Energy-efficient Femtocell Placement in LTE Networks

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***Abstract*—To enhance battery life of the user equipment and increase the data rates for indoor users in LTE network, low power nodes like Femtos are deployed in enterprise buildings. But the optimal placement of Femtos is a challenging task due to heterogeneity in building layouts and co-tier inter-cell interference. In this work, we focus on reducing the battery power consumption (uplink transmit power) while guaranteeing uplink Signal to Interference plus Noise Ratio (SINR) threshold ($USINR_{Th}$) and downlink SINR threshold ($DSINR_{Th}$). We achieve this by placing the Femtos optimally, taking into account wall attenuation factor and interference among Macro and Femto base stations. A two-step optimization model has been formulated: in step one, we formulate a Mixed Integer Programming (MIP) problem to meet $DSINR_{Th}$ and $USNR_{Th}$ while also minimizing Femto count and uplink transmission power; which yields the optimal positions of the Femtos. In step two we formulate a Linear Programming (LP) problem with the aim of guaranteeing $USINR_{Th}$ and minimizing the total uplink power, after placing the Femtos in the optimal positions obtained from step one. When compared to center K-means placement scheme, the proposed optimal placement scheme obtained by solving the two-step model registers a significant, 47%, reduction in uplink energy consumption.**

I. Introduction

With an increase in the number of smart-phone and tablet users every year, there is a significant increase in the mobile data traffic (eg.,video conference and online gaming). This increasing customer demand for ubiquitous network access and wireless services is mainly responsible for the increasing energy consumption which translates into the ever increasing carbon footprint of the mobile communications industry. Even though the LTE Macro base stations (BSs) service the traffic demand, the users who are situated at the edge of Macro cells usually operate at high power levels to be able to communicate with the Macro BS. Also user equipments (UEs) inside the building expend more power than outdoor UEs to penetrate through the walls for communicating with Macro BS, which leads to accelerated battery drain. As per the recent statistics by Cisco, 70% of the traffic comes from indoor environments. There is a pressing need to satisfy indoor UEs requirements. One solution to this problem is to reduce the distance between UEs and BS by deploying low power nodes like Wi-Fi and Femto inside the building under the coverage of a Macro cellular network. Femtos are small BSs deployed by users in their home/enterprise environments.

In the enterprise scenario, Femtos are deployed in large numbers and often at non-optimal locations. Non-optimal deployment of Femtos leads to employment of more Femtos, and subsequent increase in co-tier interference and reduction in the achievable data rates. This in turn increases the overall cost of the Femto deployment as well as increasing the amount of CO_2 emissions. This has a detrimental effect on "greeness" of a telecommunication system. The "greeness" can be measured in terms of lowering energy cost, reducing Capital Expenditure (CAPEX), and increased battery life of mobile devices. Moreover, the signal strength in certain areas may be very low, and so the users in those regions may need to spend more uplink power to connect with a Femto BS. To demonstrate the aforementioned interference problem, we considered a single-floor building with dimensions of 48×48×3 meter and placed the Femtos (N=6 and N=11, where N is number of Femtos) using center-K-means (CKM) placement. CDF of UE uplink power is plotted in Fig. 1, we can observe from the plot that as the Femto count increase, the uplink power transmitted by the UE gets reduced. This motivates us to look into an optimization problem by choosing the optimal Femto count and reducing the uplink power. At the same time considering downlink interference in the optimization because the Uplink and downlink interference influences the pattern of Femto placement. In this work, we propose two optimization models which together guarantee a certain minimum downlink SINR threshold ($DSINR_{Th}$) and uplink SINR threshold ($USINR_{Th}$) for each user inside the building and at the same time provide a green solution by minimizing the number of Femtos deployed and the total uplink power spent.

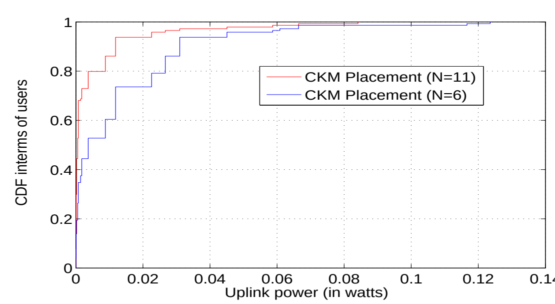

Fig. 1. CDF of UE uplink power.

