodes (LPNs) a.k.a. Femto base stations in indoors is suggested. Femto (a.k.a. Home eNodeB and enterprise eNodeB) is a low power base station connected via backhaul to LTE Evolved Packet Core (EPC) system. Bulk deployment of Femtos in enterprise environments could significantly increase user experience of cellular systems. Each Femto can be connected to its neighbouring Femtos with an X2 logical interface for interference and handover management and can serve upto 20 to 30 users within coverage range of at most 60 meters.

But the presence of a large number of Femtos can lead to problems like high inter-cell interference and frequent handovers. Though we do not address these issues in this work, we examine the issue of efficient placement of Femtos in buildings. The optimal placement is very crucial for attaining desirable SNR (Signal-to-Noise Ratio) for the indoor UEs and further helps in reducing high inter-cell interference and frequent handovers problems faced by UEs connected to Femtos. Two major parameters that determine optimal Femto location are (i) Distance between Femto and farthest point inside the building and (ii) minimum SNR needed by each UE. Solving for optimal placement of Femto locations by considering above parameters results in solving a convex optimization problem. We further simplify this convex problem to fit into Linear Programming Problem (LPP) model and solve it through GAMS tool [2].

II. Related Work

Extensive research work has been done to address the problem of poor indoor data rates. As a solution to the problem, 3GPP introduced Femtos into cellular networks [3]. Since its inception, issues such as frequent hand-offs, interference, physical cell ID (PCID) and Femto placement architectures are studied [4]. There exist works on optimal relay node placement in tunnels [5], sensor placement in terrain regions and optimal placement of Wi-Fi APs. Algorithm for optimal Femto placement based on distance between first Femto and macro BS is given in [6], [7], but authors did not consider Femto to Femto interference inside the building. In our recent work [8], Femtos are placed optimally inside the building to guarantee good SINR by considering interference between Macro and Femto but this solution does not guarantee good signal for each point inside the building. Though authors of [9], [10] claim to provided an algorithm for the Femto placement inside building, it is of limited practical importance as it ignores walls inside building. Building upon the above work, we constrained optimal Femto placement problem by considering path loss across walls inside the building, thereby making it a realistic enterprise building scenario. The resulting non-convex optimization problem is solved by approximating as an LPP.

III. Proposed work

We now propose a model for optimal placement of Femtos inside an enterprise building. We ensure that our model guarantees good SNR for indoor UEs on par with outdoor scenarios. In order to achieve this objective, the underlying idealization for enterprise building and assumptions are described below.

A. Building Dimensions

We consider the building of length L and width W. Let height of each floor is h. Each floor is further partitioned into rooms of equal dimensions as illustrated in Fig. 1 (a). The δ_{rx},

δ_{ry} are the length and width of each room, respectively. Each room is numbered as ρ_{zxy} and the numbering is explained in [Appendix A]. We assume that F Femtos are sufficient to cover the entire building and also we assume Femtos are to be placed on the ceiling of floors. ρ_f denotes the room number of f^{th} Femto. We further divide each room into sub-regions as shown in Fig. 1 (b). The imaginary dotted sub-regions are formed for ease of calculations. The length and width of sub-region are denoted by δ_x and δ_y, respectively. Each sub-region is referenced using indices i, j and k along x, y and z axes, respectively. The numbering of these sub-regions is explained in [Appendix B].

B. System Model and Assumptions

1) No cross-tier and co-tier interference, *i.e*, interference between Macro BSs and Femtos and among Femtos is ignored. We assume that joint resource allocation schemes proposed in the literature can be applied for avoiding co-tier and cross-tier interference.
2) Height of each floor is constant.
3) Length and width of each room is constant.
4) Length and width of each sub-region is constant.
5) h_m is average height of an UE on each floor.

