System Modeling and Traffic Control Methods in Heterogeneous 5G Mobile Networks

Sergey Andreev

Tampere University (of Technology), Finland

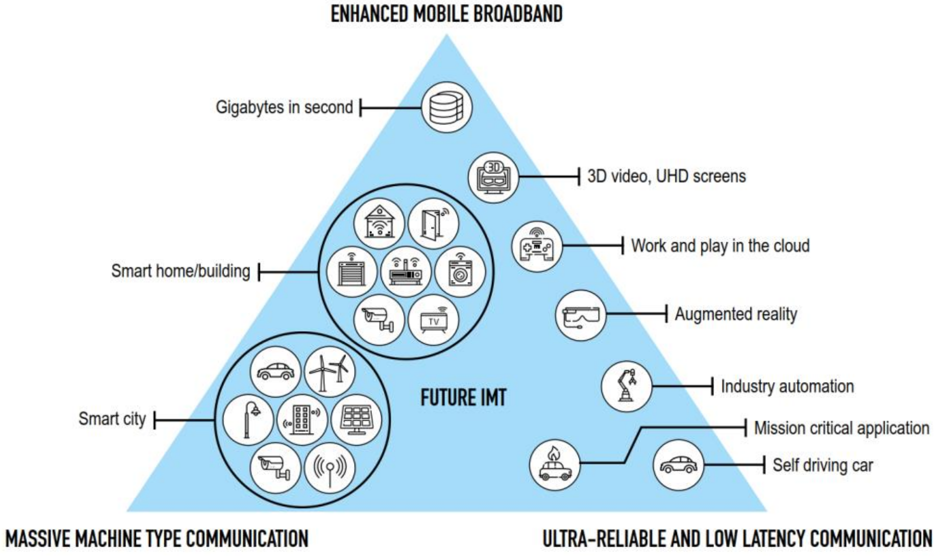
sergey.andreev@tuni.fi

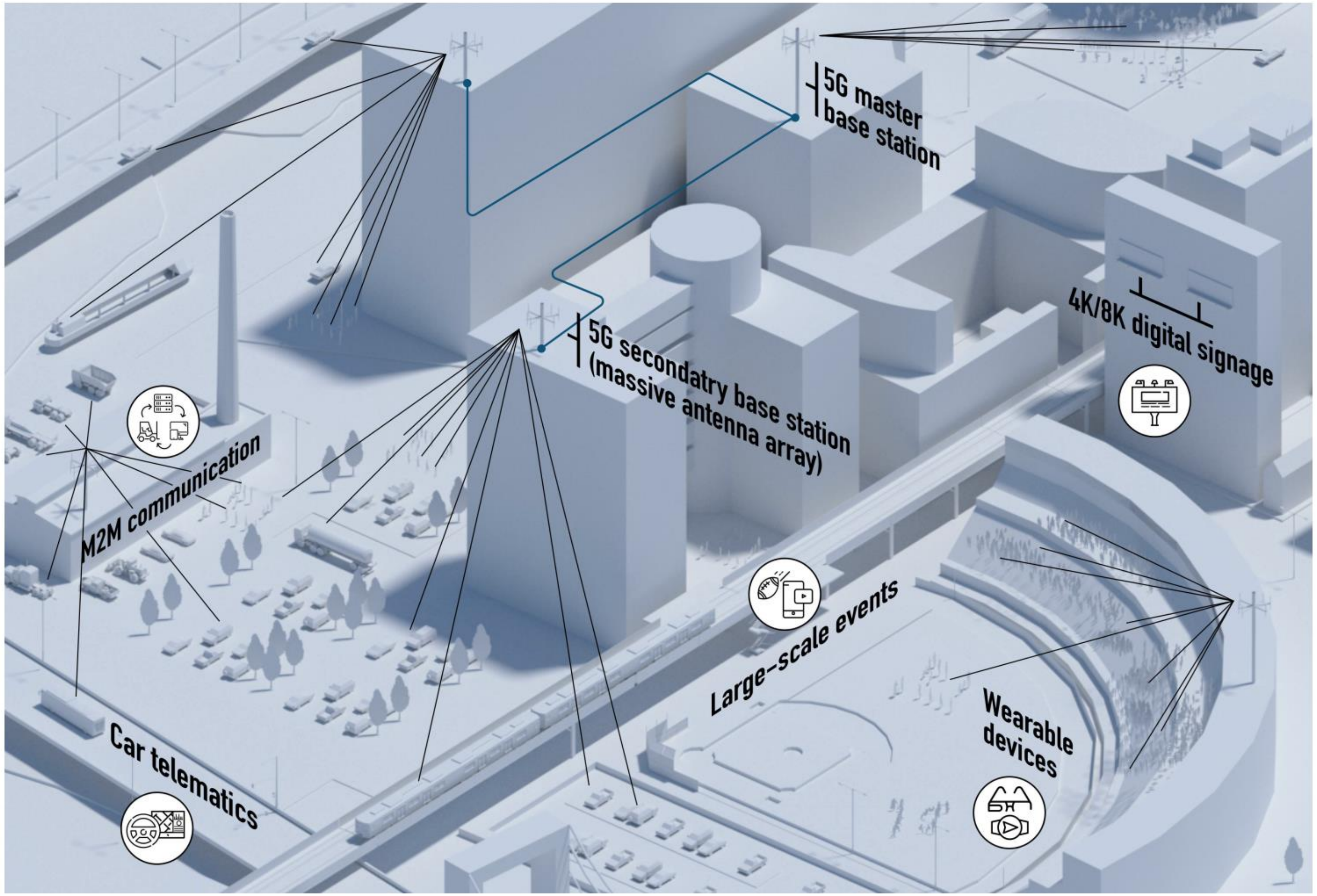
Wengen, Switzerland

Tampere University (of Technology), Finland

Emerging Vision of 5G Mobile Networks

