On Placement of LAA/LTE-U Base Stations in the Presence of Wi-Fi

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ABSTRACT

Recently, the use of LTE in unlicensed has gained a lot of attention to improve the data rate and satisfy the increasing user demand. Use of unlicensed spectrum is allowed with restricted transmission power hence mostly LAA/LTE-U nodes are Femto cells and mostly will be used to improve the indoor data rates. In future, the LAA nodes will get deployed inside residential apartment complexes and office buildings to provide high data rates for indoor User Equipment (UEs). The UEs with high Signal-to-Interference plus Noise Ratio (SINR) experience good throughput, but the SINR decreases significantly if building walls and other obstacles are present in the communication path. The coverage difference of licensed and unlicensed spectrum provides different SINR so, efficient placement of LAA Femtos in buildings with consideration of interference from other LAA Femto nodes, Wi-Fi Access Points (APs) and Macro Base Stations (BSs) is very crucial for attaining desirable SINR for the indoor UEs. In this paper, we have considered obstructions (walls, floors) and interference from Macro, Femto BSs, and Wi-Fi APs. Our goal is to find the optimal number of Femtos with minimum SINR requirements in the unlicensed band, and next thing is to achieve good SINR in all sub-regions in licensed band as well. To do this, we formulated an optimization model (MinLF) to find the minimum number of LAA/LTE-U Femtos along with its positions in indoor scenarios which resulted in Mixed Integer Linear Programming (MILP) optimization problem. Further, to maximize minimum SINR in the licensed spectrum, we formulated MinLPow model to find the optimal power of each located Femto inside the building which is Mixed Integer Non-Linear Programming (MINLP). MinLF formulation is solved using GAMS CPLEX optimization solver. After getting positions of Femtos, we solved MinLPow formulation using Genetic Algorithm. Finally, the efficiency of proposed formulation model is shown with sufficient simulation study.

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KEYWORDS

LTE in Unlicensed (LTE-U), Licensed Assisted Access (LAA), Placement, Optimization, IEEE 802.11 (Wi-Fi)

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1 INTRODUCTION

Due to the surge in usage of smartphones and tablets, there is an ever increasing demand for spectrum for data traffic. The wireless traffic is expected to expand further in coming years [2]. The users consume more data mostly in indoor scenarios with rich content including the video traffic [5]. Since the Macro BS located outside the building, the mobile operators can boost the data rates for outdoor users, but they are unable to increase the data rates for indoor users. It is difficult for high frequency electromagnetic signals to penetrate through walls and floors because of huge losses. Hence, the indoor users suffer from low signal strength. Fig. 1 shows the SINR distribution inside building for each sub-region when the Macro BS is located 500m away from first sub-region in both horizontal and vertical directions. The building model with sub-regions is shown in Fig. 2. It is clear indication from the SNR values of sub-regions in the indoor area that there is huge drop in the SNR values from room to room because of wall and floor losses. As most of the users consuming more data are the indoor uses, the low SNR in the indoor regions is a very necessary threat to be addressed and solved. One way to solve this problem is by the use of smaller sized low power BS inside the indoor regions so that SINR in indoor regions can be boosted. So the use of Femto BS helps in solving this problem to a greater extent. One thing that has to be considered is the placement of these low power nodes because placing randomly will not boost the rate because of interference from each other. In order to increase the spectrum efficiency and to boost SINR to a greater extent, these low power nodes have to be placed optimally.

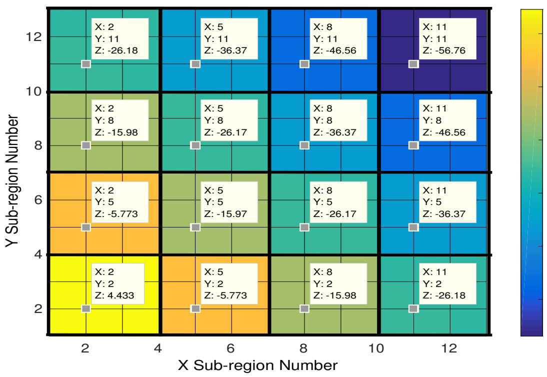

Figure 1: SNR distribution inside building with Macro BS outside building.

At the same time, recent increase in the indoor data traffic demand with limited licensed spectrum forces mobile operators to find alternate solutions. To meet such high user demand in wireless communication use of unlicensed spectrum is considered as one of the promising solution. LTE in unlicensed is achieved by fairly sharing of the unlicensed channel with other technologies like Wi-Fi. For fair sharing with Wi-Fi; Carrier Sense Adaptive Transmission (CSAT) [3] is one mechanism where LTE follows ON and OFF cycle so that Wi-Fi can get access to the channel in OFF time. The ON and OFF mechanism for fair coexistence is possible in only those countries (like India, USA) where Listen Before Talk (LBT) is not mandatory. In a region where LBT is mandatory like Japan, Europe; LTE in unlicensed can be achieved using LTE-Licensed Assisted Access [6] where LTE access a channel by following LBT mechanism.

LTE in unlicensed can be used with licensed spectrum only as the control information are transferred through licensed spectrum and by using unlicensed spectrum, the operator can boost the data rate through Carrier Aggregation. It is difficult for high frequency (λ = c / f) electromagnetic signals to penetrate through walls and floors. The operating frequency of LTE in unlicensed spectrum is in 5 GHz, hence more loss compared to licensed spectrum. Therefore coverage of unlicensed spectrum is less than that of licensed spectrum in LAA/LTE-U networks. To provide licensed and unlicensed coverage in indoor everywhere with some minimum SINR, the optimal number of LAA base stations along with its proper placement is necessary.

In this paper, we formulate MinLF model to find a minimum number of LAA/LTE-U Femtos along with its positions in indoor scenarios which resulted in Mixed Integer Linear Programming (MILP) optimization problem. The placement formulation is for unlicensed spectrum as coverage of unlicensed is less due to high frequency (*i.e,* more wall, floor loss). Once we get the optimal number of BSs with positions, the transmission in the licensed spectrum may create coverage holes (sub-regions with very low SINR) due to high power and high interference. Hence, power control in the licensed spectrum is necessary to improve the SINR of licensed in each sub-region, and at the same time, it helps to save energy. Hence, we formulated MinLPow model to maximize the minimum SINR of licensed by controlling licensed power in LAA node which resulted in Mixed Integer Non-Linear Programming (MINLP) optimization problem. The proposed approach guarantees certain minimum SINR threshold for licensed and unlicensed spectrum inside the building with minimum LAA BS and MinLPow reduces the LAA licensed transmission power to maximize minimum SINR with power saving.