II. Related Work

Earlier mobile operators were concerned about saving power consumed by Macro BSs. This was accomplished by switching off few BSs [1] during period of less traffic, using renewable energy sources [2], cell zooming [3], etc. The concern, however, has now shifted to UEs because most of the mobile phone batteries get drained faster with the advent in increased data usage. According to 3GPP in LTE network, the uplink transmission power [4] is tuned based on the feedback from Macro/Femto BS until desired SINR value is achieved. However, this tuning is more complex in heterogeneous networks due to cross-tier interference. In [5], the power for each frequency is tuned in an iterative manner. Since, the placement of Femtos was not optimal, high co-tier interference and a subsequent increase in power consumption would be observed.

The study [6] provided a solution to the joint optimal Femto placement and uplink power control problem. But their system model did not consider some realistic issues like uplink and downlink interference and building obstructions. In [7] the Femtos are placed inside a building to maximize the capacity of the users by considering only downlink interference. However, the placement of Femtos will change if we consider the uplink interference and obstructions in their model. In our recent work [8], the Femtos were placed optimally and the transmission power was dynamically adjusted to boost the SINR, by considering downlink interference and obstructions like walls and floors in the system model. To the best of our knowledge, this is the first study, where Femtos have been placed optimally by considering both uplink and downlink interference and the physical obstructions.

III. Proposed work

A. System Model

The system model consists of an enterprise building with length (L), breadth (B), and height (H), respectively. The floor is further partitioned into several rooms by the walls. Indoor users are served by one of Femto BSs deployed inside the building. In this study, we consider an LTE HetNet system comprising of Macro and Femto BSs. They are configured to operate on same frequency (*i.e.,* reuse one), which leads to high co-channel interference. Fig. 2 illustrates the aerial view inside the building in which the rooms are separated by thick walls and the grids in each room depict the sub-regions of length δ_x and width δ_y to avoid complex formulation. We assume that $SINR$ value does not vary within a sub-region (as the sub-regions are small). The objective of this work is to find the optimal sub-regions for placing the Femtos so that the uplink SINR threshold ($USINR_{Th}$) and downlink SINR threshold ($DSINR_{Th}$) are good for indoor UEs and the uplink power of the UE is also minimized.

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

$$PL_{Femto} = 37 + 30\log_{10} d + K\sigma \quad (2)$$

Where, d denotes the distance between the serving BS and the receiving UE. K denotes the number of walls crossed by the signal while traveling from the serving BS to the UE, σ is the penetration loss and f denotes the carrier frequency of the Macro BS. We now explain the Path Loss (PL) models used in the calculation of channel gain between UEs and the BSs.

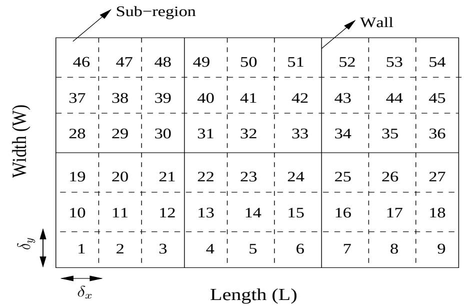

Fig. 2. Aerial view of typical floor area inside the building.

The PL from the Macro BS and Femto BS to an indoor user is given in Eqn (1) and Eqn (2) [8], respectively. This PL model is applicable for both uplink and downlink transmissions.

B. Uplink Power Control

Power control refers to the exercise of optimally setting the output power levels of the UEs for uplink transmission. The 3GPP specifications [4] define this setting of the UE transmit power for physical uplink shared channel (PUSCH) by the following equation.

$$P_{tx} = \min\{P_{max}, P_x\} \quad (3)$$

$$P_x = P_{UE} + \alpha PL + 10log_{10}(N^{'}) + fb(t)$$

Where, P_{max} is the maximum transmit power level of the UE in uplink, $\alpha \in \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$ is the path loss compensation factor signaled by higher RRC layers, PL is obtained from Eqn (1) or Eqn (2), P_{UE} is a parameter to control UE SINR target. In LTE, the bandwidth of each Resource Block (RB) is 180 KHz. Each RB consists of 12 sub-carriers and seven OFDM symbols. $N^{'}$ is the number of RBs allocated in uplink and $fb(t)$ is the UE-specific correction value at TTI t, calculated from the transmit power control command in an accumulated or absolute manner. This value is transmitted by Macro/Femto BS through DCI (downlink control information) channel to UEs.

