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37th Cycle

A Joint Optimization Approach for Power-Efficient Heterogeneous Networks

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Research context and motivation

BANYAN Big dAta aNalYtics for radio Access Networks

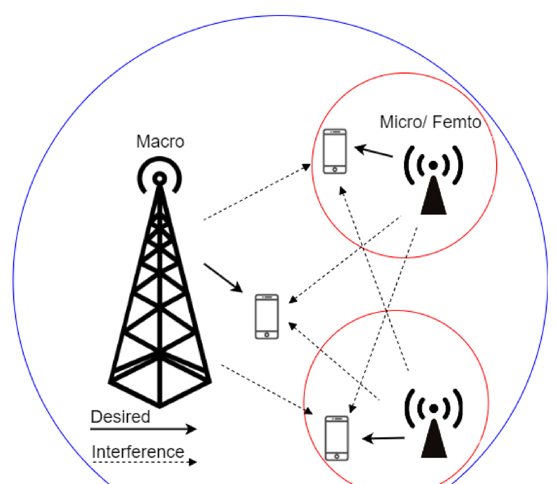

Fig. 1: Heterogeneous OFDMA network.

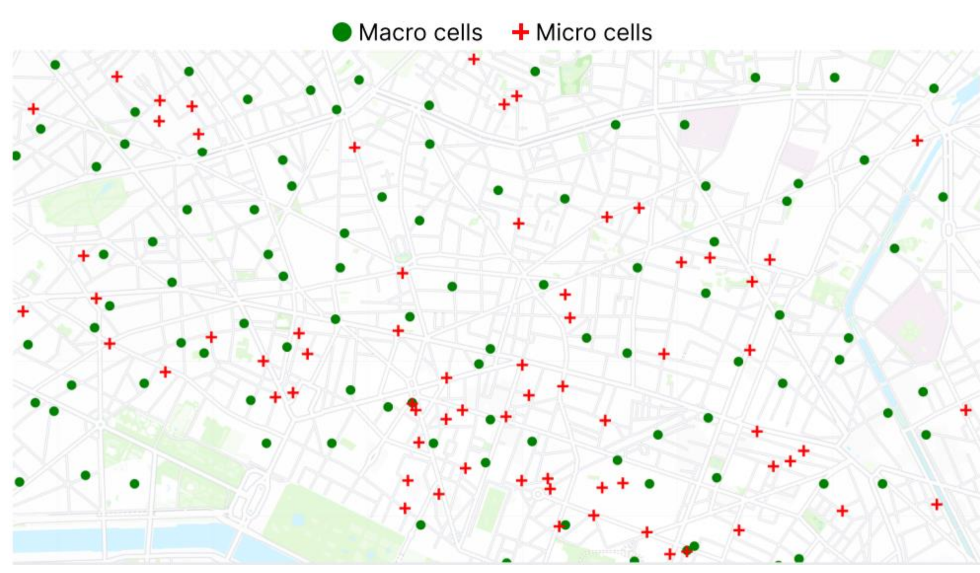

Fig. 2: HetNet deployment in a major European city.

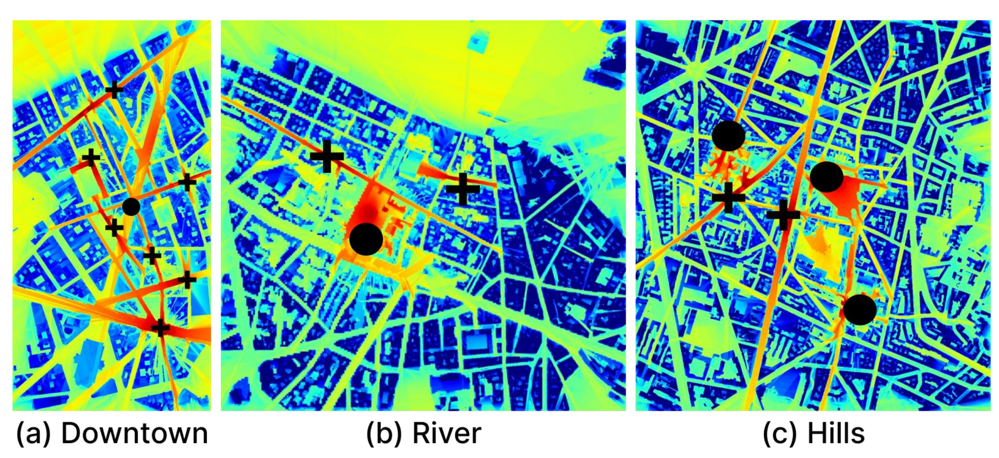

Fig. 3: Eletromagnetic waves propagation in different real-World HetNets from a major European city.

❑Why are they important?

