Universidad Carlos III de Madrid

NFV Orchestration in Edge and Fog Scenarios

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1. Generation of 5G infrastructure graphs
2. NFV Orchestration in federated environments

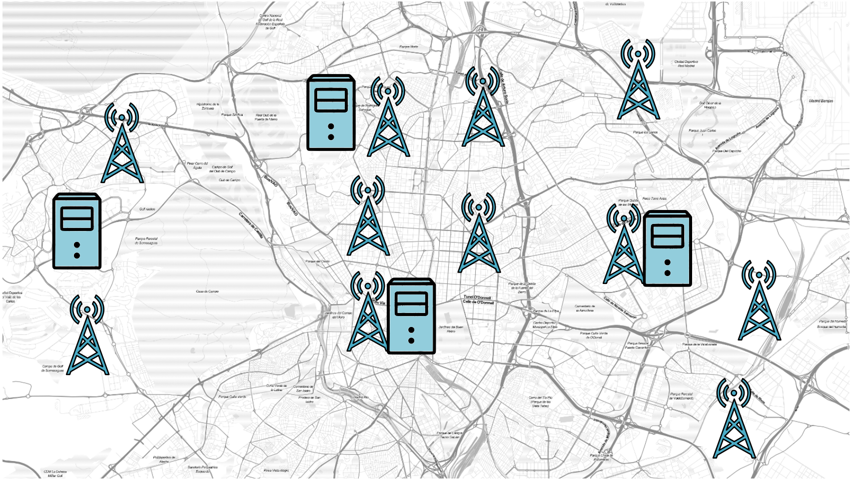

Figure 1: Illustration of BS and PoPs in Madrid

Location of BSs:

- Neyman-Scott Poisson Cluster Process [15]
- Poisson Point Processes (PPPs) [3]
  - homogeneous [16, 1]
  - hard-core [6]

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Location of MEC PoPs:

- along highways [17]
- within stadiums [5]

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Location of MEC PoPs:

- along highways [17]
- within stadiums [5]
- **population census**
- **access & aggregation rings**

Derive:

- BS location
- MEC PoP location

Meet:

- Tactile RTT of **1 ms**

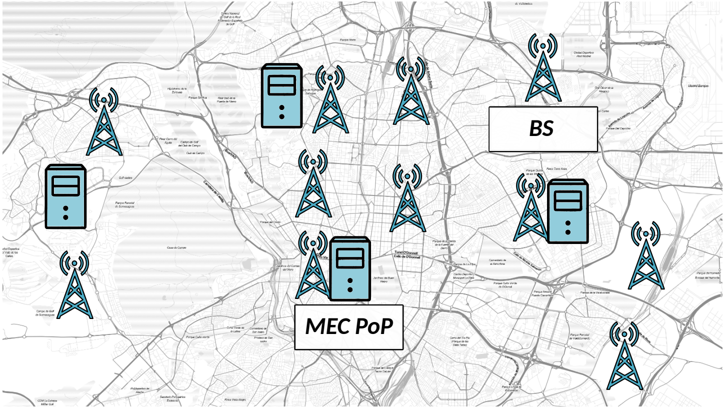

Figure 2: BS and MEC PoP locations

Higher gentrification $\implies$ more BSs

- $f_i(x)$ – revolution func.
- $G(x)$ – gentrification
- R – region of interest
- C_i – area

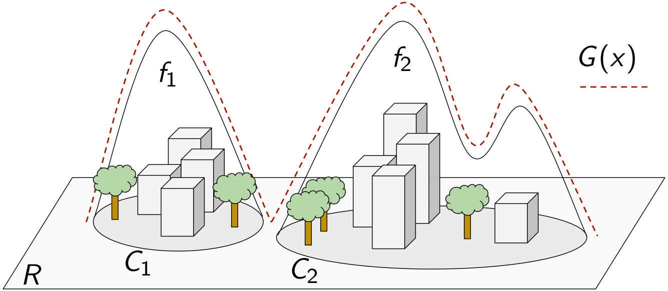

Figure 3: *Revolution functions* of a region with two building areas.

