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5GTRANSFORMER

Orchestrating a brighter world

NEC

Overbooking Network Slices through Yield-driven End-to-End Orchestration

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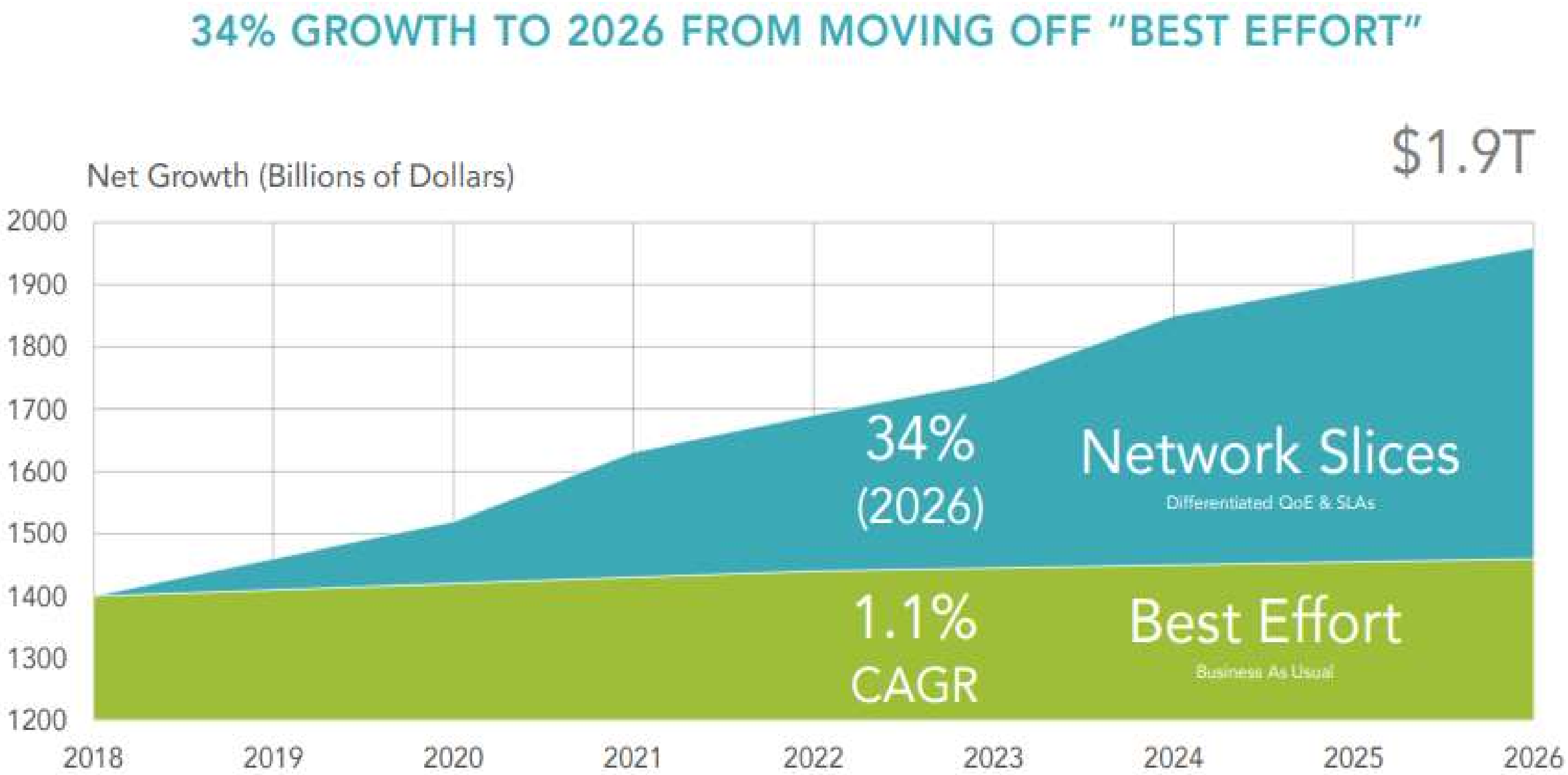
Introduction: Network Slicing

- (possibly hyper-hyped but…) Telcos and vendors expect that **NS to unlock around $300bn in business opportunities** with verticals/private enterprises