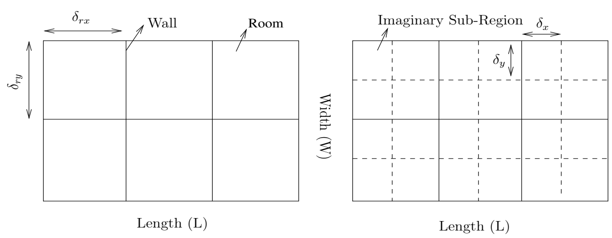

Fig. 1. **(a)** Top view of a floor in the building. **(b)** Top view of sub-regions in the building.

C. Formulation of Mathematical Model

Distance from Femto F_f having coordinates x_f, y_f and z_f to the farthest point in sub-region (i, j, k) is given by $d_{ijk}^{(f)}$ (from reference [10], Fig 2).

$$d_{ijk}^{(f)^2} = (|x_f - (i - \frac{1}{2})\delta_x| + \frac{1}{2}\delta_x)^2 + (|y_f - (j - \frac{1}{2})\delta_y| + \frac{1}{2}\delta_y)^2 + ((z_f - k + 1)h - h_m)^2 \quad (1)$$

For a Femto to efficiently service all UEs in a sub-region, the SNR at the farthest point of the sub-region must be higher than threshold SNR, γ_{min}. Since SNR decreases with increasing distance from Femto, every point in the sub-region should receive SNR greater than γ_{min}. γ_{ijk} is the SNR inside the region ijk and γ_{ijk} for a sub-region (i, j, k) is given by

$$\gamma_{ijk} = \frac{P_F}{L_{r_{ref}}(\frac{d_{ijk}}{r_{ref}})^{\alpha} P_N} \quad (2)$$

Here P_F is the transmit power of Femto, P_N is noise power, $L_{r_{ref}}$ is loss at the reference distance r_{ref} in linear scale and α is path-loss exponent. SNR in dB scale is given by

$$\gamma_{ijk}^* = P_F^* - L_{r_{ref}}^* - 10\alpha\log_{10}(\frac{d_{ijk}}{r_{ref}}) - P_N^*$$

where, γ_{ijk}^*, P_F^*, P_N^*, $L_{r_{ref}}^*$ are in dB scale. Considering attenuation factors for SNR, the total attenuation is given by

$$L_{TAF}^* = L_{FAF}^* + L_{WAF}^* \quad (3)$$

where, L_{TAF}^* is total attenuation factor and L_{FAF}^* and L_{WAF}^* is losses due to floor attenuation factor and wall Attenuation factor. SNR in dB scale considering wall losses is given by respectively.

$$\gamma_{ijk}^* = P_F^* - L_{r_{ref}}^* - 10\alpha\log_{10}(\frac{d_{ijk}}{r_{ref}}) - P_N^* - L_{TAF}^* \quad (4)$$

Let $F(\rho)$ be the function such that,

$$F(\rho) = \begin{cases} K_0 = \frac{C_0 P_n L_{r_{ref}}}{P_F {r_{ref}}^{\alpha}}, & \text{if } \rho_f \neq \rho_{ijk} \\ K_1 = \frac{C_1 P_n L_{r_{ref}}}{P_F {r_{ref}}^{\alpha}}, & \text{if } \rho_f = \rho_{ijk} \end{cases} \quad (5)$$

Here C_0 and C_1 are the constants depending on the environment. Let

$$\gamma_{ijk}' = \frac{1}{\gamma_{ijk}} \quad (6)$$

where γ_{ijk}' is a notation used for reciprocal of γ_{ijk}. γ_{min} is the minimum value of SNR and its reciprocal is γ_{min}'.

$$\gamma_{min}' = \frac{1}{\gamma_{min}} \quad (7)$$

Then (2) becomes from (8) [reference [10]].

$$(r_{ijk})^{\alpha} F(\rho) \Delta^{\rho_f \sim \rho_{ijk}} - \gamma_{ijk}' = 0 \quad (8)$$

