Towards Joint Cell Selection and Task Offloading in Cellular IoT Systems with Edge Computing

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Resume of the presenter

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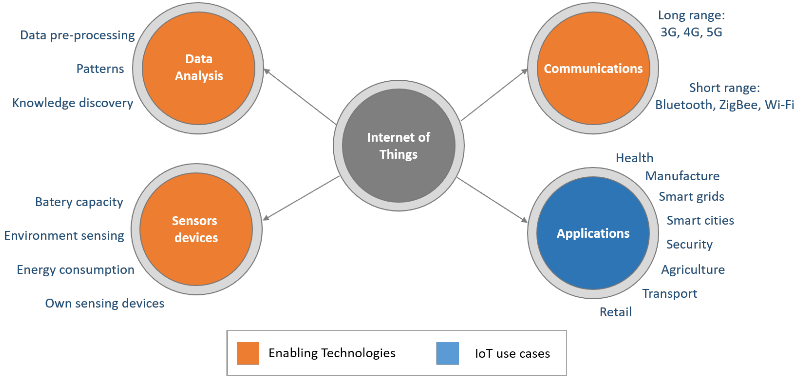
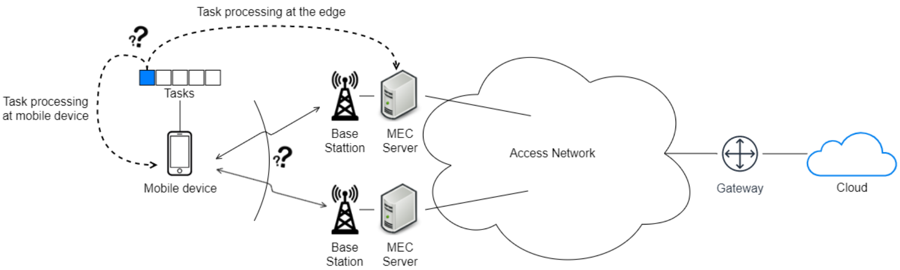
Content

1. Introduction
2. State of the Art
3. Foreseen Reasearch Work
4. Conclusion and Future Works
5. References

- Internet of Things (IoT) $\rightarrow$ Objects with **communication**, **computing** and **sensing** capabilities to collect data from their environment.
- 5G play a key role in IoT broadband applications demanding **data analytics at the network edge.**

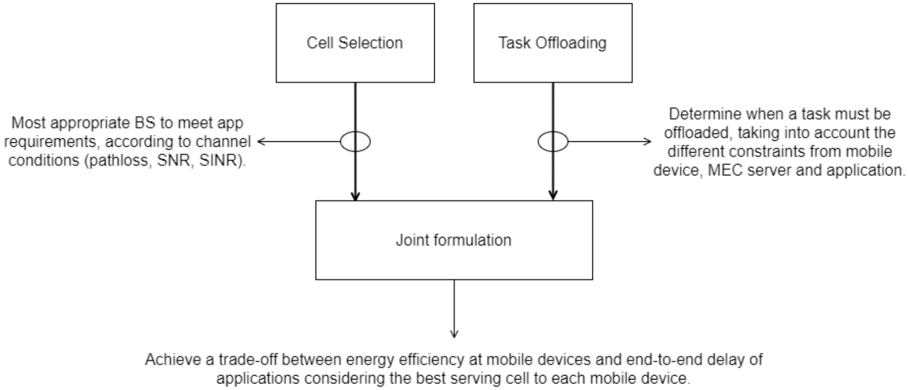


Introduction
Mobile Edge Computing (MEC) architecture



- Mobile devices send data to the edge for computation purposes (if required).
- This involves two decision making processes: 1) task offloading, and 2) cell selection. These problems **are normally studied separately.**

- Mobile device: Task processed locally.
  $\rightarrow$ Constraints: **energy, computing capabilities**.
- MEC Server: Task offloaded and processed at the edge.
  $\rightarrow$ Constraints: **limited processing resources**, delay.
- Application: Tasks to be processed at the device and/or MEC server.
  $\rightarrow$ Requeriment: application **latency** (computing latency and round-trip time delay)


Cell Selection
Task Offloading
Most appropriate BS to meet app requirements, according to channel conditions (pathloss, SNR, SINR).
Determine when a task must be offloaded, taking into account the different constraints from mobile device, MEC server and application.
Joint formulation
Achieve a trade-off between energy efficiency at mobile devices and end-to-end delay of applications considering the best serving cell to each mobile device.

State of the Art

The most relevant approaches proposed so far are summarized in Table 1. In particular, we analyzed some key aspects such as the proposed algorithm, the type of offloading, the considered constraints and service requirements. In addition, we analyze if the proposed approach considers the joint task offloading and cell selection problems.

