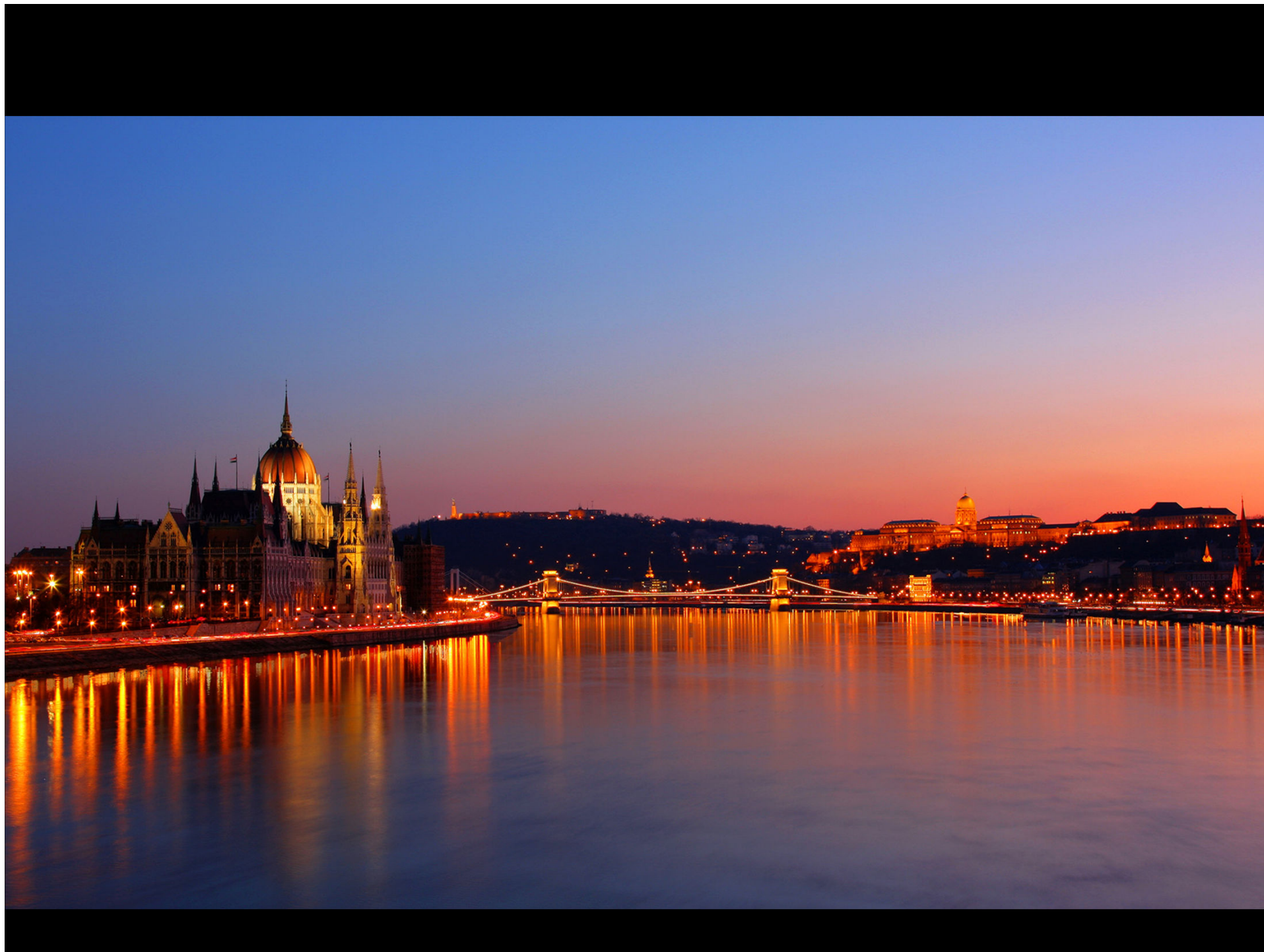
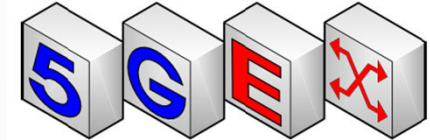






5G Architecture from Front-Haul to Core Network

(5G architektúra a fronthaul hálózattól a maghálózatig)

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Department of Telecommunications and Media Informatics (TMIT)
Budapest University of Technology and Economics (BME), Hungary

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5G

Requirements, Expectations, Wishes...

In contrast to 4G 5G should achieve:

- 1000 times the system capacity
- 10 times the spectral efficiency
- higher data rates (i.e., the peak data rate of 10 Gb/s and the user experienced rate of 1Gb/s)
- 25 times the average cell throughput
- 5 times reduction in E2E latency (<1ms)
- 100 times connectivity density
- 99,999% availability

How ?

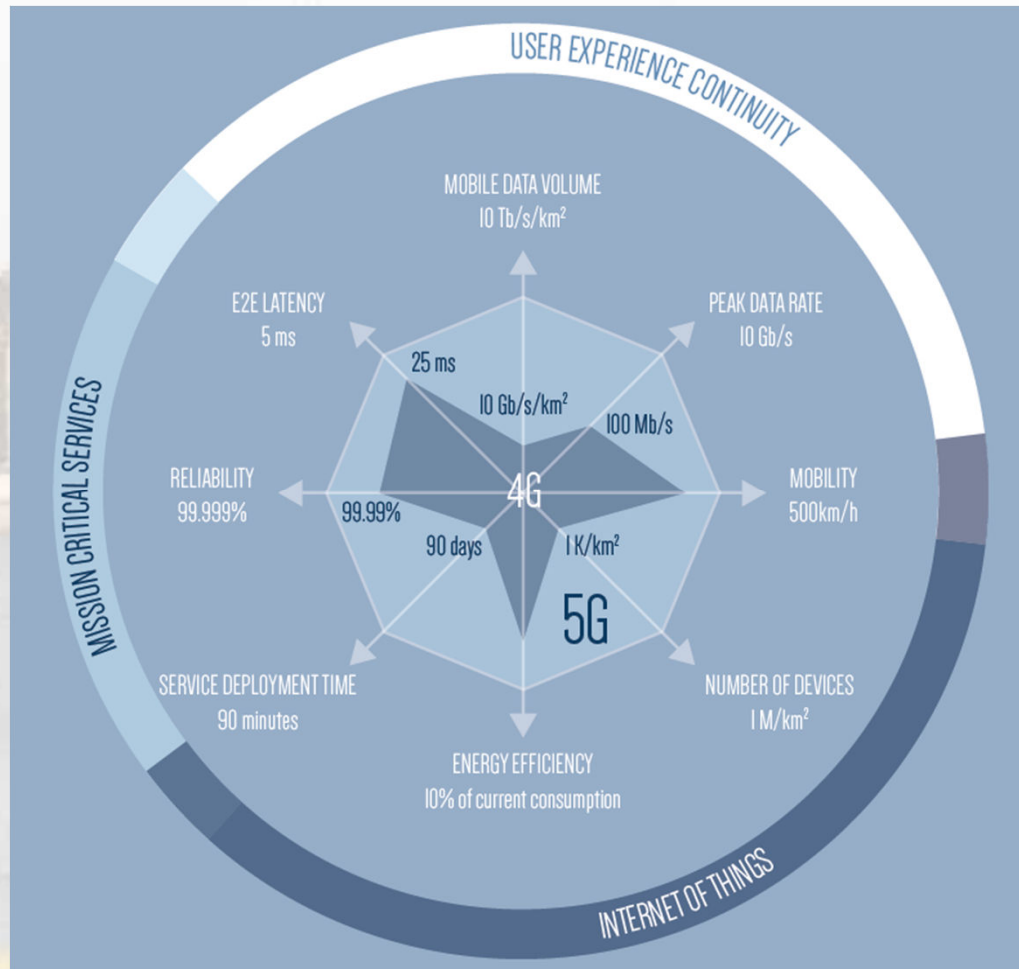
5G Requirements

Source: <https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf>

- **1,000 X mobile data volume per geographical area reaching a target ≥ 10 Tb/s/km²**
- **1,000 X number of connected devices reaching a density $\geq 1\text{M}$ terminals/km²**
- **100 X user data rate reaching a peak terminal data rate $\geq 10\text{Gb/s}$**
- **1/10 X energy consumption compared to 2010**
- **1/5 X end-to-end latency reaching 5 ms for e.g. tactile Internet and radio link latency reaching a target ≤ 1 ms for e.g. Vehicle to Vehicle communication**
- **1/5 X network management OPEX**
- **1/1,000 X service deployment time reaching a complete deployment in ≤ 90 minutes**

Further 5G requirements

Source: <https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf>



Guaranteed
user data rate

≥ 50Mb/s

Capable of human-
oriented terminals

≥ 20 billion ^{10⁹}

Capable of IoT terminals
^{10¹²}
≥ 1 trillion

Aggregate service
reliability

≥ 99.999%

Mobility support at speed
≥ 500km/h
for ground transportation

Accuracy of outdoor
terminal location

≤ 1 meter

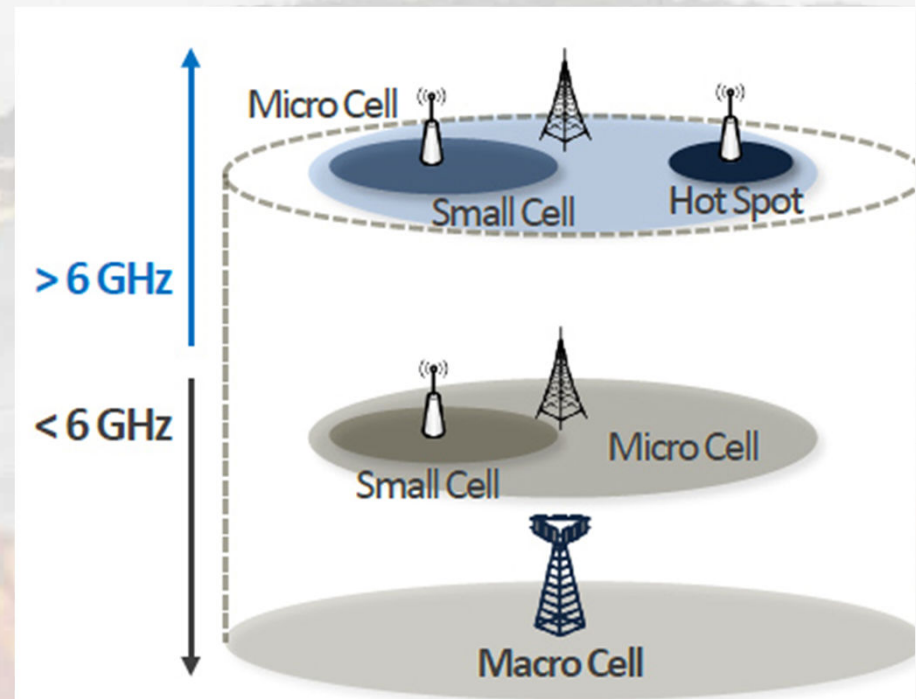
5G? <http://www.3gpp.org/>

- **LTE**
 - **LTE-Advanced**
 - **LTE-Advanced Pro**
-
- Rel. 14
 - Rel. 15. Phase 1 to be completed by H2 2018
 - Rel. 16. Phase 2 to be completed by Dec 2019 for the IMT 2020 submission and to address all identified use cases & requirements



5G

- Enhanced Mobile Broadband
- Massive Machine Type Communications (**M2M**)
- Ultra-**reliable** and **Low Latency** Communications
- New Radio (**new RAT**)
 - Non-backward-compatible
- Small Cells – Macro Cells
- Wi-Fi HS 2.0



Source: <http://www.3gpp.org>

What is the Role of 5G in Smart Cities?