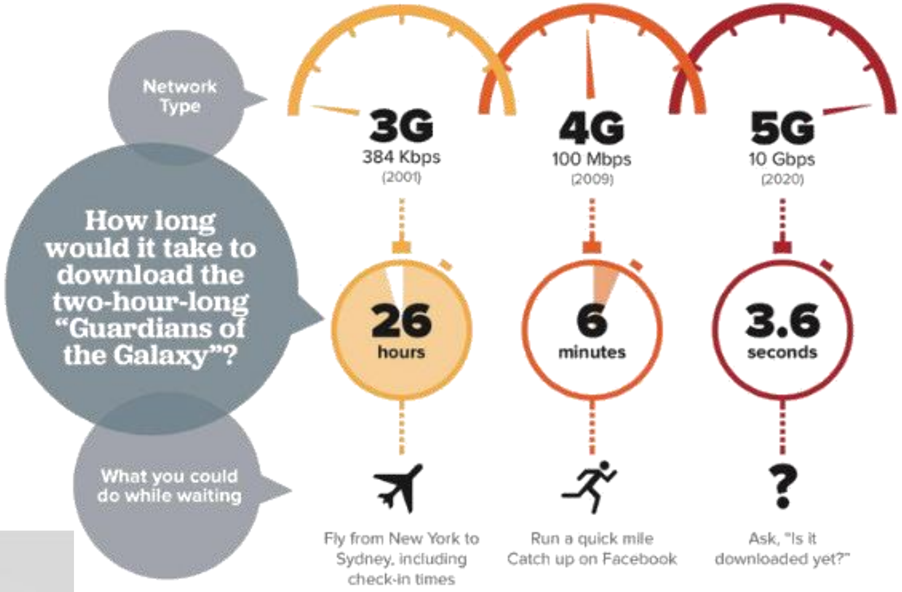
- Offer flexible and agile deployment choices
    - From ultra-dense urban
    - To massive rural layouts
- Support needs of many vertical industries





Next-Generation Wireless IoT Technology

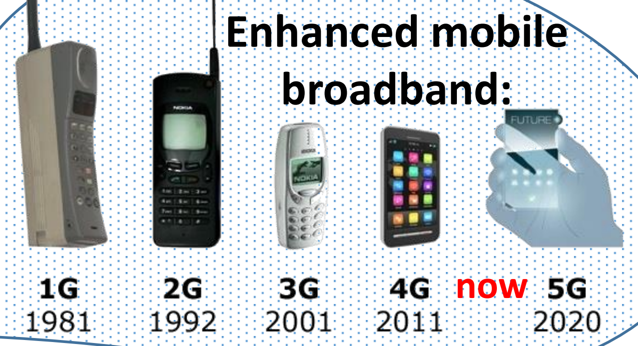
Fifth-generation (5G) wireless technology is targeting to *offer support* for numerous IoT applications



