On Placement of LAA/LTE-U Base Stations in Heterogeneous Wireless Networks

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Outline

- Introduction to LAA/LTE-U
- Motivation
- System Model of Proposed Scheme
- Objective
- Performance Evaluation
- Conclusions
- References

Abbreviations

- LAA - Licensed Assisted Access
- LTE-U - Long Term Evolution in Unlicensed Spectrum
- BS - Base Station
- AP - Access Point
- SINR - Signal to Interference plus Noise Ratio
- EDT - Energy Detection Threshold
- CSAT - Carrier Sense Adaptive Transmission
- LBT - Listen Before Talk
- EDT - Energy Detection Threshold

Introduction

- There is an ever increasing demand for mobile data [1].
- Most of the traffic demand is from indoor scenarios [2].

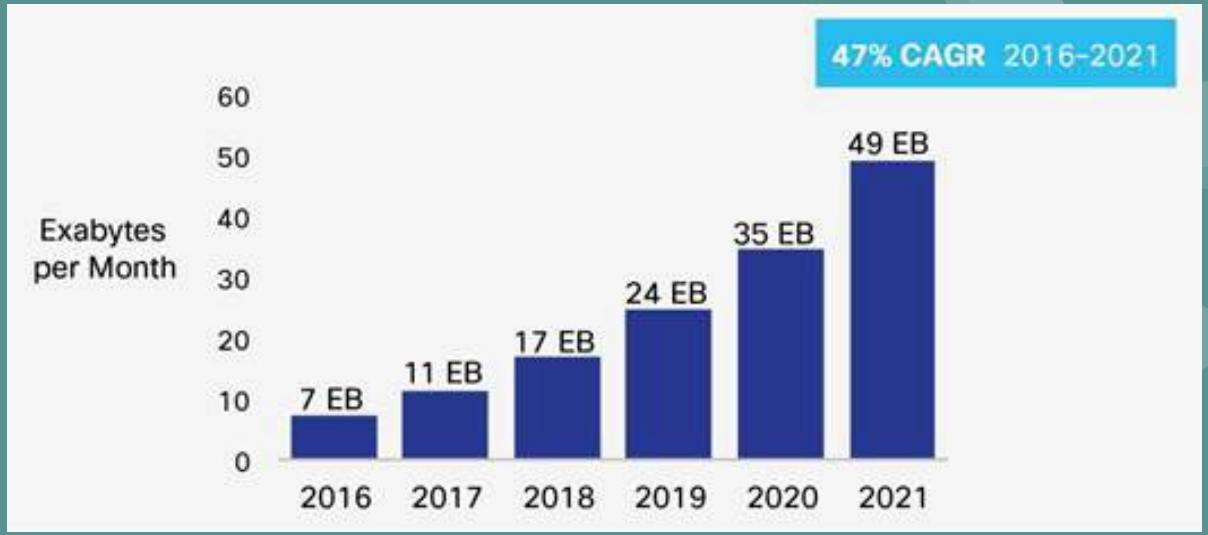

Figure 1: Growth in Mobile Traffic

Motivation

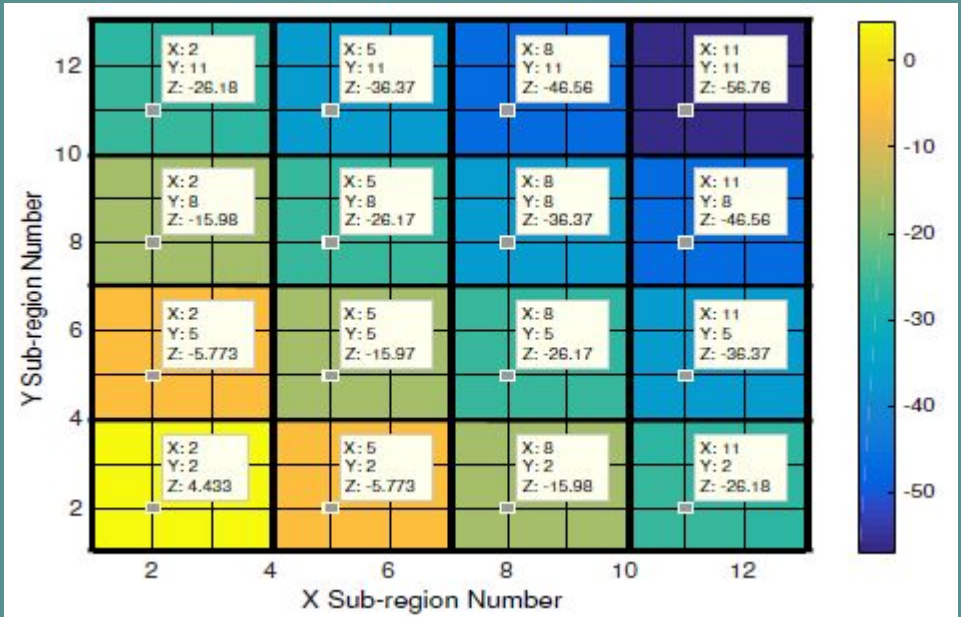

Figure 2: SINR Distribution with Macro BS

- In large buildings like apartments, malls, cricket stadiums, etc., the data rate of the users drop drastically compared to outdoor data rates.
- **Building dimensions:** 48m x 48m x 3m
- **Position of Macro BS:** 500m away from first sub-region in both horizontal and vertical directions.

Indoor Scenario

- As most of the users consuming more data are indoor users, the low SNR in the indoor regions (high penetration losses) is a very critical problem that needs to be addressed.
- One way to solve this problem is by the use of small and low power BS.
- Optimal placement of these BS will lead to maximum spectral efficiency.
- Licensed Spectrum is limited and costly.
- Limited Licensed Spectrum leads to increase in data traffic demand.
- Use of Unlicensed Spectrum is considered as one of the promising solutions.

Coexistence of LTE in Unlicensed Spectrum

- Achieved by sharing with other technologies like Wi-Fi, if the LAA/LTE-U BS is in the EDT region of Wi-Fi.
- LTE follows ON and OFF cycle [3] so that Wi-Fi can get access to channel in OFF time (CSAT).
- This mechanism is possible only in those countries where LBT is not mandatory (like India and USA) [4].
- Licensed spectrum is used for sending control signals.
- Carrier Aggregation helps to aggregate Licensed and Unlicensed spectrum.