C. Problem Formulations

In order to maintain good $USINR_{Th}$ and $DSINR_{Th}$ and to reduce the uplink power while guaranteeing the deployment of a minimum number of Femtos, we formulate a two-step optimization model. In the first step, we formulate a Minimize Femto and Uplink Transmission Power (MFUTP) MIP model to guarantee $USNR_{Th}$ (uplink signal to noise ratio) and $DSINR_{Th}$. The objective of the above model is to minimize both, the number of Femtos required for deployment and the uplink transmission power of UEs. In the second step, we formulate a LP model with the goal to maintain Uplink SINR above a certain $USINR_{Th}$ and to reduce the total uplink transmission power. We named this model as Uplink SINR Transmission Power (USTP). Table I shows the set of notations used in this work.

Step 1: MFUTP MIP Model

To address the optimal Femto placement problem, optimization model using MIP is formulated. The MFUTP MIP model is formulated in such a way that the $DSINR_{Th}$ is maintained.

TABLE I
GLOSSARY

Notation	Definition
SR	Set of all sub-regions inside the building
U_j	Set of all users in sub-region j
x_a	1 if Femto is placed at sub-region a, zero otherwise
z_{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
MBS	Set of all Macro BSs
SRB	Set of all RBs

It is very difficult to determine the uplink SINR, unless the serving Femto or connectivity region is known. In order to place the Femto with both uplink and downlink constraints, the $USNR$ is considered instead of the $USINR$ and the Femtos are placed accordingly.

Our goal is to minimize the total number of Femtos deployed and total uplink power, which is expressed by Eqn (4).

$$min(\beta_1 \sum_{a\in SR} x_a + \beta_2 \sum_{j\in SR}\sum_{m\in U_j} P^u_m/P^u_{max}) \tag{4}$$

In Eqn (4), if β_1= 0 then the optimization problem is fully based on reduction in total uplink power consumption and if β_2 = 0 then minimizing the Femto count is the optimization problem. Thus, β_1 and β_2 can be varied depending upon the operator/customer necessity. P^u_m represents power emitted by user m at sub-region j, P^u_{max} represent the maximum power emitted by UE and P^u_m/P^u_{max} is the normalized transmit power of UE. These two objectives can be met by solving a multi-objective problem but this is beyond the scope of the work. The below constraint in Eqn (5) ensures that every sub-region is connected to exactly one Femto.

$$\sum_{a\in SR} z_{ja} = 1 \qquad \forall j \in SR \tag{5}$$

If a Femto is placed at a sub-region a, x_a = 1 else x_a = 0. The constraint in Eqn (6) ensures that UE present in a sub-region j can be connected to a sub-region a only if x_a = 1 (i.e., z_{ja} = 1 only if x_a = 1). There is no case where a UE in sub-region j can connect to a sub-region a when the Femto is non-existent there. However, there can be a case where z_{ja} = 0 when x_a = 1. This happens when there is a Femto placed at sub-region a but the sub-region j is so far away or separated by walls in such a way that the Femto at sub-region a will not be able to serve the users at sub-region j.

$$z_{ja} - x_a \leq 0 \qquad \forall j, a \in SR \tag{6}$$

Each Femto operates at the maximum transmit power (P^f_{max}) in order to provide reasonably good signal strength to indoor UEs. Since all the Femtos use the same frequency, $DSINR$ degrades because of the adverse impact of the co-channel interference. Certain minimum $DSINR_{Th}$ needs to be guaranteed for all sub-regions of the building. $DSINR$ of a particular sub-region j due to the Femto located at sub-region a, is given by the L.H.S. of Eqn (7). To guarantee optimum downlink coverage, $DSINR$ of sub-regions must be maintained above the predefined threshold $DSINR_{Th}$ (λ_d), which is given by Eqn (7).

