Joint Placement and Power Control of LTE Femto Base Stations in Enterprise Environments

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***Abstract*—In order to boost the data rate for indoor users, low power nodes like Femto Base Stations (BSs) are deployed in LTE (long term evolution) networks. The placement of Femtos inside enterprise building environments can significantly affect indoor user performance. We consider a system model that takes into account the following parameters: co-channel interference between Femto BSs and Macro BSs, wall attenuation factor and user occupant probability in enterprise building environments. We solve joint placement and power control problem by formulating two Mixed Integer Programming (MIP) optimization models: Optimal Constant Threshold Signal to Interference plus Noise Ratio (OptCTSINR) and Optimal Varying threshold SINR (OptVTSINR), which optimally tune the power of Femto BS, guarantee a certain minimum SINR to users and also minimize the number of Femtos needed for the coverage of enterprise buildings. We then solve these MIP models by utilizing branch and bound framework of CPLEX solver in General Algebraic Modeling System (GAMS) tool. When compared to center K-Means (CKM) clustering based placement scheme, for a given number of Femtos, proposed scheme OptCTSINR results in average SINR improvement of 39% and proposed OptVTSINR outperforms OptCTSINR by 6.7%, respectively.**

I. Introduction

In the recent years, there has been a significant rise in the demand for higher mobile data speeds. But, the cellular coverage is poor in indoor environments as electro-magnetic waves emitted at Base Stations (BSs) cannot penetrate walls easily. Hence, in order to boost the data rate for indoor users, low power nodes like Femto BSs for indoor environments are deployed by users in their home/enterprise environments and get connected to cellular core network via broadband connection of the users. This way the indoor users enjoy not only high data rates, but telecom operators can also benefit by saving capital and operational expenditure (CAPEX and OPEX). Though the deployment of Femto BSs improves indoor data rates, it may result in a host of problems like frequent handovers and channel interference. Arbitrary/Center deployment of Femtos can lead to high co-channel cross-tier interference among Femtos and Macro BSs and also leads to coverage holes.

In enterprise buildings, it is possible to perform planned Femto deployment by considering factors like co-channel interference between Femtos and Macro BSs, wall attenuation factors and user occupant probabilities inside the building. In these scenarios, there are many possible locations for placing the Femtos, from which only the optimal locations need to be chosen subject to several constraints. If Femtos are placed without power control, this leads to high power consumption and inter-cell interference in downlink in large scale deployments. Our goal is to address the problem of a joint placement and power control problem by reducing the Femto transmit power and guaranteeing certain minimum SINR to indoor users. In this work, two MIP optimization models are formulated: Optimal Constant Threshold Signal to Interference plus Noise Ratio (OptCTSINR) model and Optimal Varying threshold SINR (OptVTSINR) model. Both the models guarantee a certain minimum SINR for each sub-region inside the building and at the same time minimize number of Femtos needed for coverage of the entire enterprise building. In OptVTSINR, placement is further optimized by taking into account variations in average traffic demands of sub-regions inside the building.

II. Related Work

Several Femto placement approaches have been proposed in the literature by considering various parameters. Authors of [1], [2] reduce the interference and maximize the throughput for outdoor and indoor environments. The former [1] moves the location of the outdoor access points (pico cells) in an iterative manner but it does not consider the traffic pattern and placement in indoor environments. The latter [2], however, considered the location of the Macro BS in deciding the Femto placement. But, this solution is not scalable for enterprise Femto deployments because the authors did not consider interference between Femtos in their system model. In [3], the authors provided a solution for joint Femto placement and uplink power control. But their system model did not consider the realistic issues like uplink interference, downlink interference and obstructions such as walls inside the building. The above discussed papers did not look into optimizing the Femtos transmission power, so all Femtos are transmitting with full power all the time. In [4], once the random placement of Femtos is done, the authors optimized the transmission power of the Femtos based on Macro BS interference and guaranteed a certain minimum SINR threshold ($SINR_{Th}$) for indoor users. But here the drawbacks are that there is an inefficient usage of radio spectrum band due to division of bandwidth into three parts (*i.e.,* reuse factor three) and all the regions inside the building are treated equally (maintained constant $SINR_{Th}$) but in reality that is not true as some regions may have higher number of users. Their model also did not consider path loss due to walls inside building in their system model. Further, the placement and power optimization is not done jointly so the number of Femtos needed to meet $SINR_{Th}$ of indoor users is not minimal.