System Model

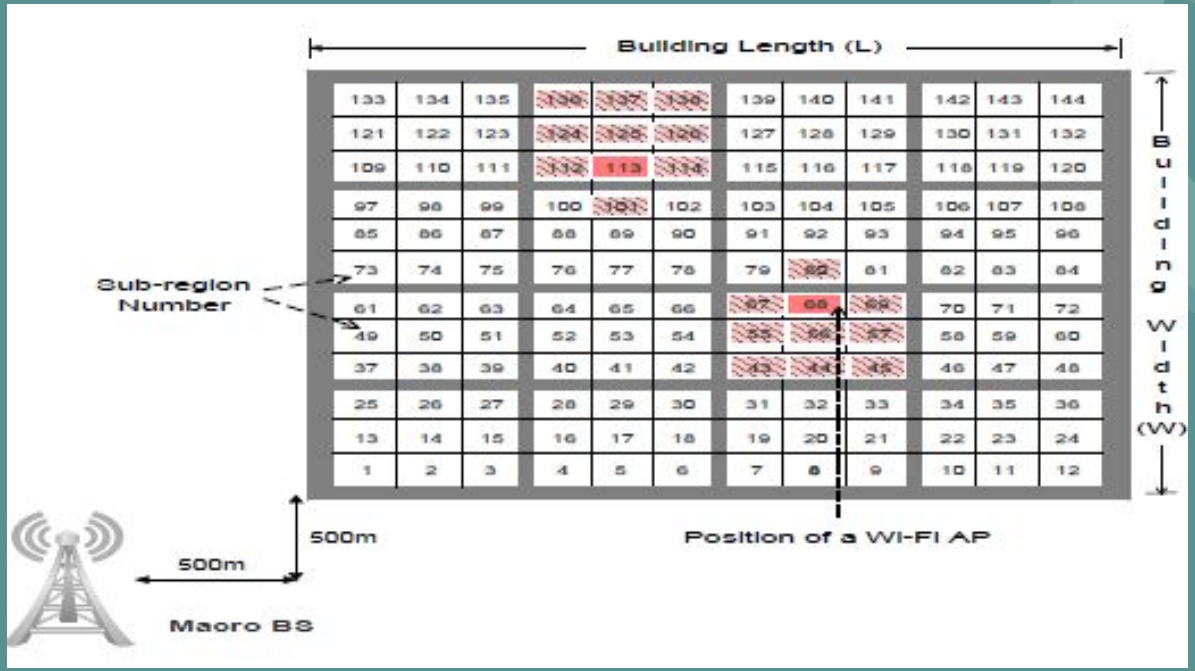

Figure 3:
System model with building having 16 rooms with one Macro BS outside the building and Wi-Fi APs inside the building with energy detection region.

Channel Model

- The path loss (in dB) between Macro BS located outside the building and the indoor sub-regions of the building [5] is

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

- The path loss in dB between LAA BS transmitting in unlicensed spectrum and sub-region is

$$PL^{u}_{Femto} = 20 \log_{10} f + 30 \log_{10} d + N\sigma^{u} - 28$$

- The path loss in dB between LAA BS transmitting in licensed spectrum and sub-region is

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

- The path loss between Wi-Fi AP and the sub-region remains the same as LAA BS in Unlicensed Spectrum

Objective

- Minimum SINR threshold in each sub-region for both Licensed and Unlicensed Spectrum with minimum number of Femto BS (MinLF).

- Maximize the minimum SINR of Licensed Spectrum in the indoor area by controlling the transmission Power (MinLPower).

Challenges

- Coverage of Unlicensed Spectrum is less compared to that of Licensed Spectrum.

- LTE in Unlicensed Spectrum is operating at 5 GHz which is very high compared to Licensed Spectrum (400 MHz to 2.6 GHz).

- Penetration Losses through walls and floors are high for Unlicensed Spectrum.

MinLF Model

- Placing the LAA/LTE-U BS based on Unlicensed Coverage.
- Transmission of Unlicensed Spectrum at P^{u}_{max}, to minimize the number of LAA/LTE-U BS.
- Licensed Spectrum coverage is better compared to Unlicensed Spectrum and if it is transmitted at maximum Power P^{l}_{max}, there will be co-tire interference.
- To improve SINR in Licensed Spectrum transmission has to be done at lower powers (MinLPower 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 region of Wi-Fi located in sub-region c

Table 1:
Glossary of MinLF Model

Formulation

- Objective is to minimize the number of LAA/LTE-U BS,

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

- To make sure that each sub-region is associated with only one Femto BS,

$$\sum_{a \in S_i} y_{ja} = 1 \forall j \in S_i \qquad y_{ja} - x_a \leq 0 \forall j, a \in S_i$$

Formulation

- To place at most one LAA/LTE-U BS in EDT region of Wi-Fi AP if necessary,

$$\sum_{d \in EDT_c} x_d \leq 1, \forall c \in S_c$$

- The following are the interferences of a sub-region associated with a Femto BS,
  - Interference from other Femto BS
  - Interference from Wi-Fi APs

Formulation

- Interference from other Femto BSs (Foreign Femto) :-
  - If Foreign Femto lies inside the EDT of any Wi-Fi AP
    - Interference from Femto during LAA/LTE-U ON cycle (Neglected)
    - Interference from Wi-Fi AP during LAA/LTE-U OFF cycle (almost same as that during LAA/LTE-U ON cycle due to similar characteristics and is considered for entire cycle).
  - **If Foreign Femto lies outside EDT** of any Wi-Fi AP, then interference from this BS exists for the entire cycle (w_b used).