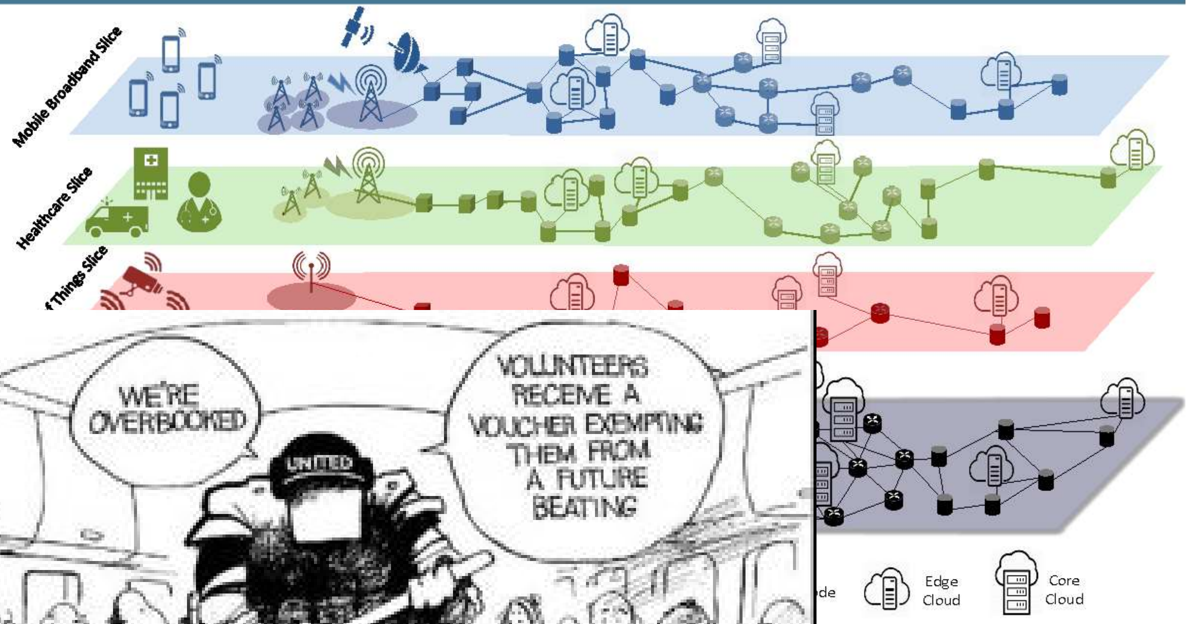


Source: Ericsson, Arthur D. Little

Challenges and Contributions

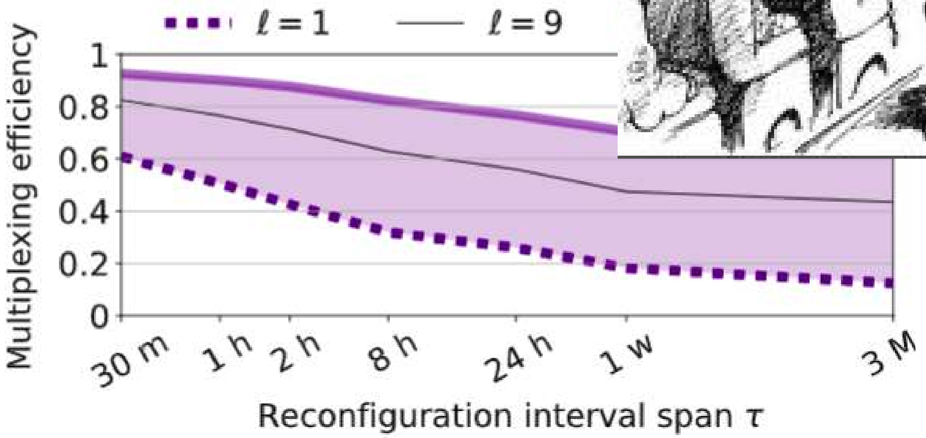
1. End-to-End Orchestration

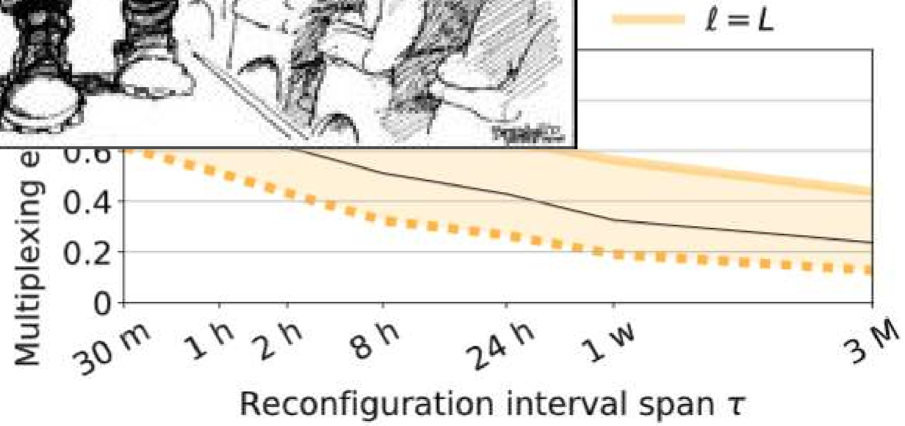
2. Network Slice Overbooking
(Admission Control and Resource Reservation mechanism)



NFV: Concepts, Architectures,
pp. 80-87, May 2017.