BS intensity function $\lambda(x) \sim G(x)$ proportional to gentrification.

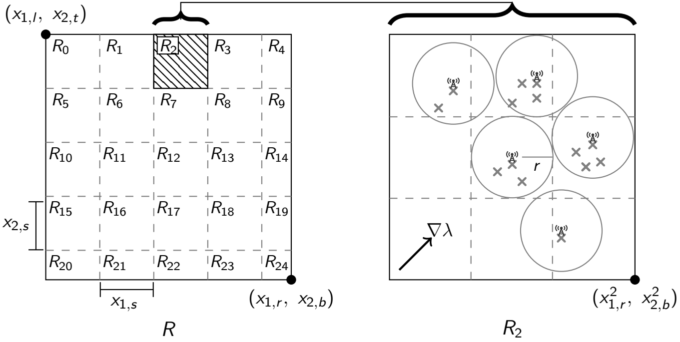

Figure 4: Gridded region (left), and inhomogeneous Mattérn II process of BSs (right).

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- $G(x)$: Madrid census
- R: Madrid city
- Inhomogeneous Mattern II PPs

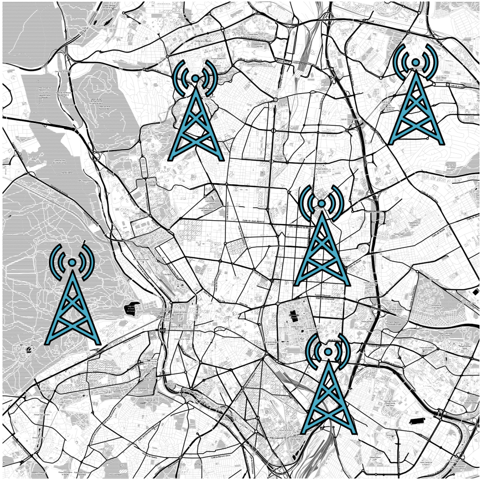

Figure 5: Location of BSs

- $G(x)$: Madrid census
- R: Madrid city
- Inhomogeneous Mattern II PPs

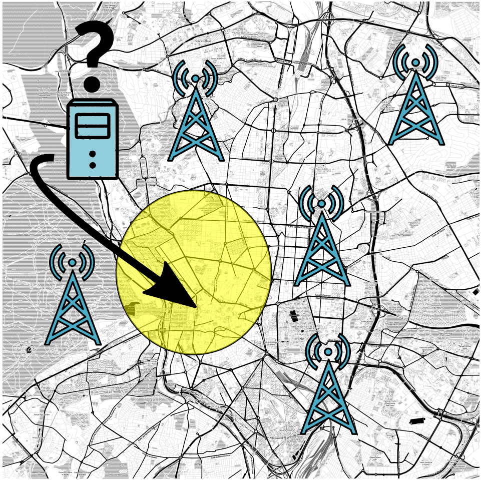

Figure 5: Location of BSs

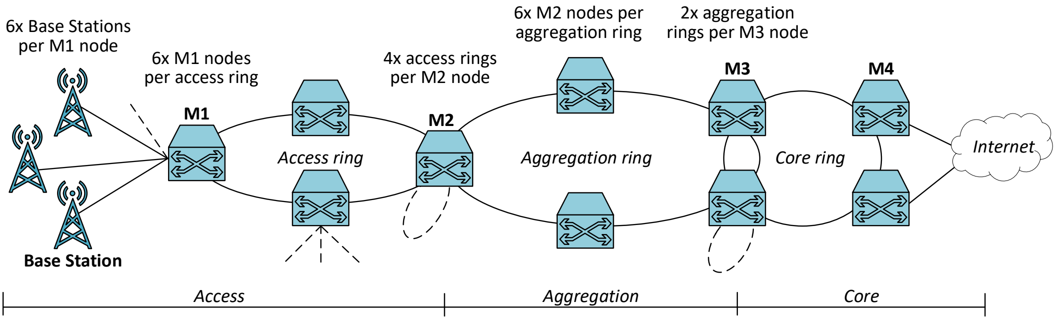

Figure 6: Reference network infrastructure as illustrated[1] in [4] and based on [7].