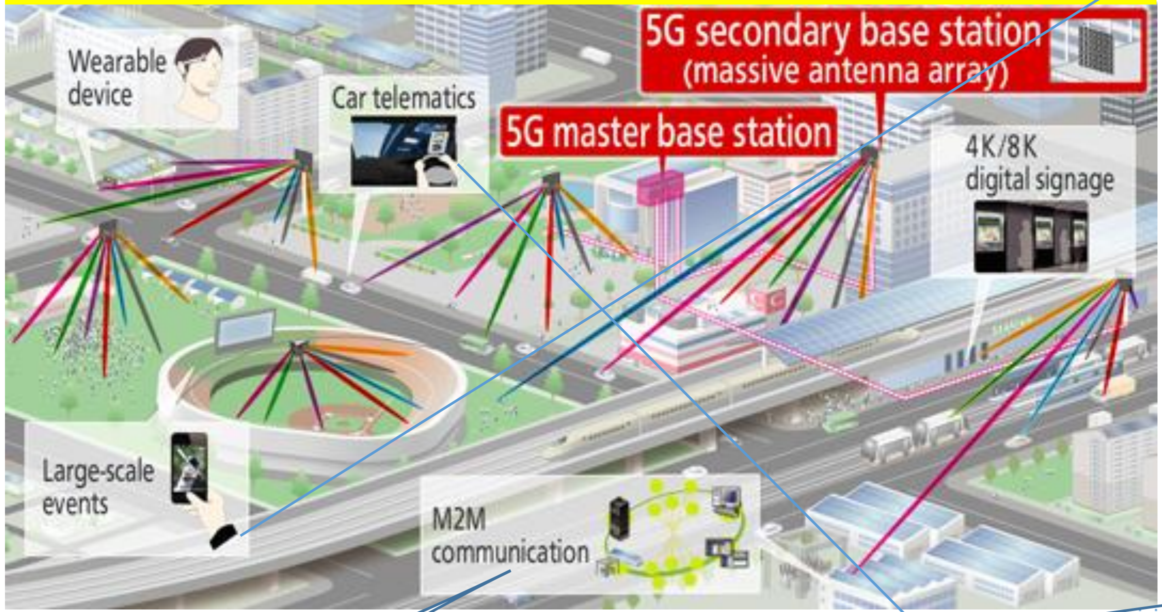
industrial iot 5g

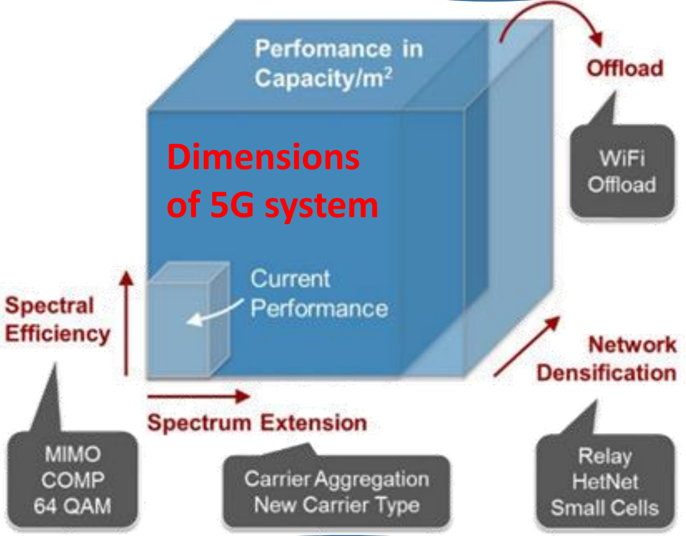
Networks in 5G Era and Beyond

Enhanced mobile broadband:



5G architecture for “human-intense” urban locations





The **‘Big Three’** 5G technologies:

- Ultra-densification
- mmWave radios
- Massive MIMO

Densification leads to **gross over-provisioning** and more complex **interference management**

(requires **massive investments** by mobile operators)

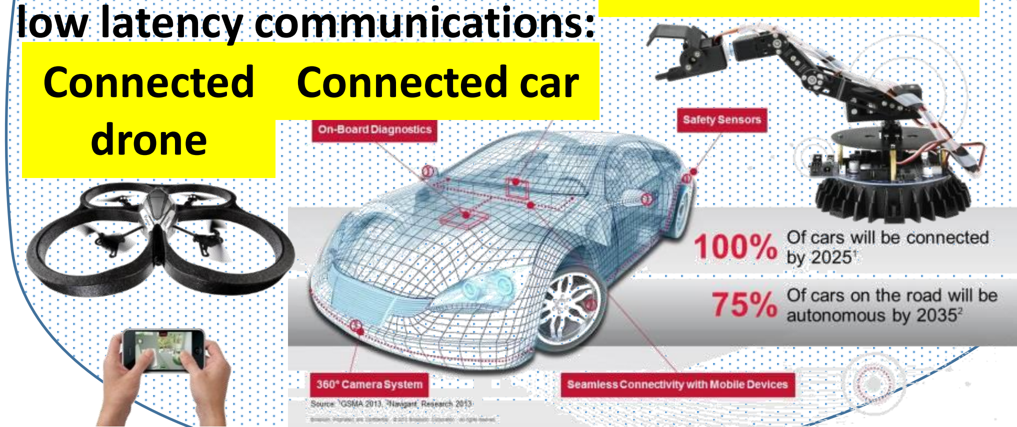
Massive machine type communications:

Ultra-reliable and low latency communications:

Connected drone

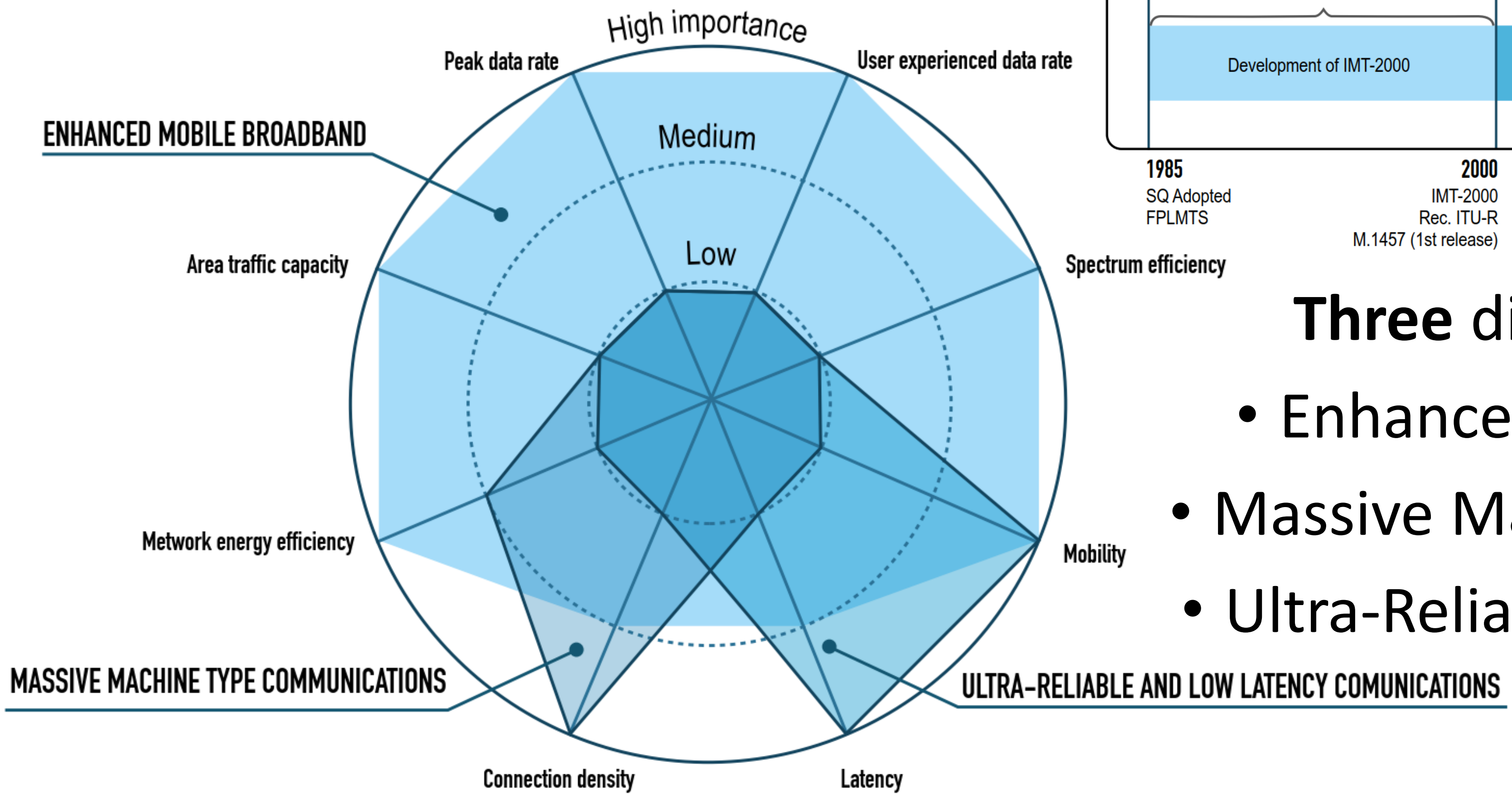
Connected car

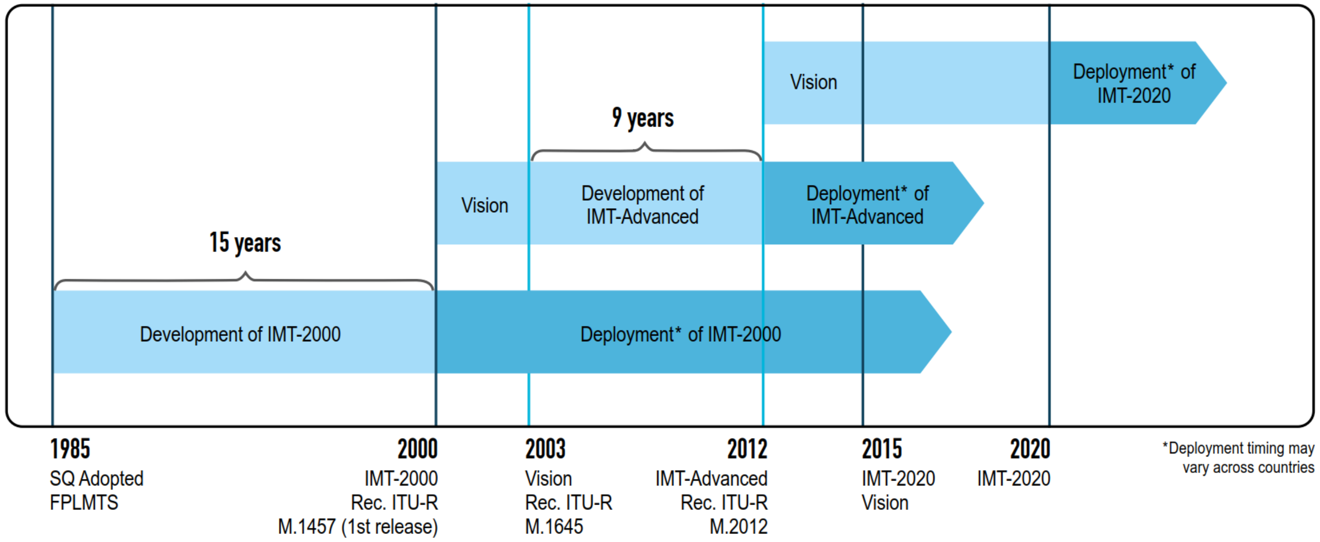
Connected robot



Main Performance Requirements and Timeline

Only **8 years** of technology development (2012-2020)!