Here Δ is a constant depending on the environment and $\rho_f \sim \rho_{ijk}$ calculation is explained in [Appendix C]. SNR received in any sub-region should be greater than minimum threshold SNR. Thus

$$\gamma_{ijk}' \leq \gamma_{min}' \quad (9)$$

Let p_{ijk} be the UE occupant probability in the sub-region (i, j, k), then placement of Femtos should be in such a way that product of $p_{ijk}\gamma_{ijk}$ should be maximum for all sub-regions. Accordingly product $p_{ijk}\gamma_{ijk}'$ should be minimum. Hence, our objective is to minimize

$$Z = \sum_{ijk} p_{ijk}\gamma_{ijk}' \text{ subject to (1), (8) and (9).}$$

But Eqns (1) and (8) are non-convex equations which cannot be solved by any available tools. Hence these equations are first converted to convex equations and then to linear equations.

D. Femto placement constraints

Let $\lambda_{f\rho}$ be the binary variable which is 1 if f^{th} Femto is in room ρ, 0 otherwise. z_f co-ordinate of a Femto F_f is an integer indicating Femto's residing floor number.

$$z_f = \sum_{\rho_z=1}^{N} \rho_z \lambda_{f\rho} \quad (10)$$

where N is the number of rooms taken individually in every axis. The x and y coordinates of Femto are bound within the limits as shown in Fig. 2. Let us assume that f^{th} Femto is residing in room with number ρ_{zxy}. The x co-ordinate of the Femto should have the value greater than the left wall and less than right wall as shown in Fig. 2.

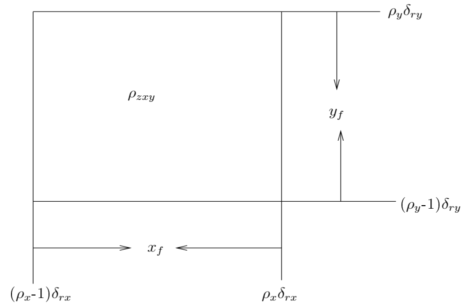

Fig. 2. Upper and lower bounds for x_f and y_f

$$x_f \geq \sum_{\rho_{x=1}}^{N} (\rho_x - 1)\delta_{rx}\lambda_{f\rho} \tag{11}$$

$$x_f \leq \sum_{\rho_{x=1}}^{N} \rho_x\delta_{rx}\lambda_{f\rho} \tag{12}$$

Similarly, the y co-ordinate of the Femto should have the value greater than the lower wall and less than upper wall as shown in Fig. 2.

$$y_f \geq \sum_{\rho_{y=1}}^{N} (\rho_y - 1)\delta_{ry}\lambda_{f\rho} \tag{13}$$

$$y_f \leq \sum_{\rho_{y=1}}^{N} \rho_y\delta_{ry}\lambda_{f\rho} \tag{14}$$

Let ${\pi_{ijk}}^{(f)}$ be the binary variable, which is 1 if f^{th} Femto is servicing sub-region (i, j, k) and 0 otherwise. We assume that a sub-region is serviced only by a single Femto which results in

$$\sum_{f=1}^{F} {\pi_{ijk}}^{(f)} = 1 \tag{15}$$

E. Linearization of Eqn (1)

Let

$${R_{ijk}}^{(f)} = ({d_{ijk}}^{(f)})^2 \tag{16}$$

$$X_{fi} = |x_f - (i - \frac{1}{2}\delta_x)| \tag{17}$$

$$Y_{fj} = |y_f - (j - \frac{1}{2}\delta_y)| \tag{18}$$

Equality can be converted into certain inequalities without loss of generality ([10], Lemma 2). Hence Eqn (1) becomes

$$(X_{fi} + \frac{1}{2}\delta_x)^2 + (Y_{fj} + \frac{1}{2}\delta_y)^2 + (hz_f - ((k-1)h + h_m))^2 - {R_{ijk}}^{(f)} \leq 0 \tag{19}$$

