On Placement and Efficient Resource Allocation of LAA/LTE-U Base Stations in HetNet

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IEEE ANTS 2017

December 18, 2017

Outline

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

Introduction

- The Phenomenal Growth in Mobile Data demand
- Limited and costly License Spectrum
- One promising solution is to use unlicensed spectrum (LAA/LTE-U)

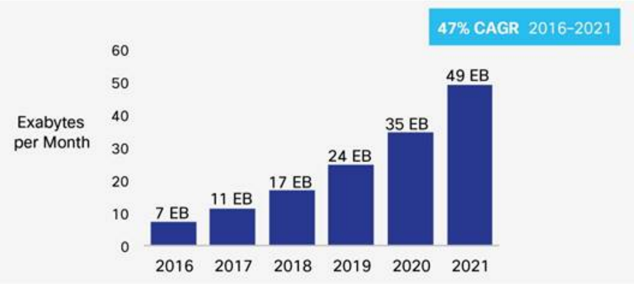

Figure 1 : Growth in Mobile Traffic[1]

[1] Reference: Cisco VNI, Mobile 2017

Indoor data demand

- In an indoor scenario, walls and other obstacles in the communication path along with co-tier and cross-tier interferences decrease the SINR significantly which results in throughput decrease.
- In large buildings like apartments, malls, cricket stadiums, etc., the data rate of the users drop drastically compared to outdoor data rates.
- Since most of the users consuming high data are indoor users, this problem has to be addressed.

Indoor Problem: Motivation

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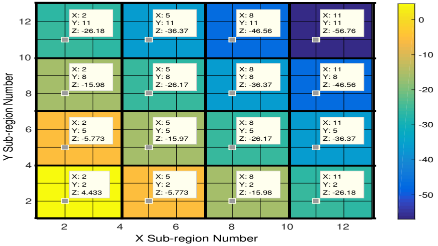

Figure 2 : SNR distribution inside the building when one Macro BS is located outside the building. The X and Y axes indicate locations where as Z-axis indicates SNR value.

Solution

- To satisfy increase in mobile traffic in indoor, LAA/LTE-U BS deployment is necessary.
- Optimal placement of BSs can reduce Capex and Opex.

Coexistence of LTE in Unlicensed Spectrum

- LTE in unlicensed uses carrier aggregation feature of LTE-Advanced where it aggregates licensed component carrier with the unlicensed component carrier.
- The licensed carrier acts as the primary cell data and control messages are transferred where as the unlicensed carrier acts as a secondary cell where only data is transmitted.
- The operating frequency of LTE in unlicensed spectrum is in 5 GHz which is higher than the operating frequency of licensed spectrum (400 MHz , 2.6 GHz), hence more wall and floor losses inside the building for secondary cell compared to primary cell.

Challenges for LTE in Unlicensed

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- Different operating frequencies results in different coverage regions and SINR values of licensed and unlicensed spectrum.
- Hence, efficient allocation of licensed and unlicensed spectrum for indoor users is necessary for better spectral efficiency.
- The presence of Wi-Fi Access Points (APs) makes the problem even more challenging as LAA/LTE-U BSs share the unlicensed channel with Wi-Fi when it is in energy detection region.
- An energy detection region is a region in which LAA BS receives Wi-Fi signal energy more than its Energy Detection Threshold (EDT).

System Model

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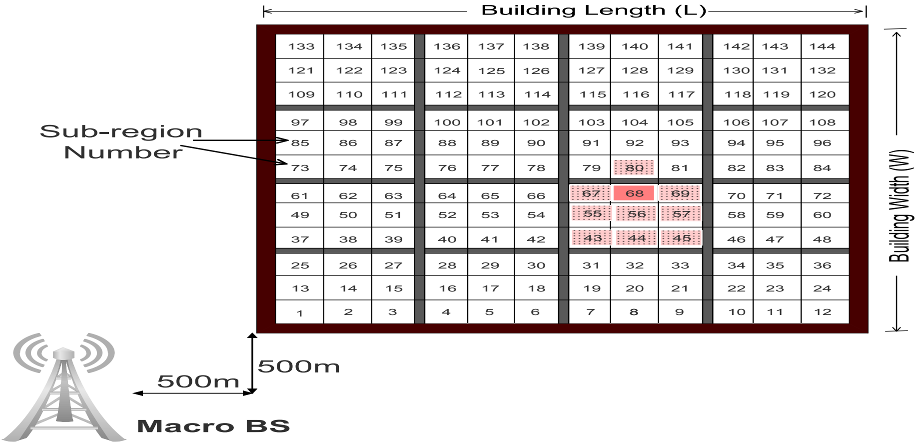

Figure 3 : System model with building having 16 rooms with one Macro BS outside the building and one Wi-Fi AP inside the building with shaded portion as the energy detection region.