2 RELATED WORK

LTE in unlicensed has grabbed a lot of attention in the research community, with a major problem of fair sharing of unlicensed spectrum band with other technologies. The benefits and challenges of LTE in unlicensed are explained in [14]. Most of the work in literature focuses on the fair coexistence of LTE-U/LAA and Wi-Fi [4, 7, 8]. But to the best of our knowledge, optimal placement of LAA/LTE-U in the indoor scenario has not received much attention. Random placement of LAA/LTE-U inside buildings can create a lot of issues like interference, frequent handovers. etc. Whereas optimal placement of the LAA/LTE-U can solve the above-mentioned problems. In literature, several optimal LTE Femto placement approaches have been proposed, taking into account different parameters such as building dimension, walls, floors..etc. In [9, 10], a single Femto is placed in a multi-room indoor environment based on the location of the Macro BS. One drawback of these approaches is it can not scale for enterprise scenario. In [13], indoor building scenario is considered for placement of LTE Femto but due to the absence of unlicensed spectrum the solution is not directly applicable to LAA/LTE-U nodes as the presence of Wi-Fi can change placement and also the coverage and capacity of both licensed and unlicensed are different. Hence, existing works which are based only on the licensed spectrum for placement can not be applied directly to LAA/LTE-U eNBs because of carrier aggregation of the licensed and unlicensed spectrum. In this paper, we considered LTE-U/LAA placement problem in the case of indoor building scenario.

3 SYSTEM MODEL

3.1 Building Model

The building is considered to be of dimensions having length L, width W and height H. The building is divided into the set of sub-regions, each having dimensions as length l, width w, and height H. The considered building scenario is as shown in Fig. 2. The inner squares represent sub-region, and the thick lines represent walls of the rooms. Because the dimensions of sub-regions are smaller compared to the entire building, we can assume that SINR in each sub-region is constant. The top view of our considered scenario is shown in Fig. 2.

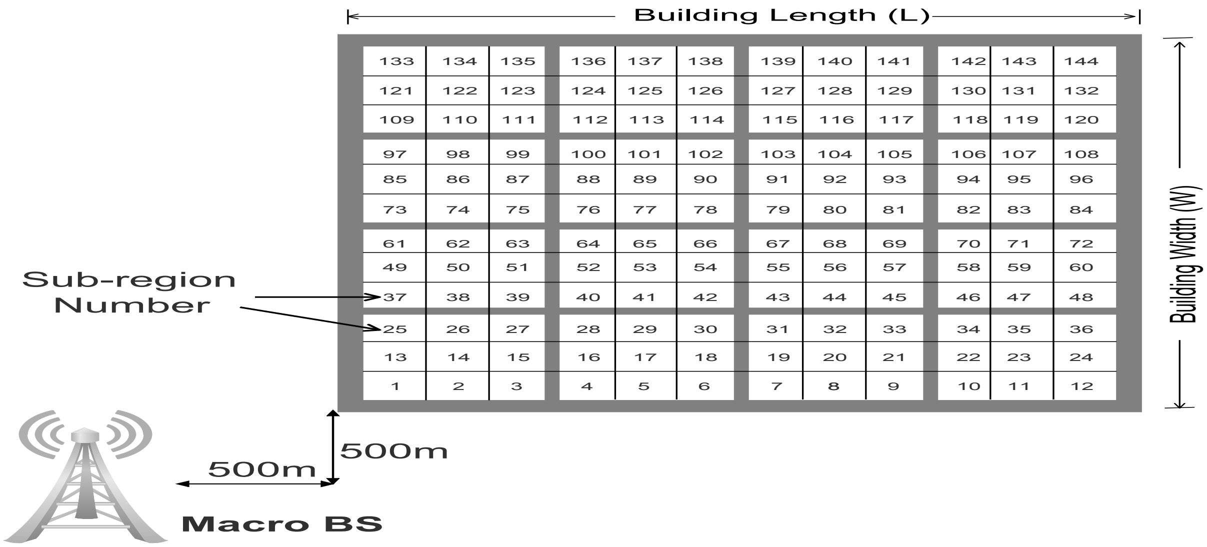

Figure 2: System model with building having 16 rooms and macro BS.

3.2 Channel Model

The Path Loss (PL) (in dB) between Macro BS located outside the building and the indoor sub-regions of the building is obtained by [11] as follows:

$$PL_{Macro} = 49 + 40\log_{10}\frac{D}{1000} + 30\log_{10}F + K\sigma^l \quad (1)$$

where D is the distance between each sub-region and the Macro BS in meters, F is the transmission frequency of Macro BS in MHz and K is the number of walls between the Maro BS and the sub-regions.

As LAA BS operates in both licensed and unlicensed spectrum, we use two different PL model for licensed and unlicensed. The PL in dB between Femto BS transmitting in unlicensed spectrum and the sub-regions in the building is obtained by:

$$PL^u_{Femto} = 20\log_{10}f + 30\log_{10}d + N\sigma^u - 28 \quad (2)$$

The PL (in dB) between Femto BS transmitting in licensed spectrum and the sub-regions in the building is obtained by [11] as follows:

$$PL^l_{Femto} = 37 + 30\log_{10}d + N\sigma^l + 18.3v^{\frac{v+2}{v+1}-0.46} \quad (3)$$

where f is the transmission frequency of unlicensed spectrum in MHz, d is the distance between Femto base station (BS) and each sub-region in meters, N is the number of walls between the Femto BS and the sub-region, σ^u and σ^l are wall losses of unlicensed and licensed spectrum in dB, respectively and v is the total number of floors in the building.

The PL between Wi-Fi Access Point (AP) and the sub-regions remains the same as PL model of Femto BS transmitting unlicensed spectrum (PL^u_{Femto}) given in Eqn. (2).

