Optimal Placement of Colocated and Non-Colocated LWA Nodes in Dense Deployments

Thomas Valerrian Pasca S†, Adharsh Srivats R¶, Antony Franklin A† and Bheemarjuna Reddy Tamma†
†Department of Computer Science and Engineering, Indian Institute of Technology Hyderabad, India
¶Department of Computer Science and Engineering, Anna University (CEG Campus), India
Email: cs13p1002@iith.ac.in, adharshsrivats@gmail.com, antony.franklin@iith.ac.in, tbr@iith.ac.in

Abstract—**Heterogeneous networks mitigate the co-tier interference which arises due to densification of homogeneous small cells deployment. LTE–Wi-Fi Aggregation (LWA) is one such realization of Hetnet which enables a tighter interworking between LTE small cells and Wi-Fi Access Points (AP) at radio level. LWA node deployment can be realized in colocated and non-colocated fashion. In this work, we have addressed the problems pertaining to dense deployment of LWA nodes. The placement of LWA nodes is done with the following objectives (i) Minimizing the number of LWA nodes without coverage hole (ii) Maximizing the Signal-to-Interference-plus-Noise Ratio (SINR) in every sub-region of a building (iii) Minimizing the power spent at the User Equipment (UE) and at the LWA node. We have formulated the problems as Mixed Integer Non-Linear Programming (MINLP) problems. The performance of the proposed optimal LWA placement has been compared with Minimum Interference Region (MIR) placement. We could observe that the proposed optimization problem has improved dual coverage region by 43% and improved SINR by 8 dB compared to MIR. Also, the proposed optimization has lead to 10% energy saving at LWA node and 36% energy saving at UE.**

I. Introduction

The demand for data is growing exponentially [1] due to data hungry applications in smartphones. It is challenging for the telecom operators to improve their cellular network capacities due to the high cost of licensed spectrum for cellular network operation. To address this ever growing demand, telecom operators look for unlicensed spectrum to cater their requirements. Long Term Evolution (LTE)–Wi-Fi Aggregation (LWA) [2] is one such technology recently standardized by the Third Generation Partnership Project (3GPP) which uses licensed and unlicensed bands simultaneously to serve the users. In LWA, the LTE small cell eNodeB (SeNB) and Wi-Fi Access Point (AP) are tightly integrated at their radio protocol stacks. Such a tighter integration has the following advantages: (i) Evolved Packet Core (EPC) need not manage Wi-Fi AP separately and it is controlled directly by SeNB. (ii) Radio level integration allows effective radio resource management across Wi-Fi and LTE. (iii) LTE acts as the anchor point for UE's communication with the network. Finer level of LTE Wi-Fi interworking is also realized at the Radio Link Control (RLC) layer [3]. Figure 1 shows the tightly integrated LTE–Wi-Fi aggregation architecture.

In this paper, we investigate the challenges in the deployment of colocated and non-colocated LWA nodes. The problem of placing LWA nodes in dense deployment is studied with the following objectives. (i) Minimize the number of LWA nodes required to serve a given building with threshold Signal-to-Interference-plus-Noise Ratio (SINR) (ii) Maximize the SINR inside the building by placing the LWA nodes at optimal locations (iii) Minimize the power spent at LWA node and at User Equipment (UE) without degrading the SINR for each UE. The objective functions are formulated as Mixed Integer Non-Linear Programming (MINLP) problems.

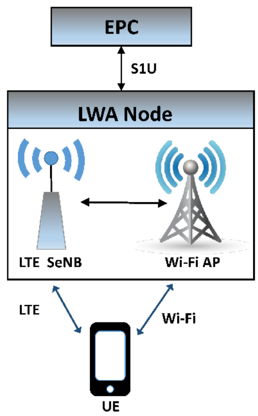


Fig. 1: LTE-Wi-Fi Aggregation architecture

The paper is organized as follows: Section 2 describes the existing literature on optimal placement of nodes. Section 3 describes the system model considered for LWA. In Section 4, the optimization problem is formulated for colocated and non-colocated deployments with different objective functions. Section 5 details thorough performance evaluation of the LWA system. Section 6 concludes the work and summarizes the insights.