$$\frac{Inf*(1-z_{ja}) + G_{ja}P^f_{max}x_a}{N^d_o + \sum_{b\in SR\setminus a} G_{jb}P^f_{max}x_b + \sum_{e\in MBS} G'_{je}P_{macro}} \geq \lambda_d \quad \forall j,a \in SR \tag{7}$$

Where, G'_{je} and G_{ja} are the channel gain from Macro and Femto, N^d_o is the downlink system noise and PL calculated using Eqn (1) and Eqn (2), respectively and P_{macro} is the power of Macro BS. In Eqn (7), Inf is a virtual infinite value [8] (a very large value like 10^6). The reason for using $Inf*(1-z_{ja})$ is that if $z_{ja}=0$ then $Inf*(1-z_{ja})$ 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 the $DSINR_{Th}$ constraint to a particular sub-region. But a single Femto is enough to give $DSINR_{Th}$ 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 $DSINR_{Th}$ constraint for a particular sub-region. Eqn (7) can be linearized as follows:

$$\begin{split} Inf*(1-z_{ja}) + G_{ja}P^f_{max}x_a \geq \{(\lambda_d N^d_o + \sum_{b\in SR\setminus a} G_{jb}P^f_{max}x_b\lambda_d + \\ \sum_{e\in MBS} G'_{je}P_{macro}\lambda_d)\} \quad \forall j,a \in SR \end{split} \tag{8}$$

Similar to downlink, certain minimum $USNR_{Th}$ is guaranteed for all the users in the building. $USNR$ of a particular user at sub-region j due to the Femto located at sub-region a, is given by the L.H.S. of Eqn (9). To guarantee coverage, $USNR$ of users must be maintained above the predefined threshold $USNR_{Th}$ (λ_u), which is given by Eqn (9). Here Inf is used to ensure that only the users who are connected to the Femto located at sub-region a receive the threshold $USNR$.

$$\frac{Inf*(1-z_{ja}) + G_{ja}P^u_m}{N^u_0} \geq \lambda_u \quad \forall j,a \in SR, \forall m \in U_j \tag{9}$$

Where, N^u_o is the uplink system noise. The Eqn (9) is further linearised as follows,

$$Inf*(1-z_{ja}) + G_{ja}P^u_m \geq \lambda_u N^u_0 \quad \forall j,a \in SR, \forall m \in U_j \tag{10}$$

Finally, the $MFUTP$ is formulated as follows,

$$min(\beta_1 \sum_{a\in SR} x_a + \beta_2 \sum_{j\in SR}\sum_{m\in U_j} P^u_m/P^u_{max}) \text{ s.t, (5), (6), (8), (10).}$$

By solving this MFUTP MIP formulation, the following values can be ascertained:

- The minimum number of Femtos needed to maintain $DSINR_{Th}$ in each sub-region of the building.
- The minimum uplink power each UE has to transmit out to maintain $USNR_{Th}$.
- The optimal locations of Femtos inside the building.
- The Femto to which the indoor users in any given sub-region will be associated with.

Step 2: USTP LP Model

Once the Femto co-ordinates and Femto serving region is known from step one we can estimate the $USINR$. Further, the uplink power transmitted by the UE can be optimized by adding the $USINR$ constraint. Our goal is to find the optimal value of uplink power in such a way that the $USINR_{Th}$ is guaranteed for each UE in the building. Fig. 3 shows a building with Femtos (F1, F2,...,F6) and the UEs (U1, U2,...,U6). The users (U1, U2, U3, U4) are connected to Femtos (F1, F2, F3, F4), respectively and are allocated the same RB1 from their respective Femtos (F1, F2, F3, F4). This will create an uplink interference as represented by the dotted lines for F1 in the diagram. If we observe UE U1, it faces interference from UEs (U2, U3, U4). This is different in the case of Femtos (F5, F6) due to allocation of different RBs.

Each Femto has N_b number of RBs and these are allocated to the users by the scheduling algorithm. For each RB, the power value can vary dynamically depending upon the impact of interference offered by the neighboring UEs to each other. The step-two (LP) model runs (in a polynomial time [10]) for every transmission time interval (TTI) of the LTE frame and dynamically varies the transmit power of each RB in such a way that it guarantees $USINR_{Th}$ and thus the total uplink power is minimized.