5G is expected to be the Universal Interconnect

- **For Cooperation**
- **For Simultaneity**
- **For Ubiquity**
- **Transportation (Mobility)**
- **Energy**
- **Health**
- **...**
- **For all data captured / acquired**
- **For all actions and management**

COMBO Overview



COMBO targets a unified access and aggregation network architecture allowing fixed and mobile networks to converge (Fixed / Mobile Convergence, FMC), enabling:

- optimal and seamless quality of experience for the end-user*
- optimized network infrastructure ensuring reduced cost and energy consumption*

■ Objectives

- Define optimised FMC architectures (economic and energy efficiency)*
- Assess multi-operator FMC scenarios*
- Demonstrate experimentally FMC in lab tests and field trials*
- Drive standardization bodies with respect to FMC architectures*

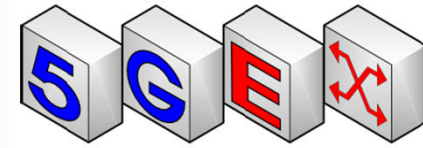
■ The COMBO consortium:

- Network operators: Deutsche Telekom, Orange (France Telecom), Telefonica, Argela (Turk Telekom)*
- Vendors: Ericsson, ADVA, Alcatel-Lucent*
- Academia & research institutes: BME, POLIMI, Lund University, Telecom Bretagne, CTTC*
- SMEs: JCP, AITIA, Telnet*

■ Two Main Contributions of BME

- 1. Techno-Economic Assesment of Candidate FMC Access Network Technologies*
- 2. Energy – Availability – QoS tradeoff for FMC via Hand-Overs between multiple operators and multiple technologies*

5GEx Overview



1. Design and specify architecture, mechanisms, algorithms and enablers for automated and fast provisioning of infrastructure services in a multi-domain/multi-operator 5G environment (**90 days to 90 minutes**)
2. Define and validate the novel 5GEx business layer, including the **abstract view of the business information model**, economic and market mechanisms that promote efficiency of **multi-domain services**
3. 5GEx partners will build a working **end-to-end system** and deploy a demonstrable prototype
4. Sandbox Exchange - **Experiment and validate** by implementing selected use cases

Why is multi-operator/multi-domain cooperation important in 5G?

- **Virtual Network Functions (VNF)**
 - Separation of functions from hardware
 - Deployable in scalable virtual environments (clouds)
- **Multiple advantages**
 - Resilience, redundancy, scalability
 - Additional advantages: eases cooperation
- **5G aims at increased efficiency and flexibility**
 - VNFs can support the implementation of this goal
 - Domain- and operator (administration) boundaries should be broken
- **Automated mechanisms for inter-operator/inter-domain cooperation**
 - Abstract interface
 - Orchestration mechanisms
 - Near-operation testbed
 - Open to willing third parties

Availability-Power-QoS Trade-off for FMC

WiFi?



micro
pico
femto cell ?
ato



makro
2G
3G ?
4G

3D

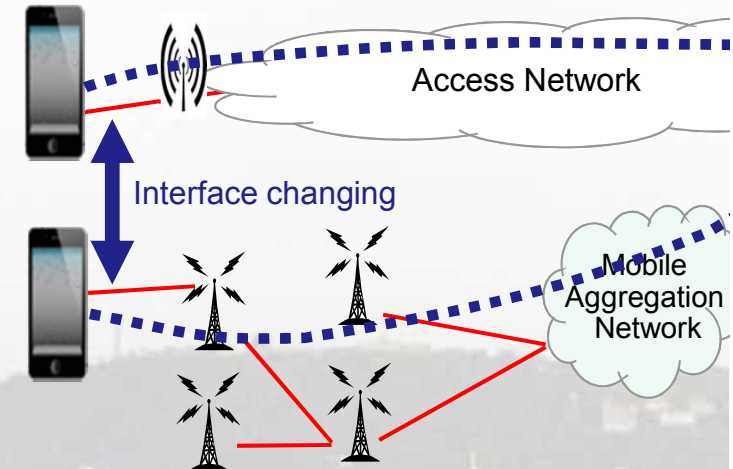
Access selection

(Interface changing/steering)
(Handover, load balancing)
(Traffic steering, dynamic shifting)

- **Horizontal ?** (Homogeneous, geographical)
- **Vertical ?** (Heterogeneous, multi-RAT)
- **Inter-Operator ?**

Selective switch-off &
Consolidation

Optimisation
Simulations

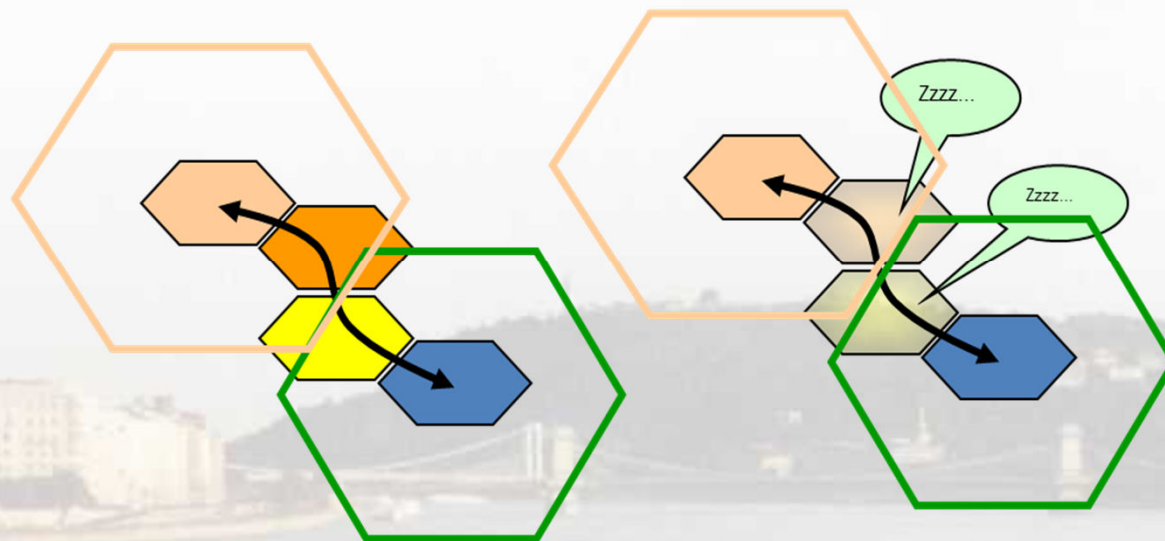
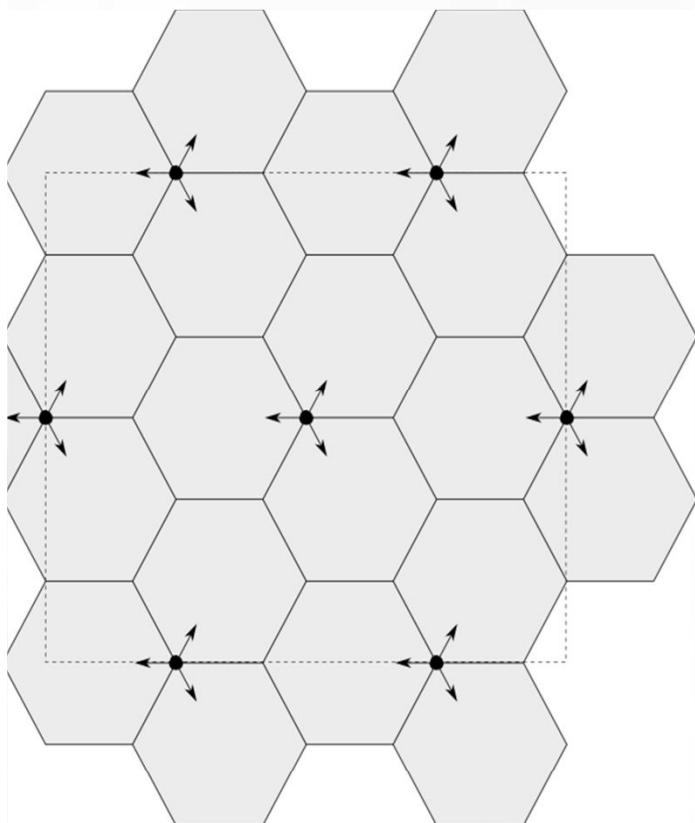


Message:

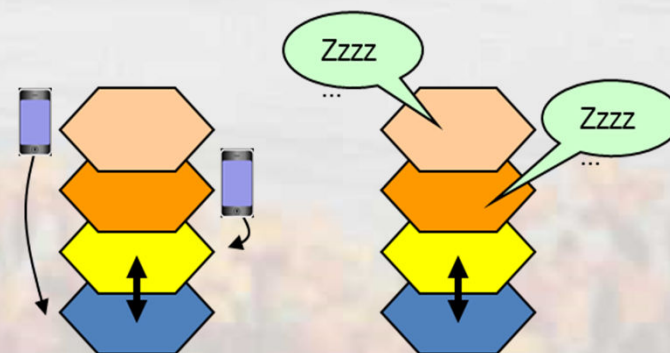
- **Availability:** can be improved
- **Energy:** reduced!!!
- **QoS:** OK



How does it work ?

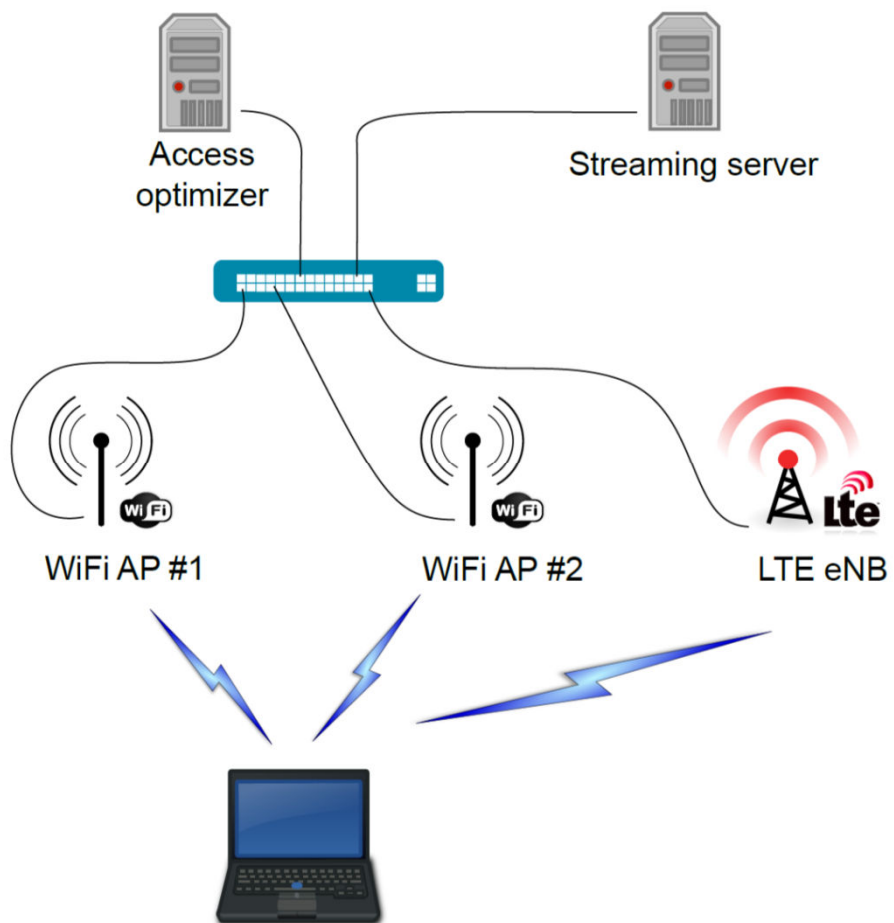


	energy [kVAh]	reach [km]	cell / GSMcell	total cells	total [kVAh]
2G: GSM	1	3	1	78	78
3G: UMTS	2	1.3	7	220	440
4G: LTE	3	0.6	24	2176	6528