II. Related Work

In this section, we discuss the literature pertaining to optimal placement of devices in dense scenario. In [4] and [5], optimal placement of single small cell inside a building is done by considering macro interference. This placement is not scalable for enterprise scenario with multiple floors. In [6], the authors have considered an enterprise scenario and formulated minimum number of LTE small cells required to ensure SINR

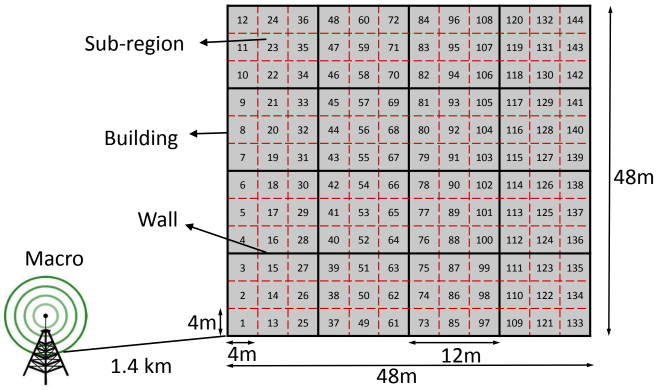


Fig. 2: Building scenario considered for modeling the problem

threshold to all regions inside a building. A limitation of this work is that the authors have considered the placement only with respect to homogeneous radio access technologies (RATs). In [7], the authors have proposed a joint femto placement and power optimization model with an objective to minimize uplink power inside the building. In this context, the authors have not considered the real challenges such as multiple walls in a building and interference from macro. In [8], the authors have detailed the challenges pertaining to tighter coupling of LTE and Wi-Fi links at physical and network layers. Authors have pointed that, in physical layer, a heterogeneous reuse of spectrum (*i.e.,* users in interference region of LTE could be served by Wi-Fi and vice-versa) would be an effective solution to handle dense deployment scenarios, but authors have not explored this property of the system. In our work, we completely focus on the colocated and non-colocated LWA deployment by considering the factors like distance between the small cell nodes and the sub-regions, interference from macro base station (in case of LTE), interference from other LWA nodes deployed and obstacles such as walls across rooms.

III. System Description

In this section, we comprehensively describe the various models which have been considered in our work.

A. Path Loss Model for LTE

We have used the 3GPP Indoor Path Loss Model (Urban Deployment) [9] for LTE.

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

Where, d is the distance of sub-region from the access point in meters, k represents the number of floors, and σ represents penetration loss in dB. In our setup, we have considered penetration loss due to walls σ as $10\ dB$.

B. Path Loss Model for Wi-Fi

We have used the International Telecommunication Union (ITU) indoor path loss model [10] for Wi-Fi. It estimates the path loss inside a room or a closed area inside a building delimited by walls of any form. This model is most suitable for the frequency range between 900 MHz and 5.2 GHz. The ITU model expression is given as follows

$$L = 20\ log_{10}(f) + N\ log_{10}(d) + P_f(n) - 28$$

Where, d is the distance of a sub-region from the access point in meters, f represents the frequency of transmission in MHz, N accounts for the distance power loss coefficient, n is the number of walls, and P_f denotes the penetration loss factor. In our setup, we have considered f = 2400 MHz and N = 30. P_f= 13 + n gives the penetration loss due to walls.

C. Building Model and Dimensions

Figure 2 shows the scenario considered for modeling the problem. Dimensions of the building considered are 48 m $\times$ 48 m $\times$ 3 m, where L x W x H corresponds to the length, width and height of the building respectively. The building has 16 rooms, each of dimension 12 m $\times$ 12 m $\times$ 3 m. Walls separate the rooms, and each room encloses nine sub-regions. Thus, the building is divided into 144 sub-regions $(I_1, I_2 ... I_{144})$. Each sub-region is of length 4 m $\times$ 4 m $\times$ 3 m, and the building has one floor. A macro base station is placed at a distance of 1.4 km from the building. As the size of a sub-region is much smaller when compared to the size of the building, we can safely assume that within every sub-region, the SINR value is constant.