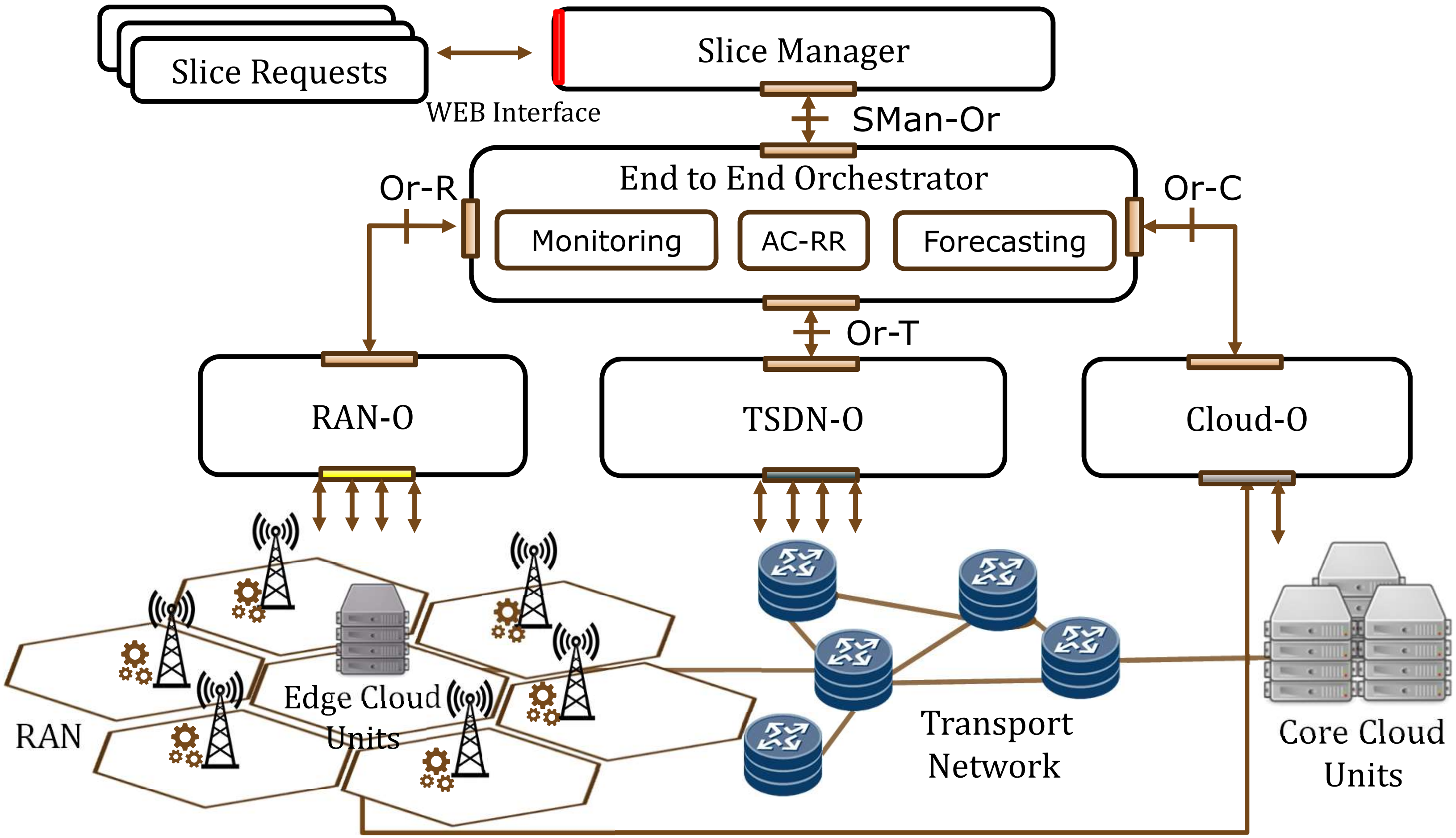
Large metropo… d city



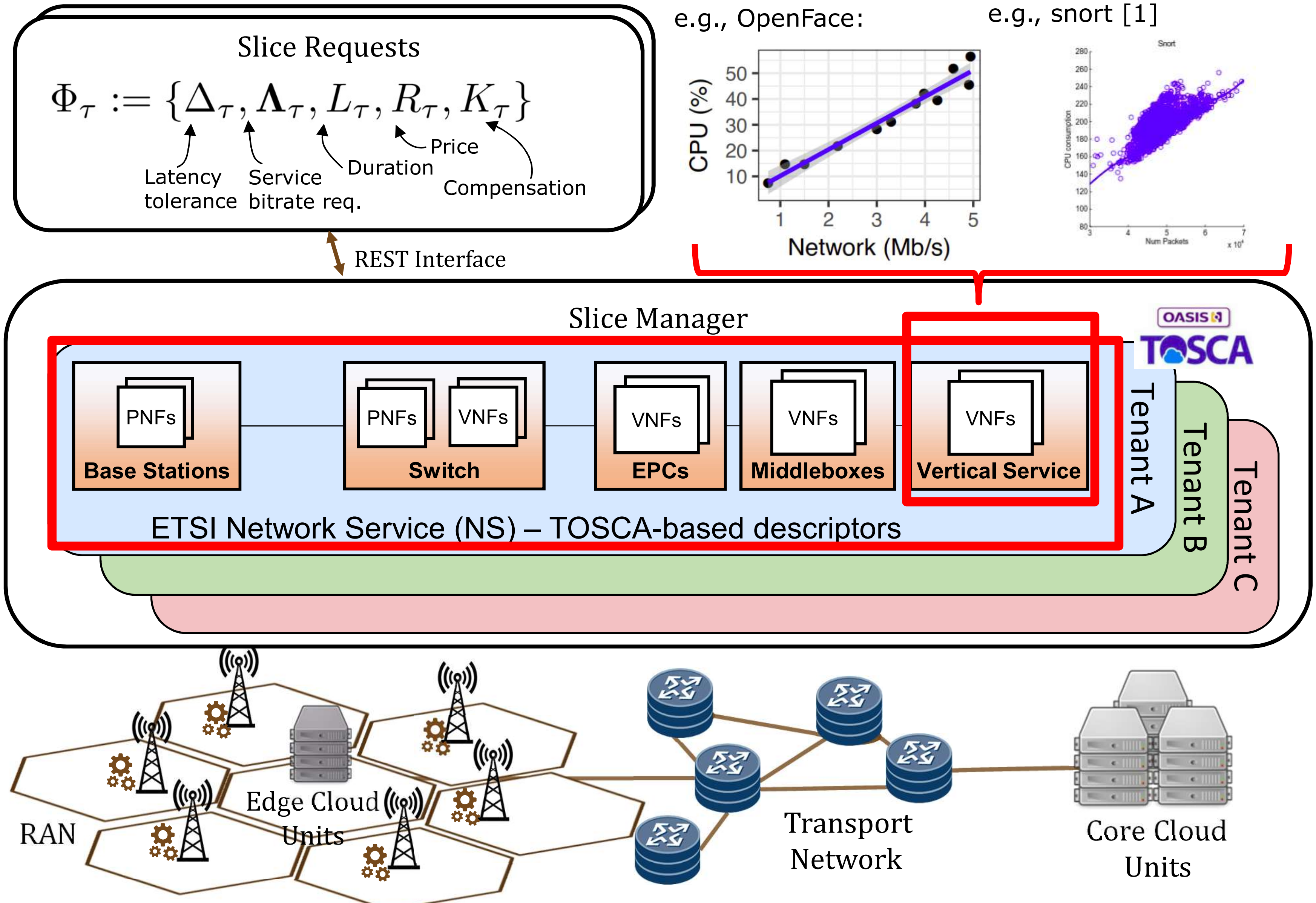


C. Marquez et al. "How Should I Slice My Network?: A Multi-Service Empirical Evaluation of Resource Sharing Efficiency". In ACM MobiCom 2018