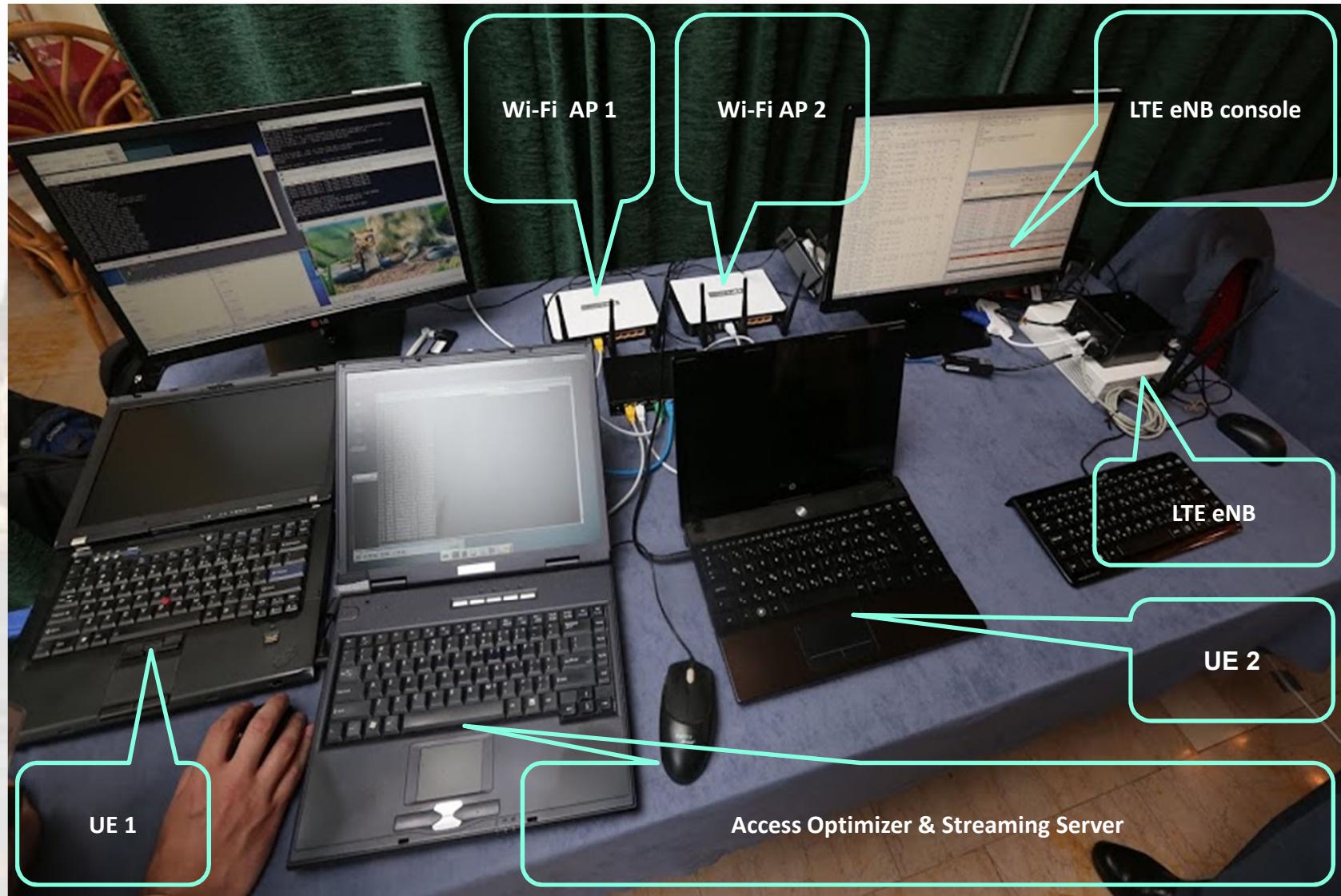


Demo

- The demo setup and its realization

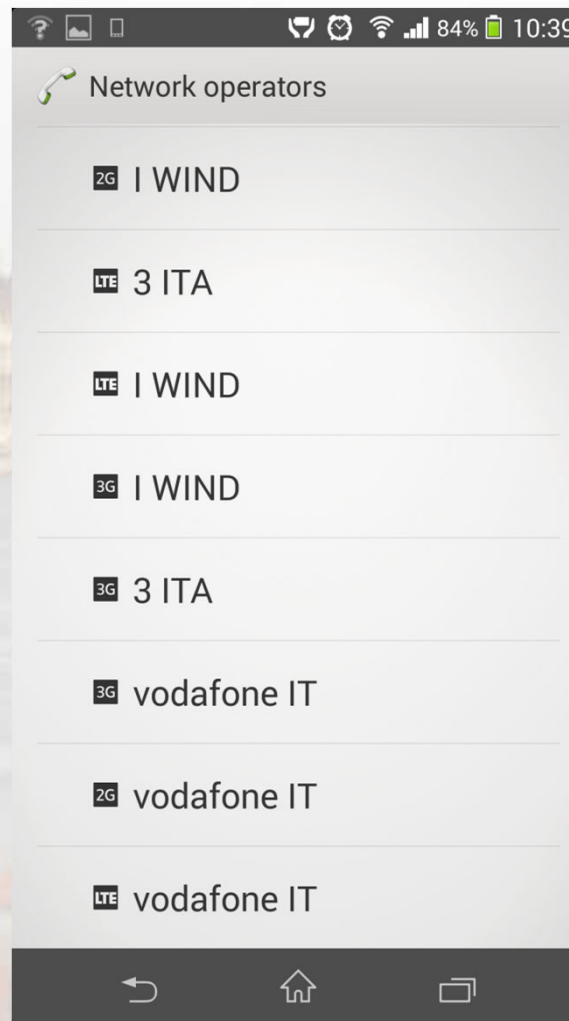
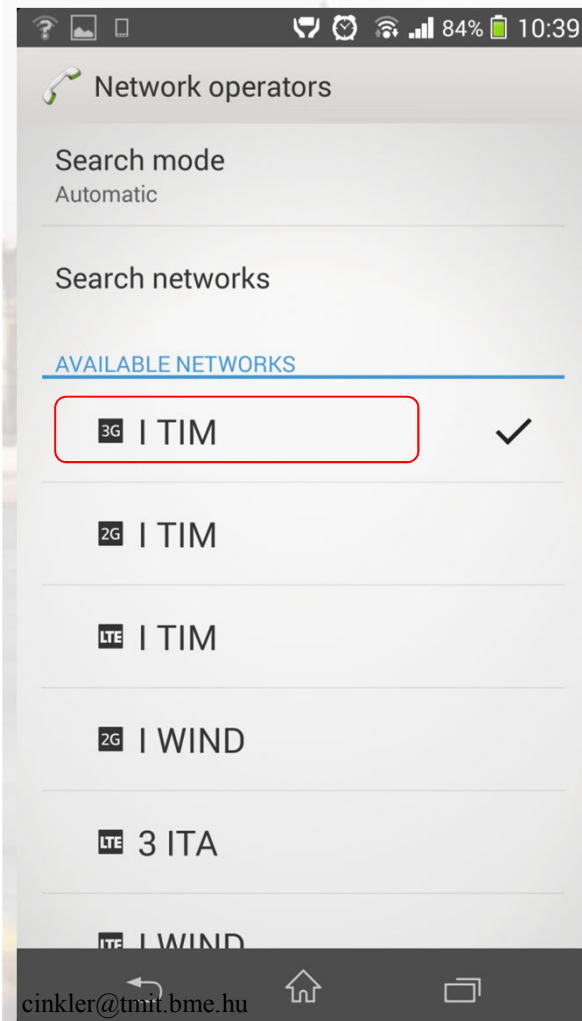