IV. Optimization Model

In this section, we formulate the optimization problem for colocated (C) and non-colocated (NC) LWA deployments with three objectives, which includes

- Minimal number of LWA nodes required to ensure coverage in the building.
- Optimal placement of LWA nodes to maximize SINR inside the building.
- Optimal placement and power regulation of LWA nodes to minimize the power spent at LWA node and UE.

A. Optimal Number of LWA Nodes

Minimum number of LWA nodes required to serve the building in the case of colocated and non-colocated deployments are formulated in this section. The notations which are used in this subsection are detailed in Table I.

1) Optimal number of NC-LWA nodes required: The objective is to find the minimum number of LTE and Wi-Fi nodes that can effectively cover the building in a non-colocated scenario ensuring threshold SINR. Here, we have considered minimum LTE threshold as -2 dB and minimum Wi-Fi threshold as 0 dB. The objective function is given as

$$Minimize\ \sum_b (\alpha_b^l + \alpha_b^w) \tag{1}$$

subject to,

$$\sum_b \beta_{s,b}^l \leq 1\ \ and\ \ \sum_b \beta_{s,b}^w \leq 1 \qquad \forall s \in R_i \tag{2}$$

$$\beta_{s,b}^l \leq \alpha_b^l\ \ and\ \ \beta_{s,b}^w \leq \alpha_b^w \qquad \forall s, b \in R_i \tag{3}$$

$$\sum_{s,b} (\beta_{s,b}^l\ +\ \beta_{s,b}^w) \geq 1 \qquad \forall s, b \in R_i \tag{4}$$

$$\sum_b \alpha_b^l \geq 1\ \ and\ \ \sum_b \alpha_b^w \geq 1 \tag{5}$$

$$\frac{Inf \times (1-\beta^l_{s,b}) + (\delta^l_{s,b}\ P^l_{max}\ \alpha^l_b)}{N_o + \sum\limits_{c \in R_i \setminus b} \delta^l_{s,c} P^l_{max} \alpha_c + \sum\limits_{e \in M} \delta^l_{s,e} P^m_{max}} \geq \lambda_l \quad \forall s, b \in R_i \tag{6}$$

$$\frac{Inf \times (1-\beta^w_{s,b}) + (\delta^w_{s,b}\ P^w_{max}\ \alpha^w_b)}{N_o + \sum\limits_{c \in R_i \setminus b} \delta^w_{s,c}\ P^w_{max}\ \alpha_c} \geq \lambda_w\ \forall s, b \in R_i \tag{7}$$

Equation (1) minimizes the sum over number of LTE small cells and Wi-Fi APs to be deployed in order to ensure threshold SINR in every sub-region of the building. Equation (2) and Equation (3) constrains a user in a subregion to be connected to utmost one LTE small cell and one Wi-Fi AP. Equation (4) ensures that a sub-region has atleast one LTE or Wi-Fi connectivity. It does not restrict a sub-region from connecting to both. Equation (5) ensures that atleast one LTE small cell and one Wi-Fi AP must exist in the non-colocated LWA placement.

For a user equipment at sub-region s to be connected to an LTE small cell or Wi-Fi AP at b, the sub-region has to obtain minimum SINR from that LTE small cell or Wi-Fi AP. Equation (6) captures this constraint on LTE SINR and Equation (7) on the Wi-Fi SINR. In the case of LTE, the macro interference is also considered. Inf in Equation (6) is an infinitely large value which is introduced for a solver to compute faster. Inf signifies that, if a sub-region s is not associated with LTE small cell or Wi-Fi AP at sub-region b, then the SINR becomes infinite. Hence the optimization solver ignores such cases.

TABLE I: Notations used in optimization model

Symbol	Definition
R_i	Set of all sub-regions
α^l_b	1 if a LTE small cell is placed at sub-region b, 0 otherwise
α^w_b	1 if Wi-Fi AP is placed at sub-region b, 0 otherwise
$\beta^l_{s,b}$	1 if sub-region s is connected to LTE small cell at b, 0 otherwise
$\beta^w_{s,b}$	1 if sub-region s is connected to Wi-Fi AP at b, 0 otherwise
$\delta^l_{s,b}$	LTE channel gain between s and b sub-regions.
$\delta^w_{s,b}$	Wi-Fi channel gain between s and b sub-regions.
γ^l_b	LTE SINR observed at sub-region b.
γ^w_b	Wi-Fi SINR observed at sub-region b.
P^l_b	LTE transmit power of LWA node or UE located at sub-region b.
P^w_b	Wi-Fi transmit power of LWA node or UE located at sub-region b.
P^m_{max}	Maximum power of macro base station
N_o	System Noise
M	Macro base station