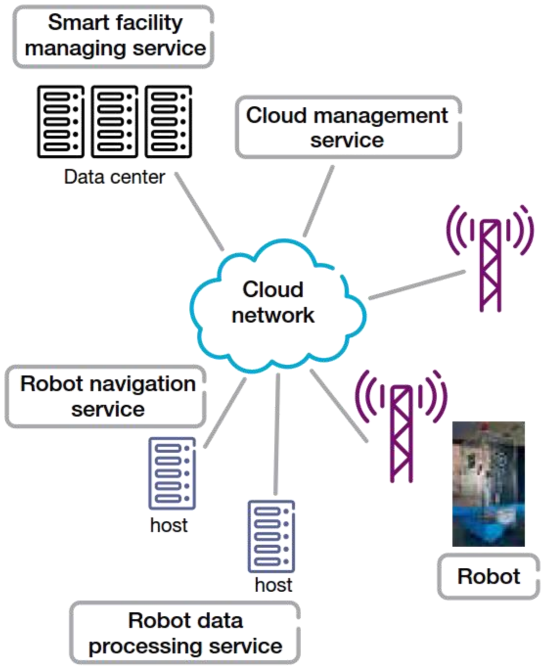


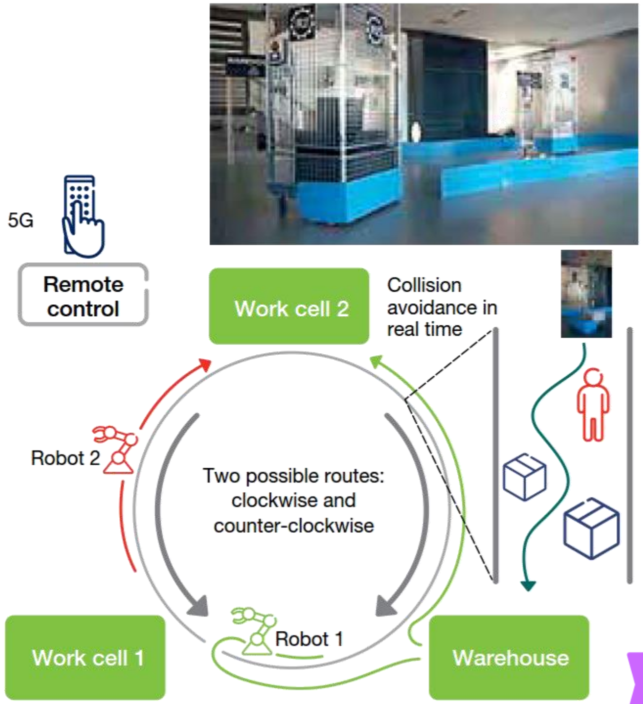


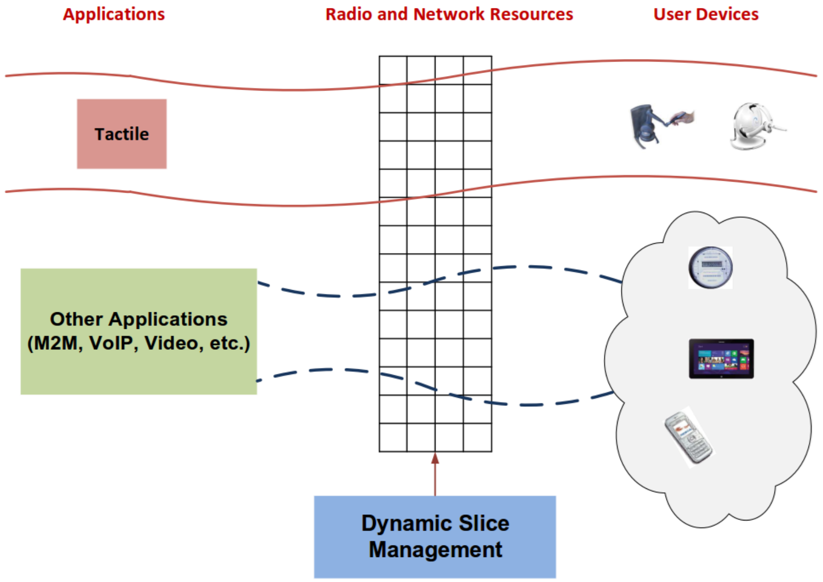
Three distinct use-cases are defined:

- Enhanced Mobile Broadband (eMBB)
- Massive Machine-Type Comms (mMTC)
- Ultra-Reliable and Low-Latency Comms (URLLC)