HPSR 2015 Demo

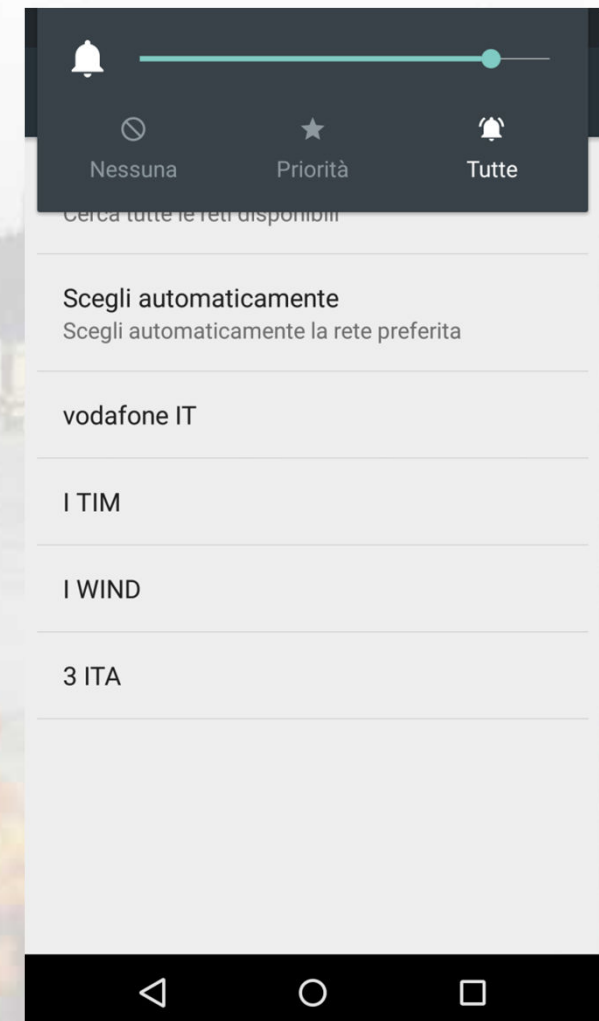


Multi-Operator

- Two or more operators: Me in roaming in Italy
 - Wi-Fi and/or LTE

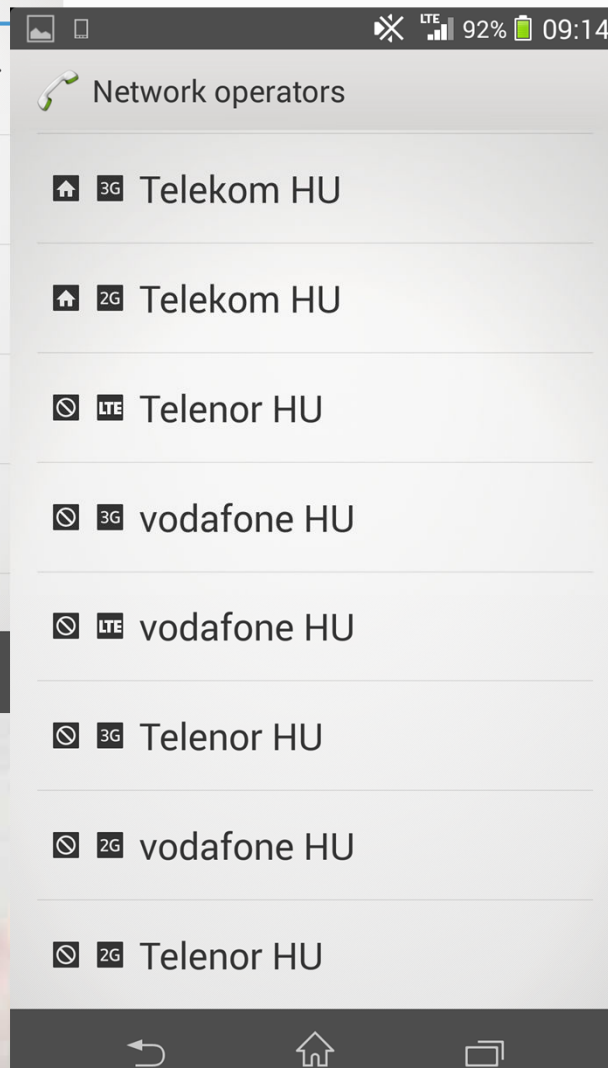
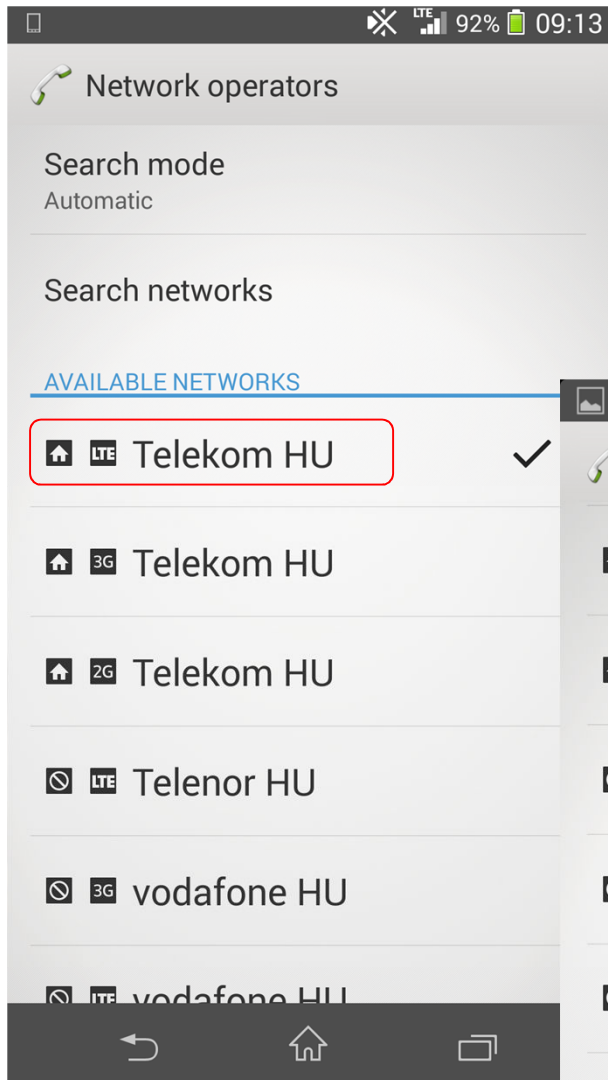


Italian Colleague's Phone



Multi-Operator

- **More operators Today: me “at home”: Home vs. Visitor**

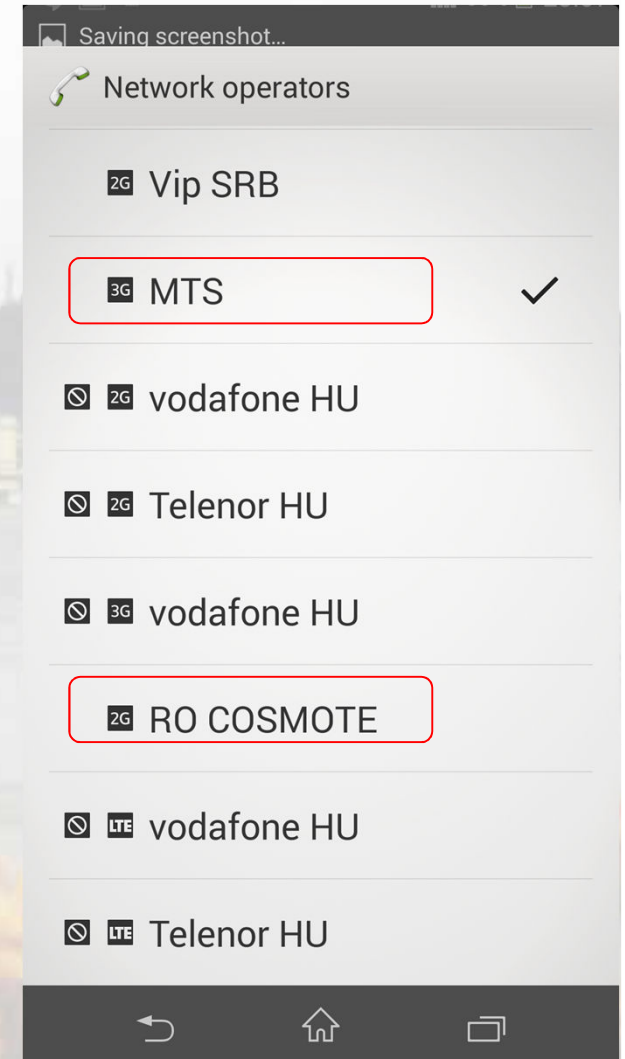
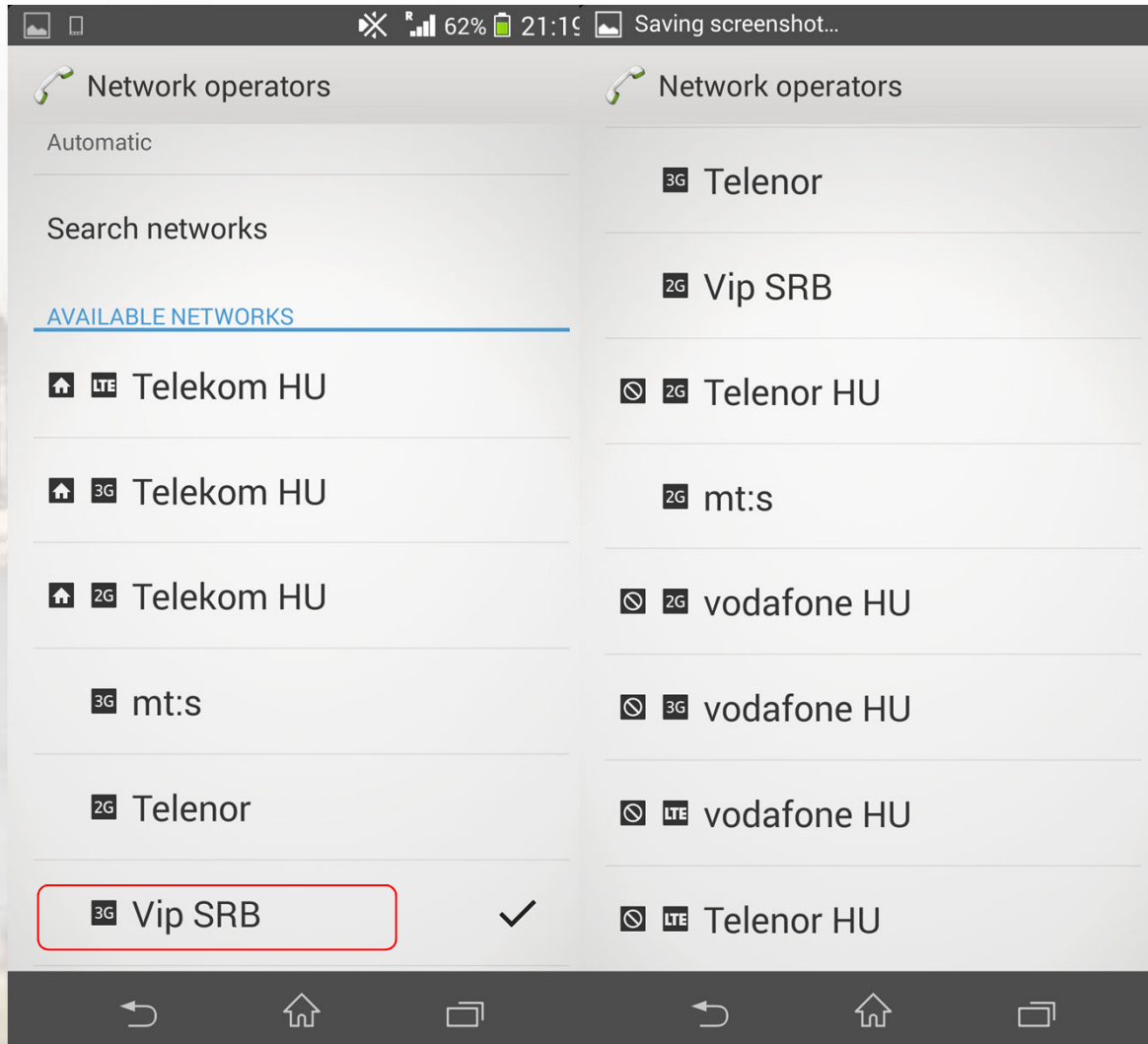


Android:

- **Settings**
- **More...**
- **Mobile Networks**
- **Network Operators**
- **Searching...**

Boarderline

- Hungary – Serbia – Rumenia



Multi-Operator Network Sharing

- **Two or more operators**

- Wi-Fi and/or LTE



- **Code-Shared Flights**

- Two different tickets for the same plane

- “A codeshare flight is a commercial flight that is operated by one airline, but marketed by others.”



- **Tax Authority in Hungary**

- Foreign SIM card is the “poor man’s” “National Roming”