2) Optimal number of C-LWA nodes required: Minimum number of colocated LWA nodes that can effectively cover the building with minimum SINR at every sub-region is given by

$$Minimize \sum_b (\alpha^l_b + \alpha^w_b) \tag{8}$$

The objective function expressed for colocated and non-colocated LWA in Equation (8) and Equation (1) are similar and their constraint functions remain the same too. The only additional constraint that the colocated deployment possesses over non-colocated deployment is the constraint on the position of LTE small cells and Wi-Fi APs.

$$\alpha^l_b \ - \ \alpha^w_b \ = \ 0 \qquad \forall b \in R_i \tag{9}$$

Equation (9) states that the location of the LTE and Wi-Fi small cells must be in the same sub-region, as a colocated deployment involves placing them together in the same box.

B. Optimal placement of C-LWA and NC-LWA nodes to Maximize SINR

The number of LTE small cells and Wi-Fi APs that have to be deployed in the building is obtained as the result of the above section. Given the number of LTE small cells and Wi-Fi APs, placing them at the optimal locations will maximize the overall SINR of the building ensuring minimum SINR for every sub-region. The objective function to maximize SINR is given by

$$Maximize \sum_b (\gamma^l_b + \gamma^w_b) \tag{10}$$

subject to,

$$\frac{Inf \times (1-\beta^l_{s,b}) + (\delta^l_{s,b}\ P^l_{max}\ \alpha^l_b)}{N_o + \sum\limits_{c \in R_i \setminus b} \delta^l_{s,c} P^l_{max} \alpha_c + \sum\limits_{e \in M} \delta^l_{s,e} P^m_{max}} \geq \lambda_l \quad \forall s, b \in R_i \tag{11}$$

$$\frac{Inf \times (1-\beta^w_{s,b}) + (\delta^w_{s,b}\ P^w_{max}\ \alpha^w_b)}{N_o + \sum\limits_{c \in R_i \setminus b} \delta^w_{s,c}\ P^w_{max}\ \alpha_c} \geq \lambda_w\ \forall s, b \in R_i \tag{12}$$

$$\sum_b \alpha^l_b = N^L \ \ and \ \sum_b \alpha^w_b = N^W \tag{13}$$

$$\sum_b \beta^l_{s,b} \leq 1 \ \ and \ \ \sum_b \beta^w_{s,b} \leq 1 \qquad \forall s \in R_i \tag{14}$$

$$\beta^l_{s,b} \leq \alpha^l_b \ \ and \ \ \beta^w_{s,b} \leq \alpha^w_b \qquad \forall s, b \in R_i \tag{15}$$

γ^l_b and γ^w_b denote the LTE SINR and Wi-Fi SINR observed at sub-region b, respectively. N^L and N^W denotes the number of LTE and Wi-Fi nodes obtained from the previous sub-problems.

C. Power Optimization

Power control in radio level interworking architecture reaps highest improvement in dense deployment scenario [11]. The placement of LWA nodes plays a vital role in optimizing the power spent both at the LWA node and the UE. We have formulated the optimization problem with the objective to minimize the energy spent at LWA node and at UE by placing the LWA nodes at optimal locations and also by setting optimal transmit power at LWA node.