[1] Author: Dr. Luca Cominardi.

Derive MEC PoP location considering:

$$RTT = \underbrace{\boxed{2d \cdot 5\frac{\mu s}{km}}}_{\text{fiber propagation}} + 2M \cdot 50\mu s + UL + DL \qquad (1)$$

- d: distance between BS and MEC PoP
- M: network ring
- UL: Uplink propagation latency
- DL: Downlink propagation latency

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Derive MEC PoP location considering:

$$RTT = 2d \cdot 5\frac{\mu s}{km} + 2M \cdot 50\mu s + \underbrace{UL + DL}_{\text{radio propagation}} \tag{1}$$

- d: distance between BS and MEC PoP
- M: network ring
- UL: Uplink propagation latency
- DL: Downlink propagation latency

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m_M: maximum distance between MEC PoP at ring M and BS

Figure 7: How to select MEC PoP location

m_2: maximum distance between MEC PoP at ring 2 and BS

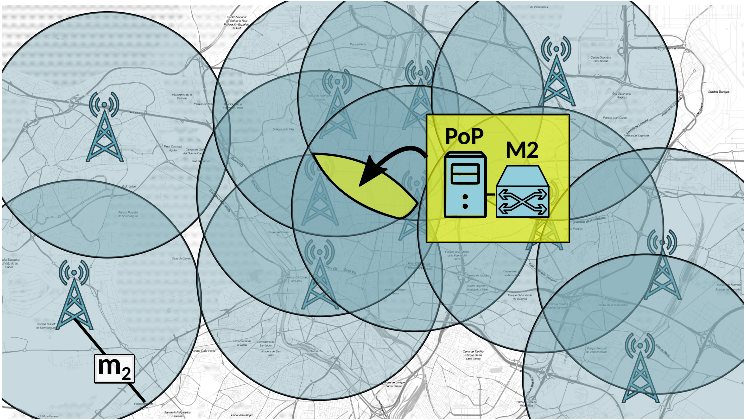
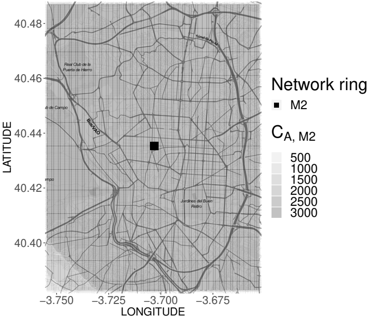
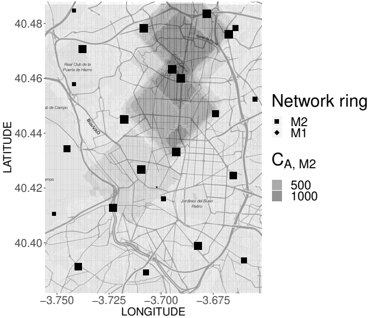