System Design and Model

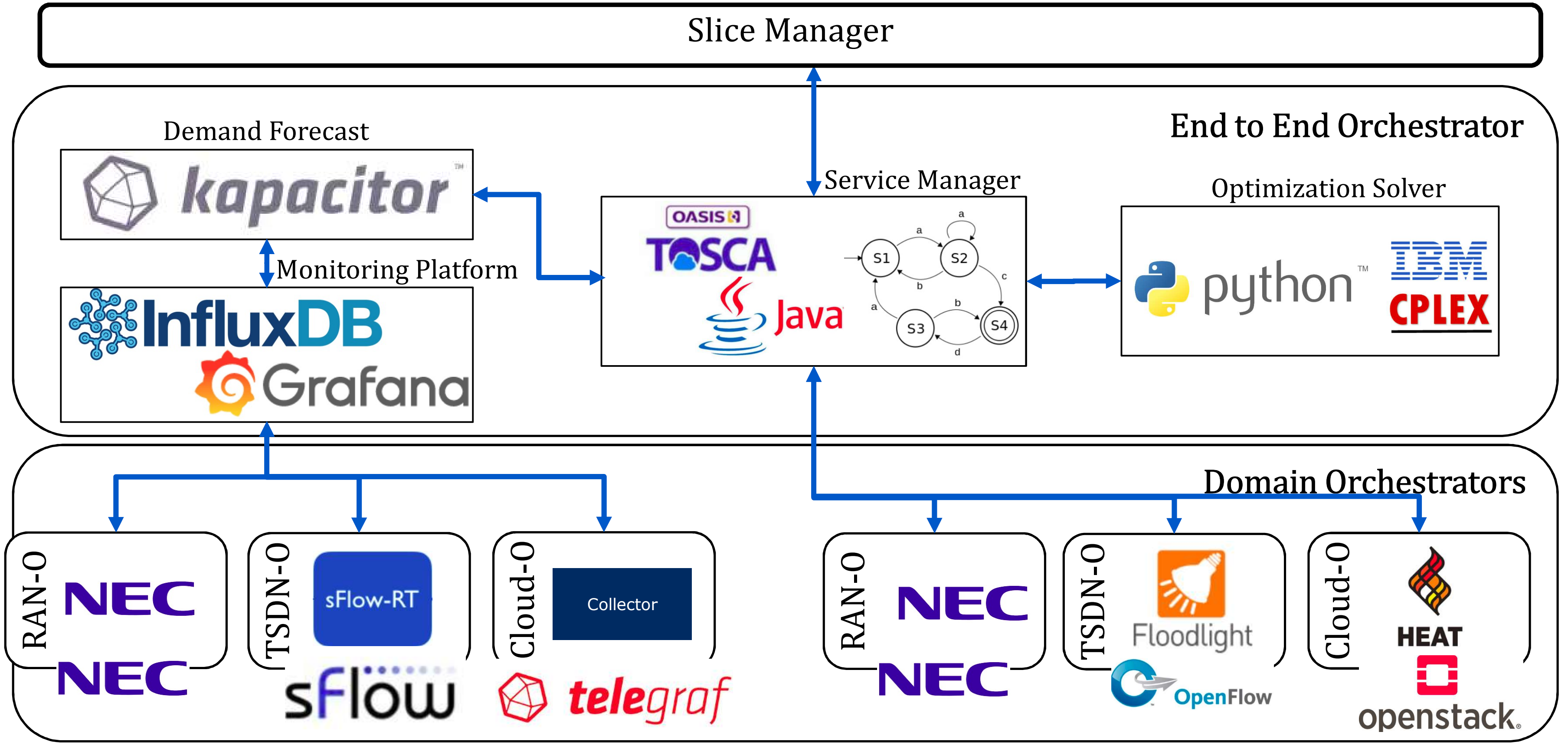


System Design and Model: NS Descriptors



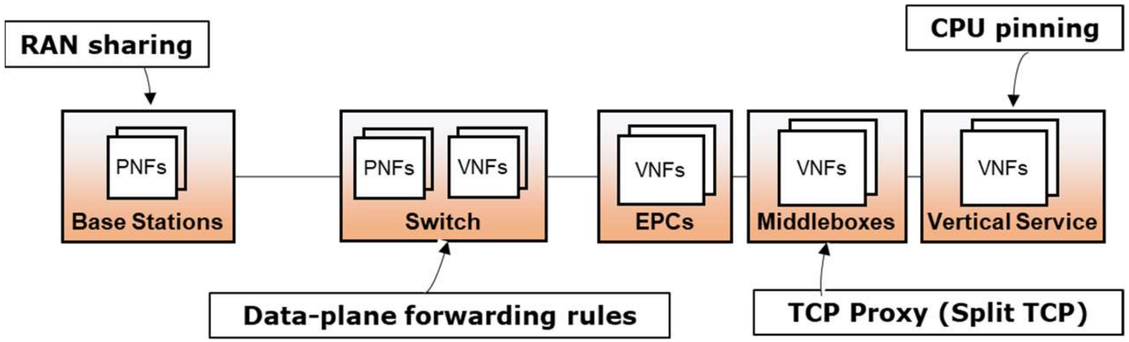
[1] Mestres, Albert, et al. "Knowledge-defined networking." ACM SIGCOMM Computer Communication Review 47.3 (2017): 2-10.