Eqns (17) and (18) are expanded as,

$$x_f - X_{fi} \leq (i - \frac{1}{2})\delta_x \tag{20}$$

$$x_f + X_{fi} \geq (i - \frac{1}{2})\delta_x \tag{21}$$

$$y_f - Y_{fj} \leq (j - \frac{1}{2})\delta_y \tag{22}$$

$$y_f + Y_{fj} \geq (j - \frac{1}{2})\delta_y \tag{23}$$

Let,

$${X_{fi}}^2 = B_{fi}$$

$${Y_{fj}}^2 = D_{fj}$$

$${z_f}^2 = E_f$$

The above equations can be written as ([10], Lemma 2)

$${X_{fi}}^2 - B_{fi} \leq 0 \tag{24}$$

$${Y_{fj}}^2 - D_{fj} \leq 0 \tag{25}$$

$${z_f}^2 - E_f \leq 0 \tag{26}$$

Then, Eqn (19) becomes,

$$B_{fi} + D_{fj} + h^2E_f + \delta_x X_{fi} + \delta_y Y_{fj} - 2h((k-1)h + h_m)z_f - {R_{ijk}}^{(f)} \leq -\frac{1}{4}{\delta_x}^2 - \frac{1}{4}{\delta_y}^2 - ((k-1)h + h_m)^2 \tag{27}$$

Eqns (24), (25) and (26) are convex constraints which are converted into linear constraints by applying PLAP (Piece-wise Linear Approximation) and leading to the deduction of the following equations,

$$\sum_{S=1}^{S_X} {w_1}^{(X)}(X_S)^2 \leq B, \sum_{S=1}^{S_X} {w_1}^{(X)}(X_S) = X, \sum_{S=1}^{S_X} w_1^{(X)} = 1 \tag{28}$$

$$\sum_{S=1}^{S_Y} {w_2}^{(Y)}(Y_S)^2 \leq D, \sum_{S=1}^{S_Y} {w_2}^{(Y)}(Y_S) = Y, \sum_{S=1}^{S_Y} w_2^{(Y)} = 1 \tag{29}$$

$$\sum_{S=1}^{S_Z} {w_3}^{(Z)}(Z_S)^2 \leq E, \sum_{S=1}^{S_Z} {w_3}^{(Z)}(Z_S) = Z, \sum_{S=1}^{S_Z} w_3^{(Z)} = 1 \tag{30}$$

where, ${w_1}^{(x)}$, ${w_2}^{(y)}$ and ${w_3}^{(z)}$ are the positive weights between 0 and 1. The X_S, Y_S and Z_S are the S pieces in their respective domains.

F. Linearization of Eqn (8)

Let,

$${\nu_{ijk}}^{(f)} = ({R_{ijk}}^{(f)})^{\frac{\alpha}{2}} \tag{31}$$

and it can be written as with the aid of (from reference [10] Lemma 2) as,

$${\nu_{ijk}}^{(f)} \geq ({R_{ijk}}^{(f)})^{\frac{\alpha}{2}} \tag{32}$$

Let,

$${g_{ijk}}^{(f\rho)} = {\nu_{ijk}}^{(f)}\lambda_{f\rho} \tag{33}$$

Then Eqn (8) can be written as

$$K_1 \sum_{\rho,\rho\neq\rho_f}^{N} ((\Delta^{\rho\sim\rho_f}){g_{ijk}}^{(f\rho)}) + K_0{g_{ijk}}^{(f\rho)} - (1 - {\pi_{ijk}}^{(f)}){\Gamma_{ijk}}^{(f)} - \gamma'_{ijk} \leq 0 \tag{34}$$

