MEC-aware Cell Association for 5G Heterogeneous Networks

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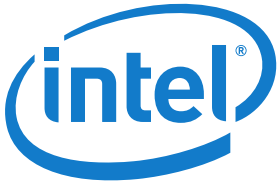


Outline

- Introduction & State-of-the-Art
- Motivation & Contribution
- System Model
- Extended Packet Delay Budget (E-PDB)
- A Computationally-aware Cell Association Rule
- Numerical Evaluation
- Conclusion and Future Work

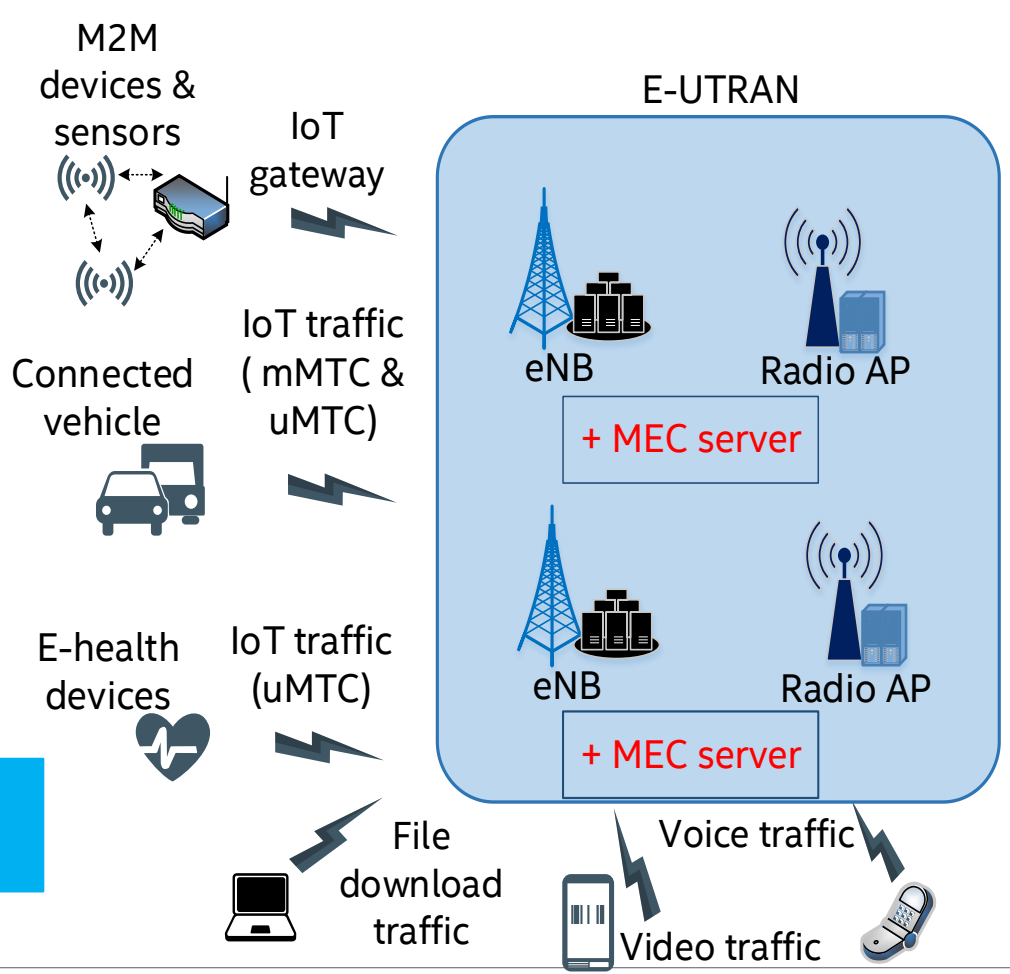
Introduction

- Evolution of mobile networks:

❑ **Diverse services** (enhanced mobile broadband and machine type communication)

❑ **New vertical business segments** (E-health, automotive and entertainment)

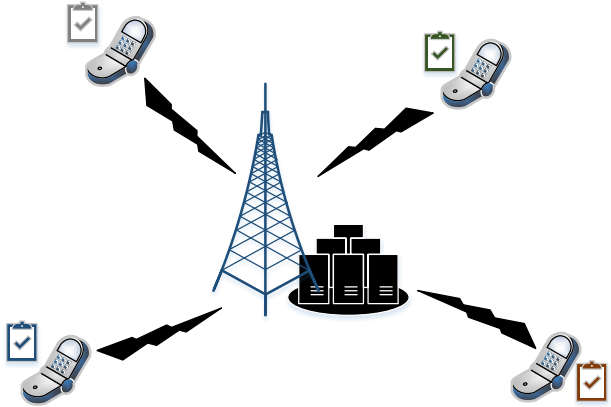
❑ Utilization of **Multi-access Edge Computing (MEC)**



Revisiting topics as connectivity, network dimensioning and exploitation of resources

Introduction (cont.)