Formulation

- Interference from Wi-Fi APs (Z_{ca} used) :-
  - If Home Femto lies inside the EDT of Wi-Fi AP
    - No interference from this Wi-Fi AP.
  - If Home Femto lies outside the EDT of Wi-Fi AP
    - Interference from these Wi-Fi APs is considered.

Formulation

- To maintain the $SINR^u_{th}$ in all the sub-regions,

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

- To find out the sub-regions inside the EDT region of Wi-Fi AP,

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

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

Formulation

- The formulation of MinLF Optimization Problem is Mixed Integer Linear Programming (MILP).
- It is solved using CPLEX solver in GAMS [6].
- MinLF model provides the optimal locations of LAA/LTE-U BS with respect to Unlicensed spectrum and connectivity of sub-regions in the building.

MinLPower Model (For Licensed Spectrum)

- After optimal placing of LAA/LTE-U BSs w.r.t Unlicensed Spectrum, the power control in Licensed Spectrum is necessary.
- Maximizing the minimum SINR to achieve the following,
  - Boosting the SINR in indoor sub-regions by increasing the minimum SINR in the building to the extent possible.
  - Power saving by finding optimal transmission powers.

Notation	Definition
g^l_{ja}	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^l_{max}	Maximum transmission power in licensed spectrum
P^l_{min}	Minimum transmission power in licensed spectrum
$SINR^l_{th}$	Minimum SINR in each sub-region
P^l_a	Optimized transmission power of Femto BS present in sub-region a
$SINR^l_j$	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

Table 2:
Glossary of MinLPower Model

Formulation

- Objective function is - $maximize(min(SINR_j^l)); \forall j \in S_i$
- SINR of licensed spectrum in each sub-region,

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

- Transmission power constraint,

$$P_{min}^l \leq P_a^l \leq P_{max}^l; \forall a \in S_i$$

Formulation

- To ensure $SINR_{th}^{l}$ in each sub-region,

$$\frac{g_{ja}^{l} P_{a}^{l} w_{a} y_{ja}}{N_o + \sum_{b \in S_i \setminus a} g_{jb}^{l} P_{a}^{l} w_b + \sum_{e \in M} G_{je} P_{macro}} \geq SINR_{th}^{l}; \forall j, a \in S_i$$

- The above optimization formulation is MINLP which cannot be solved easily using the traditional MINLP algorithms.
- Used Genetic Algorithm to solve and find the transmission power.

Genetic Algorithm

- Performs Mutation and Crossing Over of population set to form a set of available solutions.
- Uses Fitness Value to select the best possible solution.
- Fitness function is maximizing the minimum value of SINR in the building.
- It is sub-optimal because the solution varies with the population set.

Performance Evaluation

- Used GAMS CPLEX solver to solve MinLF model.
- Used GA toolbox in MATLAB to solve MinPower model.

Parameter	Value
Building dimensions	48 m × 48 m × 3 m
Room dimensions	12 m × 12 m × 3 m
Sub-region dimension	4 m × 4 m × 3 m
Number of Rooms	16
Number of inner Sub-regions	144
$SINR^{l}_{Th}$ (MinLF method)	-2 dB
$SINR^{u}_{Th}$ (MinLF method)	4 dB
Wall loss (Licensed)	10 dB
Wall loss (Unlicensed)	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 (0.1 W)
EDT	-62 dBm

Table 3:
Simulation Parameters

In the presence of two Wi-Fi APs

- Wi-Fi APs at sub-region 68 and 113.
- Solve MinLF model to obtain the optimal locations of LAA/LTE-U BS and connectivity of sub-regions.
- Solve MinLPower to obtain Licensed transmission Powers for each BS.

