Energy-efficient Femtocell Placement in LTE Networks

Arun Ramamurthy, Vanlin Sathya, Varsha Venkatesh, Rithi Ramji, Bheemarjuna Reddy Tamma

Department of Computer Science & Engineering

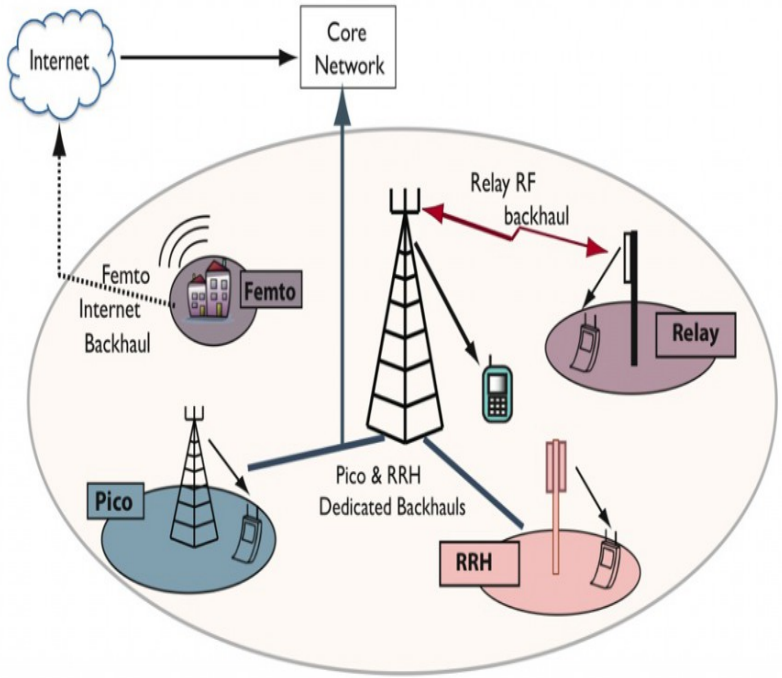
Indian Institute of Technology Hyderabad

Outline

1. Introduction to LTE HetNet
2. Motivation
3. System and Channel Model
4. Proposed work
5. Experimental Setup and Results
6. Conclusion and Future Work

Introduction to LTE HetNet

- LTE Heterogeneous Network (HetNet) system comprises of Macro and Small Cells.
- Dense deployment in enterprise/hot spots.
- Low power nodes.
- Frequency Reuse 1 $\rightarrow$ high spectral efficiency, but need to contain cross-tier and co-tier interference.



Heterogeneous Network

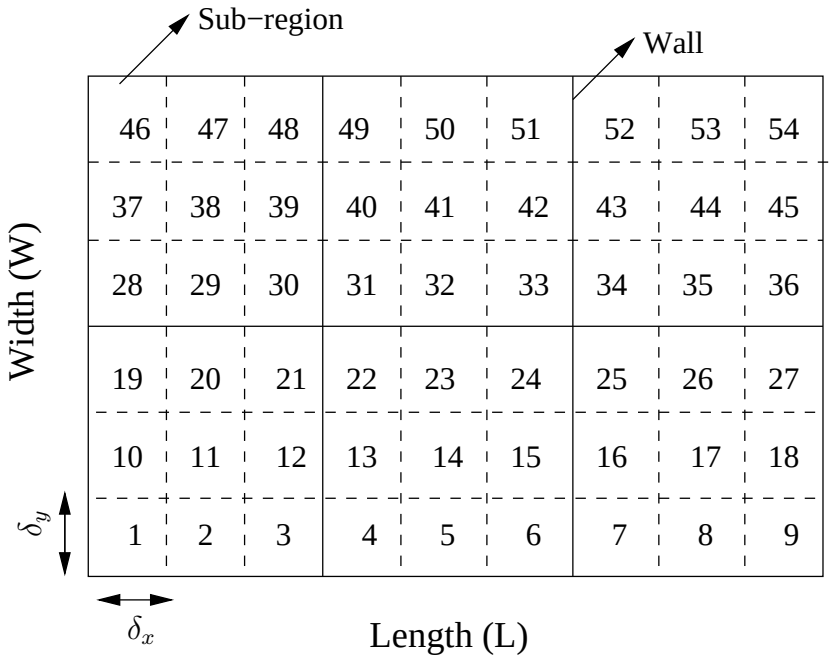
Source: Prof. Robert W. Heath Jr, UT Austin