In our recent work [5], the Femtos are first placed optimally inside the building and power of Femto BS is tuned dynamically based on the Macro and Femto users. Unlike in [4], [5], in this work, we perform joint Femto placement and power control to reduce the deployment cost by minimizing the Femto count for enterprise deployments and reduce the interference and power consumption from Femto side. In this work, we study how the optimal placement of Femtos can be achieved by assuming reuse one and considering the user occupant probabilities, the interference among Femtos and Macro BSs and building obstructions for maintaining a certain minimum downlink SINR at all the sub-regions of the enterprise buildings.

III. Proposed work

A. System Model

This work considers a LTE HetNet system comprising of Macro BSs deployed in outdoor environment and Femto BSs deployed inside the enterprise office building. The Femtos and Macro BSs are assumed to operate in the same frequency band (*i.e.,* reuse one) in LTE HetNet and therefore may experience high co-channel interference. Table I shows the set of notations used in this work.

TABLE I
GLOSSARY

Notation	Definition
S	Set of all sub-regions inside the building
w_a	1 if Femto is placed at sub-region a, zero otherwise
y_{ja}	1 if j^{th} sub-region of the building is associated with the Femto located at sub-region a, zero otherwise
g_{ja}	Channel gain between sub-regions j and a
q_j	User Occupant probability in sub-region j
M	Set of all Macro BSs
p_a	Normalized transmit power of Femto BS a, $0 \leq p_a \leq 1$

Let us consider a single-floor building having dimensions of $L \times W \times H$, where L, W and H are respectively the length, breadth and height of the building, for indoor Femto BSs deployment. The building floor is further divided by walls into several rooms as shown in Fig. 1(a). For the purpose of the study, each room is further divided logically into smaller sub-regions of length δ_x and width δ_y, which have been indexed as shown in Fig. 1(a). Walls have been depicted by thick lines and sub-regions by the small squares in the building grid. Since the size of sub-region is much smaller compared to the building size, it is assumed that inside every sub-region, the SINR remains constant and also that in the enterprise office environments, q_j (refer Table I) remains constant in any given sub-region which is quite true during business hours. The variation of q_j inside the building can be addressed by dynamic adjustment of Femto transmit power [5] but this is beyond the scope of our work. It is also assumed that q_j can be used to infer users' traffic demands.

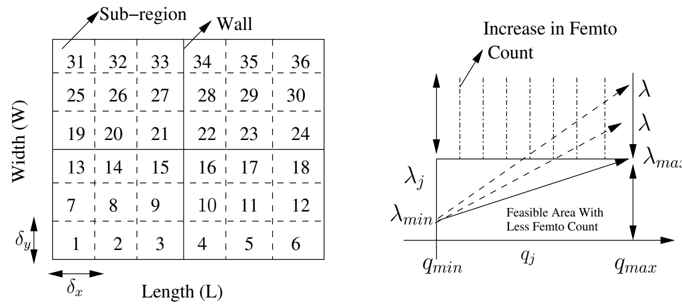

Fig. 1. **(a)** Aerial view of floor area inside the building. **(b)** Feasibility domain for OptVTSINR.

The path loss (PL) from the Macro BS (MBS) to an indoor user (IU) is given in Eqn (1) [4]:

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

where, n is the number of walls in between MBS and IU, f is the center frequency of MBS and σ is the penetration loss. The PL from Femto BS (FBS) to IU is given in Eqn (2) [4]:

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

where, k is the number of floors and d is the euclidean distance of the sub-region of IU from Femto BS in meters. These two PL models are used, in this work, for calculating the channel gain between users and various BSs with considering the effects of antenna gain.

B. Joint Placement and Power Control Formulation

To address the Joint Femto placement and power control problem, two optimization models using MIP are formulated. By solving the MIP formulations, the following values can be found out:

- The minimum number of Femtos and the transmission power of Femtos needed to maintain $SINR_{Th}$ in each sub-region of the building.
- The optimal locations of Femtos inside the building.
- The Femto to which indoor users in any given sub-region have to be associated with.