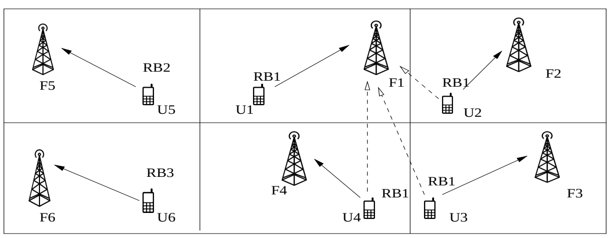

Fig. 3. Uplink Interference Scenario in Indoor Building

Certain minimum $USINR_{Th}$ is guaranteed for users inside the building. $USINR$ of a particular user connected to a Femto located at sub-region a is given by the L.H.S of Eqn (11). Depending upon the $USINR$ needs of each user in sub-region, $SINR_{Th}$ must be maintained above the threshold (λ_i) which is given by Eqn (11).

$$\frac{G_{if_i}P_i^u}{N_o^u + \sum\limits_{j \in V_r \setminus i} G_{jf_i}P_j^u} \geq \lambda_i \quad \forall i \in V_r \tag{11}$$

Where, V_r represents the set of users who are using RB r, where $r \in SRB$, uplink threshold (λ_i) varies based on the requirement of users in sub-regions, f_i is the Femto to which user i is connected. Here, P_i^u is the power emitted by UE i to maintain the $USINR_{Th}$. G_{if_i} and G_{jf_i} are the channel gain from serving UE to Femto BS and interfering UE, respectively.

The Eqn (11) is further linearised as follows,

$$G_{if_i}P_i^u \geq \lambda_i N_o^u + \lambda_i \sum_{j \in V_r \setminus i} G_{jf_i}P_j^u \quad \forall i \in V_r \tag{12}$$

Finally, the USTP is formulated as follows,

$$min \sum_{i \in U_r} P_i^u \text{ s.t, (12)} \qquad \forall r \in SRB$$

IV. Experimental Setup and Numerical Results

The building setup along with the Macro and the Femtos BS as elucidated in the system model given in section III-A is simulated using MATLAB. Macro BS is placed at 300m [8] Euclidean distance from the center of the sub-region 1. MFUTP is solved using GAMS CPLEX [9] solver. To solve such MIP based optimization problems, GAMS solver uses its branch and bound framework. GAMS solver gives the sub-region indices where the Femtos are to be placed as output. Femtos are then placed on the ceiling of the corresponding sub-regions. Various network parameters are then analyzed in this experimental scenario using MATLAB (Refer Table II).

TABLE II
Simulation Parameters

Parameters	Values
Number of floors	One
Building dimensions	48m × 48m × 3m
Room dimension	Non-uniform
Total number of sub-regions	144
Sub-region dimensions	4m × 4m
Total number of rooms	15
Macro transmit power	46 dBm
Macro BS height	30m
Femto transmit power	20 dBm
UE maximum transmit power	0.2W
LTE Mode	FDD
Users distribution	One UE in each sub-region
Operating Frequency	2.6 GHZ
$DSINR_{Th}$	0 dB
β_1	1
β_2	1

In order to visualize the importance of this optimal placement over various network parameters, it has been compared with CKM Placement scheme. CKM Placement scheme used K-Means clustering algorithm which takes the mean position of each sub-region as input, forms appropriate clusters and determines the center of each cluster. In our case; for each sub-region, the mean of the sub-region and the center of the sub-regions are the same. Hence, the center of the sub-regions are given as input to the algorithm to form clusters. The Femtos are then placed at the centroid of each cluster.

(a) Downlink:

Center (CKM) Placement: To compare CKM approach with the optimal placement scheme, we formed five clusters in the CKM placement. The user gets connected to a Femto BS which provides a good DSINR value when compared to the other Femtos. It is assumed that all the users present inside a sub-region will get connected to the same Femto. Fig. 4 shows the Femto serving sub-regions for CKM placement of Femtos. The sub-regions marked with the same color are being served by the same Femto BS. For example sub-regions colored in yellow as shown in Fig. 4 are connected to the $F5$ Femto.