Motivation

- 70% of total traffic comes from indoor environments [Cisco, 2013].
- Macros have poor indoor cellular coverage due to obstructions such as walls.
- Indoor signal strength can be improved by deploying Femtos with *frequency reuse one*.
- Random placement of Femtos can create coverage hole and/or drain user battery.
- Optimal placement of femtos considering both uplink and downlink is essential.

System and Building Model

- LTE HetNet system comprising of Macros and Femtos.
- Macros and Femtos operate on same frequency.
- Cross-tier and co-tier interference is considered.
- Enterprise building with many rooms.
- Each room is further divided into sub-regions.
- We assume that signal-to-interference-plus-noise ratio ($SINR$) does not vary within a sub-region.



Aerial view of typical floor area inside the building

Channel Model

$$PathLoss_{Macro} = 40 \log_{10} \frac{d}{1000} + 30 \log_{10} f + 49 + K\sigma$$

$$PathLoss_{Femto} = 37 + 30 \log_{10} d + K\sigma$$

Where, d is the distance between the user and the Base Station (BS), K is the number of walls between the user and the BS, f is the center frequency and σ is the penetration loss.

Overview

- Two optimization models are formulated to maintain threshold uplink SINR ($USINR_{Th}$) and downlink SINR ($DSINR_{Th}$) and to reduce the uplink power.
- **Step 1: Minimize Femto and Uplink Transmission Power (MFUTP) MILP model**
  - Minimizes the number of Femtos deployed and the total uplink transmission power.
  - Guarantees $USNR_{Th}$ and $DSINR_{Th}$ to every user.
- **Step 2: Uplink SINR Transmission Power (USTP) LP model**
  - Minimizes the total uplink transmission power.
  - Guarantees $USINR_{Th}$ to every user.

Notations used in this work

Notation	**Definition**
MBS	Set of all Macro Base Stations
SR	Set of all sub-regions inside the building
U_j	Set of all users in sub-region j
x_a	1 if Femto is placed at sub-region a, zero otherwise
z_{ja}	1 if j^{th} sub-region of the building is associated with the Femto located at sub-region a, zero otherwise
G_{ja}	Channel gain between sub-regions j and a
G'_{je}	Channel gain between sub-region j and Macro e
β_1, β_2	Objective function weightage
P_{macro}	Transmission power of the Macro

Notations used in this work

Notation	**Definition**
P^f_{max}	Maximum transmission power of Femto f
P^u_{max}	Maximum uplink transmission power
P^u_m	Uplink transmission power of user m
N^d_o	Downlink Noise
N^d_o	Uplink Noise
SRB	Set of all Resource Blocks (RBs)
V_r	Set of all users using RB r for uplink transmission
f_i	Serving Femto of user i

Step 1: MFUTP MILP Model

By solving the MFUTP MILP model, the following values can be obtained:

- The minimum number of Femtos needed to maintain $DSINR_{Th}$ in each sub-region.
- The minimum uplink power each UE has to transmit to maintain $USNR_{Th}$.
- The optimal location of Femtos inside the building.
- The Femto to which each sub-region will be connected.

Step 1: MFUTP MILP Model

- **Objective:** Minimize the total number of Femtos deployed and total uplink power.

$$min(\beta_1 \sum_{a \in SR} x_a + \beta_2 \sum_{j \in SR} \sum_{m \in U_j} P_m^u / P_{max}^u)$$

- **Constraint:** Every sub-region is connected to exactly one Femto.

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

Step 1: MFUTP MILP Model-Downlink Constraints

- A sub-region j is connected to a sub-region a only if $x_a = 1$.

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

- $DSINR$ of each sub-region must be above $DSINR_{Th}$ (λ_d).