State of the Art

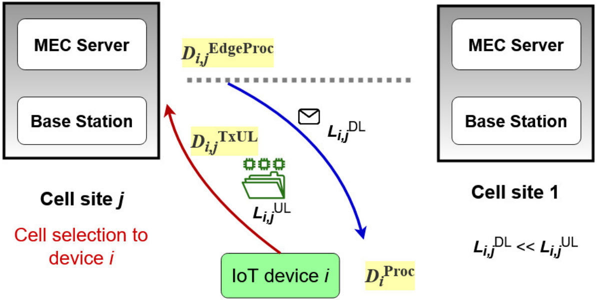
Table 1: Summary of Related Work.

Author	Year	Cell Selection	Algorithm	Task Offloading Type	Saved Energy	Reduce Latency
Xiang *et al.* [1]	2019	✗	Fragment algorithm for data processing	Full	✗	✓
Ning *et al.* [2]	2019	✗	Hybrid offloading algorithm	Full	✗	✗
Sun *et al.* [3]	2019	✗	Hybrid offloading algorithm	Partial	✗	✓
Chen *et al.* [4]	2019	✗	Adaptative offloading algorithm	Full	✓	✓
Sun *et al.* [5]	2018	✗	Greedy algorithm	Full	✓	✓
Wu *et al.* [6]	2018	✗	Offloading algorithm based on environment identification	Partial	✓	✗
Yu *et al.* [7]	2017	✗	Heuristic	Partial	✓	✗
Deng *et al.* [8]	2016	✗	Adaptative offloading algorithm for multiple users	Full	✗	✗
Zhang *et al.* [9]	2016	✗	Efficient computing algorithm	Partial	✓	✗
Huang *et al.* [10]	2012	✗	Dynamic data offloading algorithm in IoT devices	Partial	✓	✓

State of the Art

- Most of the existing approaches **are designed for centralized solutions**, where the complete information of the system is required for solving the decision making process.
- Furthermore, most of the studied works **do not consider** the joint cell selection and delay minimization problem, instead they assume a previous assignment, which is mainly based on greedy solutions.

- We study an OFDMA-based cellular system deployment with N cell sites and M IoT devices distributed over the service area; at each cell site, a MEC server is assumed to be co-located with the base station (BS) equipment.
- Resource constraints per cell site $\rightarrow$ 1) radio channel bandwidth used in the BS, and 2) computing capacity of the MEC server.



- Backhaul resources **are not considered** in the present modelling as all tasks are assumed to be processed either at the mobile device or the network edge.

- We assume that each IoT device i has delay and computation requirements for the processing of the task A_i.
- Each task A_i is modeled using a three-field notation $A_i(L_{i,j}^{\mathrm{UL}}, \gamma_{i,j}, D_i^{\mathrm{req}})$, where:
  - $L_{i,j}^{\mathrm{UL}}$ is the input data file (in bits).
  - $\gamma_{i,j}$ denotes the workload (CPU cycles/bit) for processing one-bit data.
  - D_i^{req} is the hard deadline imposed by the application.

- Total delay experienced by a file from a given device can be expressed as:

$$D_{ij} = \varphi_i D_i^{\mathrm{proc}} + [(1-\varphi_i)(D_{i,j}^{\mathrm{TxUL}} + D_{i,j}^{\mathrm{EdgeProc}} + D_{i,j}^{\mathrm{TxDL}})] \qquad (1)$$

where:

  - $\varphi_i \in \{0,1\}$ determine if a task is processed locally at the device i, or if it is offloaded to the mobile edge.
  - $D_{i,j}^{\mathrm{TxUL}}$ and $D_{i,j}^{\mathrm{TxDL}}$ denote the transmission delays in the uplink and downlink.
  - $L_{ij}^{\mathrm{DL}} << L_{ij}^{\mathrm{UL}}$ the response from the edge server to the mobile device is smaller in size than the data offloaded to the MEC server.

- The delay observed if the task is processed at the mobile device can be expressed as:

$$D_i^{\mathrm{proc}} = \frac{L_{i,j}^{UL}\gamma_{i,j}}{C_i^{\mathrm{Device}}} \tag{2}$$

  where:
  - C_i^{Device} denotes the computing capacity (CPU cycles/sec) of the mobile device.

- The delay observed if the task is processed at MEC server can be expressed as:

$$D_{ij}^{\mathrm{EdgeProc}} = \frac{L_{i,j}^{UL}\gamma_{i,j}}{C_{i,j}^{\mathrm{Edge}}} \tag{3}$$

where:

- $C_{i,j}^{\mathrm{Edge}}$ denotes the amount of computing resources (CPU cycles/sec.) assigned by the edge node j to process the task of device i.