Fig. 5 shows the DSINR of the sub-regions for the center placement. The color scale shown at the left maps the DSINR value pertaining to each color. The deepest shade of red in the color scale is mapped to the maximum DSINR value. The Femtos are placed in the sub-regions denoted by A to E and have deep red color. Due to path loss, the sub-regions that are farther from the position of the Femtos within the same room experience low DSINR value. For example, the region I within room 5 (R5) has a low DSINR value as it is relatively at a

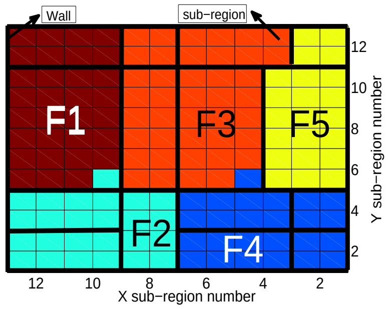

Fig. 4. Femto sub-region association for CKM Placement

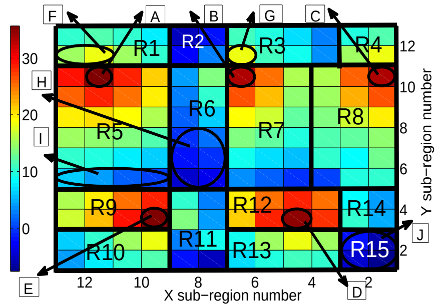

Fig. 5. DSINR (in dB) for CKM Placement of Femto

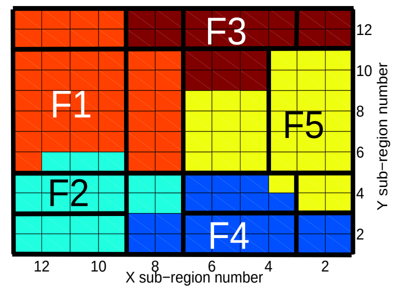

Fig. 6. Femto sub-region association for MFUTP placement

greater distance from the serving Femto located at position A. The DSINR value also degrades with the increase in the number of walls that obstruct the signal from the serving Femto. This can be seen from regions (F, G) which have a DSINR value of 10 to 15 dB when compared to regions (H, J) that get a DSINR value lesser than -10 dB. This is because regions (F, G) are closer to the serving Femto and the signal strength is eroded by a single wall while regions (H, J) are deployed at relatively farther away from their serving Femtos and obstructed by two walls instead of one. Consequently, the users in the regions (H, J) cannot communicate with the Femto BS. This is the drawback of the center placement where all the users are not guaranteed a threshold DSINR value.

Optimal MFUTP Placement: Similar to the Femto serving sub-regions in Fig. 4, Fig. 6 is the Femto serving sub-regions for the optimal positioning of Femtos. Fig. 7 shows the DSINR in optimal placement. From the color scale at the left, it can be observed that the minimum DSINR value guaranteed to all the users is 0 dB (i.e., $DSINR_{Th} = 0dB$) in contrast to the -10 dB in case of center placement. Regions $(A1, B1, C1, D1, E1)$ show the optimal locations of the Femtos. $(F1, G1, H1)$ are the regions where the users get the minimum DSINR of 0 dB. The users in these regions can still communicate with the Femto BS. Based on the path loss and wall loss described earlier, the users closer to the Femtos and within the same room as the Femtos experience a better DSINR value in comparison to the users away from them. For example, the DSINR is better to the users inside the rooms $(R3, R5, R8, R9, R13)$ because the Femtos are placed within them. Thus, the optimal placement (MFUTP, USTP) method guarantees a $DSINR_{Th}$ of 0 dB.

(b) Uplink:

CKM-Restricted Power Control (CKM-RPC): In this case, the Femtos are in CKM placement with the restriction that the users have to transmit at an uplink power of at most 0.2 watt (i.e., 23 dBm) as per 3GPP standard.

CKM-Non Restricted Power Control (CKM-NRPC): In this case, the Femtos are in CKM placement. We allow all the users to maintain $USINR_{Th}$ = -2 dB and measure the uplink power required, i.e., there is no standard uplink power limit (0.2 W).