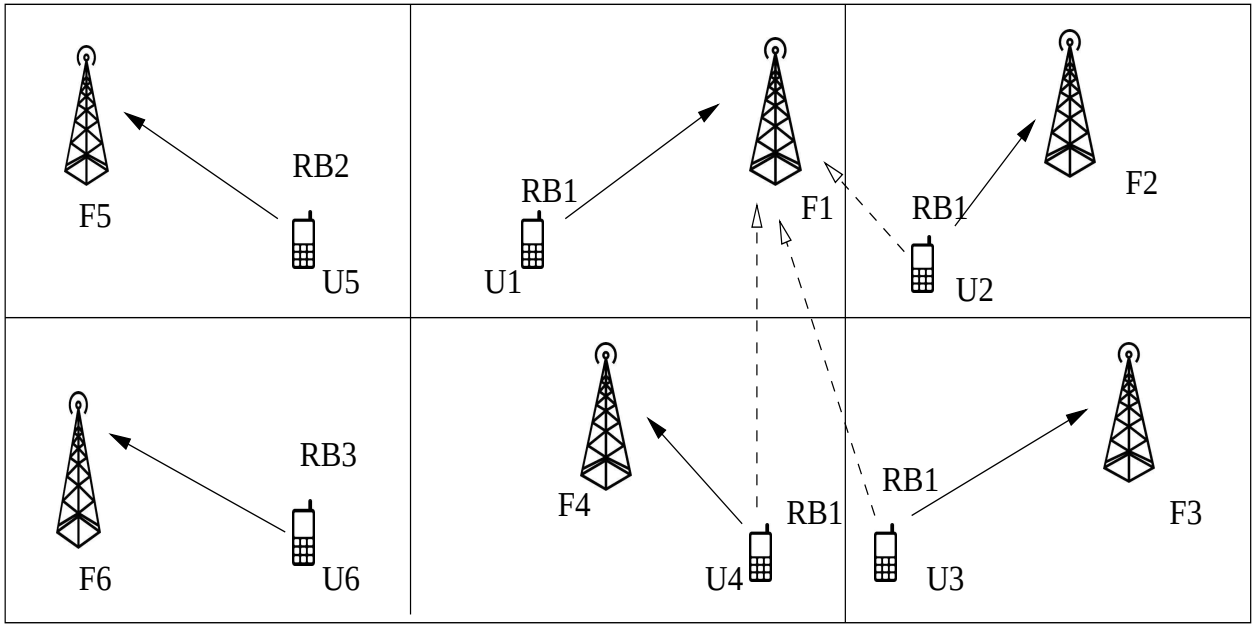
$$\frac{Inf * (1 - z_{ja}) + G_{ja} P^f_{max} x_a}{N^d_o + \sum_{b \in SR \setminus a} G_{jb} P^f_{max} x_b + \sum_{e \in MBS} G'_{je} P_{macro}} \geq \lambda_d \quad \forall j, a \in SR$$

Step 1: MFUTP MILP Model-Uplink Constraint

- $USNR$ of users must be above $USNR_{Th}$ (λ_u).

$$\frac{Inf * (1 - z_{ja}) + G_{ja} P_m^u}{N_0^u} \geq \lambda_u \quad \forall j, a \in SR, \forall m \in U_j$$

Step 2: USTP LP Model



Step 2: USTP LP Model

- **Objective:** Minimize the total uplink power.

$$min(\sum_{r \in SRB} \sum_{i \in V_r} P_i^u)$$

- **Constraint:** $USINR$ of each user must be above a threshold (λ_i) value.