Figure 7: How to select MEC PoP location

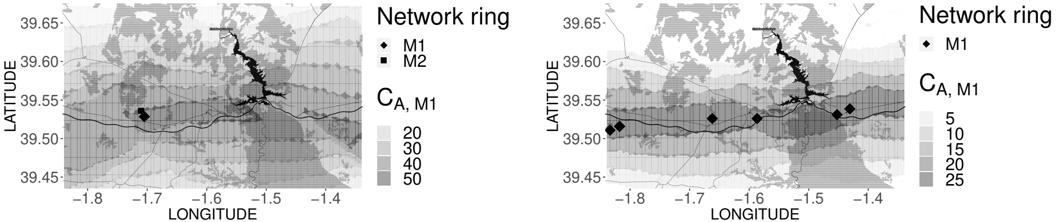


(a) FDD 120 kHz 7s



(b) TDD 120 kHz 7s

Figure 8: **Urban scenario** (Madrid city center) – $C_{A,M2}$ =covered BSs



(a) FDD 120 kHz 7s

(b) TDD 120 kHz 7s

Figure 9: **Highway scenario** (Hoces del Cabriel A3) – $C_{A,M1}$ =covered BSs by M1 MEC PoP

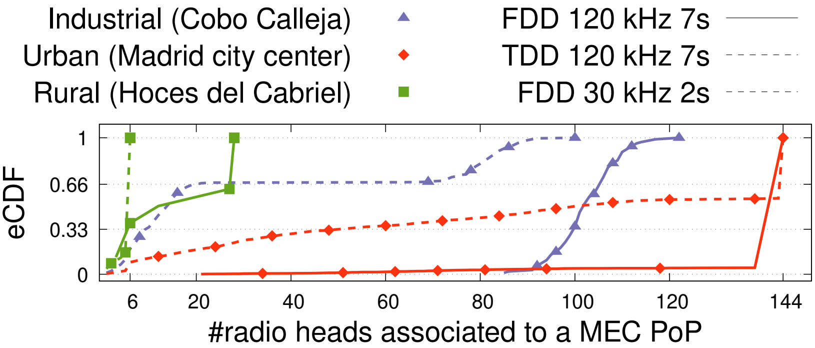


Figure 10: eCDF of the number of BSs assigned to a MEC PoP in the studied scenarios.

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Publications:

- **Martín-Pérez, Jorge**, L. Cominardi, C. J. Bernardos, A. de la Oliva, and A. Azcorra. "Modeling Mobile Edge Computing Deployments for Low Latency Multimedia Services". In: *IEEE Transactions on Broadcasting* 65.2 (2019), pp. 464–474. DOI: 10.1109/TBC.2019.2901406
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Open-source:

- github.com/MartinPJorge/mec-generator
- 5GEN R package

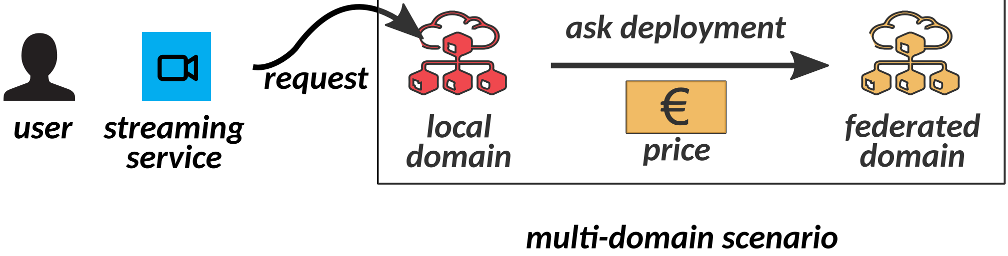

Figure 11: Service federation

Orchestration and **fixed pricing** in multi-domain:

- Alternating Direction Method of Multipliers (ADMM) [13]
- branching heuristic [8]
- graph-based message passing [18]
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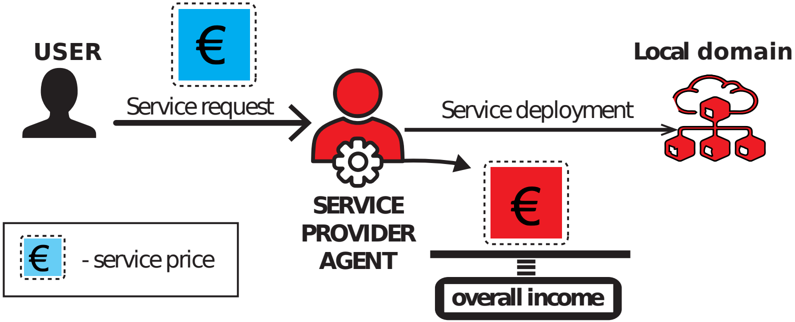