Where $\Gamma_{ijk}{}^{(f)}$ is the upper bound of γ'_{ijk}. Bilinear equation (33) holds within the bound $0 \leq \nu_{ijk}{}^{(f)} \leq \bar{\nu}^{(f)}_{ijk}$ if and only if (from reference [10])

$$g_{ijk}{}^{(f\rho)} \geq 0 \quad (35)$$

$$g_{ijk}{}^{(f\rho)} - \bar{\nu}^{(f)}_{ijk} \leq 0 \quad (36)$$

$$\sum_{\rho}^{N} g_{ijk}{}^{(f\rho)} - \nu_{ijk}{}^{(f)} = 0 \quad (37)$$

Eqn (32) is a convex constraint and is linearized by PLAP. Hence, we obain

$$\sum_{S=1}^{S_R} w_s(R_S)^{\frac{\alpha}{2}} - \nu \leq 0, \sum_{S=1}^{S_R} w_s(R_S) = R, \sum_{S=1}^{S_R} w_s = 1 \quad (38)$$

where, w_s the positive weights between 0 and 1. R_S is S pieces values in its domain.

IV. LPP Model and Solution

$$Min.Z = \sum_{ijk} p_{ijk}\gamma'_{ijk}$$

s.t.
a) Femto placement constraints:
$Eqns(9), (10), (11), (12), (13), (14), (15)$
b) Linear equations equivalent to (1) :
$Eqns(20), (21), (22), (26), (27), (28), (29), (30)$
c) Linear equations equivalent to (8) :
$Eqns(34), (35), (36), (37), (38)$

The Mixed Integer Linear Program (MILP) is solved with the application of GAMS/CPLEX solver [2]. The MILP algorithm which is used for solving the problem is actually an implementation of a branch-and-bound search with modern algorithmic features such as cuts and heuristics. In this paper, we need to solve a relatively large MILP with equations and variables. The MILP optimizer solves large and numerically difficult MILP models with features including settable priorities on integer variables, choice of different branching, and node selection strategies. Thus MILP Optimizer of GAMS/CPLEX ideally solves the MILP problem as shown in Algorithm 1.

This will enhance the algorithm by reducing the time complexity which is O(K*($\sum_{i=0}^{h} 2^h - g(NC)$)) where $g(NC)$ denotes the reduction in branches from cuts in searching for optimal solution.

$g(NC) = \sum_{j=0}^{NC} A_j(h_j)$ where $A_j(h_j) = \sum_{k=0}^{h-h_j} 2^k$, NC is number of cuts, h is height of the binary tree which has to be solved to get the final solution for MILP problem, h_j is the height of the A_j element where the branch is cut off and K is the time for solving one single sub-problem of the branch and cut MILP problems. Here, $h =$ O(min(log(M))) where, M represents the minimum required number of Femtos to ensure coverage. The algorithm basically performs a bisection search on M and repeats the Branch and Cut procedure until problem becomes feasible.

Algorithm 1 : Solution Procedure

Initialization

Step A : Let the initial problem list contain only the original problem, denoted by L. L refers to the constraints (a), (b) and (c) in the LPP Model and Solution.

Step B :Let the initial input be X^* = null and objective function value Z^* = -∞

Step C : While the list L is not empty

1) Select and remove a problem from L.
2) Solve the relaxation of the problem.
3) If the solution is infeasible, go back to $Step\ C$. Otherwise denote the solution by X with objective value Z.
4) If $Z > Z^*$ and X is integer, set $Z^* = Z$ and $X^* = X$ go back to $Step\ C$.
5) If $Z \leq Z^*$, go back to $Step\ C$.1.
6) If desired, search for cutting planes that are violated by X. It's important to note that these cuts are added by MILP optimizer heuristically depending on the particular MILP. If any are found, add them to the solution and return to ($Step\ C$ .2).
7) Branch to partition the problem into new problems with restricted feasible regions. Add these problems to L and go back to $Step\ C$.1.