4 PROPOSED WORK

Our objective is to boost the data rate for indoor users by providing minimum licensed and unlicensed SINR in each and every sub-region with help of minimum number of LAA BSs. By comparing PL^u_{femto} and PL^l_{femto}, it is seen that the coverage of unlicensed spectrum is less than licensed spectrum. It is so because, the operating frequency of LTE in unlicensed spectrum is in 5 GHz which is very high compared to that of licensed spectrum. Hence, the penetration losses through walls and floors are high for unlicensed spectrum than that of licensed spectrum. Hence, to achieve unlicensed and licensed SINR in every sub-region, the positioning of LAA BSs are based on unlicensed coverage as it is very less compared to that of licensed coverage. As the positioning of LAA BSs are based on unlicensed coverage, to minimize the number of LAA BSs used, transmission in unlicensed spectrum is with maximum power P^u_{max}. Since, licensed spectrum coverage is better compared to unlicensed spectrum coverage, if licensed spectrum is also transmitted at maximum power P^l_{max} then there will be huge SINR drop in licensed spectrum at some sub-regions due to high interference. To improve SINR in the licensed spectrum in those sub-regions, the transmission in licensed spectrum has to be done at some lower powers in order to reduce the interference. The next to be considered is the amount of reduction in transmitting powers of licensed spectrum. The parameter we have considered in our proposed work which decides the power reduction is the minimum licensed SINR i.e reduce the transmission power of licensed Powers in such a way that the minimum licensed SINR can be maximized. Hence our objectives of proposed work is briefed as follows.

- Minimum SINR threshold in each sub region for both licensed and unlicensed spectrum with the minimum number of Femto BSs possible (MinLF).

- Maximize the minimum SINR with power optimization of licensed spectrum (MinLPow).

4.1 Minimizing the number of LAA/LTE-U Femtos (MinLF)

Since the range of license spectrum is greater than that of unlicensed spectrum, to achieve both License and unlicensed spectrum, we are placing the Femto BSs based on unlicensed coverage and modulate the power of licensed spectrum which is described in the next section. Placing of Femto BSs based on coverage of unlicensed spectrum is done as follows.

- Minimize the number of LAA Femtos, LF_{min}, needed for maintaining certain $SINR^u_{th}$ in unlicensed spectrum in each inner sub-region of the building using MinLF method explained below.
- Determine the optimal locations for placement of LF_{min} Femtos in the indoor area of the building.
- Determine the associativity of each sub-region.

Table 1: Glossary of MinLF MILP Model

Notation	Definition
S_i	Set of all indoor sub-regions.
S_c	Set of all sub-regions where Wi-Fi AP is located.
x_a	1 if Femto is placed at sub-region a, 0 otherwise.
y_{ja}	1 if j^{th} sub-region of the building is associated with the Femto located at sub-region a, 0 otherwise.
g^u_{ja}	Unlicensed channel gain due to Femto BS between sub-region j and Femto BS at a.
g^w_{jc}	Channel gain between Wi-Fi AP in sub-region c and the sub-region j.
P^u_{max}	Maximum transmission power of unlicensed spectrum.
P_{WiFi}	Transmission power of Wi-Fi APs.
N_o	System noise.
$SINR^u_{th}$	Minimum required SINR of unlicensed spectrum in each sub-region.
w_{jc}	1 if jth sub-region is outside energy detection region of Wi-Fi AP at sub-region c in the building, 0 if it is inside.
EDT_c	Energy Detection Threshold region of Wi-Fi located in Sub-region c.

MinLF problem formulation

The MinLF method has been described below, and Table 2 shows the notation used in MinLF model. In order to provide a good SINR to all indoor sub-regions, every Femto operates at its peak transmit power (P^u_{max}). The goal is to minimize the total number of Femtos deployed, expressed by Eqn. (4) subjected to Eqns. (5), (6), (7), and (8) as constraints. This makes our optimization problem as MILP.

$$LF_{min} = min \sum_{a \in S_i} x_a \tag{4}$$

Eqns. (5) and (6) make sure that each sub-region is associated with one and only one Femto BS.

$$\sum_{a \in S_i} y_{ja} = 1 \qquad \forall j \in S_i \tag{5}$$

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

Once we associate each sub-region to only one Femto BS, the next constraint is to allow at most one Femto BS, if necessary in EDT of Wi-Fi AP.

$$\sum_{d \in EDT_c} x_d \leq 1 \qquad \forall c \in S_c \tag{7}$$

The next constraint is to maintain the minimum SINR *i.e.,* threshold, in each sub-region. Eqn. (8) will ensure that minimum SINR is maintained in each sub-region.

$$\frac{Inf * (1 - y_{ja}) + g^u_{ja} P^u_{max} x_a}{N_o + \sum_{b \in S_i \setminus a} g^u_{jb} P^u_{max} x_b w_b + \sum_{c \in S_c} g^w_{jc} P_{WiFi} z_{ca}} \geq SINR^u_{th} \forall j, a \in S_i \tag{8}$$

Left Hand Side (LHS) of Eqn. (8) is the ratio of received signal power from the BS to which it is associated, to the sum of system noise N_o and interference from other Femto BSs. When j^{th} sub-region is associated with Femto BS located in sub-region a, $y_{ja} = 1$. So the term $Inf * (1 - y_{ja})$ goes to zero and LHS of Eqn. (8) has to satisfy the constraint. Otherwise if $y_{ja} = 0$, the term $Inf * (1 - y_{ja})$ has virtually a very large value (of the order of 10^6). Because of this term, the numerator becomes a large value and skips the equation by ignoring it. The term $Inf * (1 - y_{ja})$ is needed because all the Femtos might not give the minimum SINR to all the sub-regions in the building. This term ensures the feasibility of the MILP equations. The denominator contains the sum of system noise, interference from other Femto BSs and interference from Wi-Fi APs. It is assumed that both Wi-Fi APs and the unlicensed spectrum from Femto BSs are transmitted at the same frequency. To evaluate the interference from Wi-Fi AP, we first have to find out the sub-regions inside Energy Detection Threshold (EDT) region of Wi-Fi AP. We use the following equation to find out sub-regions inside the EDT.

$$Z_{ca} = \begin{cases} 0, & \text{if } a \in EDT_c \\ 1, & otherwise \end{cases} \qquad a \in S_i \;\; c \in Sc$$

If a sub-region a lies inside the EDT of Wi-Fi AP located in Sub-region c, then the value of Z_{ca} is 0, otherwise 1.

$$w_b = \begin{cases} 1, & \text{if } b \notin EDT_c \quad \forall c \in S_c \\ 0, & otherwise \end{cases}$$

The value of w_b is 1 if and only if it lies outside EDT of all the Wi-Fi APs in the building, 0 otherwise.