One of our goals is to minimize the total number of Femtos deployed, which is expressed by Eqn (3).

$$min\sum_{a\in S} w_a \qquad (3)$$

Assuming that each sub-region is allowed to associate with only one Femto BS (refer Eqn (4)) inside the building, we get:

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

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

An user placed in a sub-region can never connect to a sub-region where there is no Femto. This is captured by above constraint given in Eqn (5). Above two constraints ensure that every sub-region is connected to only one Femto BS. P_{max} be the maximum power of the Femto BS. The normalized power p_a value ranges from 0 to 1 ($0 \leq p_a \leq 1$) and is 0 if w_a is 0 which is expressed in Eqn (6). 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 BS at location a is determined by $p_a * P_{max}$.

$$p_a \leq w_a \qquad \forall a \in S \tag{6}$$

Another constraint is needed on SINR. Based on this constraint, two models have been considered: Constant $SINR_{Th}$ and Varying $SINR_{Th}$.

1) ***Constant threshold SINR based MIP Model:*** In this MIP formulation, Optimal Constant Threshold SINR (OptCTSINR), a certain minimum $SINR_{Th}$ (λ) is guaranteed for all sub-regions of the building. SINR received by a particular sub-region j from the Femto located at sub-region a, is given by the L.H.S. of Eqn (7). To guarantee coverage, $SINR$ of sub-regions must be maintained above the predefined threshold λ, given in Eqn (7):

$$\frac{Inf * (1 - y_{ja}) + g_{ja} P_{Max} p_a}{N_o + \sum_{b \in S \setminus a} g_{jb} P_{Max} p_b + \sum_{e \in M} g'_{je} P_{Macro}} \geq \lambda \quad \forall j, a \in S \tag{7}$$

In Eqn (7), Inf is a virtual infinite value [4] (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 (7) tries to ensure that all the Femtos meet $SINR_{Th}$ constraint for any given sub-region. The MIP will always be infeasible if the virtual infinite value is not used, as not all Femtos can meet $SINR_{Th}$ constraint for a particular sub-region. Eqn (7) can be linearized as follows:

$$\begin{aligned} &Inf * (1 - y_{ja}) + g_{ja} P_{Max} p_a \geq \\ &(\lambda N_o + \sum_{b \in S \setminus a} g_{jb} P_{Max} p_b \lambda + \sum_{e \in M} g'_{je} P_{Macro} \lambda) \quad \forall j, a \in S \end{aligned} \tag{8}$$

g'_{je} and g_{ja} are the channel gain from Macro and Femto calculated using Eqn (1) and Eqn (2), respectively and P_{Macro} is the power of Macro BS. Finally, the OptCTSINR approach is formulated as follows,

$$min \sum_{a \in S} w_a, \text{ such that (4), (5), (6) (8).}$$

2) ***Varying Threshold SINR based MIP Model:*** This MIP formulation, Optimal Varying Threshold SINR (OptVTSINR), not only satisfies $SINR_{Th}$ constraint for the sub-regions but also allows varying $SINR_{Th}$ for different sub-regions according to their user occupant probabilities. Sub-regions having higher value of occupant probabilities (q_j) need more capacity as it is assumed that traffic demand in sub-region j is directly proportional to q_j and therefore λ_j is increased for such sub-regions, as given in Eqn (9).

$$\frac{Inf * (1 - y_{ja}) + g_{ja} P_{Max} p_a}{N_o + \sum_{b \in S \setminus a} g_{jb} p_{Max} p_b + \sum_{e \in M} g'_{je} P_{Macro}} \geq \lambda_j \quad \forall j, a \in S \tag{9}$$

Here, λ_j is the $SINR_{Th}$ at sub-region j and it is defined in Eqn (10).

$$\lambda_j = \frac{(q_j - q_{min})(\lambda_{max} - \lambda_{min})}{(q_{max} - q_{min})} + \lambda_{min} \tag{10}$$

Here, q_{min} represents the minimum occupant probability, q_{max} represents maximum occupant probability, λ_{min} represents the $SINR_{Th}$ at q_{min} region and λ_{max} represents the $SINR_{Th}$ at q_{max} region. In OptVTSINR scheme, λ_{min} is set to λ ($SINR_{Th}$ which was used in case of OptCTSINR model). The computation is started with an initial guess value for λ_{max} and then solving the MIP model. If the Femto count increases more than that was obtained from solving OptCTSINR then it is iterated by reducing λ_{max} till the same Femto count is achieved as illustrated in Fig. 1 (b). Eqn (9) can be linearised as follows.