System Design and Model: E2E Orchestrator

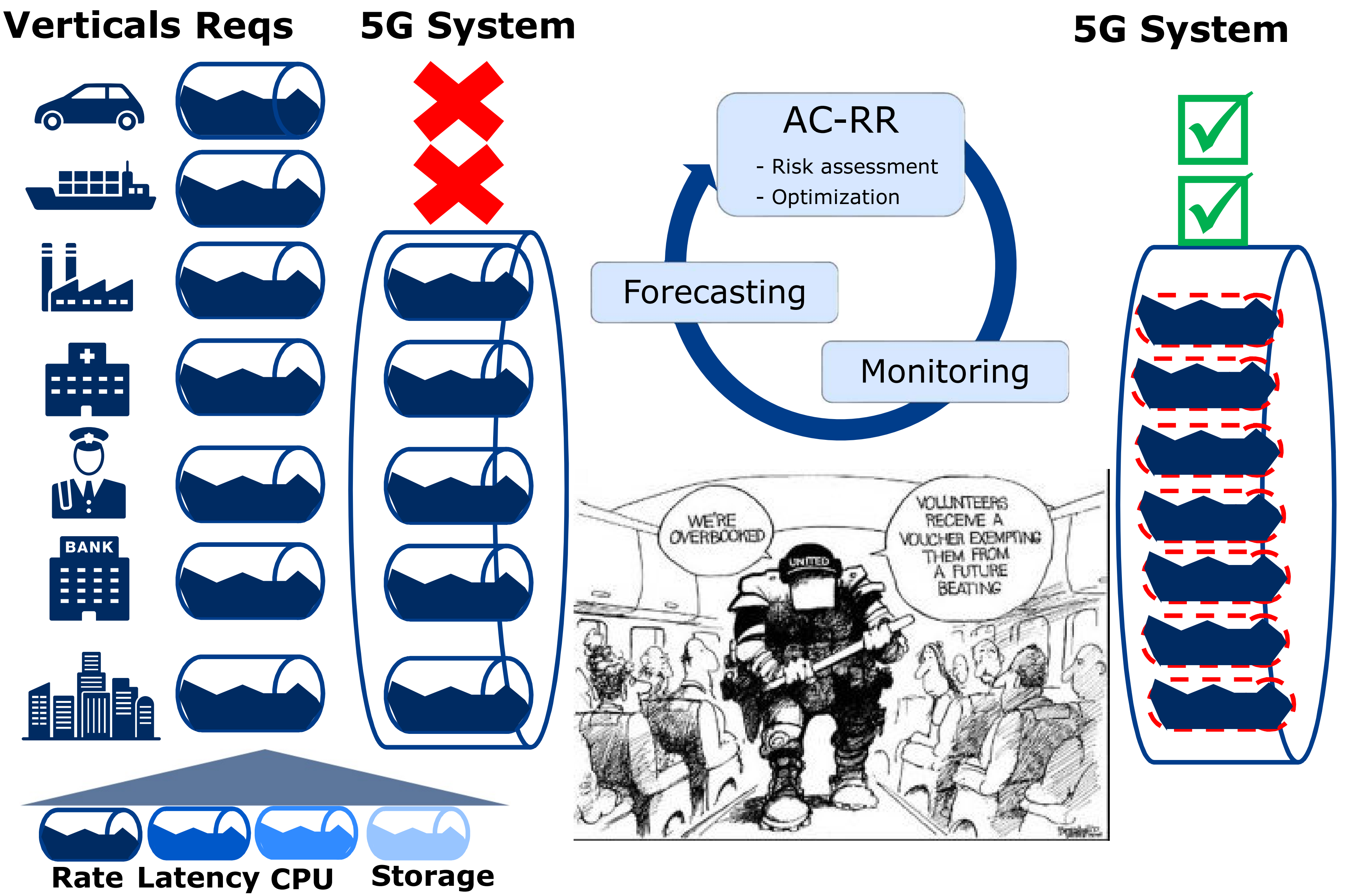


"Local" orchestrators

1. Create data-plane abstractions
2. Monitoring data-plane usage
3. Enforce orchestration decisions



System Design: Overbooking



Problem formulation

Random processes hard to characterize

Individual penalty of the slice

Individual reward of the slice

$$\min_{\boldsymbol{x}^{(t)}\in\{0,1\}^{\mathcal{S}},\,\boldsymbol{z}^{(t)}\in\mathbb{R}_+^{\mathcal{S}}} \lim_{T\to\infty}\frac{1}{T}\sum_{t=1}^{T}\sum_{\tau\in\mathcal{T}^{(t)}}\sum_{\substack{p\in\mathcal{P}_{b,c}\\ \forall b\in\mathcal{B},c\in\mathcal{C}}} \overbrace{K_\tau x^{(t)}_{\tau,p}\Pr\left[z^{(t)}_{\tau,p}<\lambda^{(t)}_{\tau,p}\right]}^{\text{Expected penalty}} - \overbrace{R_\tau x^{(t)}_{\tau,p}}^{\text{Reward}}$$

Admission Control decisions

Resource Reservation decisions

Set of the slice requests at epoch t

Probability that the reservation is less that the usage (SLA violation)

subject to (1) capacity/delay/system constraints (linear and decoupled)

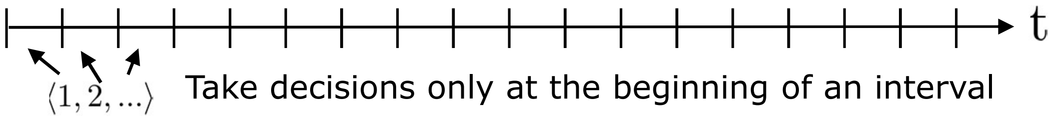
$$(2)\ z^{(t)}_{\tau,p} \leq x^{(t)}_{\tau,p}\Lambda_\tau\,, \qquad \forall\tau\in\mathcal{T},\forall\mathcal{P}_{b,c},\forall b\in\mathcal{B},\forall c\in\mathcal{C}$$

No more resources than SLA if access is granted..
… but nothing if access is rejected

Problem formulation

Practical simplifications

- L_τ is small compared to the system's time horizon.



- We do forecasting. And weight by a deterministic risk-cost function.