The following are the interferences a sub-region associated with a Femto BS will get

Interference from other Femto BSs: Interference from other Femto BSs other than the one to which it is associated exists. At the same time, if the Femto BS other than the one to which it is associated lies inside the EDT of any Wi-Fi AP, then there will not be interference from both the Femto and Wi-Fi at the same time since they will be sharing the channel. As seen from EDT range of W-Fi, if any Femto other than the one to which it is associated is located in EDT of this Wi-Fi, we have assumed that Interference from Femto when it is transmitting is same as interference from Wi-Fi when Femto is not transmitting. So in our formulation, interference from Femto other than the one to which it is associated exists only if it lies outside EDT of all the Wi-Fi APs. Hence interference from Wi-Fi AP is considered over the Femto. The use of w_b in the equation (9) solves this purpose.

Interference from Wi-Fi APs If the Femto to which a sub-region is associated lies inside EDT of a Wi-Fi AP, then there will not be any interference from this Wi-Fi AP as it is sharing the channel with the Femto. As said in the previous point, interference from Wi-Fi is considered in cases when there is also a Femto. Since only one of them transmits at a time and instead of considering each one separately, we have formulated considering only Wi-Fi interference to be existing all the time. Hence interference from all Wi-Fi APs is considered other than the one in whose EDT the considered sub-region's associated Femto BS is located. Z_{ca} in equation (9) serves this purpose. Therefore the problem formulation for minimizing the number of Femto BS is

$$min \sum_{a \in S_i} x_a \qquad \text{s.t (5), (6), (7), and (8)}$$

Once the optimal placement of Femto BSs is found with respect to unlicensed spectrum, our next task is to provide licensed spectrum to all the sub-regions which is discussed in more detail in the following section.

4.2 LAA/LTE-U licensed Power Control (MinLPow)

After placing an optimal number of LAA/LTE-U BSs in building w.r.t. unlicensed spectrum, the power control in licensed spectrum is necessary for LAA BS. Since the licensed spectrum coverage is greater than that of unlicensed spectrum, transmitting in the licensed spectrum at maximum power will cause more interference to other sub-regions which may leads to coverage holes or lower the SINR because of interference and hence has to be transmitted at optimal powers. To avoid this, we are proposing a power modulation technique where we find the optimal values of the transmission power of each Femto BS such that we are maximizing the minimum SINR of the indoor area. By doing this, we are achieving two things.

- Boosting the SINR in indoor sub-regions by increasing the minimum SINR in the building to the extent possible.
- Power saving by finding the optimal transmission powers.

MinLPow Problem Formulation

In order to maximize the minimum SINR in the building by modulating the transmission power, our objective equation is as follows.

$$maximize\ (min\,(SINR_j^l)) \qquad \forall j \in S_i \tag{9}$$

Table 2: Glossary of MinLPow Model

Notation	Definition
g_{ja}^l	Licensed channel gain due to Femto BS between sub-region j and Femto BS at a.
G_{je}	Channel gain between sub-region j and Macro Base Station outside the building.
P_{max}^l	Maximum transmission power in licensed spectrum.
P_{min}^l	Minimum transmission power in licensed spectrum.
$SINR_{th}^l$	Minimum SINR in each sub-region.
P_a^l	Optimized transmission power of Femto BS present in sub-region a.
$SINR_j^l$	SINR of licensed spectrum in sub-region j which is associated with Femto BS located in sub-region a.
P_{macro}	Transmission power of Macro BS present outside the building.

SINR in licensed spectrum for each sub-region is calculated by finding the ratio of received power from the associated Femto BS to the sum of system noise, interference from other Femto BSs and interference from outside Macro BSs. x_a and y_{ja} are the inputs from the MinLF method in the previous section. After getting these parameters, the SINR of licensed spectrum in each sub-region can be found out using Eqn. (10).

$$SINR_j^l = \frac{g_{ja}^l P_a^l x_a y_{ja}}{N_o + \sum_{b \in S_i \setminus a} g_{jb}^l P_a^l x_b + \sum_{e \in M} G_{je} P_{macro}} \qquad \forall j, a \in S_i \tag{10}$$

To ensure that the transmission power of Femto BS in licensed spectrum does not exceed the maximum transmission power and at the same time meets the minimum transmission power requirement, Eqn. (11) is used.

$$P_{min}^l \le P_a^l \le P_{max}^l \qquad \forall a \in S_i \tag{11}$$

To ensure that at least $SINR_{th}^l$ is maintained in each sub-region in the building, Eqn. (12) is necessary. This is needed because for each region having unlicensed spectrum, control signals have to be sent through licensed spectrum. To send the control signals $SINR_{th}^l$ is necessary.

$$\frac{g_{ja}^l P_a^l w_a y_{ja}}{N_o + \sum_{b \in S_i \setminus a} g_{jb}^l P_a^l w_b + \sum_{e \in M} G_{je} P_{macro}} \ge SINR_{th}^l \quad \forall j, a \in S_i \tag{12}$$

The above optimization formulation is MINLP which cannot be solved easily using the traditional MINLP algorithms. Hence we used Genetic Algorithm (GA) to solve it and find the power of each Femto in the licensed spectrum.

GA uses a fitness value to select the best possible solution among the available solutions obtained by mutation and crossing over of population set. The fitness value in our case is the maximum value of the minimum SINR in the building. Transmission powers are taken by the algorithm as population set to find the sub-optimal values. It is sub-optimal because it varies with population set and as and when the population set changes, the power values also change.