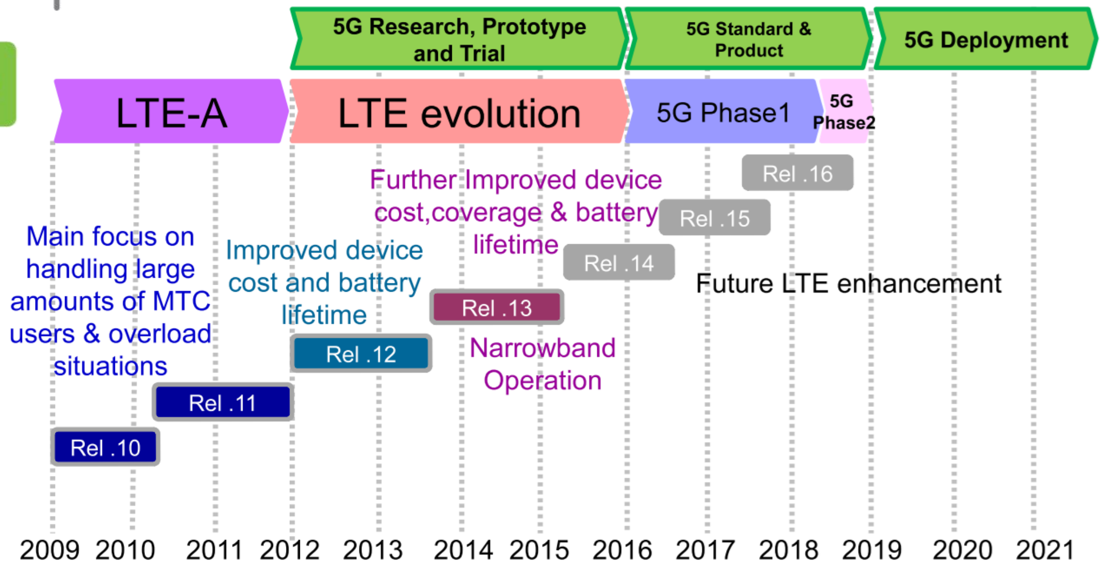
Envisioned Timeline of 5G-Grade Systems



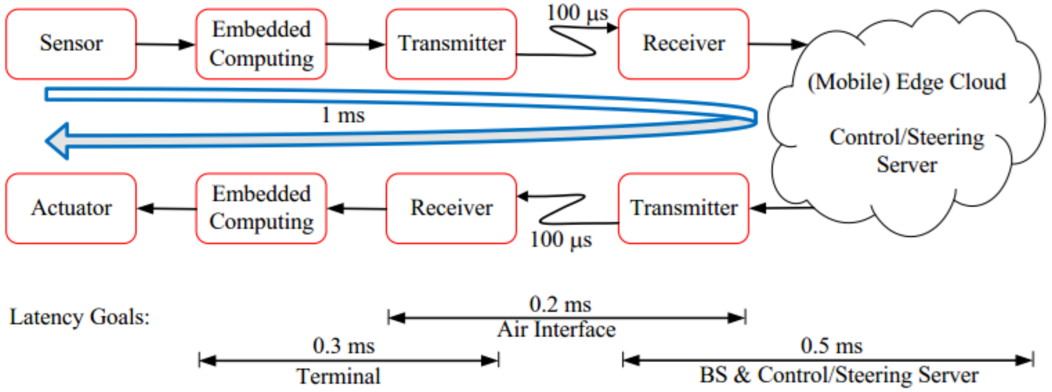


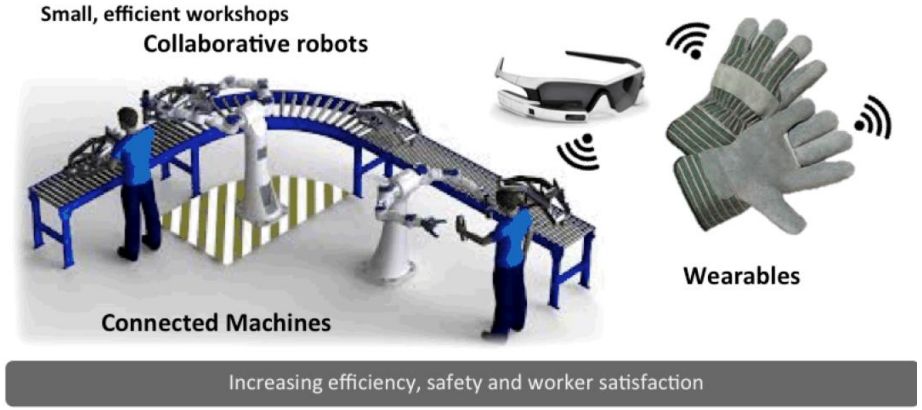