- Multi-access Edge Computing (MEC):
  - ❑ Presence of **processing capabilities** at the network's edge
  - ❑ Low packet delays due to **close proximity** to the User Equipment (UE)
  - ❑ Offering of **task offloading opportunities** to non-processing powerful UEs
    - ➢ video analytics
    - ➢ Facial recognition
    - ➢ Augmented reality

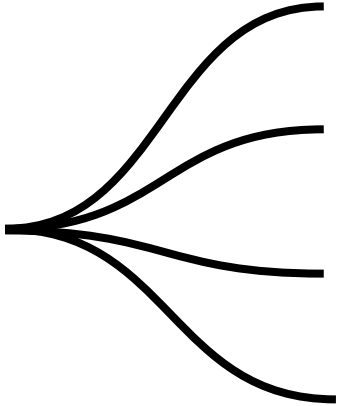


- Q: How does the cross-domain resource disparity affect the QoE?

Goal: Investigate the experienced one-way latency in a HetNet for the task offloading use-case

State-of-the-Art on Radio & Processing Resource Allocation

Handling radio & processing resources in a wireless network



<[1] Sato et. al., 2017> Distributed offloading over multiple APs

<[2] Le et. al., 2017> Joint radio and computation resources allocation in single cell scenarios

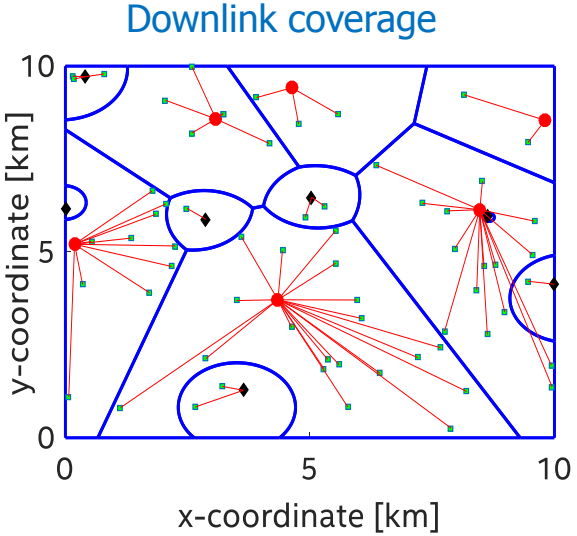
<[3] Mao et. al., 2017> Minimization of completion time under joint power and computation allocation

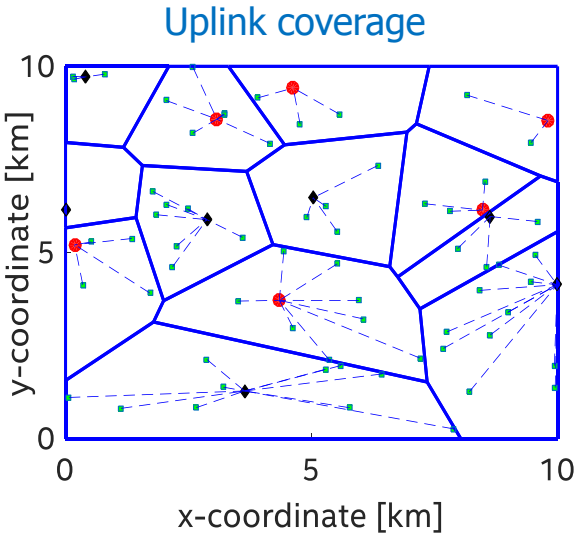
<[4] Li et. al., 2017> Joint matching between the UEs, Cloud-Radio Access Network (C-RAN) remote radio heads and MEC hosts