5 EXPERIMENTAL SETUP AND NUMERICAL RESULTS

For experimental setup, we consider the scenario as shown in Fig. 3, the position of Macro BS is 500m away from the first sub-region in horizontal and vertical directions. The system model described in Section 3 is simulated in MATLAB [12] using simulation parameters as shown in Table 3. The results are collected in two cases. In case one, only one Wi-Fi AP is inside building whereas in case two, we placed two Wi-Fi APs. Considering the locations of Wi-Fi AP is known before, to obtain the optimal positions of LAA Femto BS and associativity of sub-regions, we used GAMS CPLEX solver[1] to solve MinLF formulation. After getting the positions of LAA BS and associativity of sub-regions from GAMS using MinLF, we used GA toolbox in MATLAB to solve MinLPow formulation. Finally, we have shown the results in terms of SINR and energy saving.

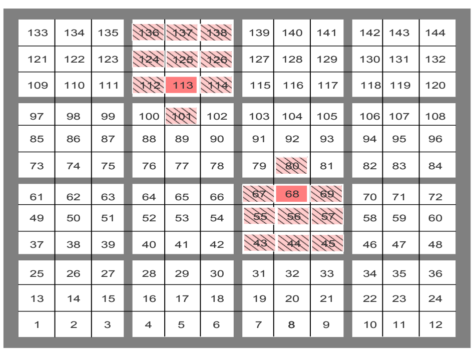

Figure 3: Considered building scenario with Wi-Fi locations at 68 and 113 sub-regions along with its energy detection region.

Table 3: Simulation Parameters

Parameter	Value
Building dimensions	48 m × 48 m × 3 m
Number of Rooms	16
Room dimensions	12m × 12m × 3m
Number of inner Sub-regions	144
Sub-region dimension	4 m × 4m × 3m
$SINR^l_{Th}$ (MinLF method)	-2 dB
$SINR^u_{Th}$ (MinLF method)	4 dB
Wall loss (L)	10 dB
Wall loss (U)	13 dB
Macro transmit power (P_{macro})	46 dBm (39.8 W)
P^l_{max}	20 dBm (0.1 W)
P^u_{max}	20 dBm (0.1 W)
P^l_{min}	10 dBm
Macro BS Height	35 m
P_{Wi-Fi}	20 dBm (0.1W)
EDT	-62 dBm

5.1 In the presence of one Wi-Fi AP

In this case, we placed one Wi-Fi AP at sub-region 68, and then solved MinLF and MinLPow to find the optimal locations for LAA BS and licensed transmission powers for each BS, respectively. Fig. 4 shows the SINR distribution in unlicensed spectrum along with LAA BS positions inside building. From the SINR plot of unlicensed spectrum in Fig. 4, it is clearly evident that $SINR^u_{Th}$ (*i.e.,* 4 dB) is maintained in each sub-region. Fig. 5 shows the associativity of each sub-regions in the building where the same color indicates that sub-regions are associated with the same BS. Similarly, Fig. 7 shows the SINR variation for licensed spectrum. It can be seen from the SINR plot of licensed that $SINR^l_{Th}$ (*i.e.,* -2 dB) is also maintained in each sub-region. After maximizing the minimum $SINR^l$ of the building, it is seen that sub-region 64 has the least licensed SINR which is 2.807 dB. Fig. 6 shows the $SINR^l$ for each sub-region when the licensed spectrum is being transmitted at maximum power (20 dBm) by all the LAA BS. It is seen that the minimum $SINR_l$ is 2.782 dB in sub-region 64. Hence we can see that by transmitting licensed spectrum at optimal powers we are maximizing the minimum $SINR^l$. The reason for it being more interference from LAA BS in sub-region 64 because of maximum powers. In Fig. 8 CDF of licensed and unlicensed SINR is given to validate each sub-region inside the building is getting minimum $SINR^u_{Th}$ and $SINR^l_{Th}$ in the unlicensed and licensed spectrum, respectively. Fig. 9 shows the energy required for transmission of licensed spectrum per day at maximum powers and at controlled powers obtained using MinLPow method. Energy consumed is collected by varying the $SINR^u_{Th}$ from 0 dB to 4 dB in step size of 2 dB as shown in Fig. 9. With varying $SINR^u_{Th}$, from 0 dB to 4 dB, the minimum number of LAA BSs required remains same (*i.e.,*3). Hence, the energy required for transmitting at maximum power (P^l_{max}) also remains same. The change in $SINR^u_{th}$ from 4 dB to 5 dB changes required number of BSs from 3 to 4 which result in more power consumption in case of Max power. Whereas in the case of optimal power ($P_{control}$) the energy required varies based on locations of LAA BS. Since 4 dB was the maximum $SINR^u_{th}$ that could be achieved with 3 Femto BS it can be seen that the positions of Femto in this case would be the most optimal positions of 3 Femto. This can also be verified by seeing the energy consumed plot where the least amount of energy was required in this case. For the considered scenario and $SINR^u_{Th}$ values it is seen that maximum energy is saved when $SINR^u_{Th}$ is 4 dB and the energy saved is 88.19%. Minimum saved energy

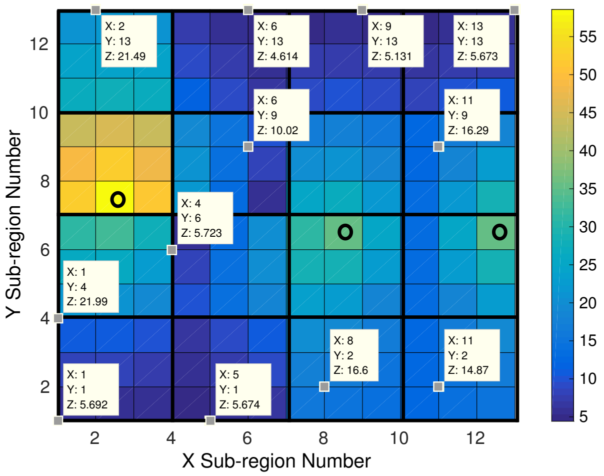

Figure 4: Unlicensed SINR distribution in dB, the small circles are positions of BS.