$$\begin{aligned} &Inf * (1 - y_{ja}) + g_{ja} P_{Max} p_a \geq \\ &(\lambda_j N_o + \sum_{b \in S \setminus a} g_{jb} P_{Max} p_b \lambda_j + \sum_{e \in M} g'_{je} P_{Macro} \lambda_j) \quad \forall j, a \in S \end{aligned} \tag{11}$$

Finally, the OptVT SINR model is formulated as follows,

$$min \sum_{a \in S} w_a, \text{ such that (4), (5), (6) (11).}$$

In OptCTSINR model, each sub-region inside the building is assumed to be independent of other sub-regions so the probability of placing Femtos in each sub-region is equal but that is not the case with OptVTSINR where the probability of placing Femtos in high user occupant sub-regions is higher and higher occupant probability sub-regions, higher $SINR_{Th}$ is maintained. Hence, we would expect higher average SINR for users in OptVTSINR compared to OptCTSINR.

IV. Experimental Setup and Numerical Results

The system model described in Section III-A is simulated using MATLAB. For the simulation a single-floor building of dimensions 48m × 48m × 3m is considered. Inside the

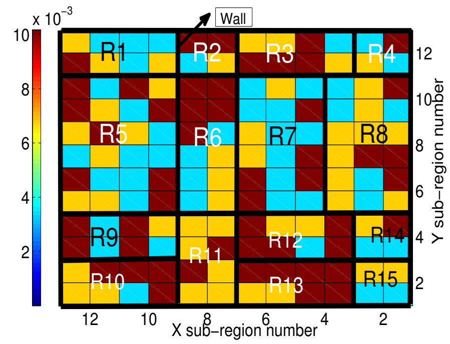

Fig. 2.User Occupant probability distribution inside the building

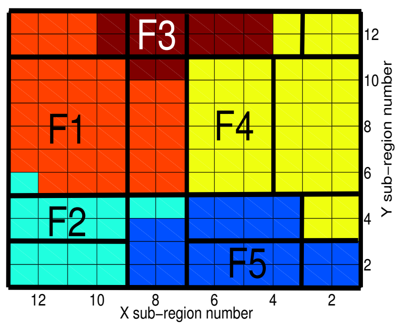

Fig. 3. Femto sub-region association for OptCTSINR (-2 dB)

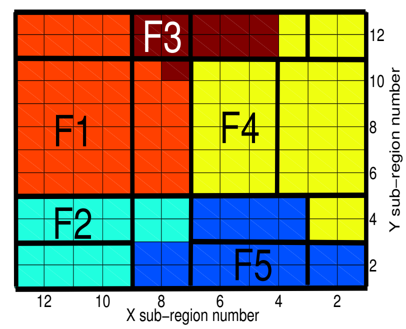

Fig. 4. Femto sub-region association for OptVTSINR (-2 to +1 dB)

building, each room has different dimensions. Every room is further divided into sub-regions, having dimensions of 4m $\times$ 4m $\times$ 3m. In all, 144 sub-regions are present inside the building. Fig. 2 shows the average of user occupant probability distribution (Blue color represents less user occupancy, similarly yellow and brown color represents medium and high occupant probability, respectively) for the building considered. For performance evaluation, an LTE HetNet system having one Macro BS located at the height of 30m is considered. The Macro BS is configured to transmit always at 46 dBm and Femto BSs can vary their transmit power in the range (0, 23] dBm. The shortest distance between building and Macro is 300 m [6] (diagonally from the center of sub-region 1). We assumed that the antenna gain for Macro and Femtos are 20 dBi and 2 dBi. Femtos are allowed to be fixed only to the ceiling of the rooms and the minimum number of Femtos with their optimal co-ordinates and corresponding sub-region indices with power values are given by GAMS CPLEX solver [7] which utilizes branch and bound framework for solving MIP based optimization problems. The output (optimal co-ordinates of Femtos and corresponding power values) of GAMS solver is then used as the input to MATLAB based HetNet system simulator.