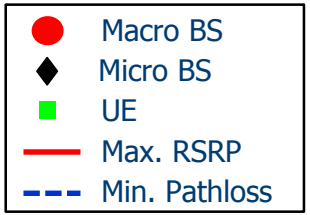
In current technical literature:

1. Conventional cell connectivity based on Reference Signal Received Power (RSRP) → **overlooking the availability of processing resources at the network side**
2. The impact of **network resource disparities** in a multi-tier network is not fully investigated

Motivation and Contribution







Parameter	Value
Tiers	2
P_{Tx} (BS)	46,30 dBm

Our contributions:

1. We propose a new, **MEC-aware connectivity metric**, in which the availability of computational resources is taken into account
2. We analyze the **Extended-Packet Delay Budget (E-PDB) performance of the new association metric** focusing on the task offloading use case, considering various resource (radio & processing) disparity regimes & deployment densities

System Model

- K-tier network
- The BS locations per tier are obtained from an independent Poisson Point Process (PPP)

$\Phi_i = \{x_i, i = 1, 2, \cdots, K\}$, where x_i represents the BS position on a two-dimensional plane $\mathbb{R}^2$

- BSs across different tiers are distinguished by:
  - ❑ Transmit Power P_i
  - ❑ Spatial density λ_i (BSs/unit area)
  - ❑ Total processing power C_i (cycles/sec)
- UE locations are modelled via a different PPP ψ of density of λ_u UEs/unit area
- We denote the disparities in the network as:

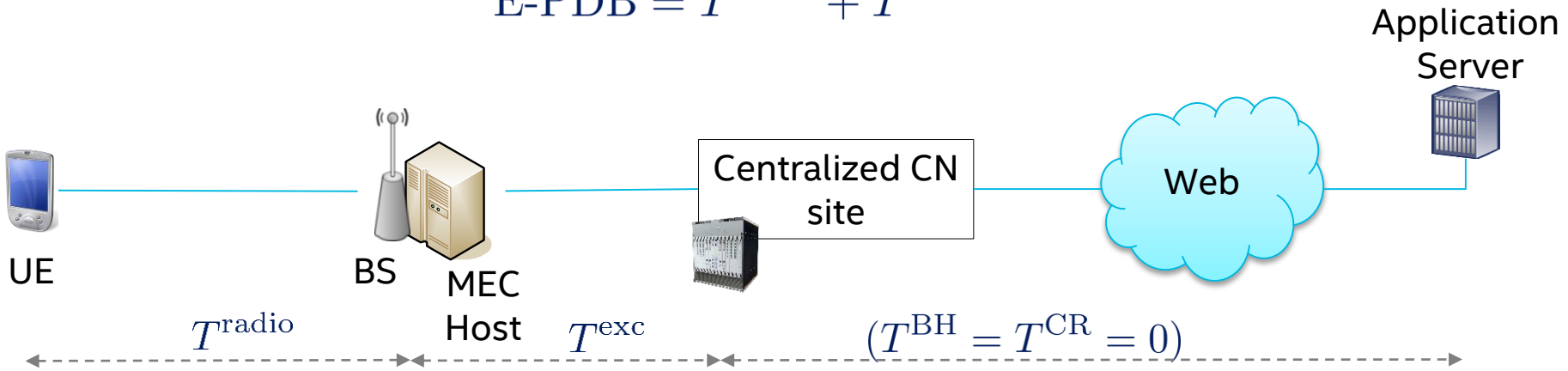
$$\rho_i = \frac{P_i}{P_{i+1}}, \ \gamma_i = \frac{C_i}{C_{i+1}} \rightarrow \omega_i = \frac{\rho_i}{\gamma_i}$$

Modeling locations randomly → Stochastic Geometry

Extended-Packet Delay Budget (E-PDB)

- The experienced E-PDB, for a given UE which decides upon offloading a task to the network, is modelled as

$$\text{E-PDB} = T^{\text{radio}} + T^{\text{exc}}$$



Goal: Proposing a new, MEC-aware UE-BS association metric and evaluate the experienced E-PDB for different network (radio & processing) HetNet disparities

A Computationally-aware Cell Association Rule

- **Overlapping** of radio & computational coverage regions
- Objective:
  - ❑ Proposal of a **computationally-aware association metric** applicable to scenarios such as the one of task offloading
  - ❑ Compare the experienced E-PDB performance obtained by applying the proposed rule to the E-PDB performance achieved when applying the max. DL RSRP rule