Step D Return

V. Experimental Setup in MATLAB and Performance Results

To represent an enterprise scenario, we have simulated in a two-storied building of dimensions (120m $\times$ 80m $\times$ 12m), with six rooms of dimensions (40m $\times$ 40m $\times$ 6m) in each floor. Further each room is divided into 4 virtual sub-regions of dimensions (20m $\times$ 20m $\times$ 6m) as illustrated in Fig. 3. Assuming UEs are distributed randomly in each floor, we considered a scenario where UE occupant probabilities in each sub-region are assigned randomly. Fig. 10 shows occupant probabilities of both the floors. We use 4 Femtos for covering the entire building ($F = 4$), guaranteeing a minimum of $-5dB$ SNR ($\gamma_{min} = -5$) with indoor path loss constant of $\alpha = 3.5$. We solved for the optimal placement of Femtos using above model. Table I provides the optimal co-ordinates of each Femto for this scenario.

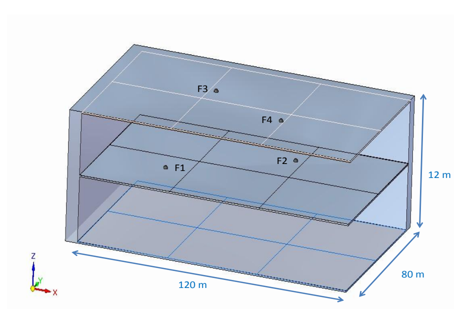

Fig. 3. Building Layout.

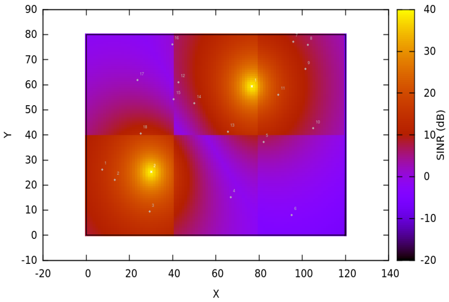

Fig. 4. Optimal Placement of Femtos in Floor 1.

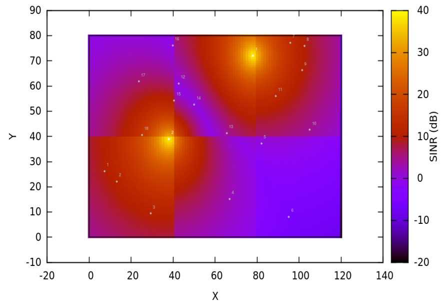

Fig. 5. Center Placement of Femtos in Floor 1.

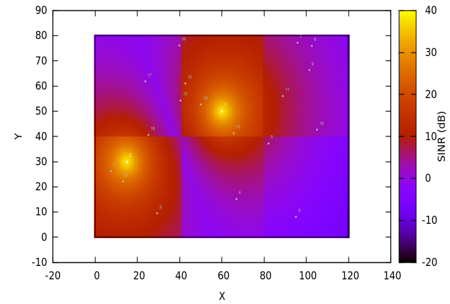

Fig. 6. Random Placement of Femtos in Floor1.