Channel Model

- The path loss in dB between LTE-U/LAA BS operating in licensed spectrum and the sub-regions in the building is given by [8]:

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

- The path loss in dB between LAA BS/Wi-Fi AP operating in unlicensed spectrum and the sub-regions in the building is:

$$PL^{u} = 20\log_{10} f + 30\log_{10} d + N\sigma^{u} - 28 \tag{2}$$

- The path loss in dB between Macro BS located outside the building and the indoor sub-regions of the building [8] is:

$$PL_{Macro} = 49 + 40\log_{10}\frac{D}{1000} + 30\log_{10} F + K\sigma^{l} \tag{3}$$

Objective

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- The objective of our work is to ensure uniform throughput (minimum guaranteed throughput) for all the sub-regions in the indoor area by minimizing the number of LAA BSs to be deployed to the extent possible.
- To achieve the objective, we provide either licensed or unlicensed spectrum (to ensure the required uniform throughput) for data transmission and provide licensed spectrum to transmit control signals for all the users inside the building.

Notations

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Table 1 : Glossary

Notation	Definition
I	Set of all indoor sub-regions
C	Set of all sub-regions where WiFi AP is located
b_i	1 if LAA BS is placed at sub-region i, otherwise 0
a^l_{ji}	1 if j^{th} sub-region of the building is associated with the licensed spectrum of BS located at sub-region i, otherwise 0
a^u_{ji}	1 if j^{th} sub-region of the building is associated with the unlicensed spectrum of BS located at sub-region i, otherwise 0
G^u_{ji}	Unlicensed channel gain to sub-region j from LAA BS at i
G^l_{ji}	Licensed channel gain to sub-region j from LAA BS at i
G^w_{jc}	Unlicensed channel gain to sub-region j from Wi-Fi AP at c
P^u_{max}	Maximum Tx power of unlicensed spectrum from LAA BS
P^l_{max}	Maximum Tx power in licensed spectrum from LAA BS
P^w	Tx power of Wi-Fi AP
P^m	Tx power of licensed spectrum from Macro BS
N	System noise
R_{min}	Minimum throughput required for each sub-region (in Mbps)
u_j	1 if jth sub-region is outside energy detection region of all the Wi-Fi APs in the building, otherwise 0
v_{jc}	0 if jth sub-region is inside energy detection region of the Wi-Fi AP located at sub-region c, otherwise 1
OPT_{Pos}	Optimal positions of LAA BSs returned by MinBS Algorithm
EDT_c	Set of all sub-regions inside energy detection region of Wi-Fi located in sub-region c

Problem Formulation: MinLAA

- Objective of the formulation is to minimize the number of LAA BSs

$$min \sum_{i \in I} b_i \tag{4}$$

- Eqn. (5) and Eqn. (6) are used to find the $SINR^l$ and $SINR^u$, respectively in each sub-region.

$$SINR_j^l = \frac{G_{ji}^l P_{max}^l a_{ji}^l}{N + \sum_{k \in I \setminus i} G_{jk}^l P_{max}^l b_k + \sum_{m \in M} G_{jm}^m P^m} \quad \forall j, i \in I \tag{5}$$

$$SINR_j^u = \frac{G_{ji}^u P_{max}^u a_{ji}^u}{N + \sum_{k \in I \setminus i} G_{jk}^u P_{max}^u b_k u_k + \sum_{c \in C} G_{jc}^w P^w v_{ic}} \quad \forall j, i \in I \tag{6}$$

- Eqns. (7) and (8) ensure that SINR for all sub-regions exceed $SINR_{th}^l$.

$$Inf * (1 - a_{ji}^l) + SINR_j^l b_i \geq SINR_{th}^l \quad \forall j, i \in I \tag{7}$$

$$Inf * (1 - a_{ji}^u) + SINR_j^l b_i \geq SINR_{th}^l \quad \forall j, i \in I \tag{8}$$

Problem Formulation: MinLAA (Cont..)