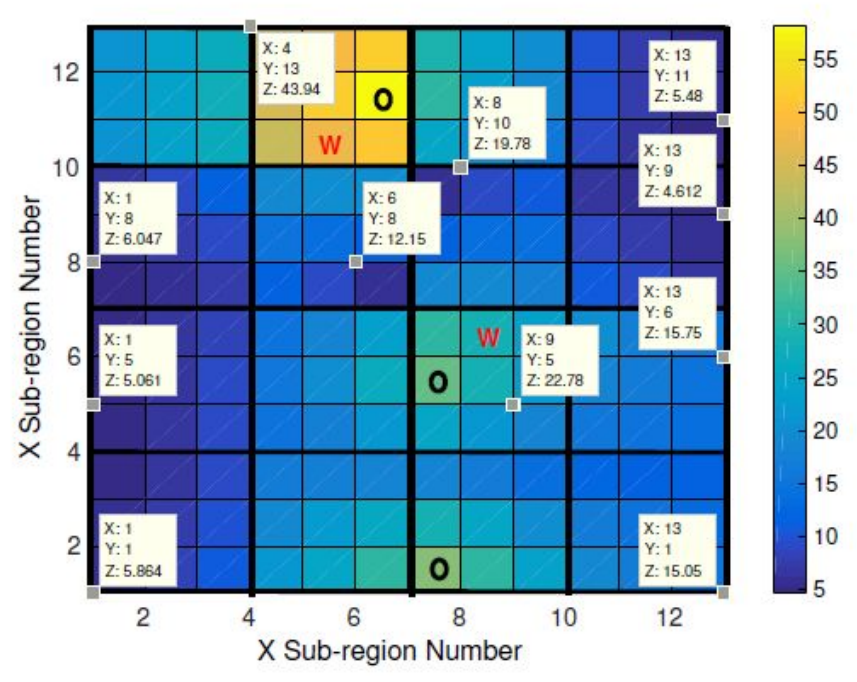

Figure 11:
SINR (in dB) in Unlicensed Spectrum

- LAA BS at (7,55,126)
- $SINR_{th}^{u}$ (i.e., 4dB) is maintained everywhere.
- It is observed that inside EDT of Wi-Fi there has to be a LAA/LTE-U BS so that it shares the channel and the Interference reduces.

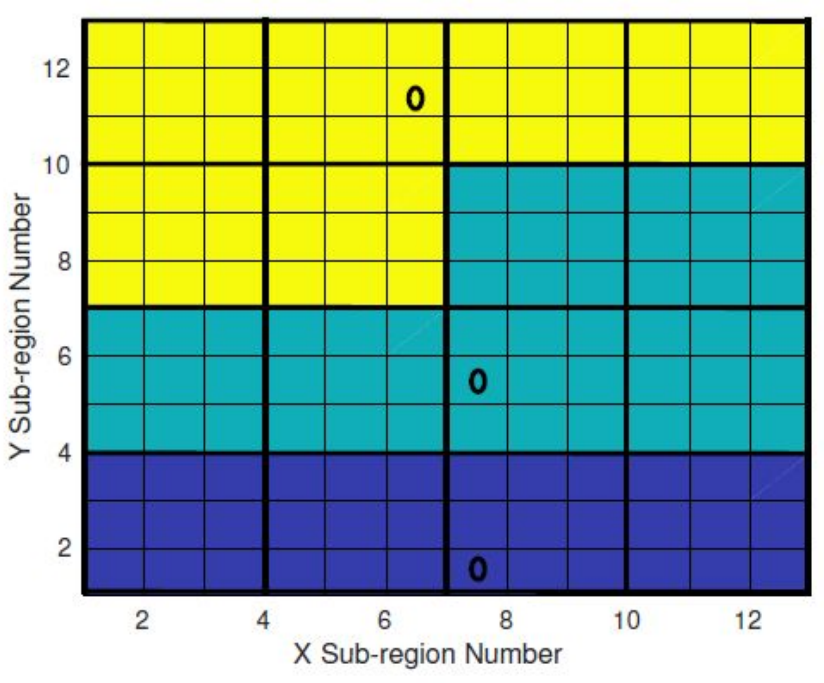

Figure 12:
Connectivity of sub-regions

- By just changing the positions of LAA/LTE-U BS the $SINR_{th}^{u}$ (i.e., 4dB) is maintained everywhere.