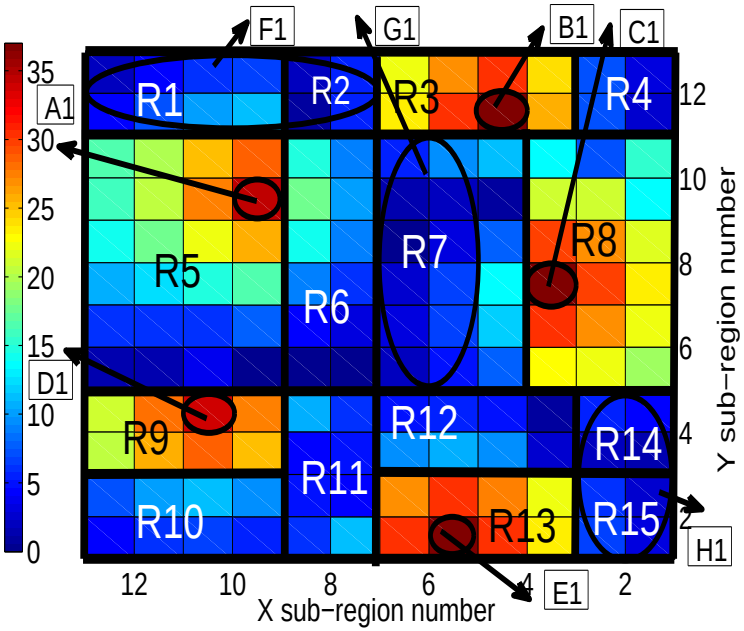
$$\frac{G_{if_i} P_i^u}{N_o^u + \sum_{j \in V_r \setminus i} G_{jf_i} P_j^u} \geq \lambda_i \quad \forall i \in V_r, r \in SRB$$