1) Power optimization at LWA nodes to save energy: Energy spent at LWA node can be reduced by minimizing the transmit power of LWA node still ensuring threshold SINR to every associated sub-region.

$$Minimize \sum_{b \in R_i} ((\alpha^l_b * P^l_b) + (\alpha^w_b * P^w_b)) \tag{16}$$

subject to,

$$\frac{Inf \times (1-\beta^l_{s,b}) + (\delta^l_{s,b}\ P^l_b\ \alpha^l_b)}{N_o + \sum\limits_{c \in R_i \setminus b} \delta^l_{s,c} P^l_b \alpha_c + \sum\limits_{e \in M} \delta^l_{s,e} P^m_{max}} \geq \lambda_l \quad (17)$$
$$\forall s, b \in R_i$$

$$\frac{Inf \times (1-\beta^w_{s,b}) + (\delta^w_{s,b}\ P^w_b\ \alpha^w_b)}{N_o + \sum\limits_{c \in R_i \setminus b} \delta^w_{s,c}\ P^w_b\ \alpha_c} \geq \lambda_w\ \forall s, b \in R_i \quad (18)$$

$$P^l_{min} \leq P^l_b \leq P^l_{max}\ \forall b \in R_i \quad (19)$$

$$P^w_{min} \leq P^w_b \leq P^w_{max}\ \forall b \in R_i \quad (20)$$

$$\beta^l_{s,b} \leq \alpha^l_b \ \ and\ \ \beta^w_{s,b} \leq \alpha^w_b \qquad \forall s, b \in R_i \quad (21)$$

$$\sum_b \alpha^l_b = N^L \ \ and\ \ \sum_b \alpha^w_b = N^W \quad (22)$$

Equation(16) shows the objective function to minimize the energy spent at LWA node. Constraints shown in Equations (17)-(22) ensure the SINR, power and associativity conditions.

2) Power optimization to save UE energy: The energy spent at UE can be reduced by placing the LWA nodes at optimal positions. We formulate the optimization problem to find the optimal locations for the LWA nodes which can minimize the energy spent at UE as follows

$$Minimize \sum_{b \in R_i} ((\beta^l_{s,b} * P^l_b) + (\beta^w_{s,b} * P^w_b)) \quad (23)$$

subject to,

$$\frac{Inf \times (1-\beta^l_{s,b}) + (\delta^l_{s,b}\ P^l_b\ \alpha^l_b)}{N_o} \geq \lambda_l\ \forall s, b \in R_i \quad (24)$$

$$\frac{Inf \times (1-\beta^w_{s,b}) + (\delta^w_{s,b}\ P^w_b\ \alpha^w_b)}{N_o} \geq \lambda_w\ \forall s, b \in R_i \quad (25)$$

$$P^l_{min} \leq P^l_b \leq P^l_{max}\ \forall b \in R_i \quad (26)$$

$$P^w_{min} \leq P^w_b \leq P^w_{max}\ \forall b \in R_i \quad (27)$$

$$\beta^l_{s,b} \leq \alpha^l_b \ \ and\ \ \beta^w_{s,b} \leq \alpha^w_b \qquad \forall s, b \in R_i \quad (28)$$

$$\sum_b \alpha^l_b = N^L \ \ and\ \ \sum_b \alpha^w_b = N^W \quad (29)$$

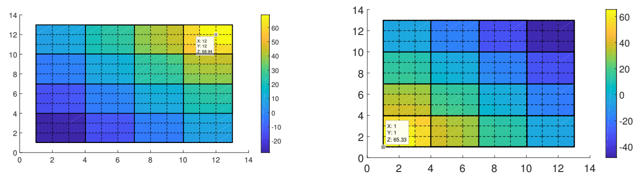
The objective function shown in Equation (23) minimizes the overall energy spent by UE located in every sub-region. We have assumed that the number of UEs in each sub-region is same. Equations (24)–(29) show the constraints on SINR, power and association. Solving the problem gives the optimal locations to place LWA nodes and optimal power for transmission.

V. Performance Evaluation

The performance of LWA in case of colocated and non-colocated deployments are evaluated for three different objective functions. The results are compared with the placement of LWA nodes at Minimum Interference Region (MIR). MIR is the ideal way of placing LWA node, *i.e.,* LTE small cell is placed in the building at a sub-region with minimum interference and Wi-Fi AP is placed in a sub-region with maximum interference from the LTE macro. Thereby potential sub-regions which receive high interference from macro are served using Wi-Fi.