OptCTSINR (-2 dB $SINR_{Th}$): Fig. 3 shows the Femto serving areas with color coding. The MIP solver for OptCTSINR (-2 dB $SINR_{Th}$) model gave five Femtos as the minimum to achieve the constant threshold in each sub-region. Fig. 5 shows the SINR received by each of the sub-regions and the dark brown regions ($A1$, $B1$, $C1$, $D1$, $E1$) represent the Femto locations. In joint placement and power control method, each Femto ($A1$= 0.0319W, $B1$= 0.0902W, $C1$= 0.0862W, $D1$= 0.0634W, $E1$=0.0862W) is transmitting with different power to maintain $SINR_{Th}$ of -2 dB. The users in sub-regions represented by ($A1$, $B1$, $C1$, $D1$, $E1$) enjoy the highest SINR as the Femtos are placed there. The users in sub-regions represented by $F1$ experience comparatively lesser SINR due to increase in distance from their associated Femtos (refer Fig. 3). The users in rooms R1, R4, R6, R11, R12, R14, R15 get approximately -2 dB SINR. This greater decrease in SINR is owing to the fact that the serving Femto (refer Fig. 3) is separated from the user by a wall. Certain sub-regions represented by $I1$ are colored light green have stronger signals even though the Femto is placed closer to the wall. But that is not the case in region $J1$ because the Femtos placed in the sub-region $E1$ and $C1$ are very close to each other and also the signal from Femto crossing only one wall so there will be a chance of interference between the Femtos. This in turn reduced the SINR value in region $J1$.

OptVTSINR (-2 to +1 dB $SINR_{Th}$): Fig. 4 shows the five Femto serving areas with color coding. In OptCTSINR, we maintained a constant $SINR_{Th}$ (i.e -2 dB $SINR_{Th}$) in all sub-regions. But, in real scenarios, some sub-regions need high $SINR_{Th}$ to meet the traffic demand. Our goal in OptVTSINR is to boost the average SINR with the same count of Femtos as in OptCTSINR where the traffic demand is high. In OptVTSINR, λ_{min} is fixed (-2 dB $SINR_{Th}$). The computation is started with an initial guess value for λ_{max} and then the MIP model is solved. If the number of Femtos required is more than 5 then λ_{max} value is iteratively reduced till the same Femto count (i.e., 5) is achieved. By doing so the system was able to achieve +1 dB $SINR_{Th}$ for certain sub-regions with same Femtos count as in OptCTSINR. In Fig. 6, the sub-regions represented by $A2$, $B2$, $C2$, $D2$, $E2$ have higher SINR as the Femtos have been placed there and the Femtos are transmitting with ($A2$= 0.0967W, $B2$= 0.033W, $C2$= 0.085W, $D2$= 0.0529W, $E2$= 0.055W). If we observe Figs. 2 and 6, the sub-region with high q_j are getting high SINR.

In order to study the dependence of reception of SINR by the users in different sub-regions on the location of Femtos in the building, the following center placement scheme is considered for comparison against proposed placement schemes: Center k-Means (CKM) Placement: The co-ordinates of the exact mean locations of every sub-region are assumed to be given as the input. These mean locations happen to be the centers of the sub-regions. By K-Means clustering algorithm [8], the required number of clusters are formed using these coordinates. The Femtos are then placed at centroid of each cluster. In order to compare its

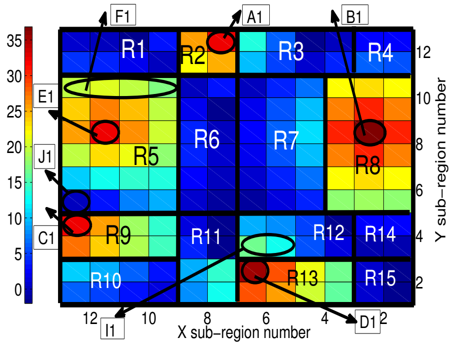

Fig. 5. Variation of SINR (in dB) across sub-regions for OptCTSINR (-2 dB)

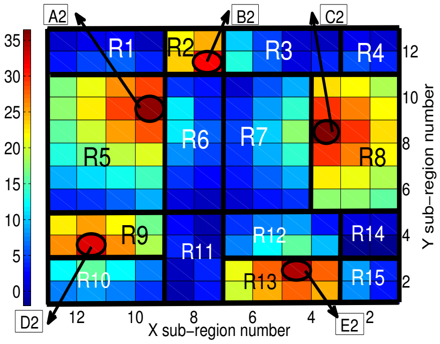

Fig. 6. Variation of SINR (in dB) across sub-regions for OptVTSINR (-2 to +1 dB)

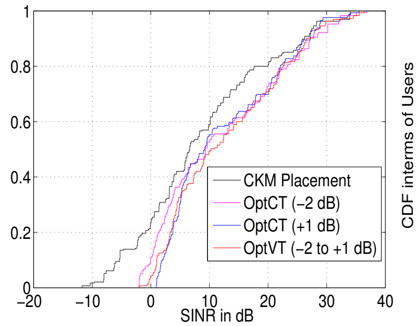

Fig. 7. SINR variation inside the building.