- 5G propagation loss
- Connected devices
- Users' traffic demands
- When optimized: low latency, wider cell coverage, offload macro BS, increase QoS.

Novel contributions

- Change of variables $P_j = e^{y_j}$ and $x_{ij} = e^{u_{ij}}$ and piecewise concave approximation $\log_2\left(1+\frac{P_j g_{ij}}{\sigma+\sum_{k\neq j}^{N} P_k g_{ik}}\right) \simeq a\left(\frac{P_j g_{ij}}{\sigma+\sum_{k\neq j}^{N} P_k g_{ik}}\right)^b$. Mixed-Integer Geometric Program (MIGP):

$$\text{minimize}_{u,z,y} \quad \sum_{j=1}^{N} e^{y_j}$$

subject to:

- $e^{u_{ij}} \leq 1, \quad i \in [n],\ j \in [N]$
- $\sum_{i=1}^{n} e^{u_{ij}} \leq 1, \quad j \in [N]$
- $\sum_{j=1}^{N} \bar{z}_{ij} = N-1, \quad i \in [n]$
- $z_{ij} \in \{0,1\}, \quad i \in [n],\ j \in [N]$
- $\tilde{f}(u_{ij}, y) \leq \frac{\log\left(\frac{B_j a}{t_i}\right)}{b} + M\bar{z}_{ij}, \quad i \in [n],\ j \in [N], \quad$ with

$$\tilde{f}(u_{ij}, y) = \log\left(\frac{\sigma}{g_{ij}} e^{y_j - \frac{u_{ij}}{b}} + \sum_{k\neq j}^{N} \frac{g_{ik}}{g_{ij}} e^{y_k - y_j - \frac{u_{ij}}{b}}\right) \leq \frac{\log\left(\frac{B_j a}{t_i}\right)}{b} + M\bar{z}_{ij}$$

Log-sum-exp: convex! No product!

Main Contributions

- ❖ Non-iterative or sequential
- ❖ x, z, P simultaneously
- ❖ Individual QoS

Addressed research questions/problems

- Given a Heterogeneous OFDMA Network:
  - N base stations (BS);
  - n users' equipaments (UE).

Intuitively:

1- Where should we connect each user?
2- How much resource (bandwidth) to each user?
3- Since there is signal interference, how much transmission power for each BS?
4- How do we optimize w.r.t the previous points and still satisfy individual QoS?

Mathematically:

$$\text{minimize}_{x,z,P} \quad \sum_{j=1}^{N} P_j$$

subject to:

- ❖ 5G NR is known to be two to three times more energy consuming than its 4G equivalent.
- ❖ 90% of leading mobile network operators have expressed concerns about the rise in energy costs.

- Each user i must be connected to just one BS j:
$$\sum_{j=1}^{N} z_{ij} = 1, \quad i \in [n]$$
- A BS cannot provide more resources than available:
$$\sum_{i=1}^{n} x_{ij} \leq 1, \quad j \in [N]$$
- Each user i connected to j has a minimum required throughput t_i (*bits/s*):
$$\sum_{j=1}^{N} z_{ij}\, x_{ij} B_j \log_2\left(1+\frac{P_j g_{ij}}{\sigma+\sum_{k\neq j}^{N} P_k g_{ik}}\right) \geq t_i, \quad i \in [n]$$

Product between variables!

Highly non-convex function!