Experimental Setup

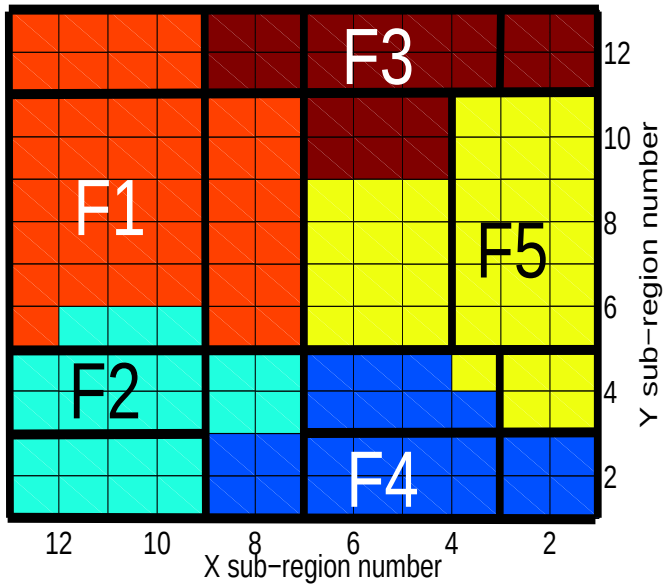
Table: Simulation Parameters

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

MFUTP Placement: Downlink Results



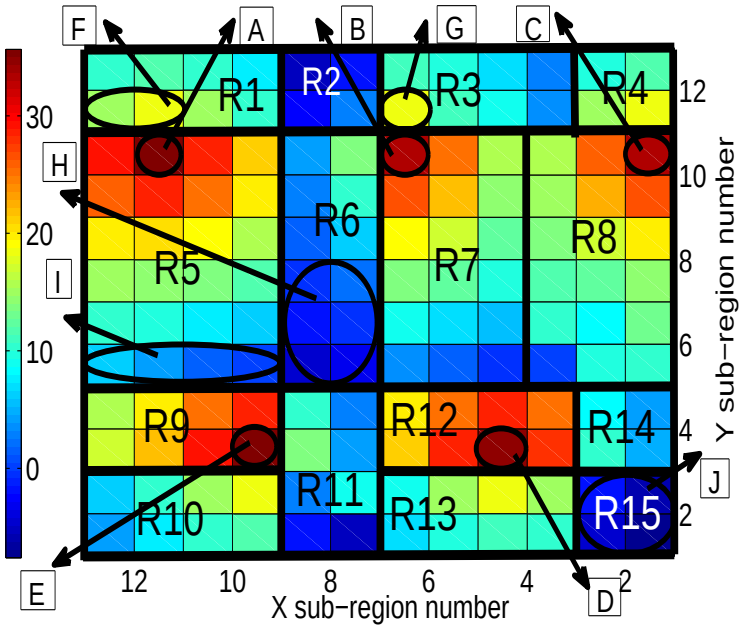
DSINR (in dB) REM in MFUTP Placement



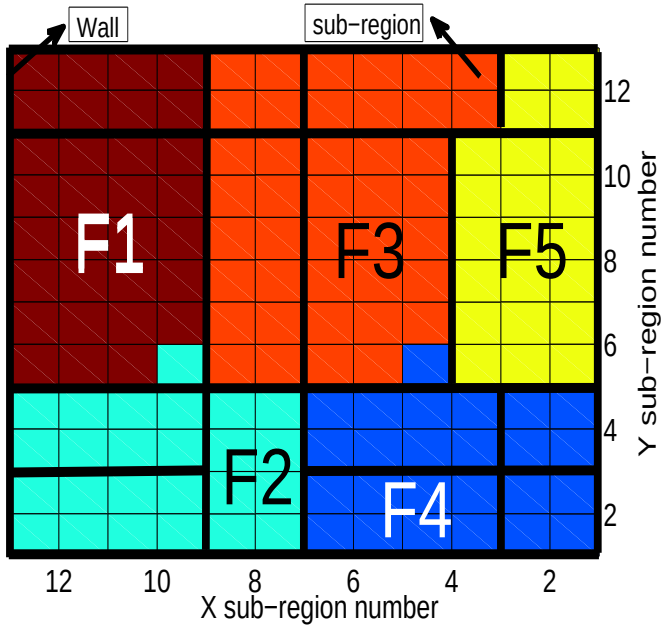
Femto sub-region association in MFUTP placement

MFUTP placement guarantees $DSINR_{Th}$ to every sub-region inside the building.

Center K-Means (CKM) Placement: Downlink results



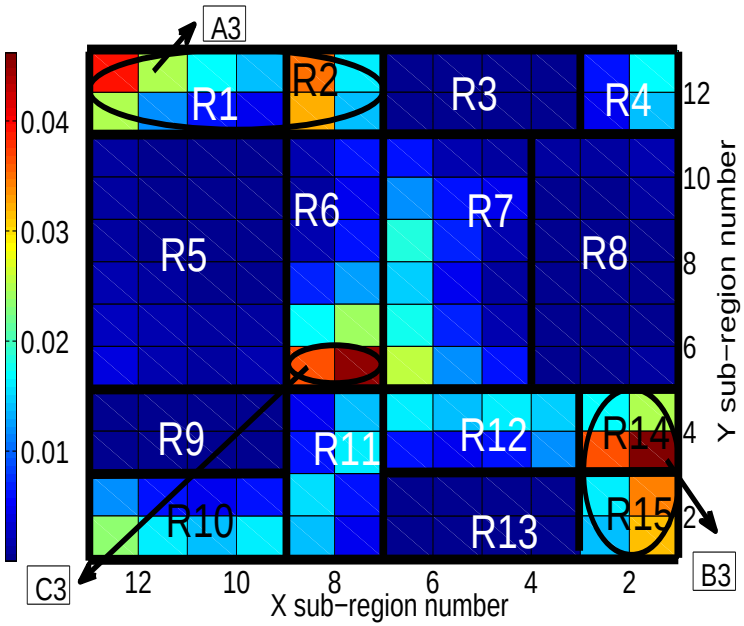
DSINR (in dB) REM in CKM Placement



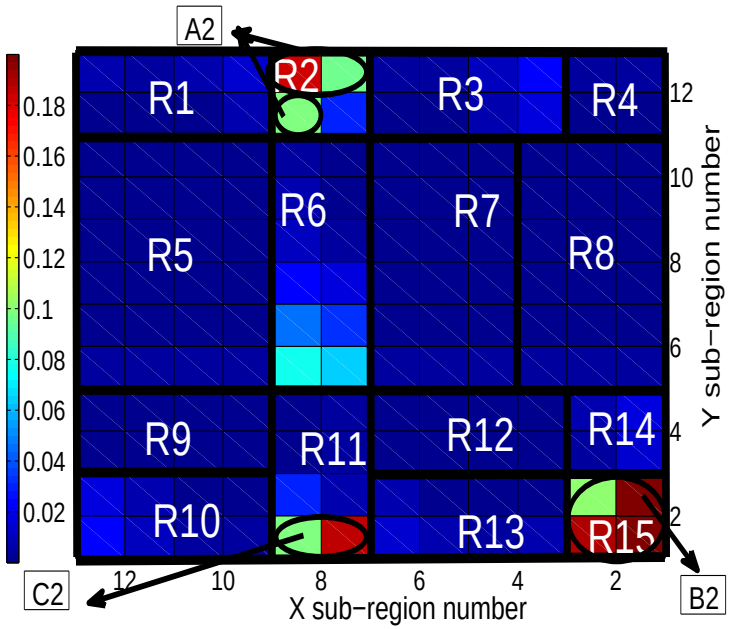
Femto sub-region association in CKM Placement