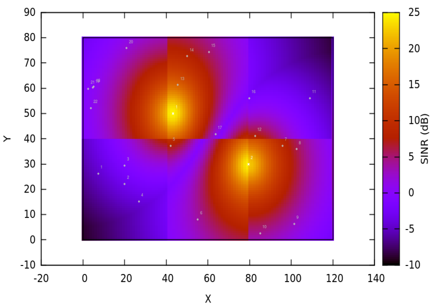

Fig. 7. Optimal Placement of Femtos in Floor 2

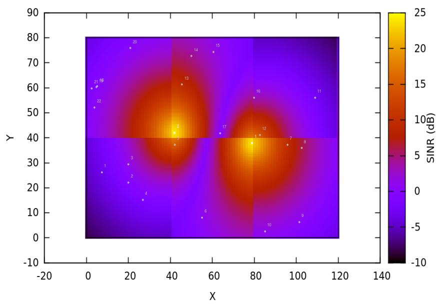

Fig. 8. Center Placement of Femtos in Floor 2

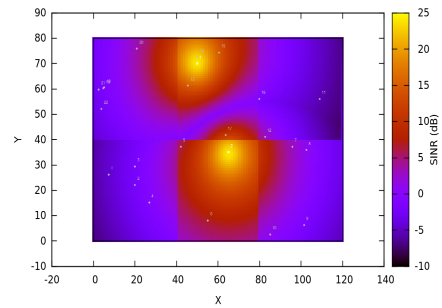

Fig. 9. Random Placement of Femtos in Floor2

TABLE I
OPTIMAL FEMTO CO-ORDINATES FOR OCCUPANT PROBABILITY

Femo	x_m	y_m	z_m(**floor**)
F_1	30.0	25.22	1
F_2	76.68	59.34	1
F_3	43.32	50.0	2
F_4	79.05	30.0	2

A. Performance evaluation

To show the optimality of our Femto placement, we compared capacity received by each of UEs by placing Femtos (i) Randomly[1]: Femtos are placed randomly inside the building irrespective of UE occupant probabilities (ii) Center of the building: Placing Femto in the center of each room. Femtos are placed in room number 111, 121, 221, 222. (iii) Optimally: Derived from our proposed algorithm. Fig. 11 shows cumulative density plot of SNR for three placement algorithms. The optimal placement performance is 14.41% and 35.95% better than random and center placement, respectively. The above simulation results indicate that the optimal placement provides a means to determine better SNR compared to random and center placement algorithms of Femtos.

B. Simulation Results

We cross validated performance of our optimal Femto placement model using NS-3 simulator. We extensively tested our placement algorithm even by considering a more practical setup with interference from neighbouring Femtos *i.e.,* with high co-tier interference among Femtos.

In all our experiments, we used an enterprise building model of same dimensions (120m $\times$ 80m $\times$ 6m) as given above. In NS-3 simulations, we set transmit power of Femto to 23 dBm with building pathloss model. Fig. 4, Fig. 5 and Fig. 6 show the optimal, center and random placement of Femtos respectively in Floor one. As our method of Femto placement is based on UE occupant probability distribution, the probability of finding the user in low SINR region is less when compared to other schemes. As illustrated in Fig. 4 most of the UEs in Floor 1 are in good visibility to Femto coverage which indicates that our placement is optimal when compare to center and random

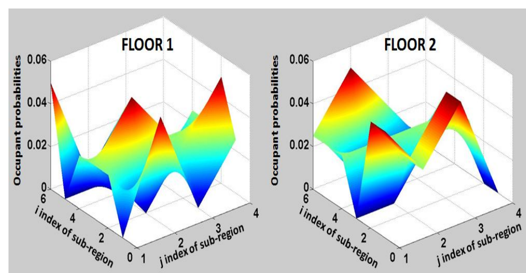

Fig. 10. UE Occupant Probabilities inside the building.

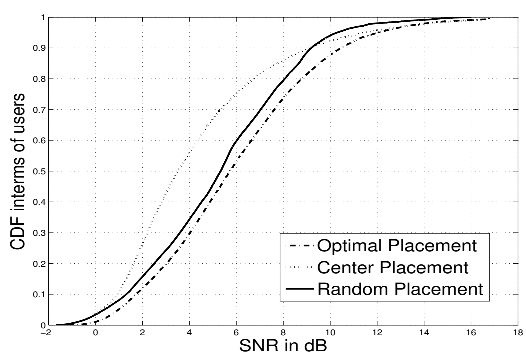

Fig. 11. Variation of SNR inside the building.

[1]Results reported by averaging 5 cases of random co-ordinate placements

placement. A similar kind of pattern is observed in Floor 2. Fig. 7, Fig. 8 and Fig. 9 represent optimal, center and random placement of Femtos in Floor 2. Most of the users in Fig. 7 are close to Femto confirming the optimality of our model. As most of the users in our model are in close vicinity to Femto they are guaranteed to receive better SINR compared to random/center placement. Further we constrained our model to guarantee minimum SINR to all users, including those in the least occupant probability region. Therefore our model has better fairness compare to center and random placement.