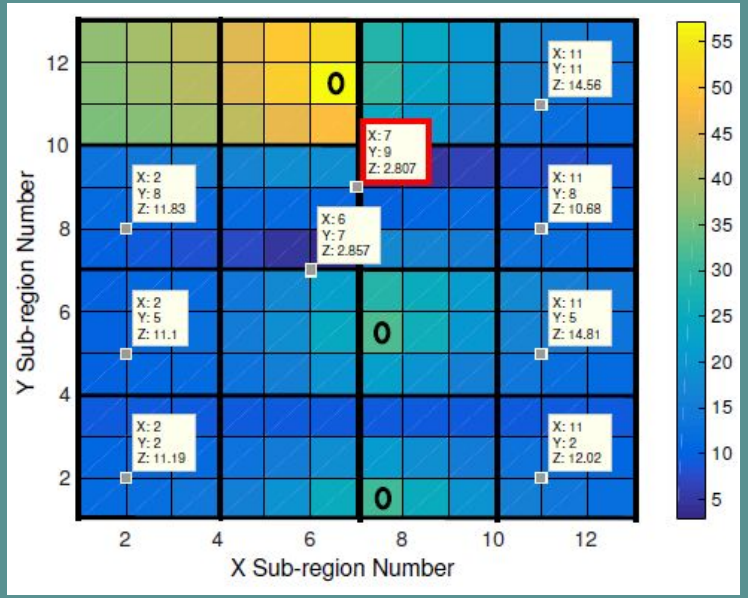

Figure 13: SINR (in dB) Licensed Spectrum with MinLPower Scheme

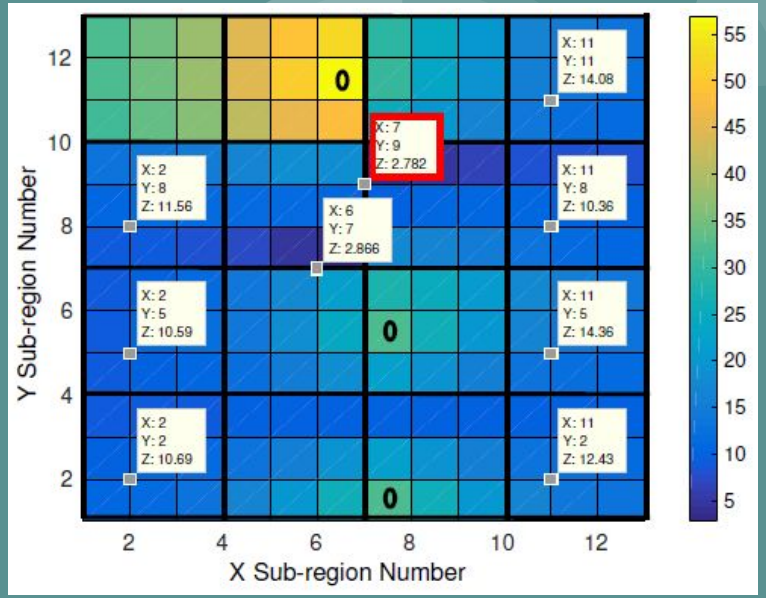

Figure 14: SINR (in dB) Licensed Spectrum with MaxLPower

- $SINR_{th}^{l}$ (i.e., -2 dB) is maintained everywhere
- Sub-region **103** has the least SINR (**2.807** with Power Control and **2.782** without Power Control)