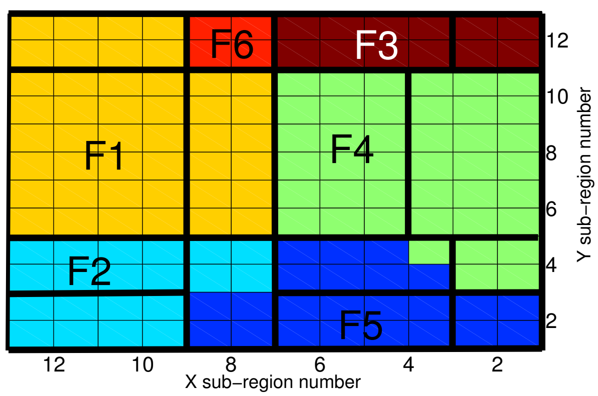

Fig. 8. Femto Sub-region Association for OptCTSINR (+1 dB)

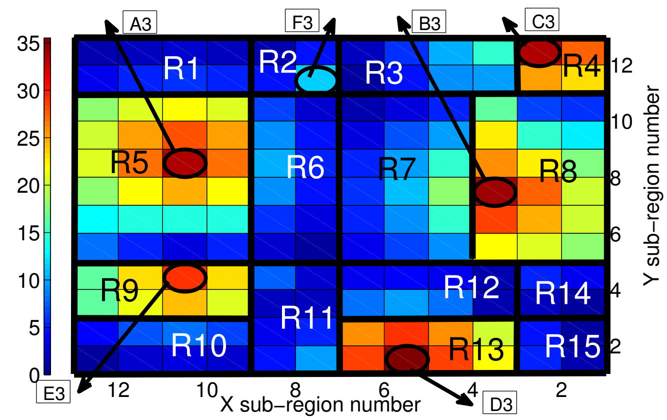

Fig. 9. Variation of SINR (in dB) across sub-regions for OptCTSINR (+1 dB)

performance with the OptVTSINR and OptCTSINR models of Femto placement, only five clusters are considered in this case. Again using K-Means algorithm, five clusters are formed and the results are compared with OptCTSINR and OptVTSINR.

Fig. 7 shows the CDF in terms of users with SINR for various placement schemes (CKM, OptCT, OptVT). Compared to CKM placement, OptCTSINR placement scheme provides better average SINR with the improvement is 39% and OptVTSINR outperforms OptCTSINR by 6.7%. In CKM placement 15% of users inside the building have SINR less than -5 dB as shown in Fig. 7, and hence they are not able to transmit any data [9]. In OptCTSINR (- 2 dB $SINR_{Th}$), 14% of the users achieves less than +1 dB as a minimum $SINR_{Th}$ but in OptVTSINR (-2 to +1 dB $SINR_{Th}$) 7% of the users achieves less than +1 dB as shown in Fig. 7. We redid the simulation for OptCTSINR (+1 dB $SINR_{Th}$) and observed that the Femto count got increased to 6 as shown in Fig. 9. The Femto deployed in room $R2$ is transmitting very less power to maintain +1 dB in those sub-regions (observe Fig. 8 and Fig. 9). In OptVTSINR, we can achieve the same $SINR_{Th}$ for certain sub-regions (high occupancy users) with only 5 Femtos which reduces the overall deployment cost.

Hence, proposed optimal placement (OptCTSINR and OptVTSINR) schemes are better than CKM scheme. Owing to these trends in the results obtained, it can be concluded that OptVTSINR is the better scheme for Femto placement in HetNets.

V. Conclusions and Future Work

In this work, we formulated two MIP optimization models: OptCTSINR and OptVTSINR to solve joint placement and power control problem, which ensured minimum number of Femtos and guaranteed good SINR for all users inside the enterprise office building. When compare to a center placement, proposed OptCTSINR results in average SINR improvement of 39% and the OptVTSINR scheme outperforms OptCTSINR by 6.7%.

Future work involves justifying the size of the sub-region, reducing the ping-pong handovers inside a room and introducing Macro user in our system model.

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