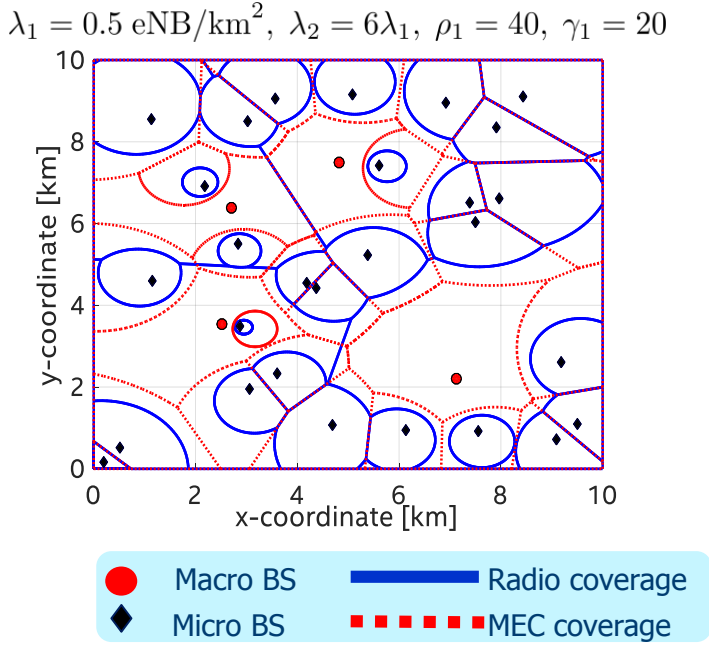
- Mathematically, the location of the serving BS x_o is computed as

$$x_i = \arg\max_{x \in \phi_i} (\eta_i ||x - y||^{-\alpha}), \forall i = 1, 2, \cdots, K,$$