- Eqn. (9) ensures that for the sub-regions allocated with unlicensed spectrum, $SINR^u_{th}$ is satisfied or not.

$$Inf * (1 - a^u_{ji}) + SINR^u_j b_i \geq SINR^u_{th} \quad \forall j, i \in I \tag{9}$$

$$\sum_{j \in I} a^l_{ji} + a^u_{ji} = 1 \qquad \forall i \in I \tag{10}$$

- The bandwidth allocation to achieve minimum throughput is based on Shanon's Capacity theorem.

$$BW^l_{ji} = \frac{a^l_{ji} R_{min}}{log_2(1 + SINR^l_j)} \quad \forall j, i \in I \tag{11}$$

- The bandwidth to be allocated is calculated using Eqn. (11) and Eqn. (12) for licensed and unlicensed spectrum, respectively.

$$BW^u_{ji} = \frac{a^u_{ji} R_{min}}{log_2(1 + SINR^u_j)}((1 - u_i) + 1) \quad \forall j, i \in I \tag{12}$$

Problem Formulation: MinLAA (Cont..)

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- Eqn. (13) ensures that the total allocated unlicensed bandwidth does not exceed the total available bandwidth of that LAA BS.

$$\sum_{i \in I} \sum_{j \in I} BW_{ji}^{u} a_{ji}^{u} \leq TBW_{i}^{u} \tag{13}$$

- Similarly, Eqn. (14) for licensed bandwidth.

$$\sum_{i \in I} \sum_{j \in I} BW_{ji}^{l} a_{ji}^{l} \leq TBW_{i}^{l} \tag{14}$$

- The objective function for MinLAA model is Eqn. (4) subject to SINR constraints given in Eqns. (7), (8), (9), subject to associating with licensed or unlicensed spectrum given in Eqn. (10), (13) and (14).
- The formulation for MinLAA model is MINLP problem which cannot be easily solved, hence we proposed a heuristic algorithm.

MinBS Algorithm

Algorithm 1 : MinBS algorithm

Inputs: R_{min}, $SINR^{l}_{th}$, $SINR^{u}_{th}$, C, TBW^{l}_{i}, TBW^{u}_{i}, P^{l}_{max}, P^{u}_{max}, and P^{w}.
Outputs: OPT_{Pos} and associativity.

Initialization: {I} ← Set of all sub-regions in the building; {O} ← Set of centre sub-regions of each room in the building, MAXBS ← Number of rooms
for BS = 1 to MAXBS **do**
  {P} ← Combinations(O, BS); /* Set of combinations of O with size as BS */
  for {p} ∈ {P} **do**
    Associativity(p, {O}); /* Find associativity of {O} with LAA BS locations in {p} */
    if ∀ sub-regions ∈ {O} are associated with R_{min} **then**
      $\{T_i\}$ ← Set of sub-regions in i^{th} room, $\forall i \in \{p\}$;
      $\{W_i\}$ ← Combinations(T_i,1);
      {S} ← all possible sets formed by combining one element from each $\{W_i\}$ $\forall i \in p$;
      for r ∈ $\{S\}$ **do**
        Associativity(r, {O});
        if ∀ sub-regions ∈ {O} are associated with R_{min} **then**
          Associativity(r, {I});
          if ∀ sub-regions ∈ {I} are associated with R_{min} **then**
            OPT_{Pos} ← r; /* optimal position of BS */
            Exit(); /* Stop the algorithm */;
          end if
        end if
      end for
    end if
  end for
end for

Associativity Function

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Algorithm 2 : Associativity

Inputs: Positions of LAA BSs and set of sub-regions.
Outputs: Associativity of given set of sub-regions to LAA BSs.

```
Initialization: B ← Set of sub-regions having LAA BS; I ← Set of sub-regions to be associated; TBW_i^l ← total licensed BW and TBW_i^u ← total unlicensed BW, ∀ i ∈ B
for j ∈ I do
    for i ∈ B do
        Calculate SINR_ji^l using Eqn. (5)
        Calculate SINR_ji^u using Eqn. (6)
    end for
    LAA BS at sub-region m is the one which gives maximum SINR in licensed spectrum to a sub-region j.
    if (SINR_ji^l ≥ SINR_th^l) then
        if (SINR_jm^l ≥ SINR_jm^u) && (BW_jm^l ≤ TBW_m^l) then
            Associate j with licensed spectrum of LAA BS at m.
            TBW_m^l ← TBW_m^l - BW_jm^l;        /* Calculate BW_jm^l using Eqn. (11) */
        else if (BW_jm^U ≤ TBW_m^U) && (SINR_ji^u ≥ SINR_th^u) then
            Associate j with unlicensed spectrum of LAA BS at m.
            TBW_m^u ← TBW_m^u - BW_jm^u;        /* Calculate BW_jm^u using Eqn. (12) */
        end if
    end if
end for
```