Figure 12: Business model - local deployment[2]

[2]Based on Kiril Antevski illustration

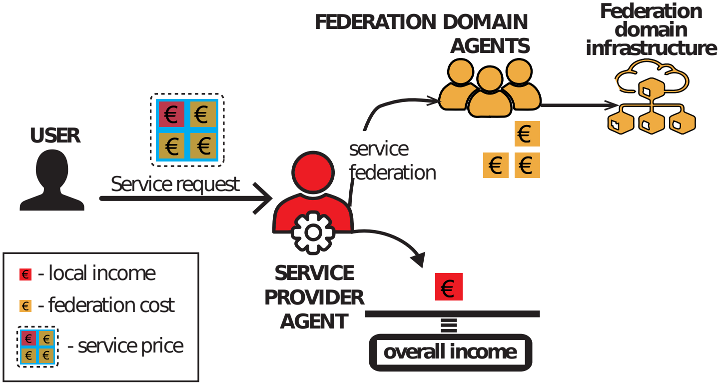

Figure 13: Business model - federate deployment[3]

[3]Based on Kiril Antevski illustration

t3a.small:

- 2 CPUs
- memory 2 GB
- storage 100 GB

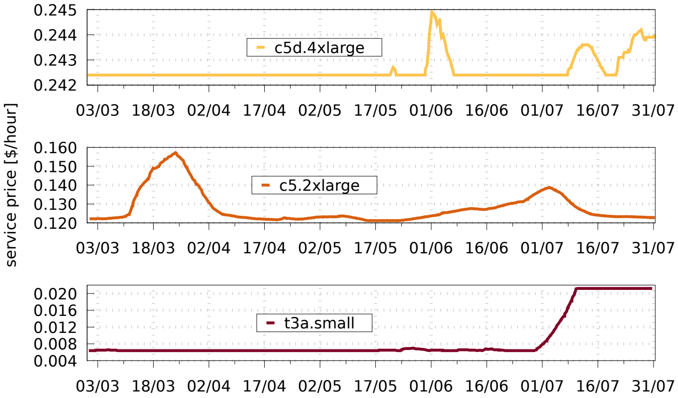

Figure 14: AWS service prices during 2020 in west Europe

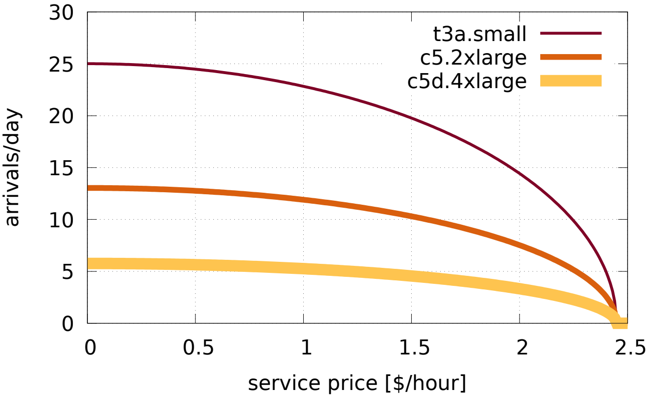

Figure 15: impact of prices on arriving users – based on tid study [14] and [**xavierpricing**]

Considering:

- Price changes
- Available resources (CPU, memory, disk)
- Service lifetime (e.g., 2 days)

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For each service σ, decide / take an **action**:

- $x(\sigma) = 0$: **reject**
- $x(\sigma) = 1$: **local**
- $x(\sigma) = 2$: **federate**

Reward based on:

- expenditure (federation fee)
- earnings
- deployed services

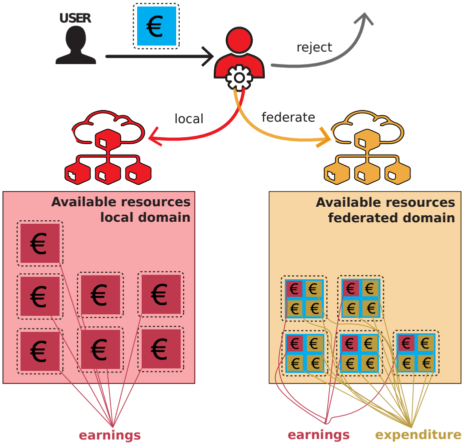

Figure 16: Environment snapshot at time t.

Online optimization problem:

- objective: $\max_{X_t} \frac{1}{T} \sum_t r^{(t)}(X_t)$
- constraints:
  - CPU
  - memory
  - disk

NP-hard: knapsack problem equivalence

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Markov Decision Problem (MDP):

- find policy π to:
  $\max_\pi \mathbb{E}_{x(\sigma)\sim\pi} \left[\sum_t \gamma^t \; r^{(t)}(\pi)\right]$
- action space $\mathcal{A} = \{0, 1, 2\}$
- state space $\mathcal{S}$:
  - available & requested resources
  - current prices
  - service lifetime
- instant reward $r^{(t)}(\pi)$

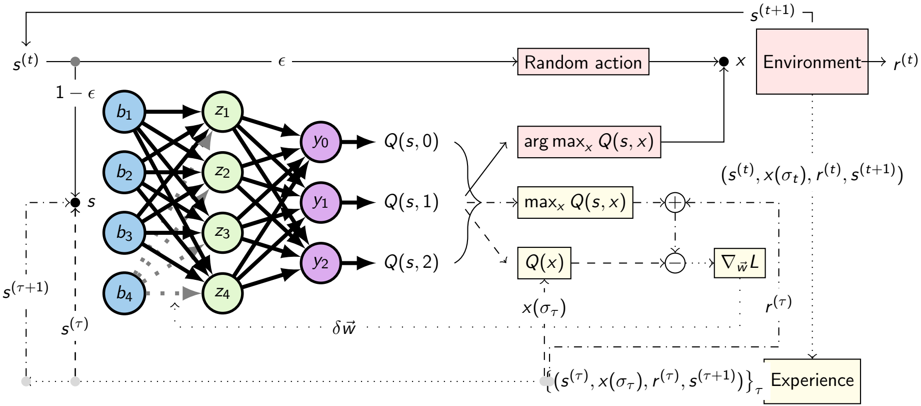

Figure 17: DQN architecture to decide rejection/local/federate

Experimentation:

- TID infrastructure & resources [14]

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- AWS prices dataset:
  - training 29/02/2020 – 02/05/2020
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- TID infrastructure & resources [14]
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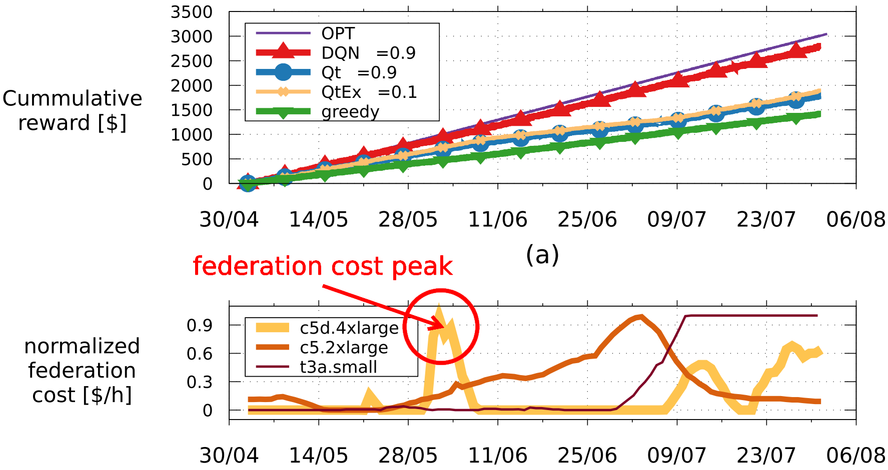
- Poissonian arrival of users