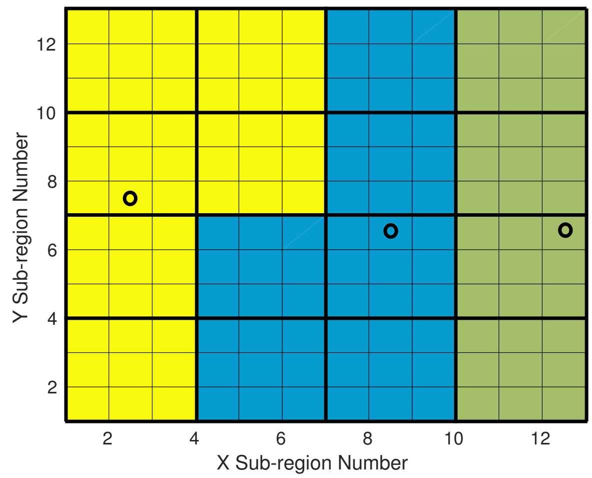

Figure 5: Connectivity of sub-regions to LAA BS where same color indicate connected to same BS.

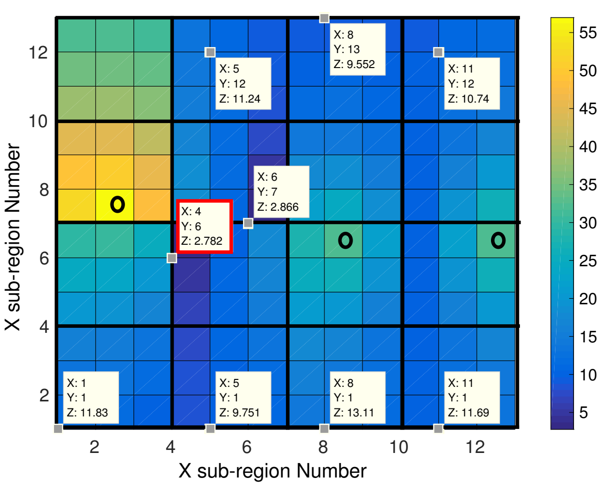

Figure 6: Licensed SINR distribution in dB with maximum power.

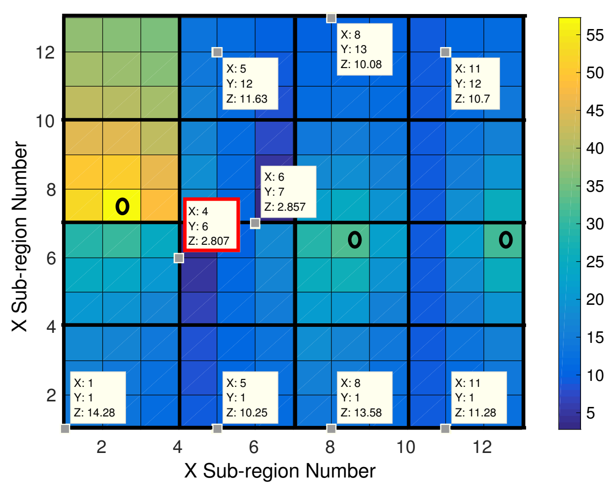

Figure 7: Licensed SINR distribution in dB with controlled power.

is 48.81% when $SINR_{Th}^{u}$ is 5 dB. The average percent of energy saved by varying $SINR_{Th}^{u}$ is 64.90%. Even though we are transmitting licensed spectrum at controlled powers it is seen from Fig. 10 that $SINR_{j}^{l}$ is almost same compared to that of transmitting at P_{max}^{l}. Finally, Table 4 shows the optimal number of BSs, the position of BSs, controlled power of each BS, and percentage of energy saving compared to max power transmission for the considered scenario.

5.2 In the presence of two Wi-Fi APs

By looking at the locations of LAA BS when only one Wi-Fi AP is located at sub-region 68, we are considering one more Wi-Fi AP in such a way that we can validate the theoretical expectations. Suppose we place an additional Wi-Fi AP in sub-region 113, for the surrounding sub-regions there will be more interference and as expected logically by presumption we would change the location of LAA BS in sub-region 74 to somewhere near 113. By doing this there will not be much interference around Wi-Fi AP because of channel sharing and for sub-regions around 74 which may be associated with this LAA BS, interference will not be there from the newly added Wi-Fi AP because of channel sharing. For studying this practically through simulation, in this case, along with Wi-Fi AP at sub-region 68, we added another AP at sub-region 113. It can be seen from the simulation results that all the inferences met with one Wi-Fi AP hold true here as well. By

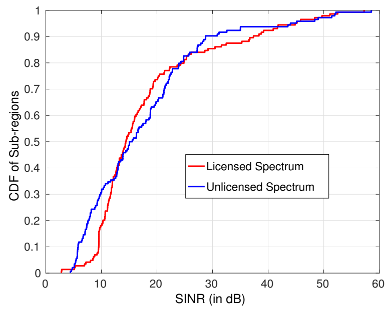

Figure 8: SINR CDF of licensed and unlicensed spectrums.

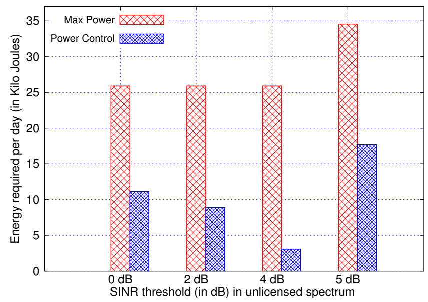

Figure 9: Energy required with maximum and controlled power.

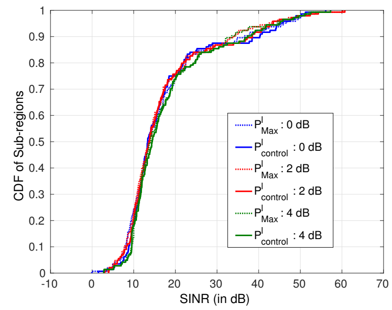

Figure 10: SINR CDF with maximum and controlled powers.

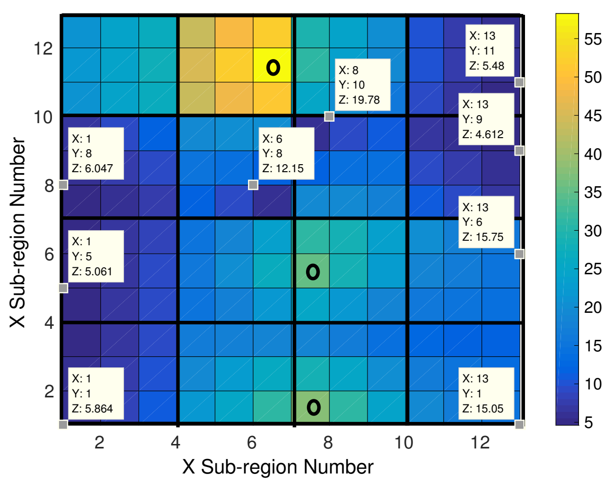

Figure 11: Unlicensed SINR distribution in dB, the small circles are positions of BS.