Uplink power in CKM-RPC and (MFUTP, USTP) Placement: In order to make a fair comparison, the uplink power of the every UE is to be maintained at - 2 dB $USINR_{Th}$ for these placements (CKM-RPC, (MFUTP, USTP)). Fig. 8 shows the uplink power in CKM-RPC placement. We have to compare Fig. 4, Fig. 5 and Fig. 8 to observe the serving sub-regions of Femtos, the placement of Femtos and uplink power metrics of the users in CKM-RPC placement. The users in the room $(R5, R7, R8, R9, R12)$ transmit at low power $(0.02W)$ as shown in color scale of Fig. 8 to meet the $USINR_{Th}$ = -2 dB because the Femtos are deployed in those rooms. But some users in the sub-regions $(A2, B2, C2)$ must transmit at a higher power $(0.2W)$ to maintain the $USINR_{Th}$ as the Femtos are farther from them (path loss) and the number of walls obstructing the signal from the Femto $(F2, F3, F4)$ in Fig. 4 is more than the former. Also, some percentage of users are not able to maintain the $USINR_{Th}$ in CKM-RPC placement. This has well explained in terms of CDF graphs.

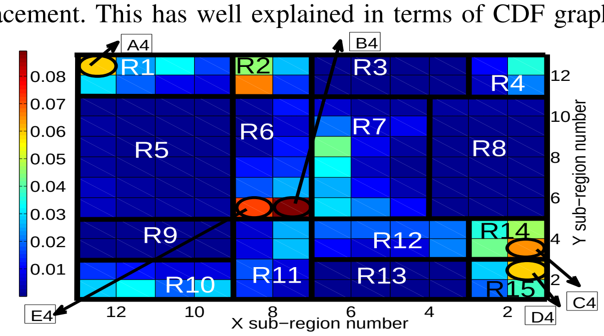

Fig. 13. Variation of Uplink Power (in Watts) based on $SINR_{Th}$ in (MFUTP, USTP) placement

Similarly, we compare Fig. 6, Fig. 7 and Fig. 9 to observe the serving sub-regions of Femto, placement of Femtos and uplink power in (MFUTP, USTP) placement. The users in the rooms $(R5, R3, R8, R9, R13)$ transmit at low power $(0.005W)$ as is evident from the color scale of Fig. 9 to meet the $USINR_{Th}$. As the Femtos are deployed in those rooms, and the users in the regions $(A3, B3, C3)$ transmit at a higher power $(0.045W)$ to maintain the $USINR_{Th}$. The (MFUTP, USTP) placement uplink power values are considerably lesser than in CKM-RPC placement.

CDF interms of uplink power and SINR: The two graphs shown in Fig. 10 and Fig. 11 give an insight into the comparison of all the three placements (CKM-RPC, CKM-NRPC, (MFUTP, USTP)) with respect to the uplink power and SINR. The Fig. 10 shows the CDF of users versus USINR for all the placements. It can be seen that the USINR value goes upto -5 dB in CKM-RPC, whereas the optimal (MFUTP, USTP) placement maintains the $USINR_{Th}$ at -2 dB for all the users so that there are no connectivity issues. In

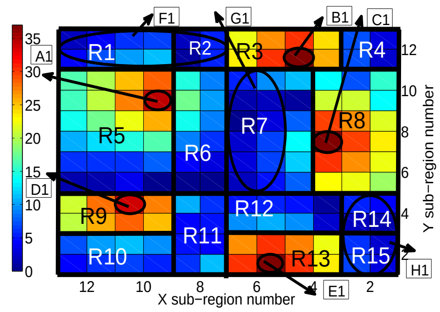

Fig. 7. DSINR (in dB) for MFUTP Placement of Femto

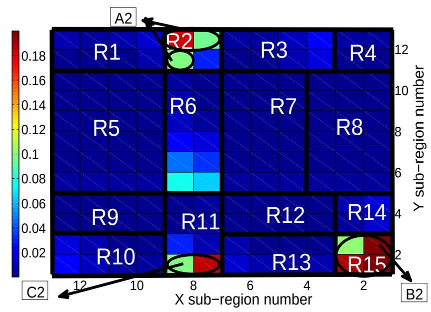

Fig. 8. Uplink power (in Watts) for CKM-RPC Placement of Femto.