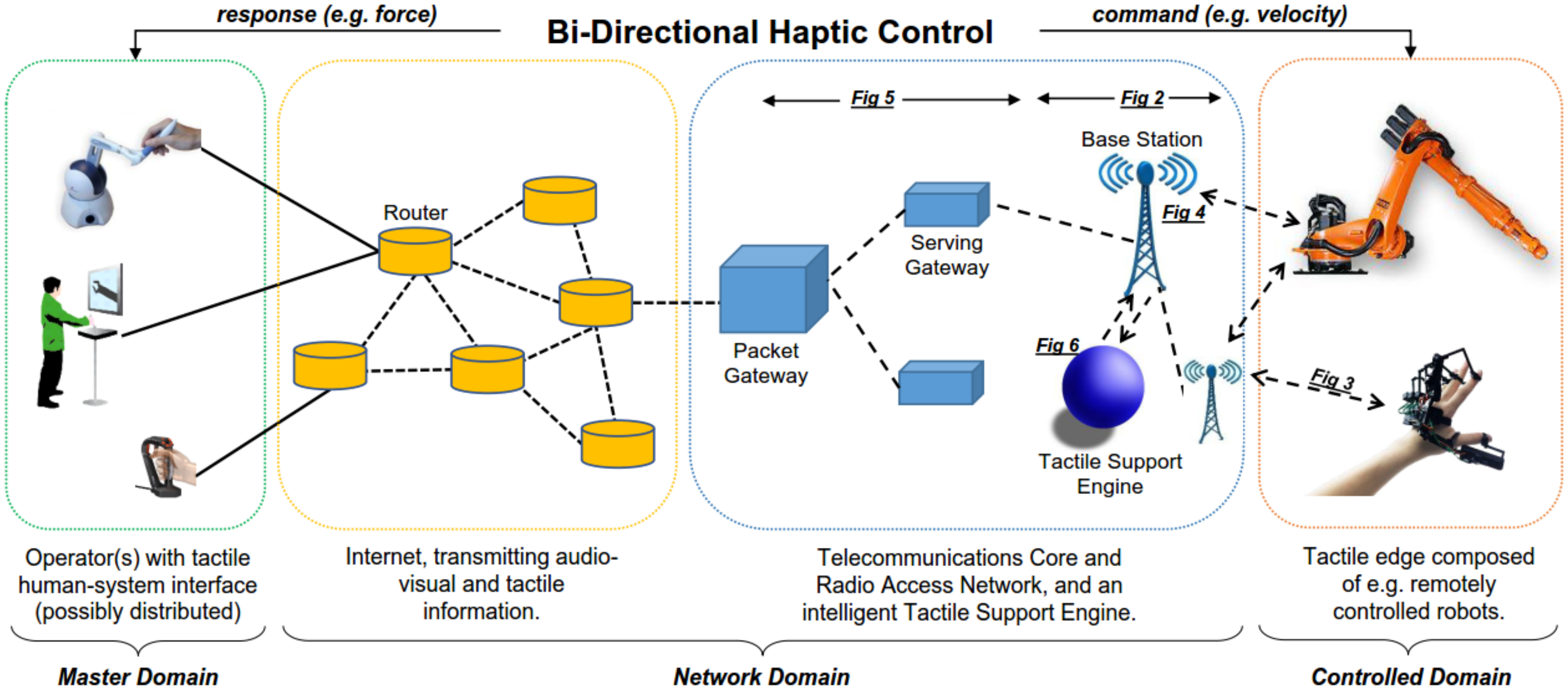
Cellular **3GPP standards** are constantly evolving to meet IoT requirements and characteristics towards future *5G-grade systems*