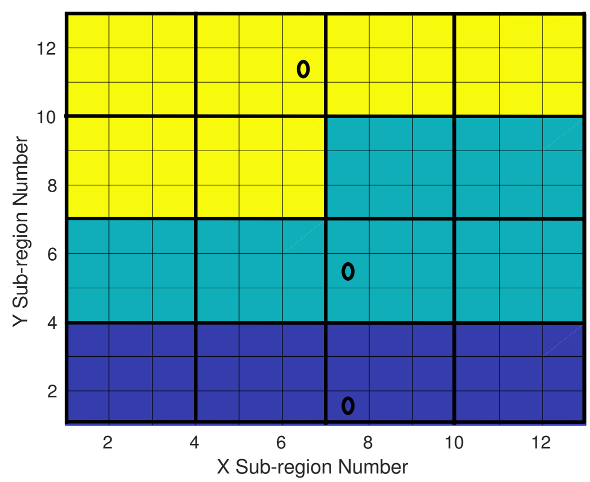

Figure 12: Connectivity of sub-regions to LAA BS where same color indicate connected to same BS.

Table 4: Results with One Wi-Fi AP at sub-region 68

$SINR^u_{th}$	0 dB	2 dB	4 dB	5 dB
No. of BS	3	3	3	4
BS sub-region	7,43, 113	7,43, 138	68,72, 74	56,74, 119,135
Licensed power in dBm	18.36, 16.66, 11.48	17.53, 13.78, 13.52	11.06, 10, 11.02	19.68,18.13, 15.20,11.36
% Energy Saving	57.02	65.66	88.19	48.81

just changing the position of LAA BS from sub-region 74 to sub-region 126, $SINR^u_{Th}$ is maintained in each sub-region as seen from Fig. 11. Associativity of all sub-regions is shown in Fig. 12. The sub-region 103 (highlighted in red color) has the minimum licensed SINR which is 2.807 dB as shown in Fig. 14. It can be seen from Fig. 13 that by transmitting licensed spectrum at maximum powers by all LAA BS, the minimum $SINR^l$ is 2.782 in the sub-region 103. Hence by transmitting the licensed spectrum at optimal powers as shown in Table 5, we are maximizing the minimum $SINR^l$ and also saving energy at the same time. Fig. 15 shows the CDF of licensed and unlicensed SINR which shows the minimum SINR is maintained in licensed as well as unlicensed. 88.19% is the maximum energy saved when $SINR^u_{Th}$ is 4 dB, and 32.39% is the minimum energy saved when $SINR^u_{Th}$ is 5 dB whereas the average percentage of energy saved is 58.65% for given thresholds in the considered scenario. It can be seen from Fig. 17 that $SINR^l$ is same or better compared to that of transmitting at P^l_{max}. Hence, along with better SINR, we are saving energy compared to transmission at maximum power in licensed spectrum. Finally, Table 5 shows the optimal number of BSs, the position of BS and controlled power of each BS along with percentage energy saving for the considered scenario. The change in $SINR^u_{th}$ from 4 dB to 5 dB changes required number of BSs from 3 to 6 which result in more power consumption in case of Max power. Whereas

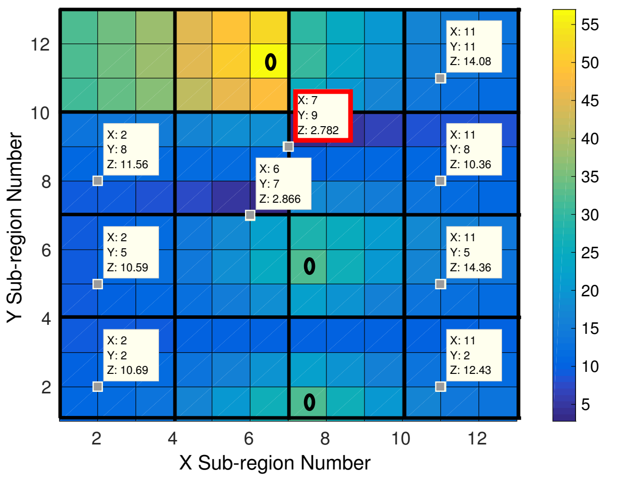

Figure 13: Licensed SINR distribution in dB with maximum power.

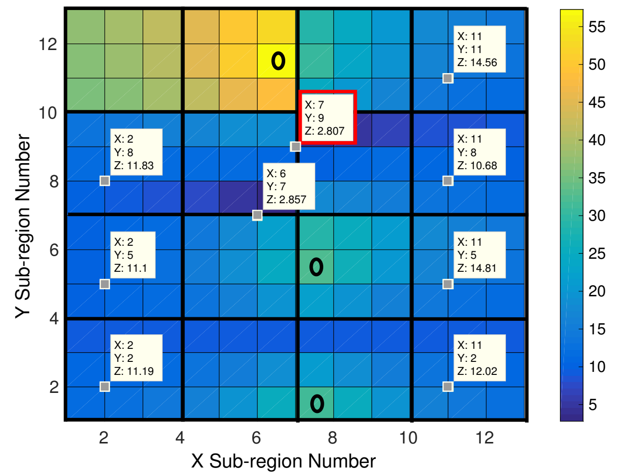

Figure 14: Licensed SINR distribution in dB with controlled power.

in the case of optimal power ($P_{control}$) the energy required varies based on locations of LAA BS. Since 4 dB was the maximum $SINR^u_{th}$ that could be achieved with 3 Femto BS it can be seen that the positions of Femto in this case would be the most optimal positions of 3 Femto. This can also be verified by seeing the energy consumed plot where the least amount of energy was required in this case.