Performance Evaluation

Table 2 : Simulation Parameters

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
TBW^{l}_{i}, TBW^{l}_{i}	20 MHz
Number of APs	1

MinBS Placement Results

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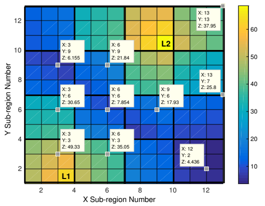

Figure 4 : SINR (in dB) distribution in licensed spectrum inside the building.

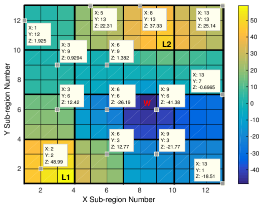

Figure 5 : SINR (in dB) distribution in unlicensed spectrum inside the building.

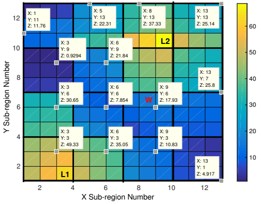

Figure 6 : Combined SINR (in dB) distribution (SINR of allocated spectrum) in each sub-region.

Observations

- Minimum no. of LAA BSs required for the given system model is two.
- Sub-regions facing high interference from Wi-Fi are allocated to licensed spectrum.

Associativity Results

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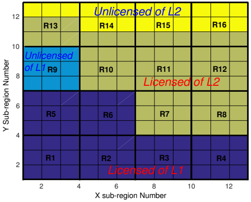

Figure 7 : Associativity of each sub-region along with licensed and unlicensed.

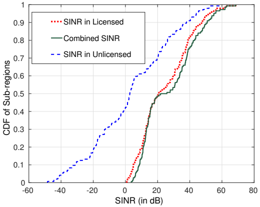

Figure 8 : SINR in licensed, unlicensed, and combined SINR CDF of sub-regions.

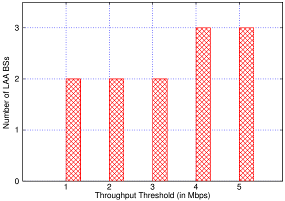

Figure 9 : Number of LAA BSs required with varying R_{min}.

Observations

- The placement and allocation is done in such a way that it will take less BSs to satisfy the required data demand.
- Room # 7 has AP, hence it is served by licensed spectrum of LAA BS.
- Combined SINR is better as it is the SINR of allocated spectrum.

Results with varying number of APs

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Table 3 : Results with varying number of Wi-Fi APs

No. of APs	AP Positions (sub-region No.)	Required No. of BSs	BS Positions (sub-region No.)
1	68	2	3, 117
2	68, 113	2	64, 68
3	26, 68, 113	2	43, 138
4	26, 68, 113, 119	3	25, 30, 120
5	26, 68, 74, 113, 119	3	2, 32, 116

Observations

- With increase in number of APs inside the building, unlicensed interference increases which may result in increase in number of LAA BSs.
- We can observe some times just by changing the position of LAA BSs, we can solve the issue of increasing no. of APs.

Conclusions

- To guarantee minimum throughput for each user either using licensed or unlicensed spectrum with minimum number of LAA/LTE-U BSs, we formulated an optimal LAA/LTE-U BS placement problem.
- Proposed MinBS algorithm allocates licensed and unlicensed spectrum based on SINR further, it allocates bandwidth to each sub-region in such a way that minimum throughput of each sub-region is satisfied with minimum number of LAA/LTE-U BSs.
- Increasing no. of APs from 1 to 5 inside the building or changing minimum throughput threshold from 1 Mbps to 5 Mbps results in increasing no. of LAA/LTE-U BSs from 2 to 3.
- The efficiency of proposed algorithm is shown with sufficient simulation study.

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Acknowledgement

This work is supported by the project Converged Cloud Communication Technologies, MeitY, Govt. of India

सत्यमेव जयते

Ministry of Communications
& Information Technology
(Government of India)

Thank you!

Queries

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