Risk of resource deficit

$$P_{\tau,p} := \frac{\Lambda_{\tau,p} - z_{\tau,p}}{\Lambda_{\tau,p} - \hat{\lambda}_{\tau,p}}, \quad 0 \leq P_{\tau,p} \leq 1$$

Risk of wrong predictions
(forecast uncertainty amplified by slice duration)

$$\xi_{\tau,p} := \hat{\sigma}_{\tau,p} L_\tau, \quad 0 < \xi_{\tau,p} \leq L_\tau$$

$$\min_{\boldsymbol{x}^{(t)}\in\{0,1\}^{\mathcal{S}},\, \boldsymbol{z}^{(t)}\in\mathbb{R}_+^{\mathcal{S}}} \cancel{\lim_{T\to\infty}\frac{1}{T}\sum_{t=1}^{T}} \sum_{\tau\in\mathcal{T}^{(t)}} \sum_{\substack{p\in\mathcal{P}_{b,c}\\ \forall b\in\mathcal{B}\ c\in\mathcal{C}}} \overbrace{K_\tau x^{(t)}_{\tau,p}\, P_{\tau,p}\, \cancel{\Pr\left[z^{(t)}_{\tau,p} < \Lambda^{(t)}_{\tau,p}\right]}}^{\text{Expected penalty}} - \overbrace{R_\tau x^{(t)}_{\tau,p}}^{\text{Reward}}$$

subject to (1) Capacity/delay/system constraints (linear and decoupled)

(2) $x^{(t)}_{\tau,p}\hat{\lambda}^{(t)}_{\tau,p} \leq z^{(t)}_{\tau,p} \leq x^{(t)}_{\tau,p}\Lambda_\tau$, $\quad \forall\tau\in\mathcal{T}, \forall\mathcal{P}_{b,c}, \forall b\in\mathcal{B}, \forall c\in\mathcal{C}$

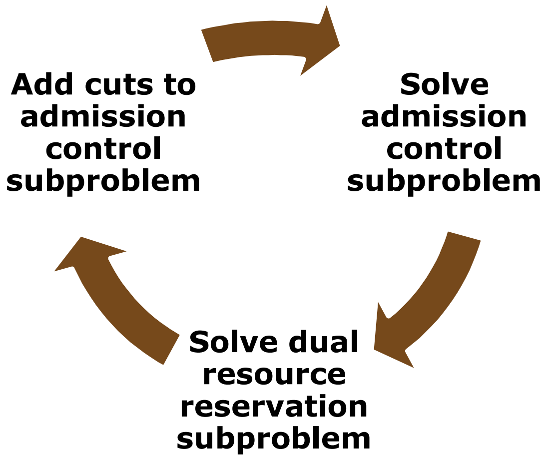
No less resources than forecasted peak demand

No more resources than SLA if access is granted

Problem formulation

We can linearize our problem easily

- … but still a MILP with coupled constraints (NP-hard)

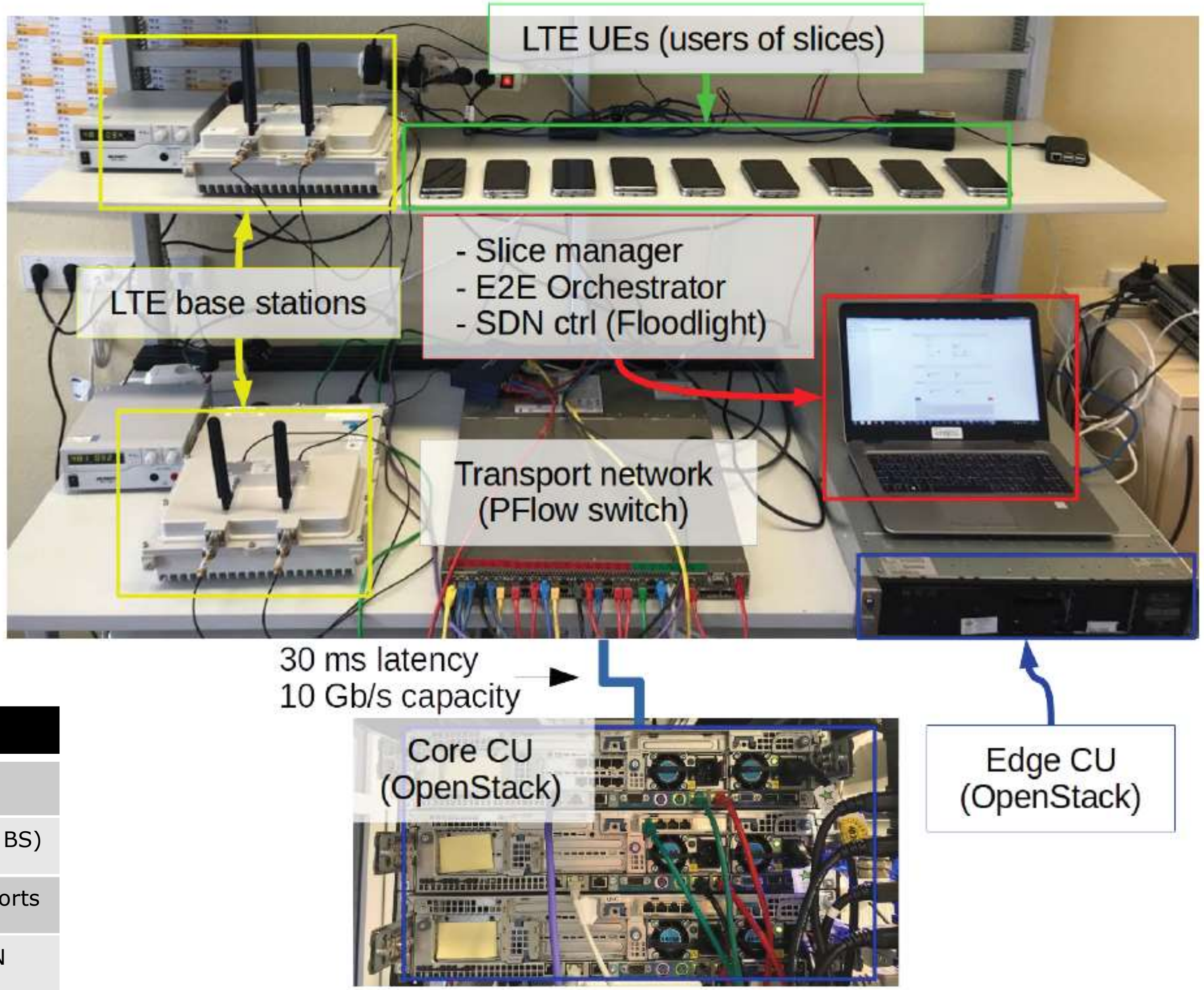


We use two methods to solve this problem

- **Bender’s decomposition**
  - Developed in 1960s, increasingly popular last years.
  - Finds an exact solution, but no guarantees for the time needed