TODO - here just show 3x CDFs (resource usage with DQN)



(a)

(b)

Thanks for your attention!

OKpi is open-source, and it is implemented in python's placement module as FPTASMapper:

`https://github.com/MartinPJorge/placement`

[1] M. Afshang and H. S. Dhillon. "Poisson Cluster Process Based Analysis of HetNets With Correlated User and Base Station Locations". In: *IEEE Transactions on Wireless Communications* 17.4 (Apr. 2018), pp. 2417–2431. ISSN: 1536-1276. DOI: 10.1109/TWC.2018.2794983.

[2] K. Antevski, **J. Martín-Pérez**, A. Garcia-Saavedra, C. J. Bernardos, X. Li, J. Baranda, J. Mangues-Bafalluy, R. Martnez, and L. Vettori. "A Q-learning strategy for federation of 5G services". In: *ICC 2020 - 2020 IEEE International Conference on Communications (ICC)*. 2020, pp. 1–6. DOI: 10.1109/ICC40277.2020.9149082.

[3] A. Baddeley, C. internazionale matematico estivo, and W. Weil. *Stochastic Geometry: Lectures Given at the C.I.M.E. Summer School Held in Martina Franca, Italy, September 13-18, 2004*. Lecture Notes in Mathematics / C.I.M.E. Foundation Subseries. Springer, 2007. ISBN: 9783540381747.

[4] L. Cominardi, L. M. Contreras, C. J. Bernardos, and I. Berberana. "Understanding QoS Applicability in 5G Transport Networks". In: *2018 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*. June 2018, pp. 1–5. DOI: 10.1109/BMSB.2018.8436847. URL: https://e-archivo.uc3m.es/bitstream/handle/10016/27393/understanding_BMSB_2018_ps.pdf (visited on 01/10/2019).

[5] V. Frascolla et al. "5G-MiEdge: Design, standardization and deployment of 5G phase II technologies: MEC and mmWaves joint development for Tokyo 2020 Olympic games". In: *2017 IEEE Conference on Standards for Communications and Networking (CSCN)*. Sept. 2017, pp. 54–59. DOI: 10.1109/CSCN.2017.8088598.

[6] A. M. Ibrahim, T. ElBatt, and A. El-Keyi. "Coverage probability analysis for wireless networks using repulsive point processes". In: *2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*. Sept. 2013, pp. 1002–1007. DOI: 10.1109/PIMRC.2013.6666284.

[7] ITU-T. *Consideration on 5G transport network reference architecture and bandwidth requirements*. Study Group 15 Contribution 0462. International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), Feb. 2018.

[8] G. Li, H. Zhou, B. Feng, and G. Li. "Context-Aware Service Function Chaining and Its Cost-Effective Orchestration in Multi-Domain Networks". In: *IEEE Access* 6 (2018), pp. 34976–34991. DOI: 10.1109/ACCESS.2018.2848266.

[9] **Martín-Pérez, Jorge**, L. Cominardi, C. J. Bernardos, and A. Mourad. "5GEN: A tool to generate 5G infrastructure graphs". In: *2019 IEEE Conference on Standards for Communications and Networking (CSCN)*. 2019, pp. 1–4. DOI: 10.1109/CSCN.2019.8931334.