Table 5: Results with two Wi-Fi APs at sub-region 68 and 113

$SINR^u_{th}$	0 dB	2 dB	4 dB	5 dB
No. of BS	3	3	3	6
BS sub-region	3,67, 112	32,68, 138	7,55, 126	41,69,88 92,115,126
Licensed power in dBm	13.67, 12.57, 18.32	13.26, 15.03, 19.81	10.00, 11.06, 11.02	18.26,18.75 16.93,19.99 16.94,18.14
% Energy Saving	63.58	50.42	88.19	32.39

For $SINR^u_{Th}$ up to 4 dB, we found the optimal number of BSs are three in the case of both one AP and two AP scenarios. The interesting point which we observed is, the LAA BS positions are changing with unlicensed SINR threshold and in both the cases, we found one BS is placed inside EDT region of Wi-Fi.

By varying number of Wi-Fi APs beyond 2:
To study the variation of number of LAA BSs required with varying number of Wi-Fi APs in the considered building, we considered cases having 4, 6, 8 and 10 Wi-Fi APs randomly placed (assuming only one Wi-Fi AP located in each room) inside the building. The simulation results for this are shown in Table 6. After studying the results, it is seen from the positions of Wi-Fi APs and the resulting Femto locations; one Femto BS has to be placed inside the EDT region of each Wi-Fi AP to serve the sub-regions inside EDT. Hence, for the considered building the number of Femto required to serve should be at least equal to the number of Wi-Fi APs or may be more. Since we need one Femto BS inside each Wi-Fi EDT regions, by increasing the Wi-Fi APs the number of Femto also increase. With this increase in Femto BS, there is a possibility that few sub-regions get very high interference, due to which some more Femto have to be placed in those regions to serve them, because of which we may need Femto BS more than the number of Wi-Fi APs.

Table 6: Placement of LAA BS by varying number of Wi-Fi APs

No. of Wi-Fi APs	Co-ordinates of APs (Sub-region No.)	No. of LAA BSs required	Co-ordinates of Femtos (Sub-region No.)
0	NA	3	58,74,102
2	68,113	3	3,67,112
4	54,60,85,91	5	42,70,75,79,141
6	21,54,60, 85,91,124	8	9,40,43,47, 77,99,105,136
8	15,21,54,60 85,91,124,130	10	10,27,31,55,71 86,90,118,121,126
10	15,21,24,54,60 85,91,121,124,130	10	10,27,31,55,59 74,90,109,114,118

By varying number of rooms in building:
We increased room dimensions 4×4 rooms (*i.e., 48m* × *48m* or total of 16 rooms) to 7×7 rooms (*i.e., 84m* × *84m* or

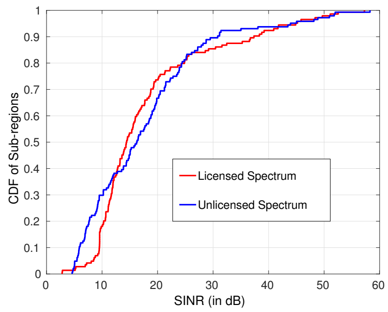

Figure 15: SINR CDF of licensed and unlicensed spectrums.

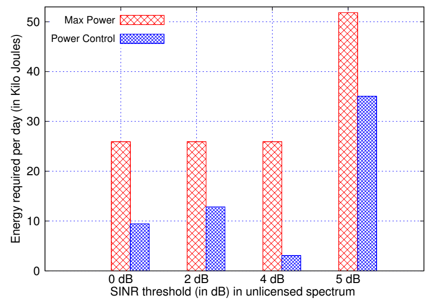

Figure 16: Energy required with maximum and controlled powers.

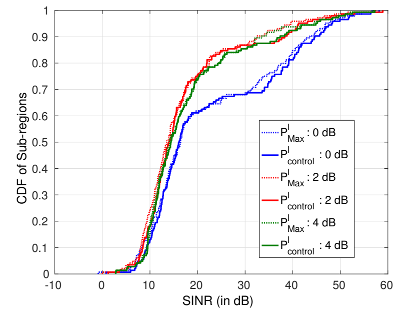

Figure 17: SINR CDF with maximum and controlled powers.

total of 49 rooms) with step size of 1×1 room and calculated number of LAA BSs required using proposed scheme. Fig.18, it is clear that increasing building dimensions and increasing $SINR_{th}^{u}$ both results in an increase in the number of LAA BSs required in the building. For 16 rooms we require 3 BS up to SINR threshold of 4 dB and then for 6 dB threshold we need minimum 4 BS. For 25 room scenario for all $SINR_{th}^{u}$ (*i.e.,* 0 dB to 6 dB) the minimum number of BSs are 4. Further for 35 rooms the number of BSs required increases to 5 for $SINR_{th}^{u}$ of 0 and 2 dB whereas it further increases to 6 for 4 and 6 dB threshold. Finally, for 49 room scenario, the number of BSs required remains 6 up to $SINR_{th}^{u}$ of 4 dB but it increased to 9 BS at $SINR_{th}^{u}$ of 6 dB.

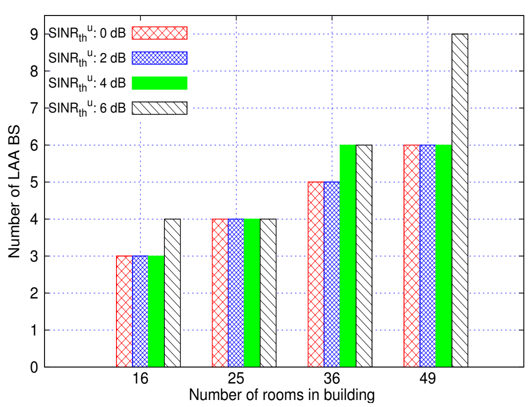

Figure 18: Number of LAA BS required with increasing number of rooms in the building.

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6 CONCLUSIONS

To guarantee minimum SINR in the licensed and unlicensed spectrum with the minimum number of Femtos, we formulated an optimal Femto placement problem with respect to unlicensed spectrum. Further energy saving model is proposed to control the transmission power of licensed spectrum such that minimum SINR of licensed spectrum in the building is maximized. The simulation results show the efficiency of proposed scheme to find the optimal number of Femtos in the presence of Wi-Fi networks. Our formulation helps to find out the optimal number of Femtos along with its locations and associativity of each sub-region to Femto. The efficiency of proposed optimization formulation is validated using sufficient simulation results in the presence of Wi-Fi AP.

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