VI. Conclusions and Future work

In this paper, we have provided a model for optimal placement of Femtos based on occupant probabilities inside an enterprise building scenario considering realistic constraints. We demonstrated the goodness of our model through extensive experiments in both MATLAB and NS-3. In future, we intend to provide an algorithm for optimal Femto placement for various environments considering more complex scenarios involving interference and load balancing between Femtos.

Appendix A

Assume that a building has got rooms uniform in dimensions with δ_{rx} as length and δ_{ry} as width. Every room is numbered with a unique number ρ_{zxy}, which can also be denoted as $\rho_z\rho_x\rho_y$. It is a three digit numerical scheme, in which first digit signifies the floor number, second digit varies along x-axis and third digit varies along y-axis as shown in Fig.12. If room number is referred as ρ_x , it indicates that room number is varied along x-axis only. For e.g. if $\rho_{zxy} = 122$ and if $\rho_x{+}1$ operation is applied, then $\rho_{zxy} = 132$

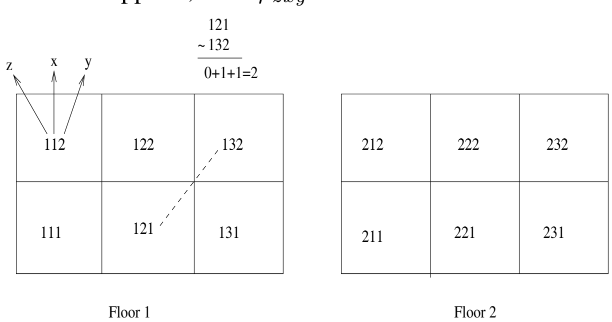

Fig. 12. Numbering of rooms and calculation of number of walls between Femto and sub-region.

Appendix B

Building has got sub-regions with δ_x as length and δ_y as width. Every sub-region is numbered with indices i,j,k. (ijk) triplet scheme is adapted, in which first index (or digit) varies along x- axis, second index varies along y-axis and third index signifies the floor number as shown in Fig 13.

Appendix C

$\rho_f \sim \rho_{ijk}$ is calculated in such a way that it gives the number of obstructions (walls or floors) lying between sub-region (i, j, k) and f^{th} Femto. This special difference ($\sim$) is the absolute value of digit wise difference between ρ_f and

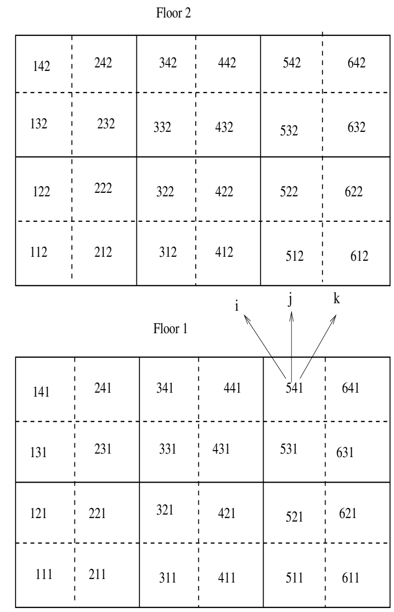

Fig. 13. Numbering of sub-regions in Floor 1 and Floor 2.

ρ_{ijk}. For e.g. as shown in Fig 12.

a) consider $\rho_f = 121$ and $\rho_{ijk} = 132$.
$\rho_f \sim \rho_{ijk} = 121 \sim 132 = |1-1|\beta + |2-3| + |1-2| = 2$
Where, $\beta = T_{FAF} + T_{WAF}$.
Hence, 2 walls are separating rooms 121 and 132

b) consider $\rho_f = 121$ and $\rho_{ijk} = 231$.
$\rho_f \sim \rho_{ijk} = 121 \sim 231 = |1-2|\beta + |2-3| + |1-1| = 1 + \beta$
Co-efficient of β indicates the number of floors separating f^{th} Femto and sub-region (i, j, k). Hence, one floor and one wall is separating rooms 121 and 231.

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