- (Telenor, T-Mobil, Vodafone) all three - for improved coverage

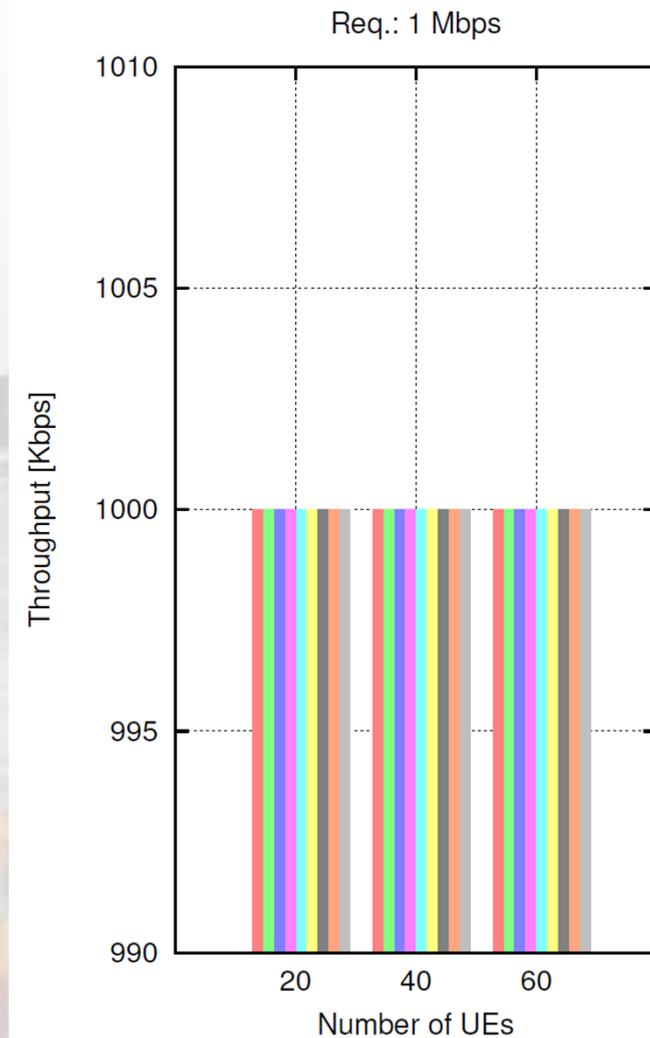
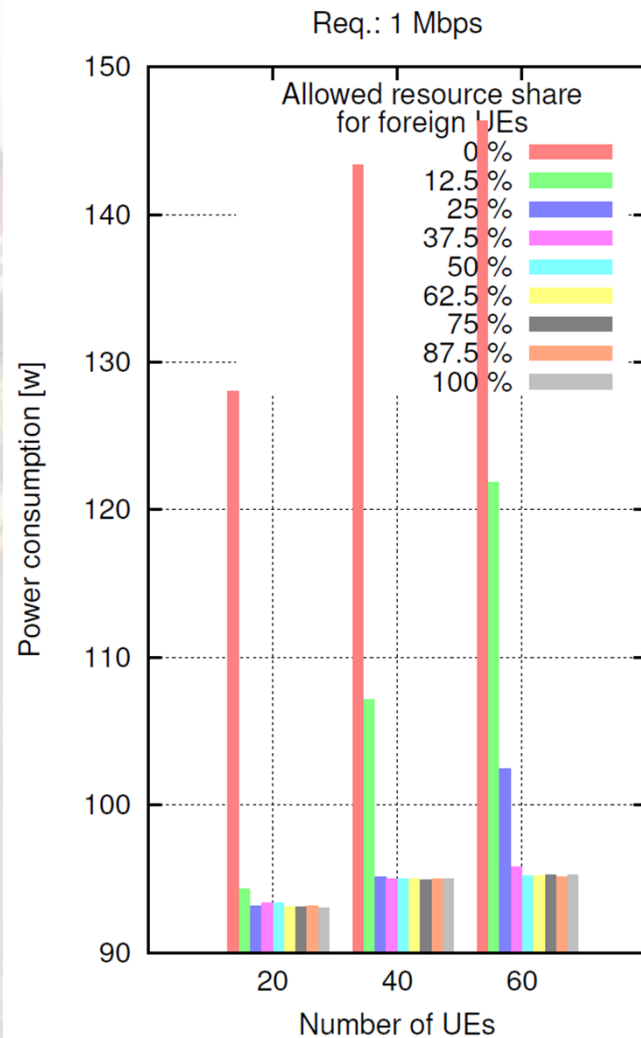


Multi-Operator

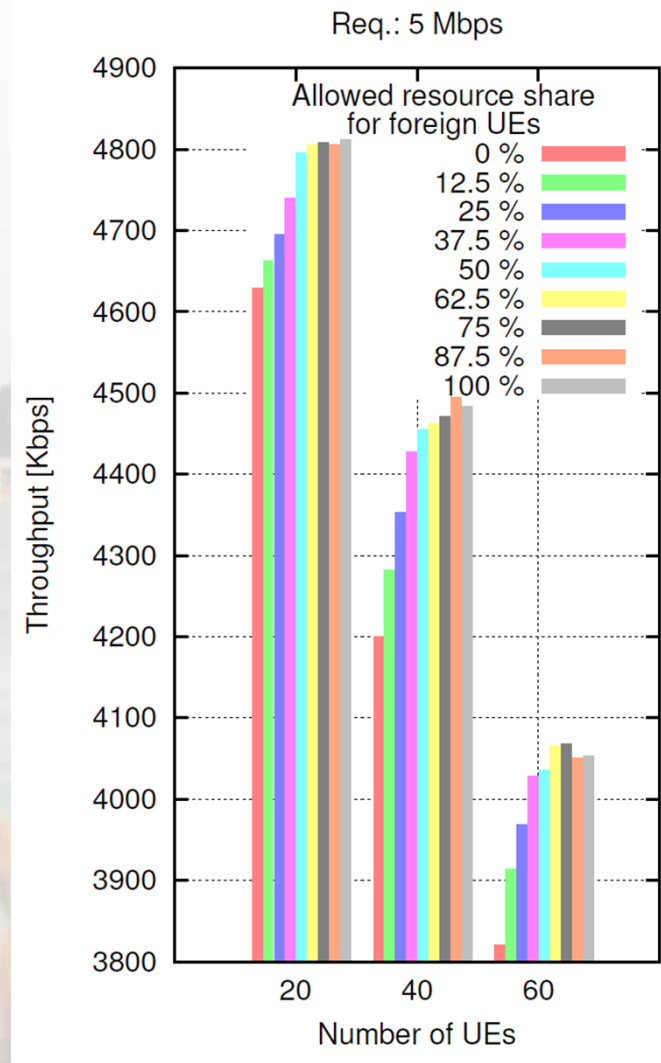
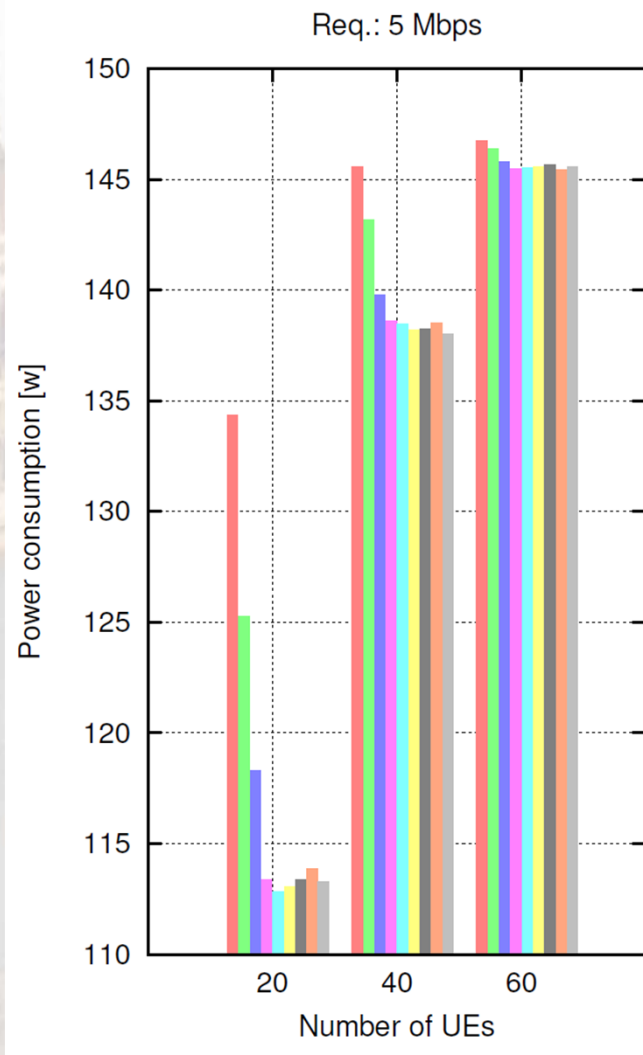
T-Mobile (Magyar Telekom) and Telenor in Hungary (vs. Vodafone)

- Country shared not in frequency but in geography (Limes: Danube)
- http://itcafe.hu/cikk/kozos_4g-t_fejleszt_a_telenor_es_a_telekom/megallapodtak_jovahagytak.html
- **Sharing the 800 MHz range**
 - 20 MHz geographically shared instead of 10+10 MHz
- **Regulatory authority accepted**
 - NMHH: National Media and Infocommunications Authority
- **Competition Authority complained**
 - GVH: Hungarian Competition Authority
 - http://english.nmhh.hu/cikk/167048/Firm_Action_on_Behalf_of_Subscribers_NMHH_is_investigating_the_legality_of_the_contractual_amendments_planned_by_two_mobile_operators_as_of_July

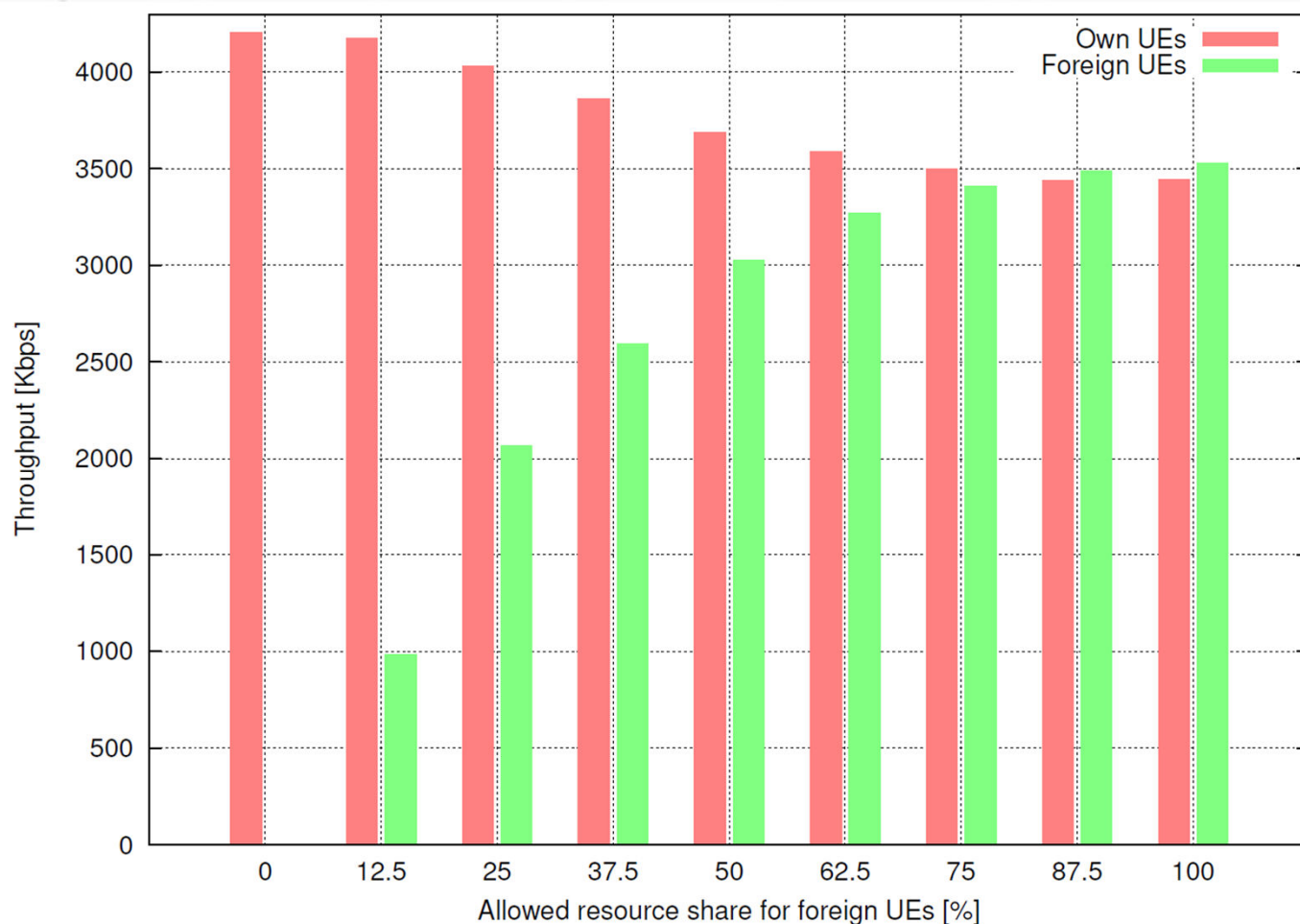
Multi-Operator Case: Power vs. Throughput – Resource Block Limit