- **Heuristic algorithm**
  1. Cast the admission control subproblem into a classical 0-1 Knapsack problem and use an heuristic to solve it.
  2. Add only feasibility cuts

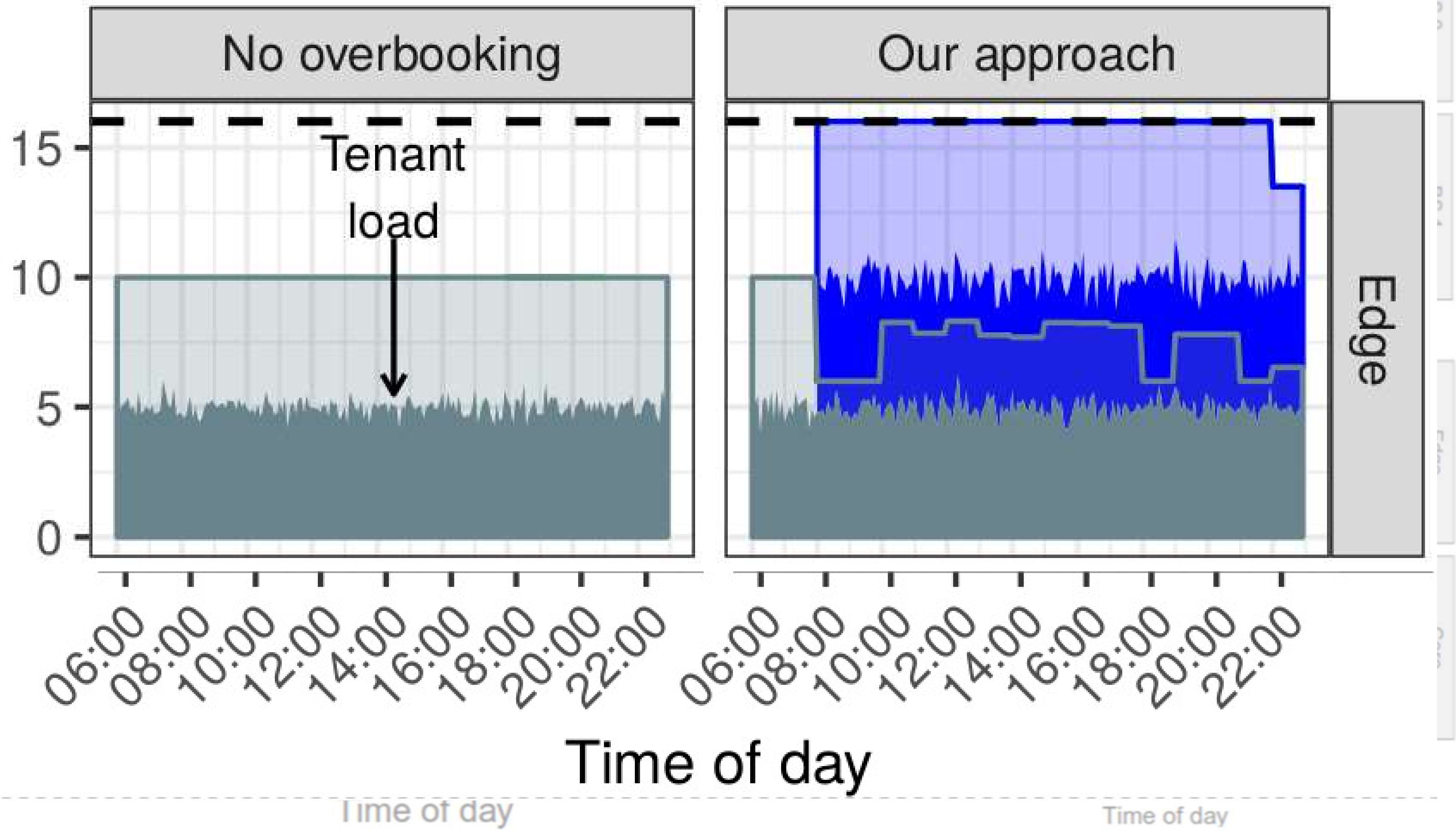
Evaluation: Experimental proof-of-concept



Device	Description
vEPCs	OpenEPC Rel. 7 (1x per slice)
UEs	Samsung Galaxy 7 (1x per slice and BS)
BH	Openflow 1.5 switch w/ 48 1-Gb/s ports
RAN	2x 20-MHz NEC small cell w/ RAN sharing
CUs	OpenStack Queens w/ 16 (Edge) and 64 (Core) cores

Evaluation: Experimental proof-of-concept

Type	Delay req. (ms)	Service bitrate req. (Mb/s)	CPU req. (number of CPUS)	Price (monetary units)	Penalty (monetary units)
eMBB	30	50	0	1	1/50
mMTC	30	10	2λ	3	3/10
uRLLC	5	25	0.2λ	2	2/25