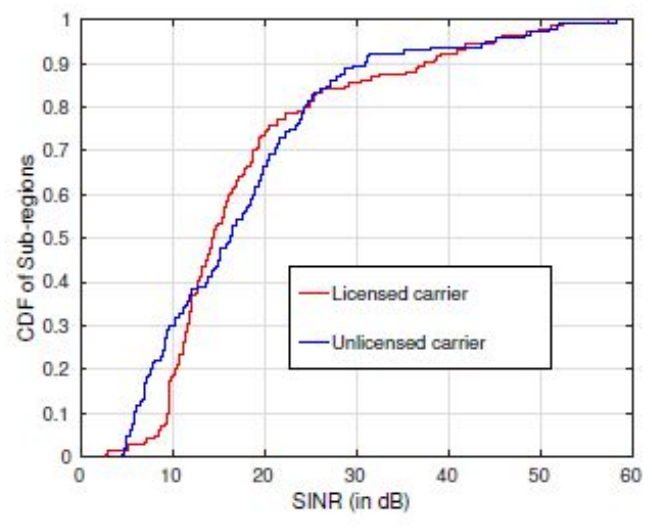

Figure 15: SINR CDF of Licensed and Unlicensed carriers

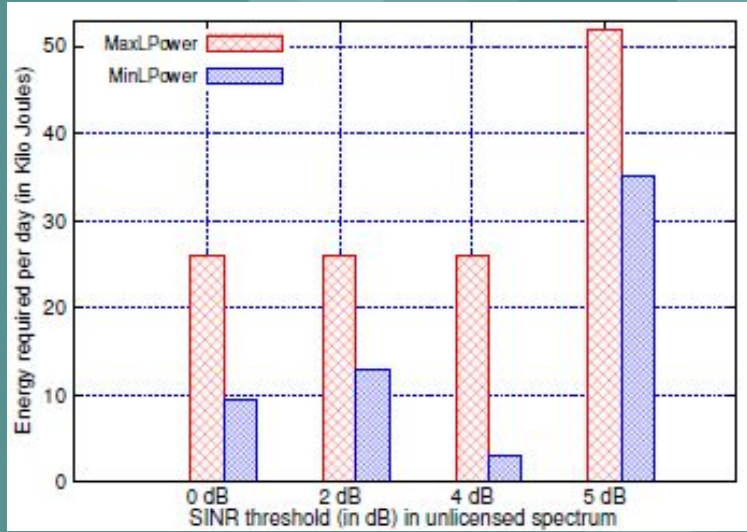

Figure 16: Energy required with MaxLPower and MinLPower schemes

- Minimum number of LAA BSs required still remains the same (i.e., 3) till 4 dB and increases to 6 for 5 dB.

$SINR_{th}^{u}$	0 dB	2 dB	4 dB	5 dB
No. of BSs	3	3	3	6
BS sub-region no.	3,67, 112	32,68, 138	7,55, 126	41,69,88 92,115,126
Tx power (dBm) in licensed	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 Savings	63.58	50.42	88.19	32.39

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

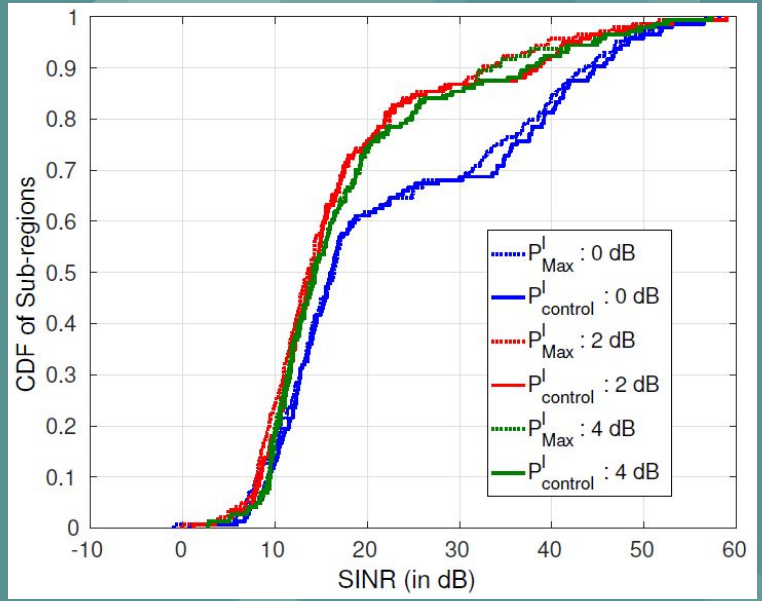

Figure 17: SINR CDF of Licensed Spectrum with MaxLPower and MinLPower Schemes

By varying number of Wi-Fi APs beyond 2

No. of Wi-Fi APs	Co-ordinates of APs (Sub-region No.)	LAA BSs re-quired	Co-ordinates of Femtos (Sub-region No.)
0	–	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

Table 6: Varying number of Wi-Fi AP

- It is observed that one Femto BS has to be placed inside EDT region of each Wi-Fi AP.
- By increasing Wi-Fi APs, the number of Femto BS also increases.
- Greater than or equal to the number of Wi-Fi APs present.
- Greater than Wi-Fi APs due to the increase in interference with the increase in number of Femto BS.