$$x_o = \arg\max_{x \in x_i : i = 1, \cdots K} (\eta_i ||x - y||^{-\alpha})$$

RSRP $\eta_i = P_i$

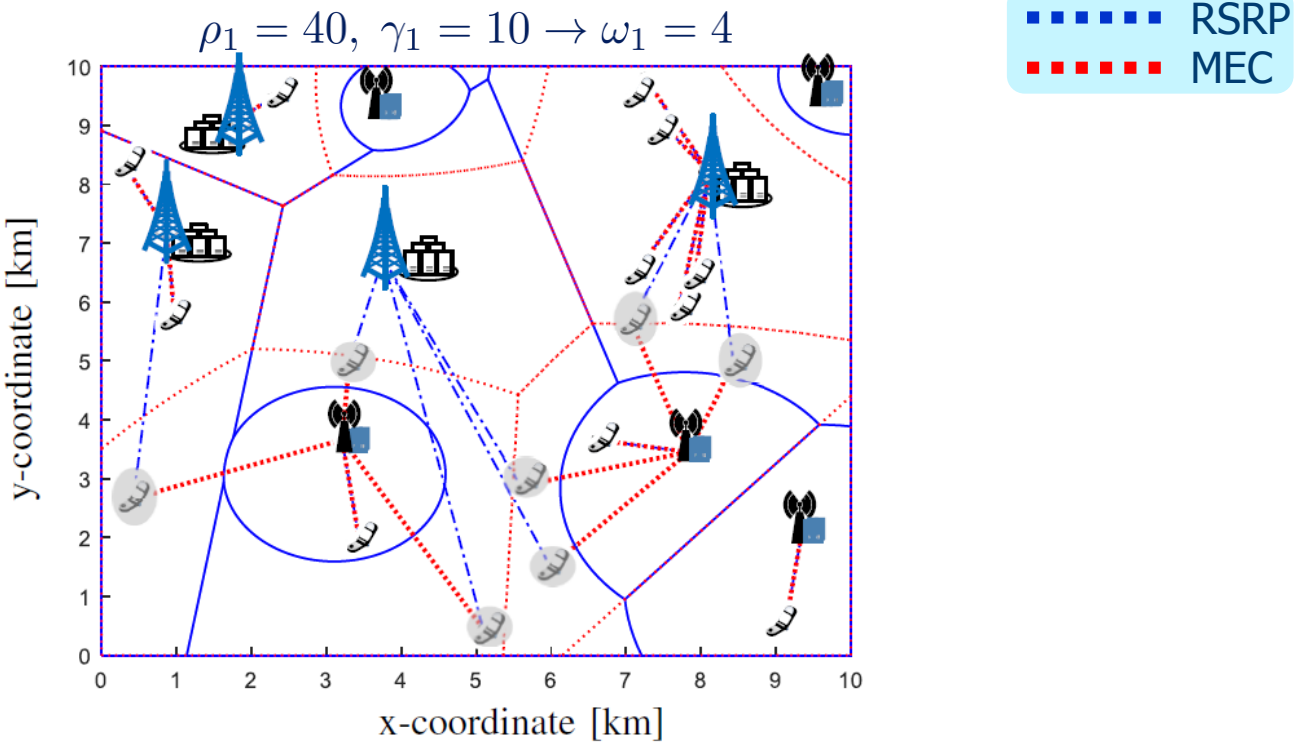
MEC $\eta_i = C_i$



Proposing a **processing proximity-based connectivity rule**

A Computationally-aware Cell Association Rule (cont.)

- Implications on DL/ UL connectivity decisions by applying the two rules



Numerical Evaluation

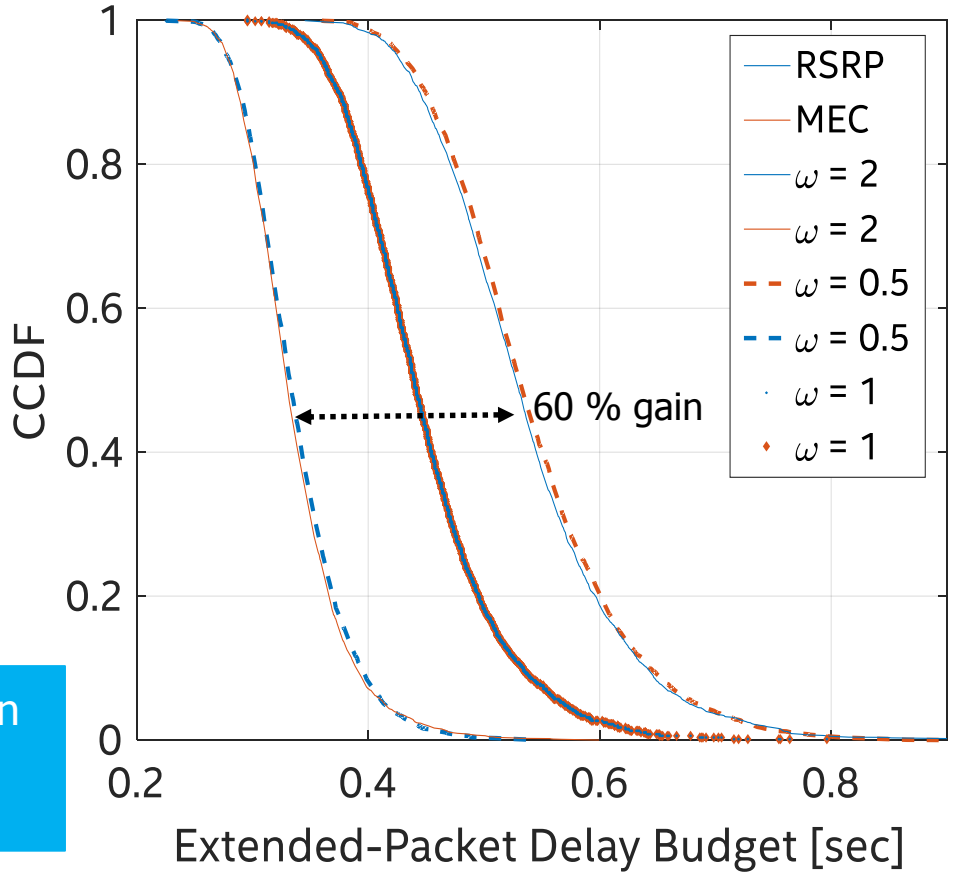
- Provide insight on the E-PDB enhancements achieved via the new proposed MEC-aware association metric
- Investigate effect of network disparity (radio and computational resources) on E-PDB performance
- We quantify the ratio of radio to computational resource disparities as

$$\omega = \frac{\rho}{\gamma}$$

Parameter	Value
Number of tiers (K)	2
BSs Deployment densities $(\boldsymbol{\lambda} = [\lambda_1,\ \lambda_2])$	$(0.5, 3)$ eNB/km^2
User density (λ_{u})	30 UE/km^2
Packets size (l_k)	$\sim U[100, 500]$ kbits
Processing requirements (f_k)	$\sim U[500, 1500]$
Bandwidth/tier (BW_i)	10 MHz
Pathloss exponent (α)	4