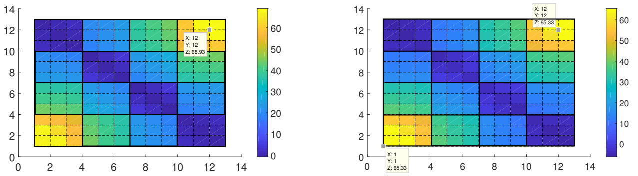
A. Optimal Number of NC-LWA and C-LWA nodes

The optimal number of LWA nodes required to cover the given building dimension in non-colocated deployment is found to be one LTE small cell and one Wi-Fi AP. Figure 3 shows SINR distribution when the LTE small cell and Wi-Fi AP are placed at MIR. This set up ensures minimum SINR to every sub-region either through LTE or Wi-Fi or both. In case of colocated deployment, the optimal number of nodes to be placed is found to be two *i.e.,* two LTE small cells and two Wi-Fi APs. Figure 4 captures the SINR distribution when the colocated nodes are placed at MIR in the building.



(a) LTE SINR graph **(b)** Wi-Fi SINR graph

Fig. 3: Non-colocated LWA placement at MIR

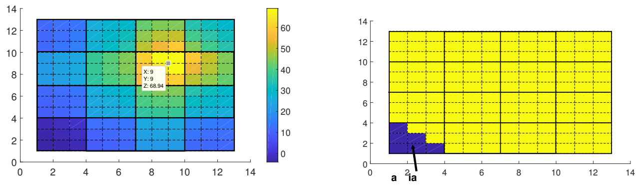


(a) LTE SINR graph **(b)** Wi-Fi SINR graph

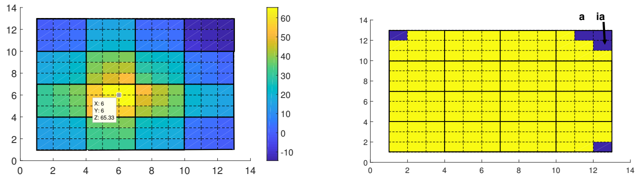
Fig. 4: Colocated LWA placement at MIR

B. Maximize SINR in C-LWA and NC-LWA

The LWA nodes placed at MIR does not ensure maximized SINR. Solving equation (10) gives the optimal positions for LTE small cells and Wi-Fi APs in case of colocated and non-colocated deployments. Figures 5a and 5b capture the LTE and Wi-Fi SINR distribution across different sub-regions in the building when LTE and Wi-Fi APs are placed at optimal positions. It can be noted from the figures that in case of optimal placement, LTE and Wi-Fi could not serve all the sub-regions individually. But when combined they could serve the entire building. In case of colocated LWA, we have obtained from the above optimization problem that two LWA nodes are required to serve all the sub-regions in the building. Figures 6a and 6b capture the LTE and Wi-Fi SINR in the building. They also capture the sub-regions associated with the respective LTE small cells and Wi-Fi APs. It is clear from the figures that LTE small cells in colocated LWA deployment could serve all the sub-regions but Wi-Fi APs fail to serve some sub-regions. We have compared the SINR distribution of all the sub-regions in case of optimal and MIR placement of the LWA nodes. Figure 7 shows the comparison between non-colocated LWA optimal placement and MIR placement. Figure 8 captures the SINR improvement for sub-regions in