CKM placement doesn't guarantee $DSINR_{Th}$ to every sub-region inside the building.

MFUTP and CKM Placement: Uplink Results



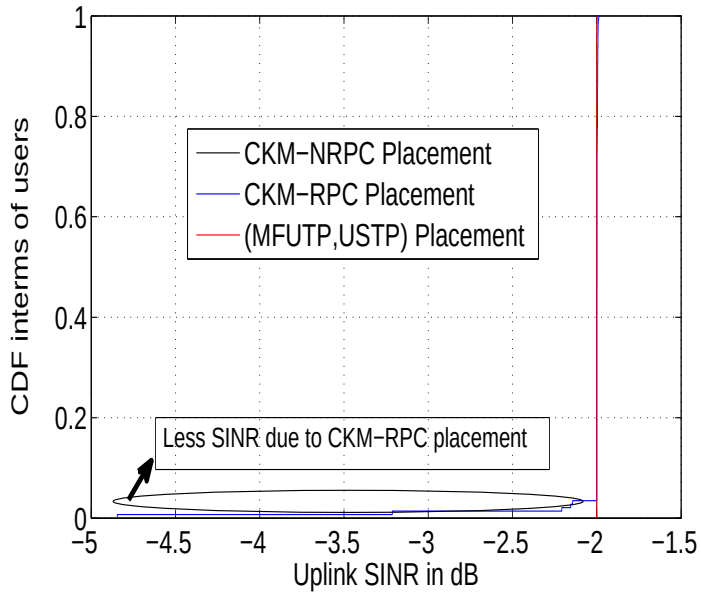
Uplink Power (in W) in MFUTP Placement.



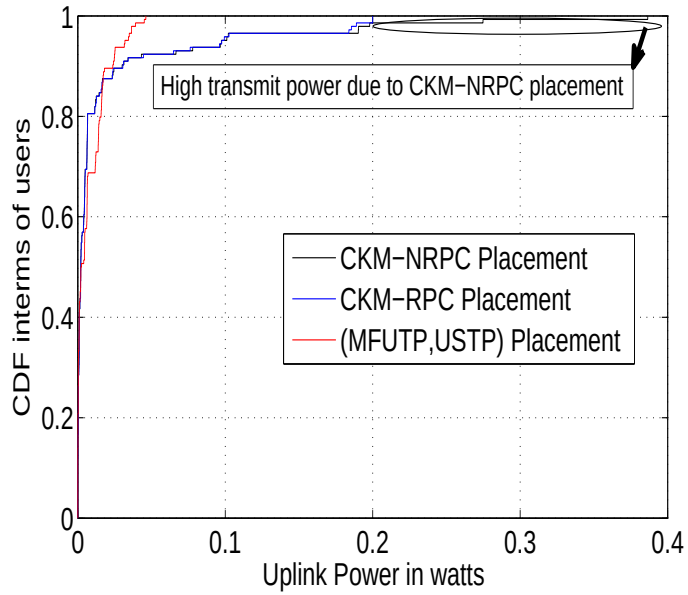
Uplink power (in W) in CKM Placement.

Compared to CKM placement, uplink power consumption is 47% lesser in MFUTP placement.