Multi-Operator Case: Power vs. Throughput – Resource Block Limit

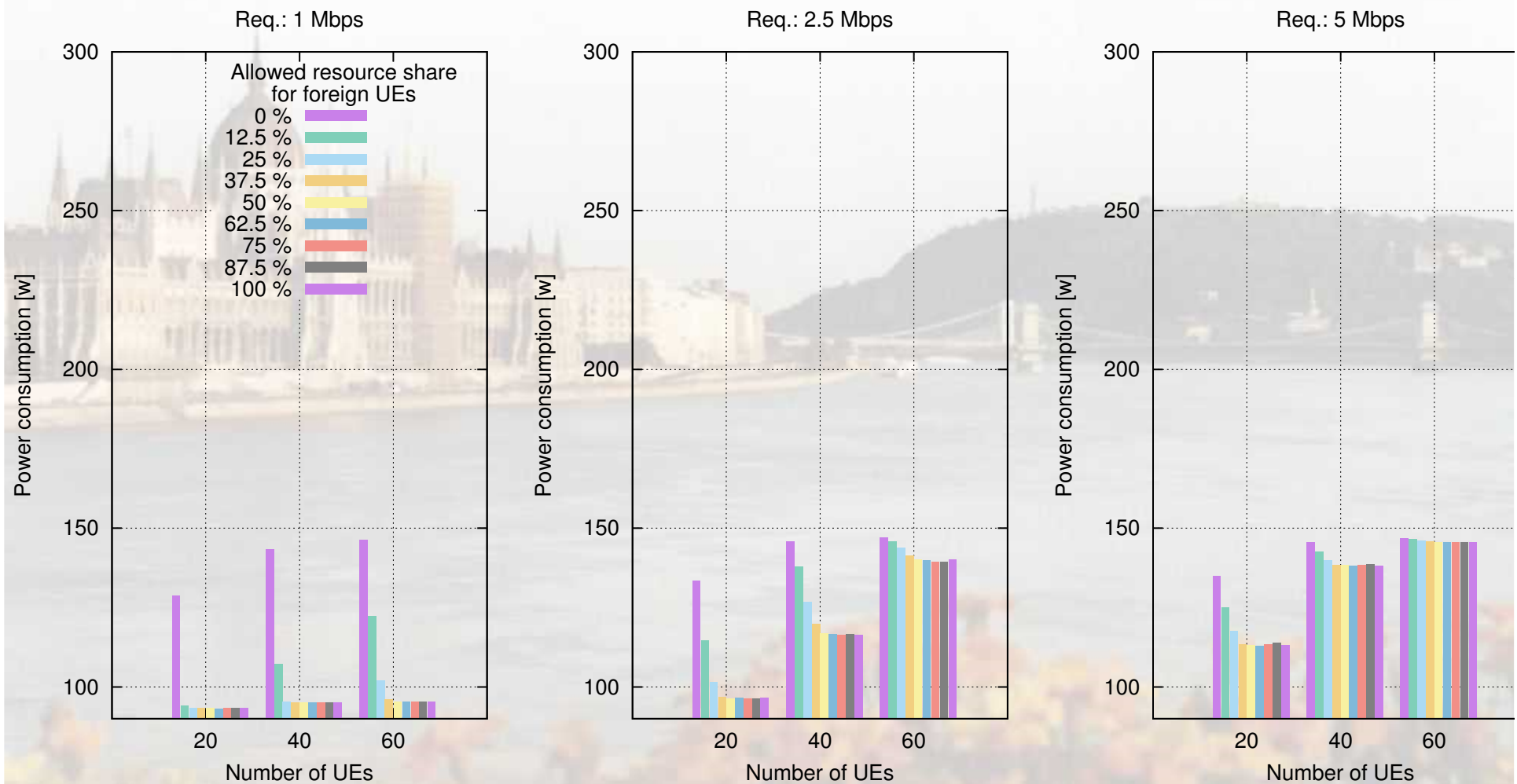


Multi-Operator Case: Throughput in case of Failure

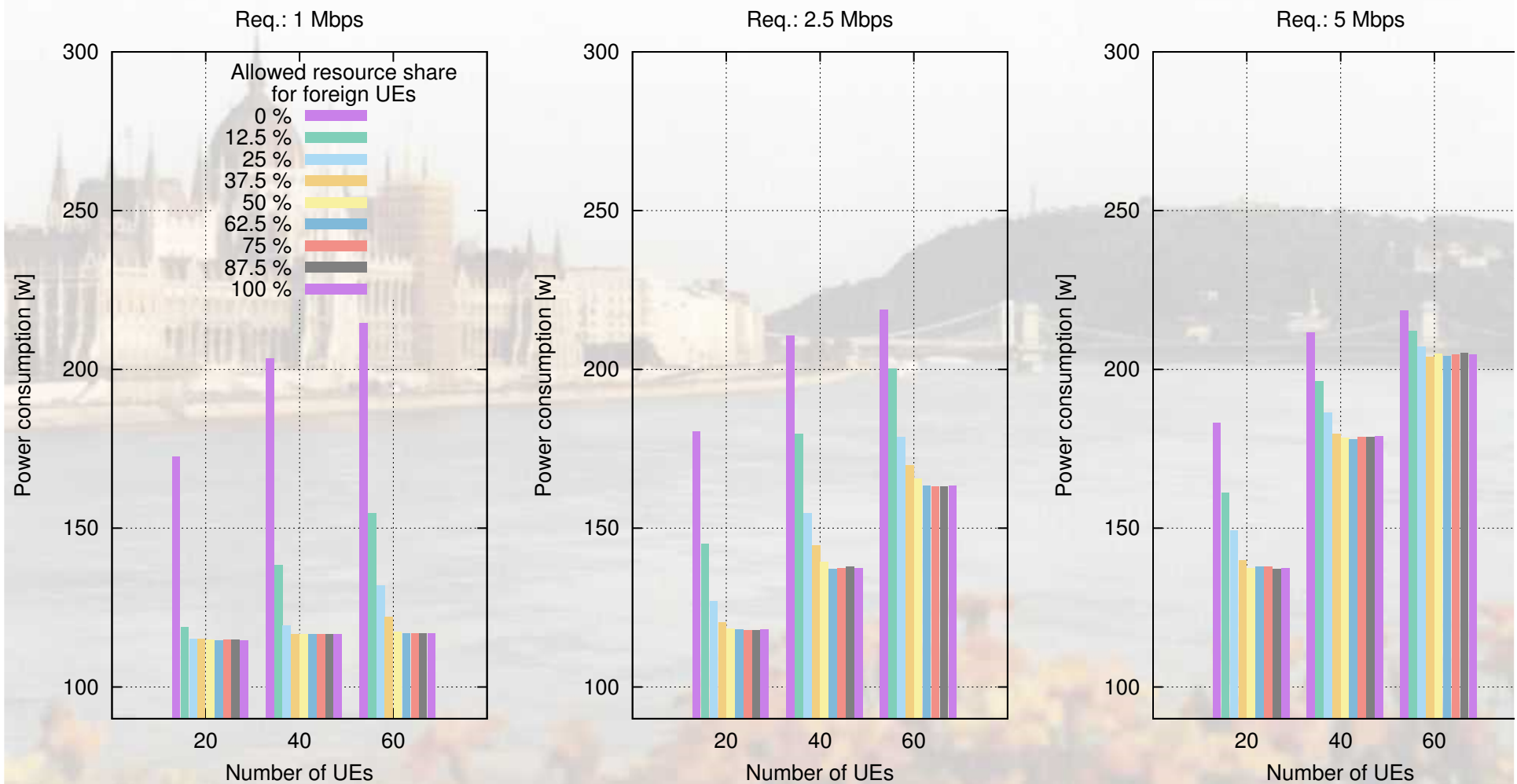


5 Mbps
demands

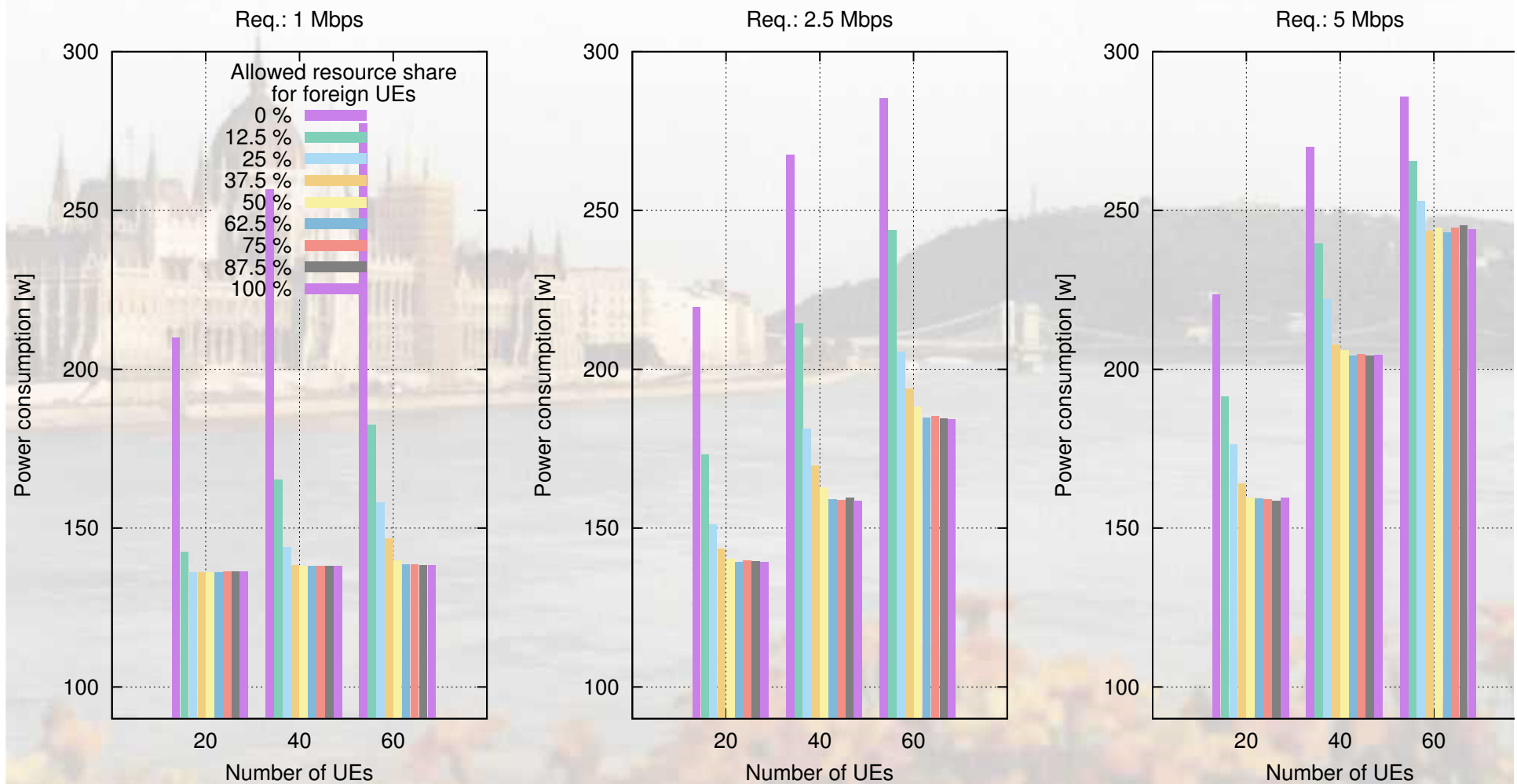
Power: 2 operators



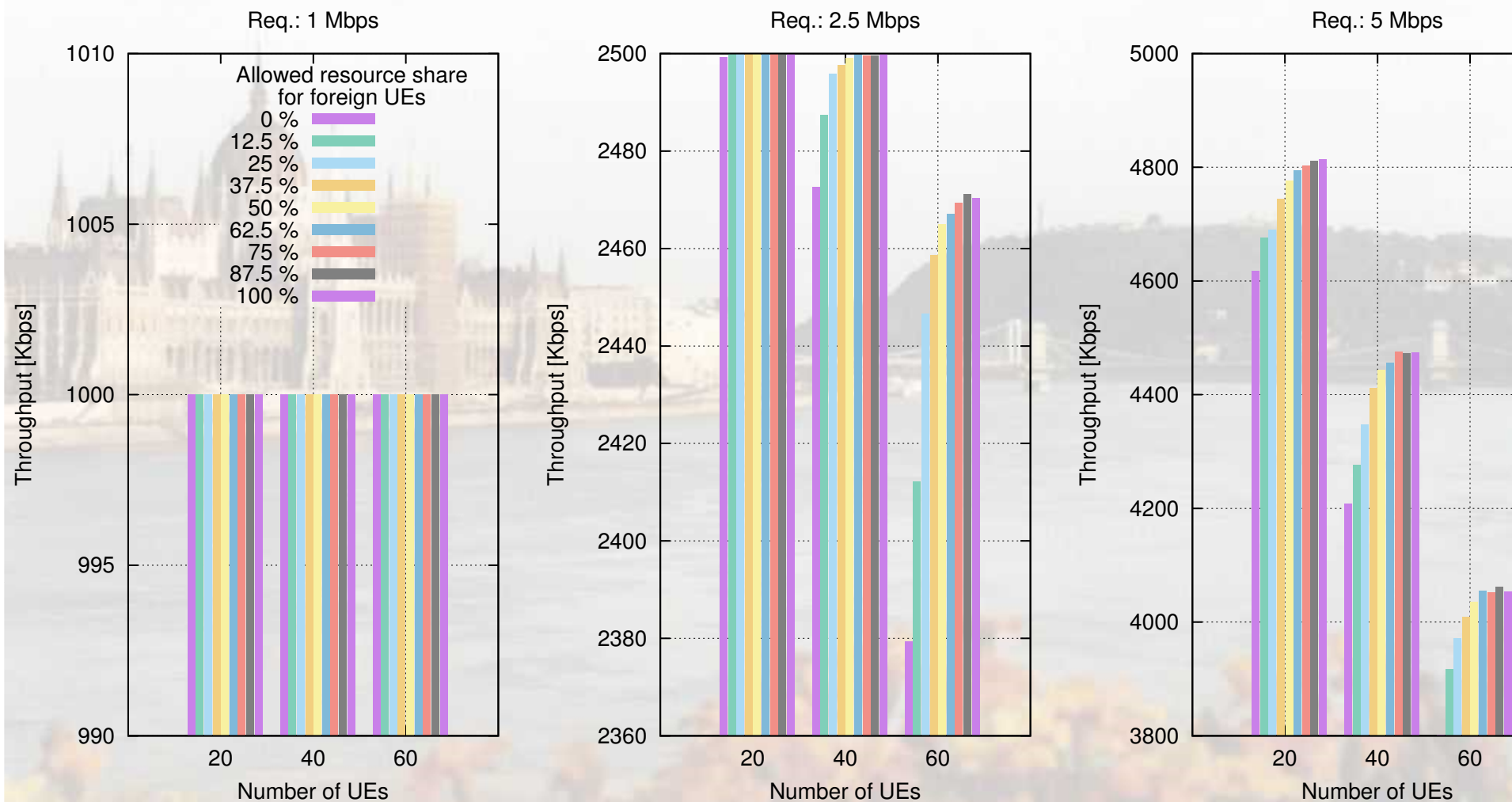