- The energy consumption for the task processing at the mobile device is expressed as follows [11]:

$$E_i = (L_i^{\mathrm{UL}} \gamma_i) f_i \tag{4}$$

where:

- f_i denotes the required energy to process one bit at the mobile device.

- Minimize total delay of all devices while satisfying the computing resources at each node j as well as the energy constraint of IoT devices.

$$\min \quad \sum_{j=1}^{N} \sum_{i=1}^{M} D_{ij} b_{i,j} \tag{5a}$$

$$\text{s.t.} \quad \sum_{i=1}^{M} C_{i,j}^{\text{Edge}} b_{i,j} \leq 1, \; j = 1, \ldots, N \tag{5b}$$

$$D_{ij} \leq D_i^{\text{req}}, i = 1, \ldots, M \tag{5c}$$

$$\sum_{j=1}^{N} b_{i,j} \leq 1, \; i = 1, \ldots, M \tag{5d}$$

$$b_{i,j} \in \{0, 1\} \tag{5e}$$

- *RQ1:* ¿Is it possible to design a cell selection criteria to steer device associations based on radio/computation conditions at the MEC servers and delay requirements of applications?
- *RQ2:* ¿How to design an efficient distributed cell selection algorithm that operating with network partial state information could find the optimal assignment of communication and computation resources in order to minimize the system delay?
- *RQ3:* ¿How to properly model a decision making mechanism to determine if a task should be processed locally, at the MEC server or a partial offloading?

Conclusion and Future Works

- In this work in progress, we presented a joint cell selection and task offloading approach aims to determine: a) **when to offload** a task to a MEC server, and b) **where to offload** using a distributed cell selection approach aware of resource constraints and delay application requirements.
- We aim to evaluate our approach in terms of the total average delay achieved by the algorithms when offloading the tasks to the edge server or computed locally at the mobile device.

References I

B. Xiang, J. Elias, F. Martignon y E. Di Nitto, “Joint network slicing and mobile edge computing in 5G networks,” en *ICC 2019-2019 IEEE International Conference on Communications (ICC)*, IEEE, 2019, págs. 1-7.

Z. Ning, X. Wang, J. J. Rodrigues y F. Xia, “Joint computation offloading, power allocation, and channel assignment for 5G-enabled traffic management systems,” *IEEE Transactions on Industrial Informatics*, vol. 15, n.º 5, págs. 3058-3067, 2019.

H. Sun, F. Zhou y R. Q. Hu, “Joint offloading and computation energy efficiency maximization in a mobile edge computing system,” *IEEE Transactions on Vehicular Technology*, vol. 68, n.º 3, págs. 3052-3056, 2019.

References II

X. Chen, S. Chen, Y. Ma, B. Liu, Y. Zhang y G. Huang, "An adaptive offloading framework for Android applications in mobile edge computing," *Science China Information Sciences*, vol. 62, n.º 8, pág. 82 102, 2019.

Y. Sun, Z. Hao e Y. Zhang, "An Efficient offloading scheme for MEC system considering delay and energy consumption," en *Journal of Physics: Conf. Ser*, vol. 960, 2018.

H. Wu, Y. Sun y K. Wolter, "Energy-efficient decision making for mobile cloud offloading," *IEEE Transactions on Cloud Computing*, 2018.

S. Yu, X. Wang y R. Langar, "Computation offloading for mobile edge computing: A deep learning approach," en *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, IEEE, 2017, págs. 1-6.

References III

M. Deng, H. Tian y X. Lyu, “Adaptive sequential offloading game for multi-cell mobile edge computing,” en *2016 23rd international conference on telecommunications (ICT)*, IEEE, 2016, págs. 1-5.

K. Zhang, Y. Mao, S. Leng, Q. Zhao, L. Li, X. Peng, L. Pan, S. Maharjan e Y. Zhang, “Energy-efficient offloading for mobile edge computing in 5G heterogeneous networks,” *IEEE access*, vol. 4, págs. 5896-5907, 2016.

D. Huang, P. Wang y D. Niyato, “A dynamic offloading algorithm for mobile computing,” *IEEE Transactions on Wireless Communications*, vol. 11, n.º 6, págs. 1991-1995, 2012.

Y. Pei, Z. Peng, W. Zhenling y H. Wang, “Energy-Efficient Mobile Edge Computing: Three-Tier Computing under Heterogeneous Networks,” *Wireless Communications and Mobile Computing*, vol. 2020, págs. 1-17, abr. de 2020. DOI: 10.1155/2020/6098786.