Numerical Evaluation: Dynamic Cell Connectivity

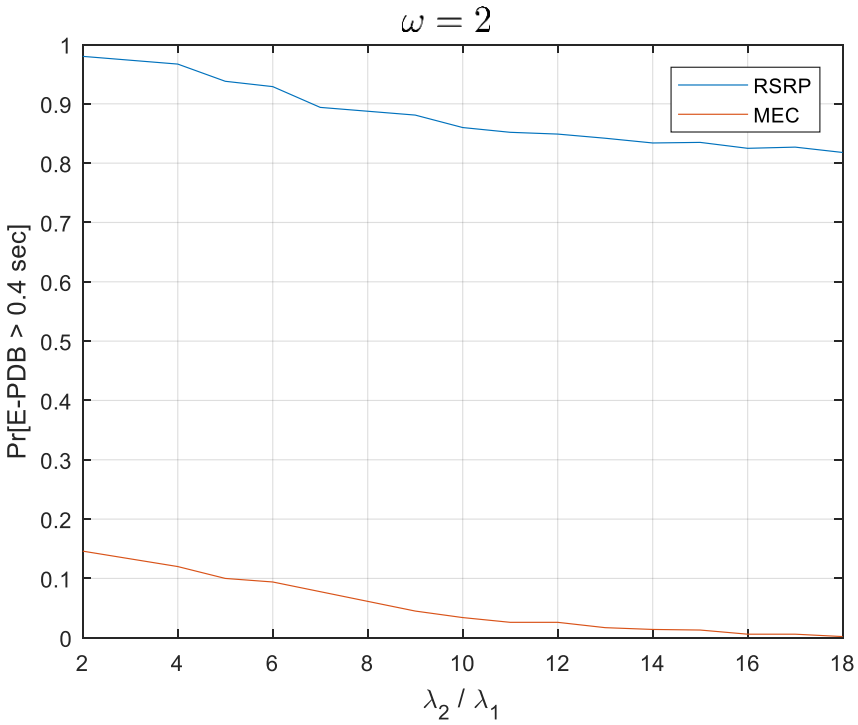
- The experienced E-PDB is highly dependent on the HetNet resource disparities (3 investigated disparity cases)
  - ❑ Load imbalance between the different tiers
- The MEC-aware association rule accounts for the level of "processing proximity" to decide upon cell connectivity
- For equal radio/ MEC cross-tier disparities, no gain is observed (full overlap of the two respective coverage areas)



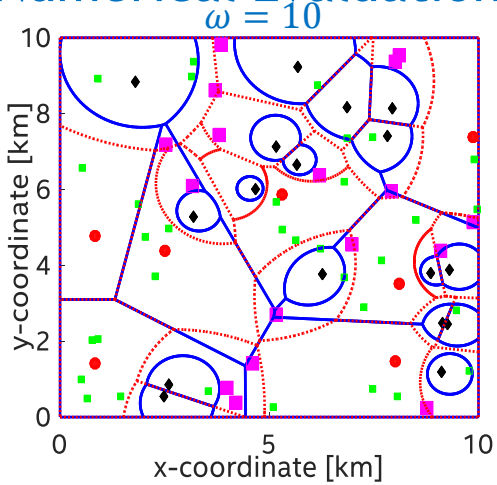
Solution: adapting the applied association rule to the radio/ processing resource disparity across the HetNet tiers

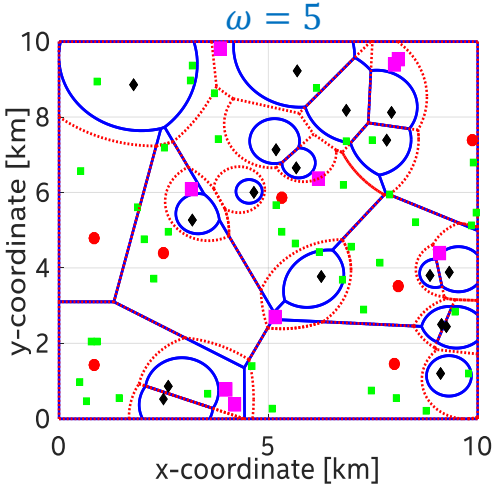
Numerical Evaluation: Spatial Heterogeneity