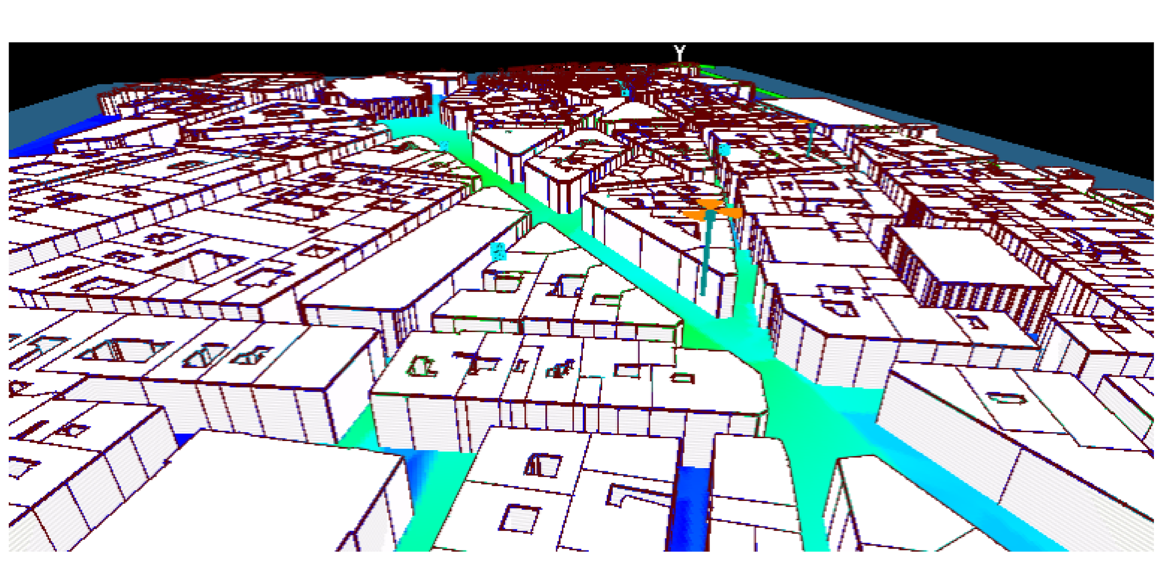

Fig. 4: Channel gains g_{ij} estimation with a 3D ray tracing propagation software (path loss, shadowing, multipath).

- $x_{ij} \in [0,1], \ z_{ij} \in \{0,1\}, \quad i \in [n],\ j \in [N]$

Adopted methodologies

Solving for a scenario: N = 5 n= 400

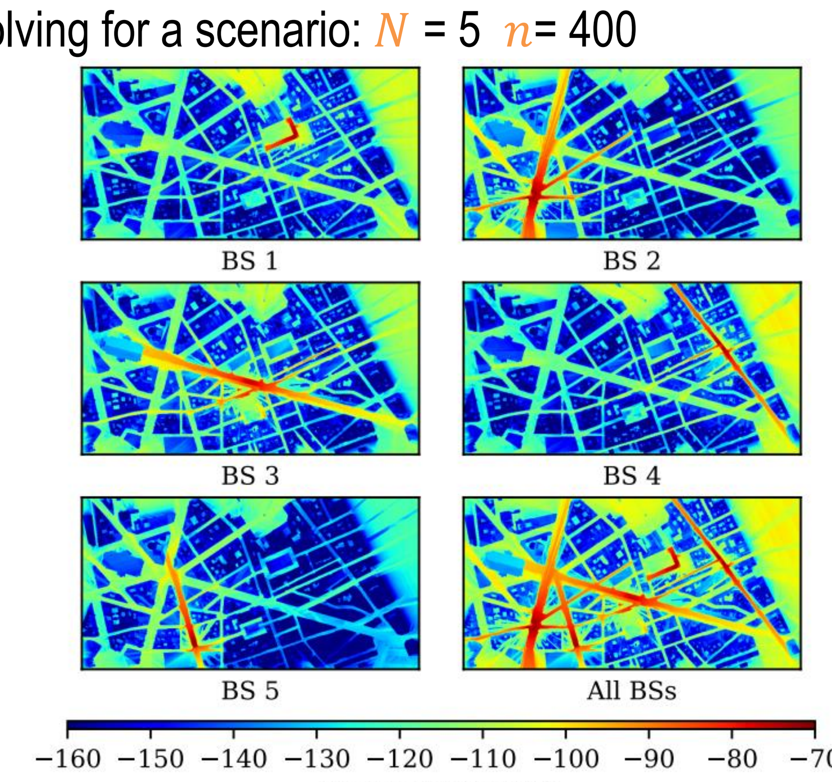

Fig. 5: Channel gains g_{ij} of each BS.