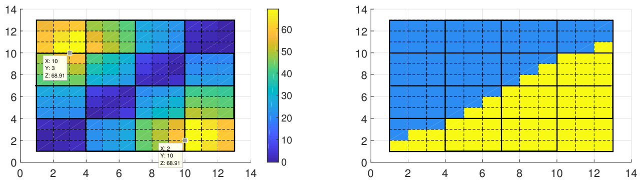


(a) LTE SINR and sub-regions associativity

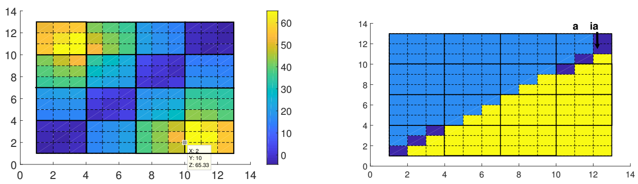


(b) Wi-Fi SINR and sub-regions associativity

Fig. 5: Non-Colocated - Optimal Placement



(a) LTE SINR and sub-regions associativity



(b) Wi-Fi SINR and sub-regions associativity

Fig. 6: Colocated - Optimal Placement

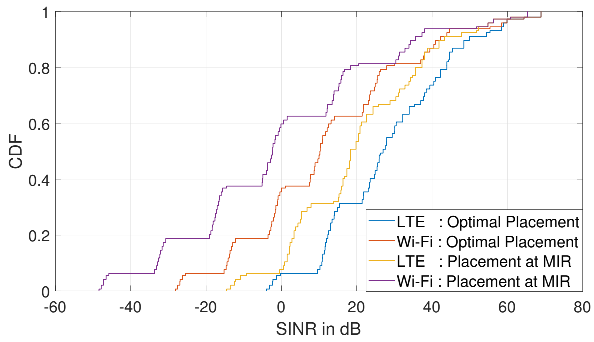


Fig. 7: CDF plots for all the sub-region SINR value in non-colocated scenario

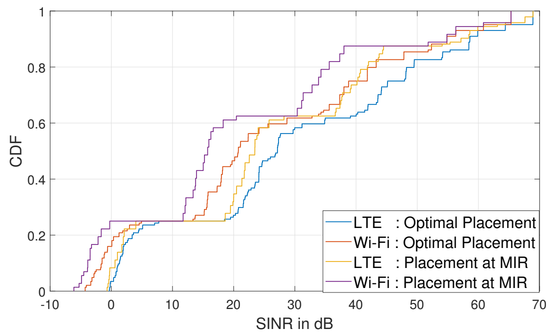


Fig. 8: CDF plots for all the sub-region SINR value in colocated scenario

case of optimal placement compared to MIR placement in a colocated LWA deployment. Optimal placement of LTE and Wi-Fi has improved average SINR by 8 dB compared to MIR placement. This is because MIR placement focuses on minimizing the co-tier interference (either with macro or with other small cell) but it fails to maximize SINR for every sub-region. From figures 5a and 5b, it is clear that optimal locations for maximizing SINR lie towards the center of the building but MIR placement is confined towards the corners. Figures 9 and 10 show the number of sub-regions associated only with LTE, only with Wi-Fi and both LTE and Wi-Fi in case of colocated and non-colocated deployments. It can be clearly observed that the number of sub-regions associated with both LTE and Wi-Fi in case of optimal position has improved by 43% on average compared to LWA placement at MIR.

C. Power Optimization

In order to minimize the power spent at LWA node and at UE, the LWA nodes have to be placed in optimal locations and varying the power of LWA nodes still ensures the threshold SINR in all the sub-regions. The optimization problem described in Section IV-C with the above objectives is evaluated here. The optimization problem thrives to obtain the optimal locations for placement of LWA nodes and minimal power that can cover all the sub-regions.

1) Power optimization at LWA node: The energy consumed by the LWA node has a significant difference when the power values are optimized. A comparison is made between the energy values when the nodes are operated at full power and placed at MIR, also with optimal power and placed at optimal positions. Figures 11 and 12 capture the energy spent in Joules in case of non-colocated and colocated LWA deployments. Setting optimal transmit power at LWA nodes has reduced the energy spent by 15% and 72% as compared to full power operation of LWA node in non-colocated and colocated deployments respectively. This is because the number of LTE and Wi-Fi nodes are high in colocated compared to non-colocated deployment and in case of colocated deployment the optimal reuse of the spectrum is employed. The optimal reuse of spectrum involves regulation of power in LTE and Wi-Fi links of LWA node. In a given LWA node, the UEs in the inner coverage region are served using LTE and those UEs which lie in the outer coverage region node are be served using Wi-Fi. This pattern [8] happens alternatively in adjacent colocated LWA node (where the outer coverage region is served by LTE and inner coverage is served by Wi-Fi). This alternate pattern avoids outer coverage region of two adjacent colocated LWA nodes served using the same RAT viz., LTE or Wi-Fi, thereby using the spectrum efficiently.