Power: 3 operators



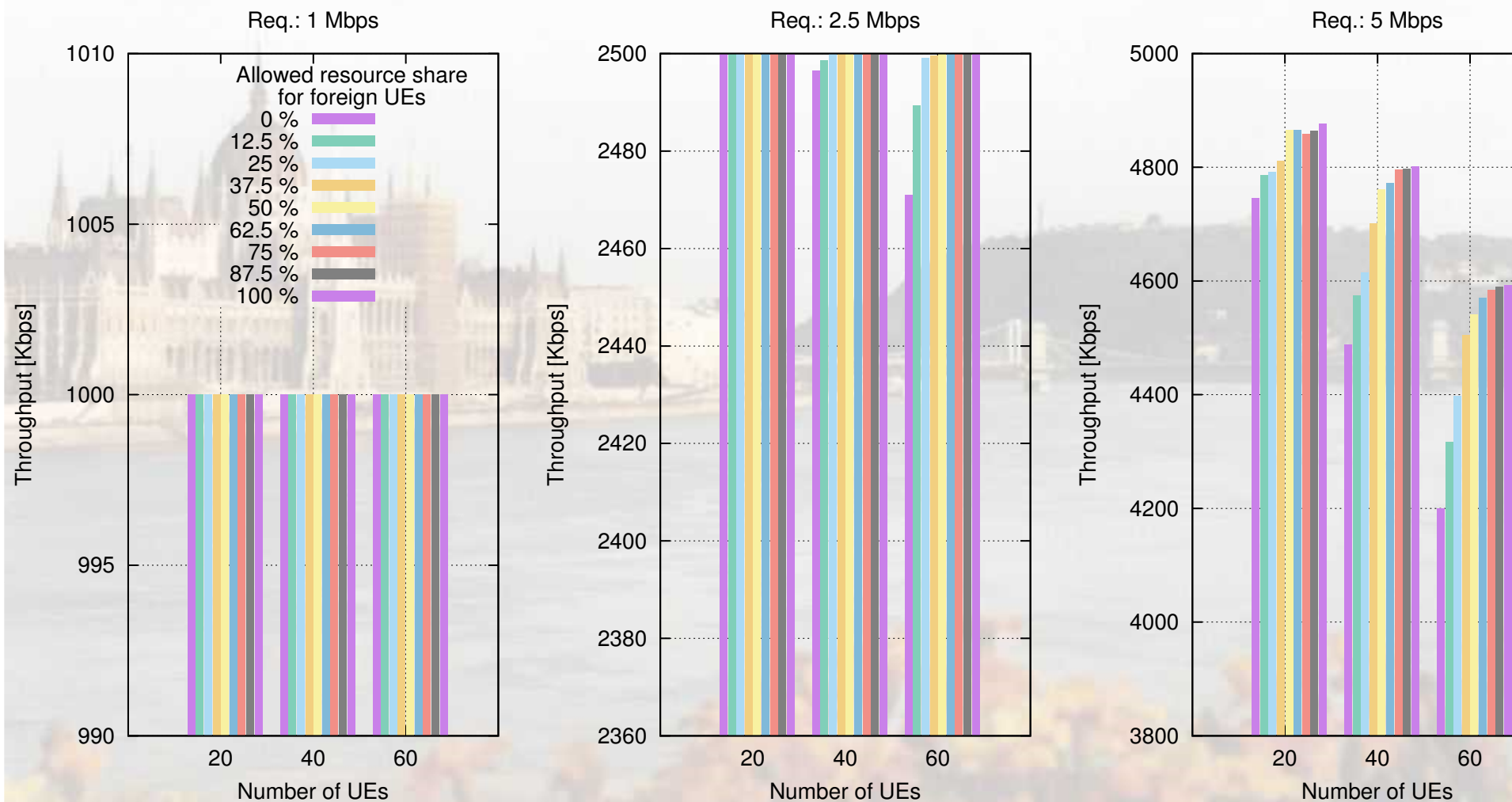
Power: 4 operators



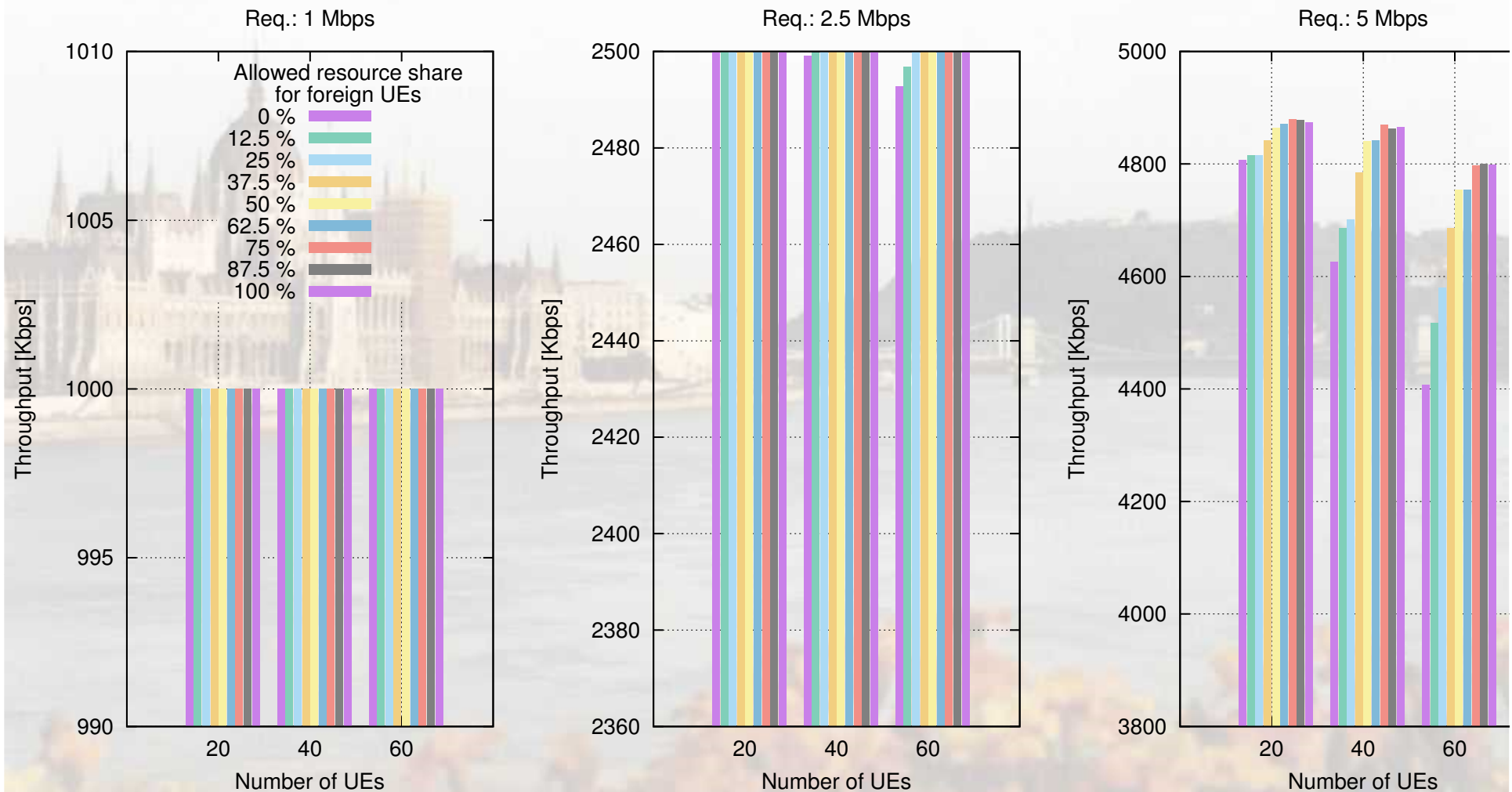
Throughput: 2 operators



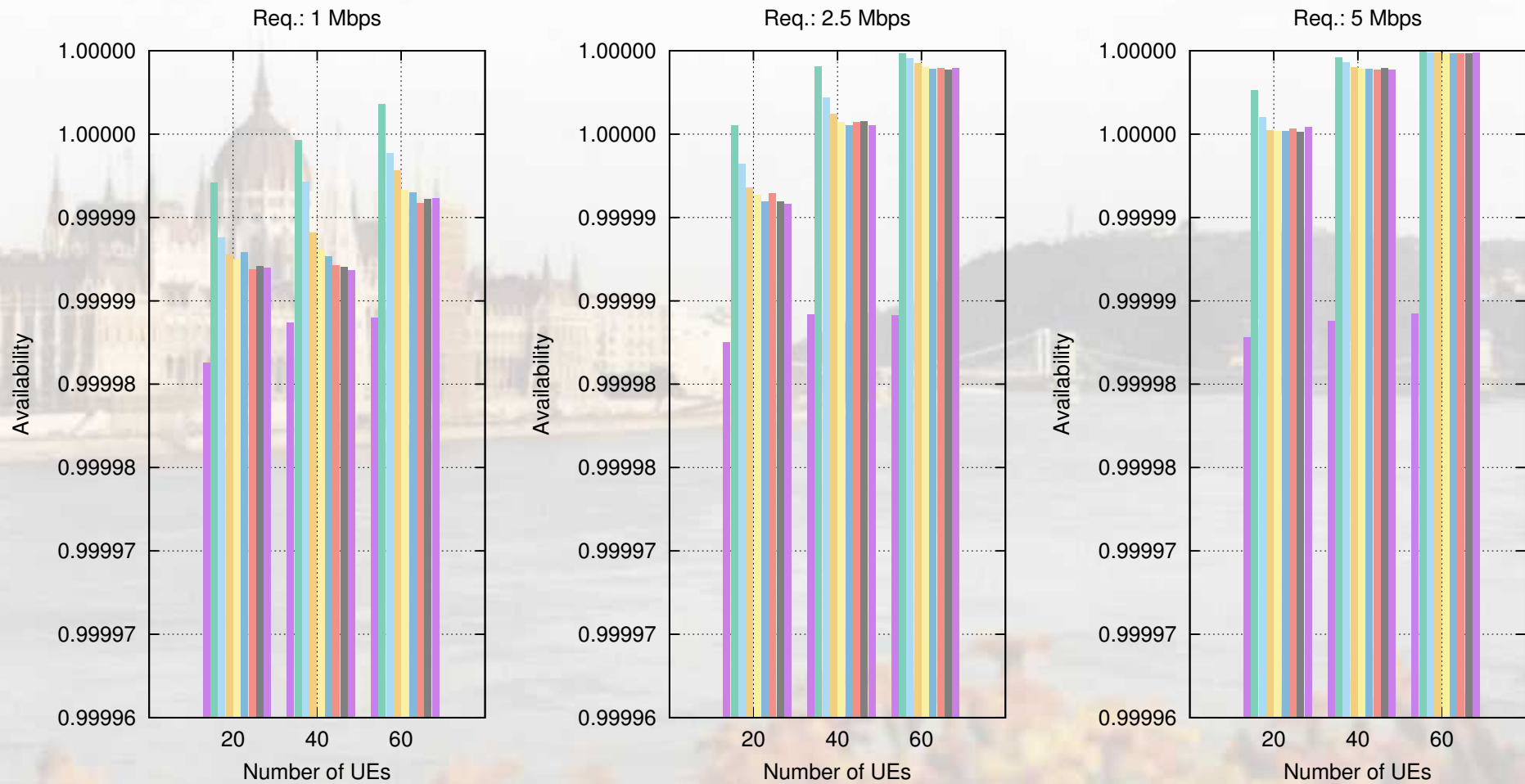
Throughput: 3 operators



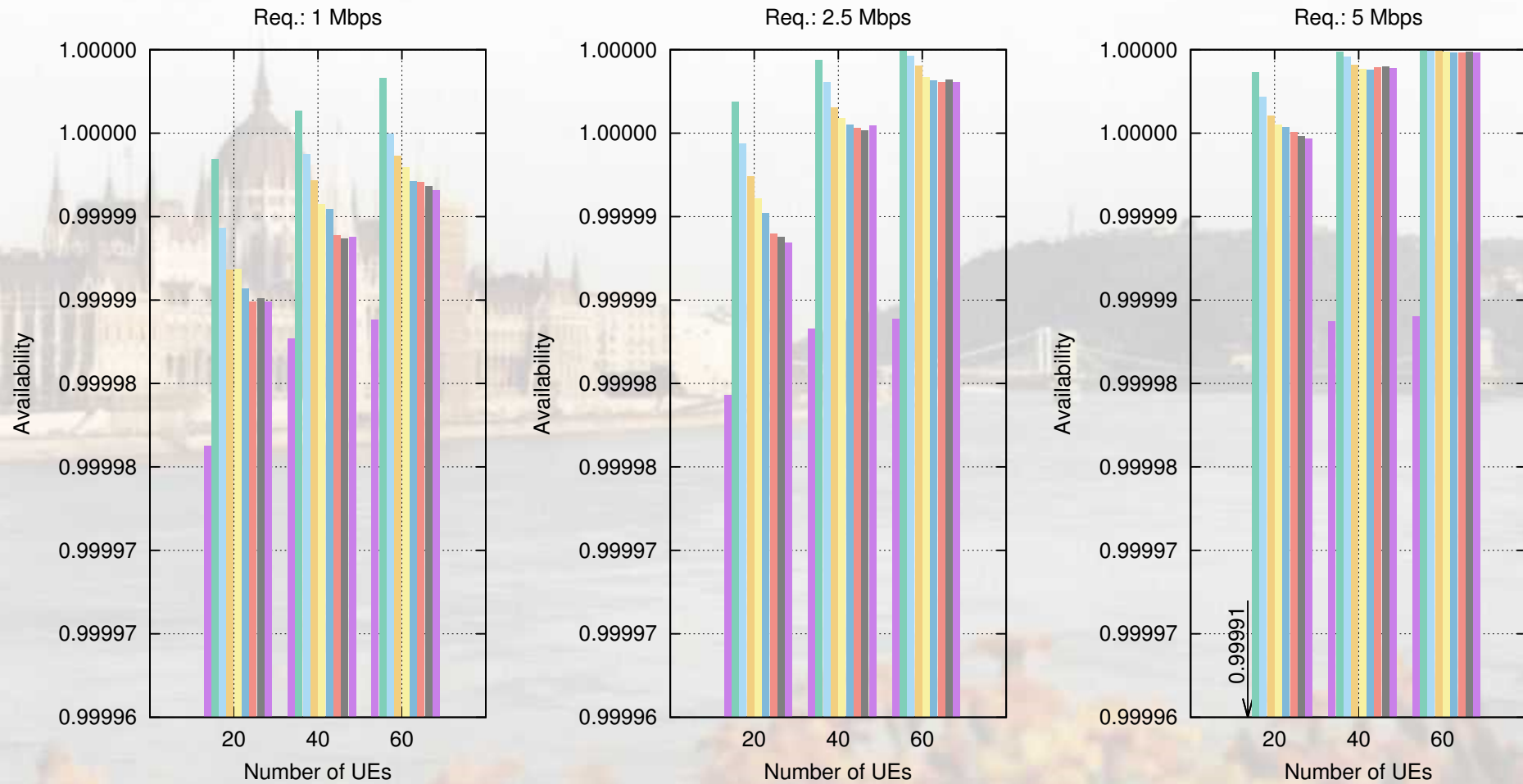
Throughput: 4 operators