Uplink SINR and Power CDF



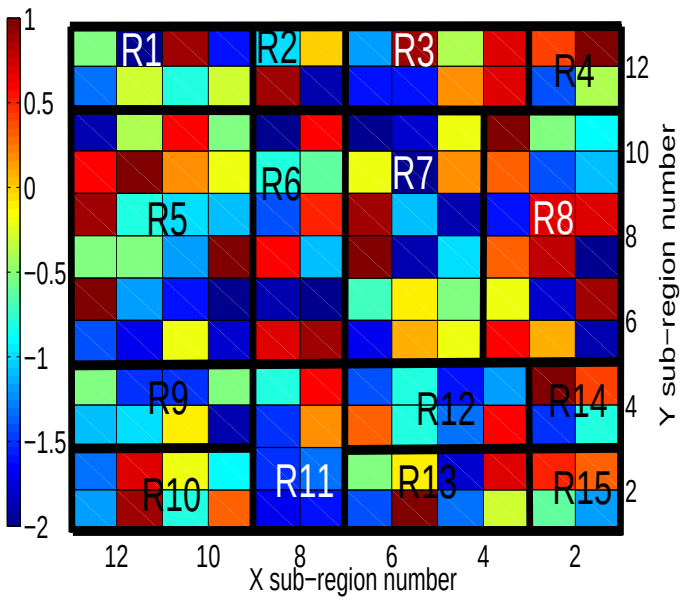
Uplink SINR CDF



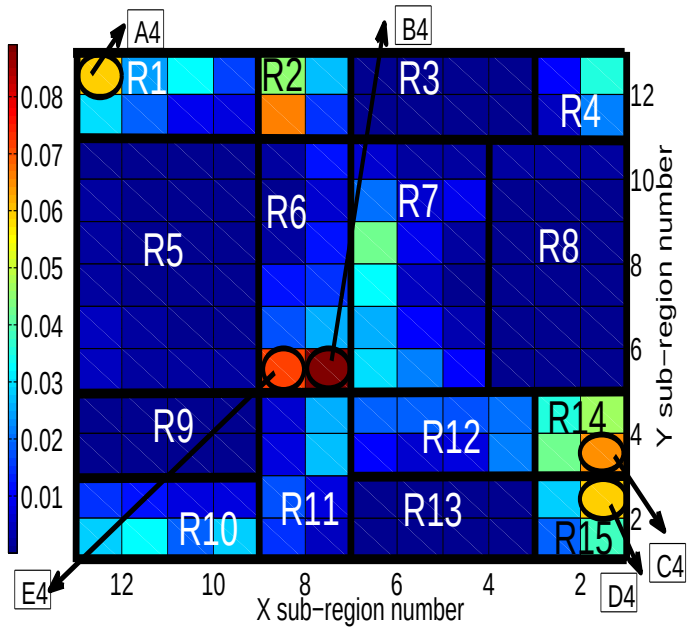
Uplink Power CDF

Every user attains $USINR_{Th}$ without exceeding the power limit, in MFUTP placement.

Uplink SINR and Power



Uplink $SINR_{Th}$ variation across sub-regions



Uplink Power variation across sub-regions

Depending on users' $USINR_{Th}$, USTP LP model has allocated the optimal power.

Conclusion and Future Work

- The placement of Femtos are done based on uplink and downlink interference.
- Uplink energy consumption in MFUTP placement is 47% lesser than CKM placement.
- In future, the Macro users and efficient RB allocation will also be considered in the system model.

Questions ?

References

Views on rel-12 and onwards for lte and umts.

Future Radio in 3GPP, CISCO, 2013.

GAMS.

`http://www.gams.com/`.

Yuanye Wang and Shankar Venkatraman.

Uplink power control in lte heterogeneous networks.
In *Globecom Workshops, 2012 IEEE*, pages 592–597. IEEE, 2012.

Weisi Guo, Siyi Wang, Xiaoli Chu, Jie Zhang, Jiming Chen, and Hui Song.

Automated small-cell deployment for heterogeneous cellular networks.
Communications Magazine, IEEE, 51(5):46–53, 2013.

Vanlin Sathya, Arun Ramamurthy, and Bheemarjuna Reddy.

On placement and dynamic power control of femtocells in lte hetnets.
In *GLOBECOM Wirless Network Symposium*. IEEE, 2014.

Narendra Karmarkar.

A new polynomial-time algorithm for linear programming.
In *Proceedings of the sixteenth annual ACM symposium on Theory of computing*, pages 302–311. ACM, 1984.

Thank You !!!