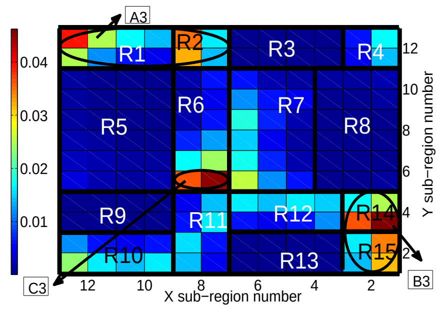

Fig. 9. Uplink Power (in Watts) for (MFUTP, USTP) Placement of Femto.

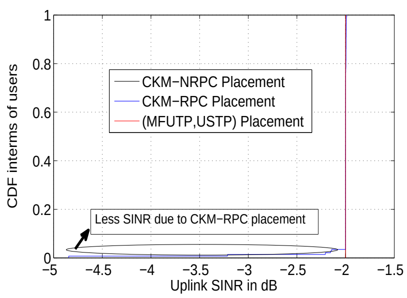

Fig. 10. Uplink SINR (in dB) interms of users

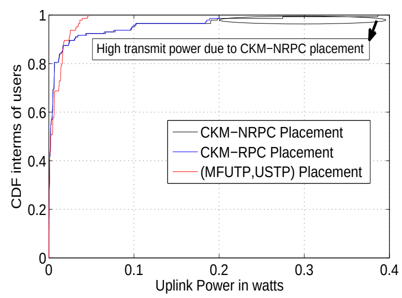

Fig. 11. Uplink Power interms of users

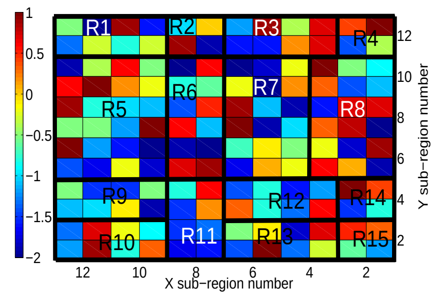

Fig. 12. Variation of Uplink $SINR_{Th}$ (-2 to 1) dB across sub-regions in (MFUTP, USTP) placement

CKM-NRPC too, $USINR_{Th}$ is maintained at -2 dB but the transmitted uplink power is greater than 0.2 watt. It is further well explained in Fig. 11.

In Fig. 11, it can be perceived that the CKM-NRPC requires upto 0.4 watts to achieve the $USINR_{Th}$, which is practically impossible as the UE can transmit upto a maximum of only 0.2 Watts. This implies that 2% of the users are in high uplink transmission power. Similarly in CKM-RPC placement, if the UEs want to maintain -2 dB $USINR_{Th}$ they have to transmit at 0.2 Watts. Whereas in optimal (MFUTP, USTP) placement, the same threshold can be obtained with lesser power than the permitted value of 0.2 Watts for the UE. The $USINR_{Th}$ can be achieved with less than 0.05 Watts. By using optimal (MFUTP, USTP) placement, energy consumption for the entire building is 47% lesser than in CKM-RPC placement. Thus, the (MFUTP, USTP) placement saves more uplink energy and reduces CO_2 emissions in the Green HetNet system.

Variation of uplink $SINR_{Th}$ across sub-regions in (MFUTP, USTP) placement: We repeated the same experiment for random variations of $USINR_{Th}$ (-2 to 1 dB). Fig. 12 shows the color scale variation of $SINR_{Th}$ from -2 to 1 dB across the sub-region. Fig. 13 shows the variation in the uplink transmission power. The circled region $A4$ should maintain roughly a $SINR_{Th}$ of -1 dB (refer Fig. 12 as shown on the left side of color scale) but the region $A4$ is connected to the Femto $F1$, placed in room $R5$ as shown in Fig. 6. As the signal would need to cross one wall from the Femto $F1$, the user in region $A4$ should transmit nearly at $(0.06W)$ to maintain the $SINR_{Th}$ -1 dB. Similar is the case in regions $(B4, C4, D4, E4)$.

V. Conclusions and Future Work

In this work, Femtos were optimally placed considering both uplink and downlink interference. We ensured that energy consumption in Green HetNet (uplink) building is 47% lesser than CKM-RPC placement. In addition to that, we also assure a reasonably good $SINR$ for uplink and downlink. In future, the Macro users and an efficient RB allocation will also be considered in the system model.

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