By varying number of Rooms inside the building

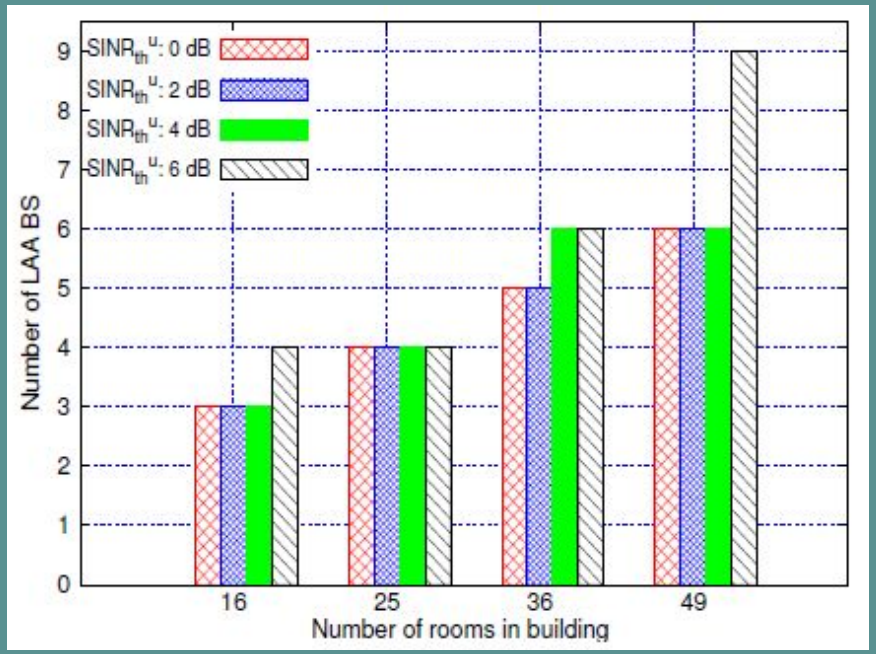

Figure 19: Number of LAA BS by varying number of rooms

- Varying from 4x4 rooms (16 rooms) to 7x7 rooms (49 rooms) with step size of 1x1 room for different values of $SINR_{th}^{u}$.
- It is observed that by increasing the building dimensions and increasing $SINR_{th}^{u}$, the number of LAA BS required also increases.

Conclusions

- Guaranteed SINR in Licensed and Unlicensed Spectrum.
- Optimal Placement with respect to Unlicensed Spectrum.
- Power Control of Licensed Spectrum maximized the minimum SINR.
- Power Control also leaded to Energy Saving.
- Simulation results showed the efficiency of the proposed scheme.

References

[1] Cisco White Paper. Feb 2017. Cisco Visual Networking Index: global mobile data traffic forecast update, 2016-2021. (Feb 2017).

[2] Ericsson. June 2017. Ericsson mobility report. (June 2017).

[3] Qualcomm White Paper. 2015. LTE in Unlicensed Spectrum: Harmonious Coexistence with Wi-Fi. (2015).

[4] 3GPP. 2015. TSGRAN; Study on Licensed-Assisted Access to Unlicensed Spectrum. Technical Report TR 36.889 V13.0.0.

References

[5] Kwanghun Han, Youngkyu Choi, Dongmyoung Kim, Minsoo Na, Sunghyun Choi, and Kiyoung Han. 2009. Optimization of femtocell network configuration under interference constraints. In WiOPT 2009. IEEE.

[6] GAMS. 2017. GAMS online. (2017). Retrieved March 2017 from http://www.gams.com/

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Any Questions?

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Thank You!