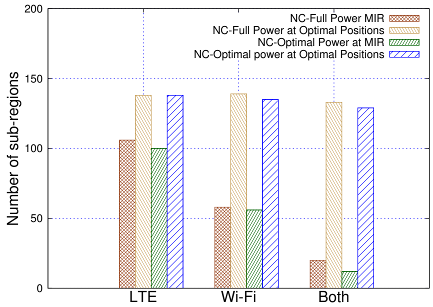


Fig. 9: Sub-regions associativity : Non-colocated placement

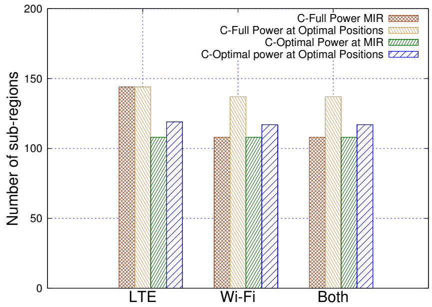


Fig. 10: Sub-regions associativity : Colocated placement

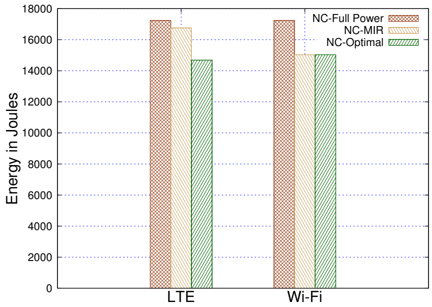


Fig. 11: Energy consumed at LWA node : Non-colocated placement

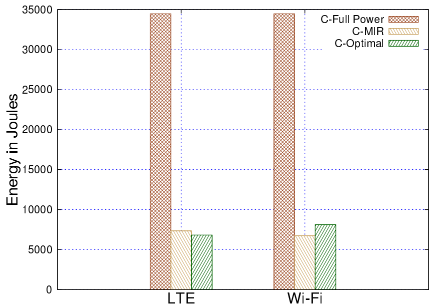


Fig. 12: Energy consumed at LWA node : Colocated placement

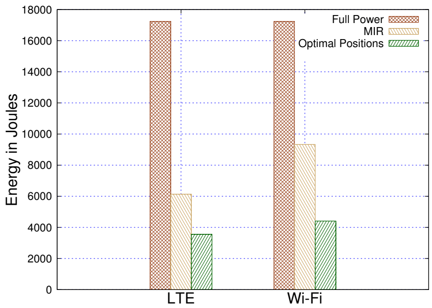


Fig. 13: Average energy spent by an UE : Non-colocated placement

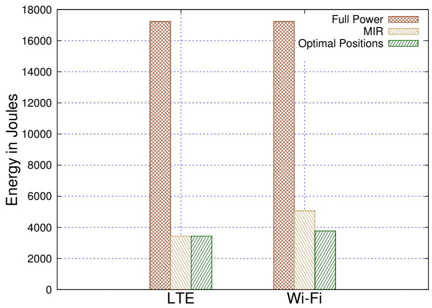


Fig. 14: Average energy spent by an UE : Colocated placement

2) Power Optimization at UE: The power spent at UE side can be minimized by placing the LWA nodes at optimal locations. Figures 13 and 14 capture the energy spent at UE for different deployment scenarios. In case of non-colocated deployment, placement at optimal locations has reduced the energy spent at UE side by 47% as compared to placement at MIR. In case of colocated deployment, the energy spent at UE has reduced by 25% compared to operating LWA nodes at MIR. In both figures, full power is given for reference which shows the energy spent by each UE if they operate at full power. Placement concerning UE power optimization has reduced the energy expenditure by 46% as compared to a UE operating with full power.

VI. Conclusions and Future Work

The placement of LWA nodes has a significant impact on the SINR and the rate achieved in different sub-regions of a building. We have addressed the placement problem with three major objectives, which include (i) Minimizing the number of LWA nodes to be placed (ii) Maximizing the SINR for all sub-regions (iii) Minimizing the power spent at UE and LWA nodes. Solutions obtained for these optimization problems have improved the performance of LWA system significantly. The optimization solutions have achieved 8 dB improvement in SINR and 43% improvement in dual coverage compared to MIR placement. Also, the power optimization solution leads to 10% power saving at LWA node and 36% power saving at UE side compared to MIR placement. As a part of future work, we wish to extend the above work by employing mixed deployment of colocated and non-colocated LWA nodes which can improve with coverage without degrading UE data rates.

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