[10] **Martín-Pérez, Jorge**, L. Cominardi, C. J. Bernardos, A. de la Oliva, and A. Azcorra. "Modeling Mobile Edge Computing Deployments for Low Latency Multimedia Services". In: *IEEE Transactions on Broadcasting* 65.2 (2019), pp. 464–474. DOI: 10.1109/TBC.2019.2901406.

[11] J. Martín-Pérez and C. J. Bernardos. "Multi-Domain VNF Mapping Algorithms". In: *2018 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*. 2018, pp. 1–6. DOI: 10.1109/BMSB.2018.8436765.

[12] B. Németh, B. Sonkoly, M. Rost, and S. Schmid. "Efficient service graph embedding: A practical approach". In: *2016 IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN)*. 2016, pp. 19–25. DOI: 10.1109/NFV-SDN.2016.7919470.

[13] P. T. A. Quang, A. Bradai, K. D. Singh, G. Picard, and R. Riggio. "Single and Multi-Domain Adaptive Allocation Algorithms for VNF Forwarding Graph Embedding". In: *IEEE Transactions on Network and Service Management* 16.1 (2019), pp. 98–112. DOI: 10.1109/TNSM.2018.2876623.

[14] A. Solano and L. M. Contreras. "Information Exchange to Support Multi-Domain Slice Service Provision for 5G/NFV". In: *2020 IFIP Networking Conference (Networking)*. 2020, pp. 773–778.

[15] V. Suryaprakash, J. Møller, and G. Fettweis. "On the Modeling and Analysis of Heterogeneous Radio Access Networks Using a Poisson Cluster Process". In: *IEEE Transactions on Wireless Communications* 14.2 (Feb. 2015), pp. 1035–1047. ISSN: 1536-1276. DOI: 10.1109/TWC.2014.2363454.

[16] V. Suryaprakash, P. Rost, and G. Fettweis. "Are Heterogeneous Cloud-Based Radio Access Networks Cost Effective?" In: *IEEE Journal on Selected Areas in Communications* 33.10 (Oct. 2015), pp. 2239–2251. ISSN: 0733-8716. DOI: 10.1109/JSAC.2015.2435275.

[17] M. Syamkumar, P. Barford, and R. Durairajan. "Deployment Characteristics of "The Edge" in Mobile Edge Computing". In: *Proceedings of the 2018 Workshop on Mobile Edge Communications*. MECOMM'18. Budapest, Hungary: ACM, 2018, pp. 43–49. ISBN: 978-1-4503-5906-1. DOI: 10.1145/3229556.3229557. URL: http://doi.acm.org/10.1145/3229556.3229557.

[18] Q. Zhang, X. Wang, I. Kim, P. Palacharla, and T. Ikeuchi. "Service function chaining in multi-domain networks". In: *2016 Optical Fiber Communications Conference and Exhibition (OFC)*. 2016, pp. 1–3.

Lemma

Given an inhomogeneous marked PPP X with intensity function λ, the thinning function l_2, and marks $m \sim \frac{1}{\lambda(x)}$, the resulting thinned point process, called inhomogeneous Matérn II PP, has the following average number of points at C:

$$\mathbb{E}\left[N(C)\right] := \int_C e^{-\int_{B(x,r)} \mathbb{1}(\lambda(u)>\lambda(x))\lambda(u)du} \lambda(x)\ dx \tag{2}$$

where r is the thinning radius of l_2.

with

$$l_2(x, m, X, M_X) := \begin{cases} 1 & \text{if } m = \min_{m' \in M_X} \left\{(x', m') : x' \in B(x, r)\right\} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

The RTT considered is computed as

$$RTT := 2l\left(\|x-m\|_1\right) + 2p(M) + UL + DL \tag{4}$$

We find m_M, the maximum distance from MEC PoP m to the BS at position x, as:

$$\|x-m\|_1 \leq l^{-1}\left(\frac{RTT - 2p(M) - t_r}{2}\right) = m_M \tag{5}$$

with $\|\cdot\|_1$ denoting the Manhattan distance.