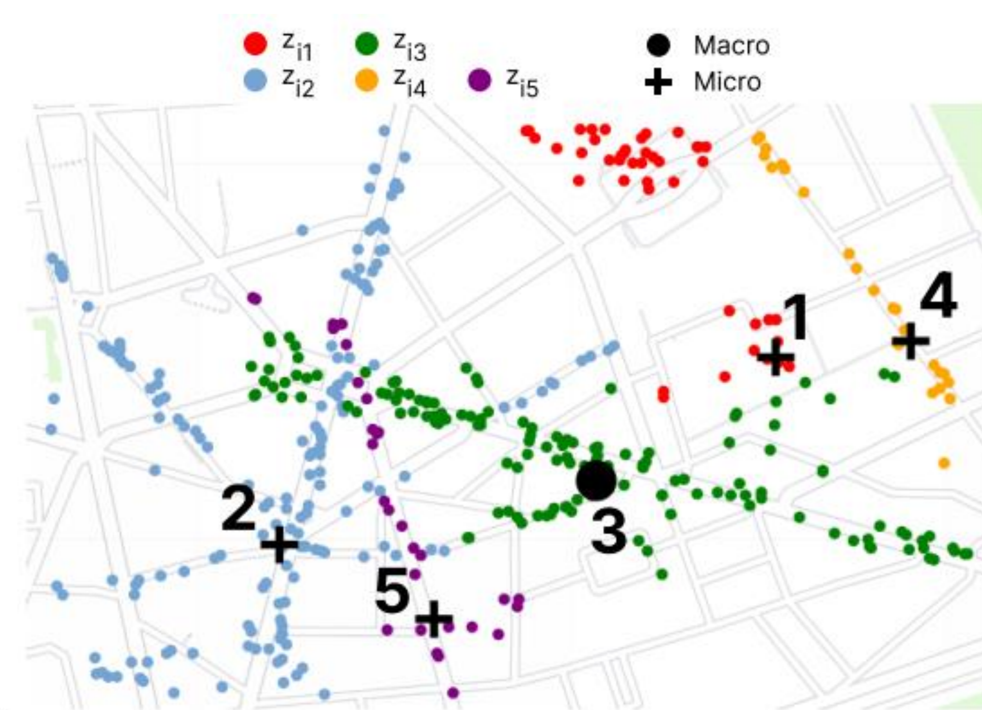

Fig. 6: Assignements after MIGP optimization.

Comparison with other approches :

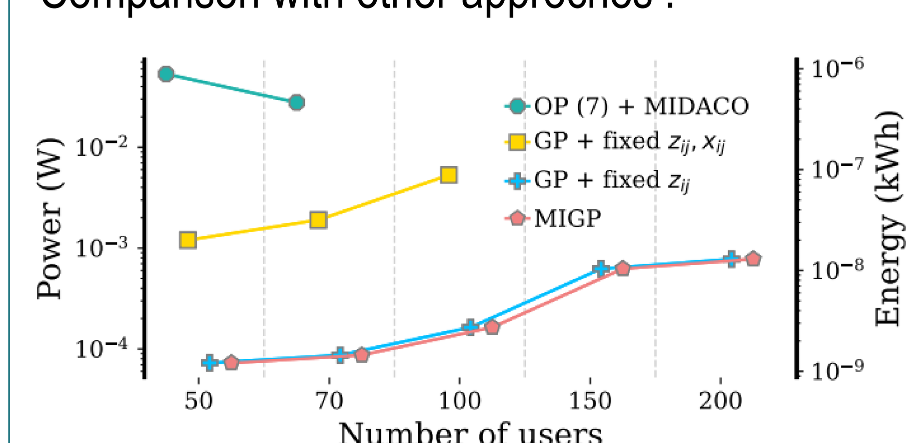

Fig. 7: Optimal value and number of users.

Other scenarios:

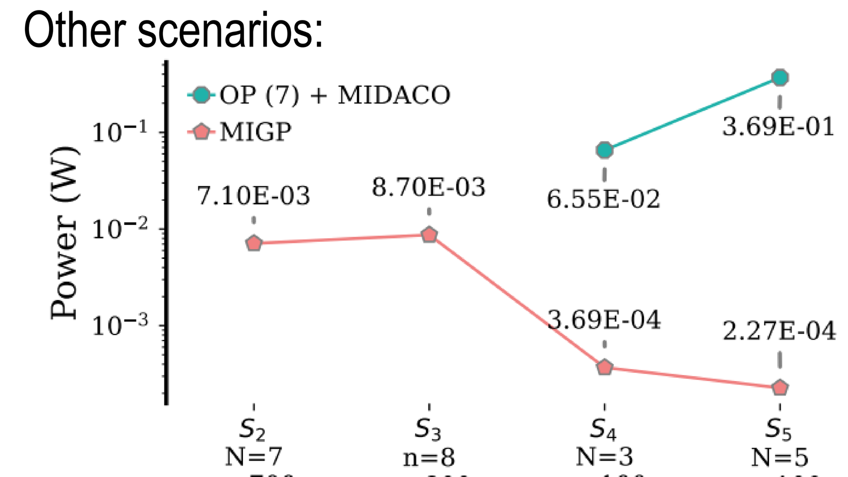

Fig. 8: Optimal value for different HetNets.

Future work

- Temporal aspect of the network:
  1- handovers between BS;
  2- varying channel gains;
  3- UE mobility patterns.

orange

1- leading telecommunication operator (287M costumers);
2- mobile applications usage data;
3- 5G network planning and optimization.

Publications

- Published works: 2 journals, 2 conferences.
- Submitted works: 1 conference. [INFOCOM]

- G. O. Ferreira, C. Ravazzi, F. Dabbene, G. C. Calafiore and M. Fiore, "Forecasting Network Traffic: A Survey and Tutorial With Open-Source Comparative Evaluation", in *IEEE Access*, vol. 11, pp. 6018-6044, 2023.
- G. O. Ferreira, L. Figueiredo, M. J. Lacerda, and V. J. S. Leite, "ISS control for continuous-time systems with filtered time-varying parameter and saturating actuators", *Asian Journal of Control*, pp.1-13, 2022.

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