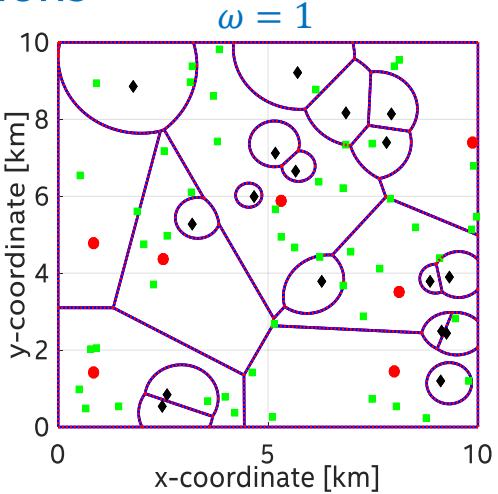
- Effect of deployment density on the probability of violating a targeted E-PDB value (0.4 sec)
  - Almost constant association-based outage reduction, **in favor of the proposed MEC-aware association rule**
  - Increasing spatial deployment heterogeneity → lower experienced latency → lower E-PDB violation probability
    - Many tier-2 BSs → High probability of closer BSs → exploitation of **high "processing proximity" for speedy task offloading**
    - Less UEs are associated to tier-1 BSs → **lower UE load** for these BSs

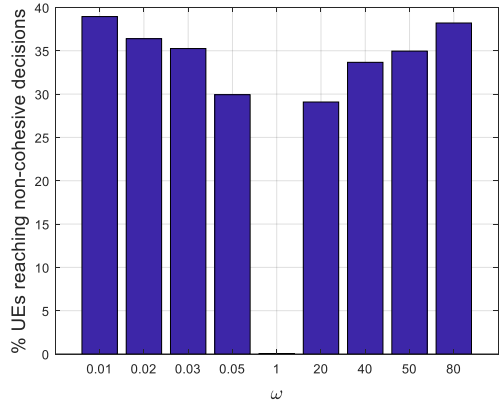


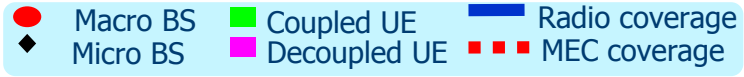
Numerical Evaluation: Non-Cohesive Association Decisions











- Recall: $\omega = \dfrac{P_1/P_2}{C_1/C_2} = \dfrac{\rho}{\gamma}$ → Fixed in this evaluation
- An almost "mirrored" fraction of UEs reaching non-cohesive decisions when applying the two rules is realized, depending on the cross-tier resource characteristics
- $\omega = 1$ → Full overlap of radio and MEC regions is achieved

Conclusion & Future Work

➢ Conclusion

- Leveraging the **MEC degree of freedom** in planning and dimensioning cellular systems
- Investigating the **impact of disparities** in both radio and MEC resource domains
- E-PDB minimization can be achieved by means of a UE-cell association metric evaluating **processing proximity**

➢ Future Work

- Generalizing the work by taking into account the co-existence of services of **dissimilar performance requirements**
- Further optimized connectivity by considering **other dynamic system attributes**

References

- [1] K. Sato and T. Fujii, “Radio environment aware computation offloading with multiple mobile edge computing servers,” in 2017 IEEE Wireless Communications and Networking Conference Workshops (WCNCW), March 2017, pp. 1–5.
- [2] H. Q. Le, H. Al-Shatri, and A. Klein, “Efficient resource allocation in mobile-edge computation offloading: Completion time minimization,” in 2017 IEEE International Symposium on Information Theory (ISIT), June 2017, pp. 2513–2517.
- [3] Y. Mao, J. Zhang, and K. B. Letaief, “Joint task offloading scheduling and transmit power allocation for mobile-edge computing systems,” in 2017 IEEE Wireless Communications and Networking Conference (WCNC), March 2017, pp. 1–6.
- [4] T. Li, C. S. Magurawalage, K. Wang, K. Xu, K. Yang, and H. Wang, “On efficient offloading control in cloud radio access network with mobile edge computing,” in 2017 IEEE 37th International Conference on Distributed Computing Systems (ICDCS), June 2017, pp. 2258–2263.

Thanks!

Questions?