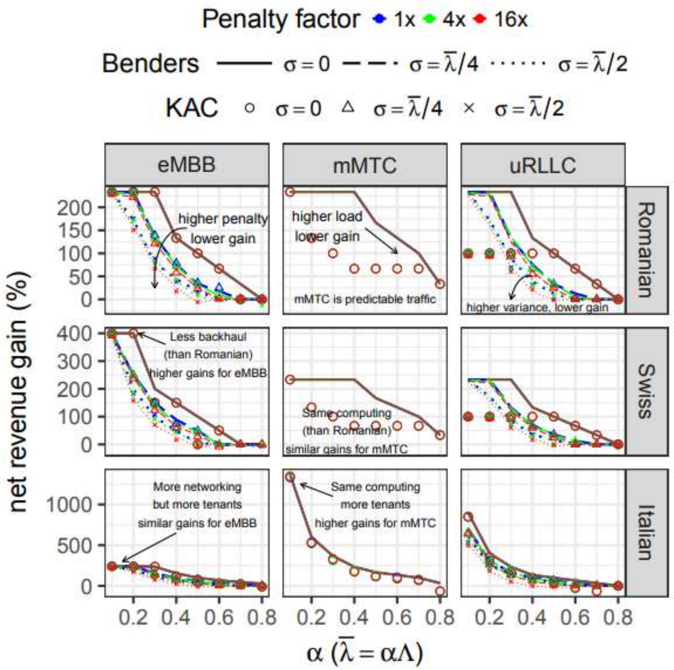


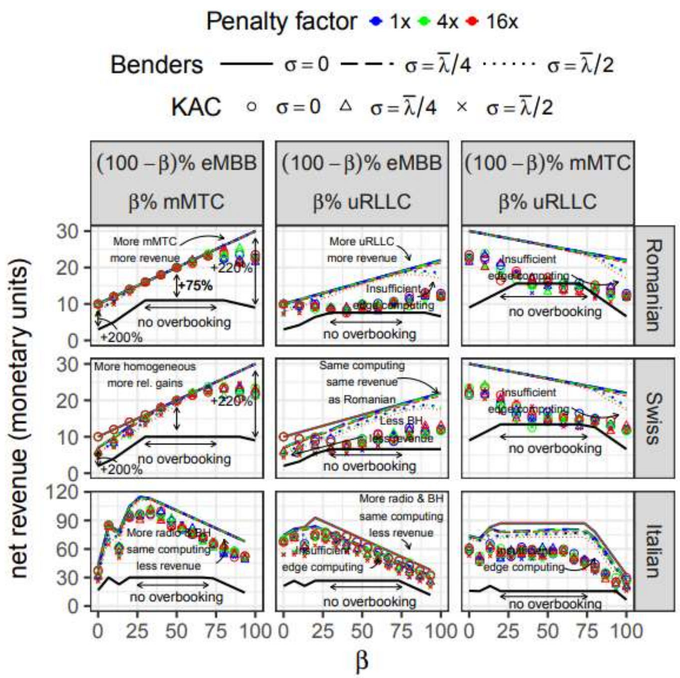
Overbooking brings significant gains

- 3 real network topologies (Romanian, Swiss and Italian)

(a) Romanian topology (N1). (b) Swiss topology (N2). (c) Italian topology (N3). (d) Path Capacity Distribution (e) Path Delay Distribution

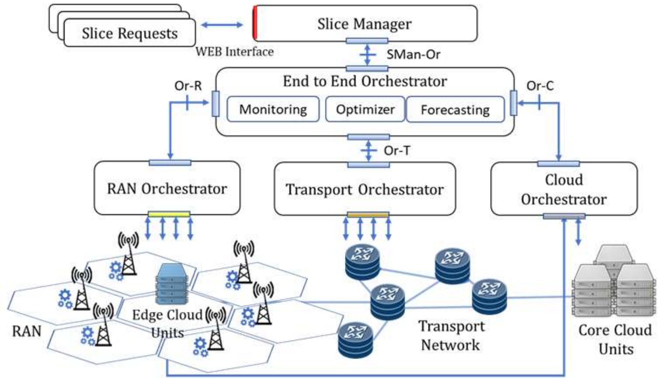
- Evaluation: Wide set of penalty, traffic load and traffic variability
- Up to 200% revenue gains when load is low and is predictable

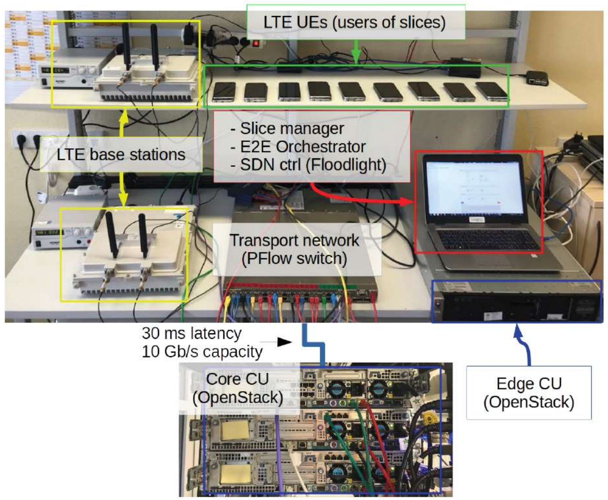


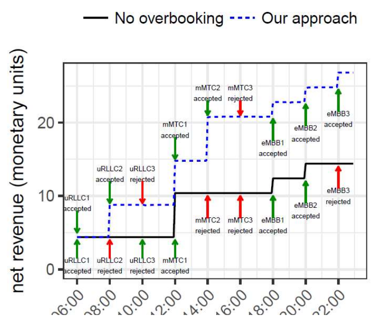


Conclusions

- **Network Slicing will be a key technology for 5G**
  - New sources of revenue for mobile operators **and** vendors
- **Two main challenges:**
  - Service/Slice **Orchestration Platform**
    - Hierarchical orchestration for large-scale
    - Feedback loop -> monitoring/control
  - Admission Control and Resource Reservation
    - We explore the concept of **slice overbooking**
    - 2 algorithms, 1 experimental PoC, 3 large-scale topologies







(a) Romanian topology (N1). (b) Swiss topology (N2). (c) Italian topology (N3).

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