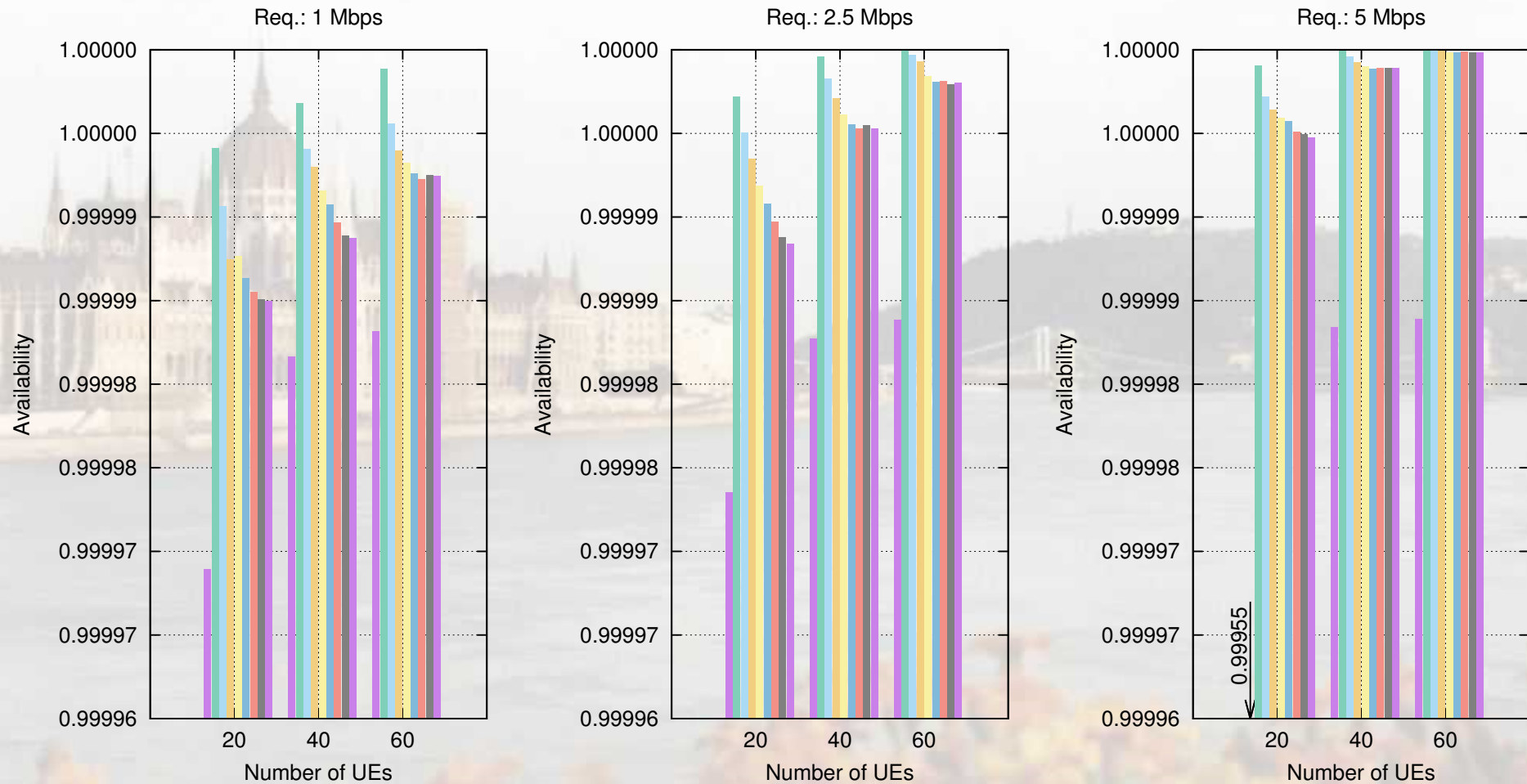
Availability: 2 operators



Availability: 3 operators



Availability: 4 operators



Conclusion

- Increased Throughput (QoS / QoE)
- Increased Availability (mostly)
- Decreased Energy Requirement
- Concertation of Multiple Operators
- No SmartCity without 5G networks?