Tactile Internet: Our Next Destination?

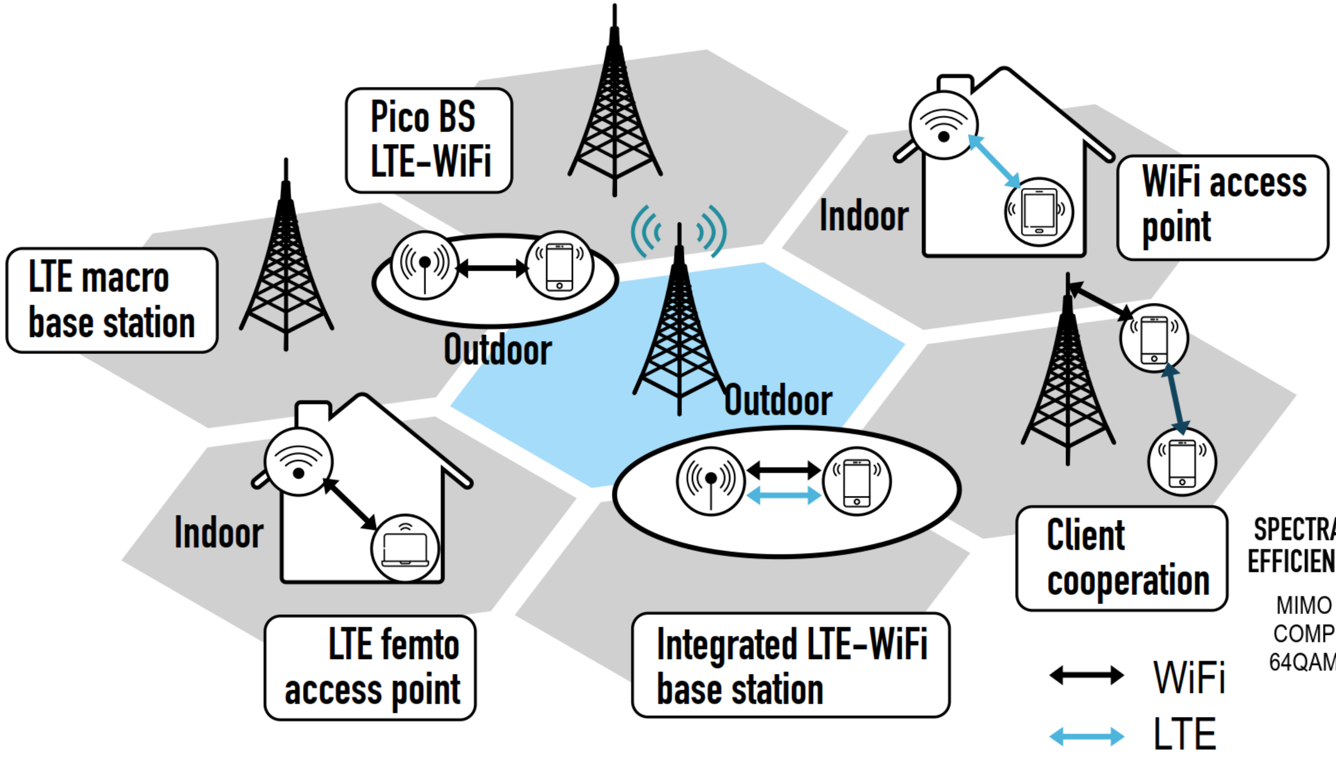


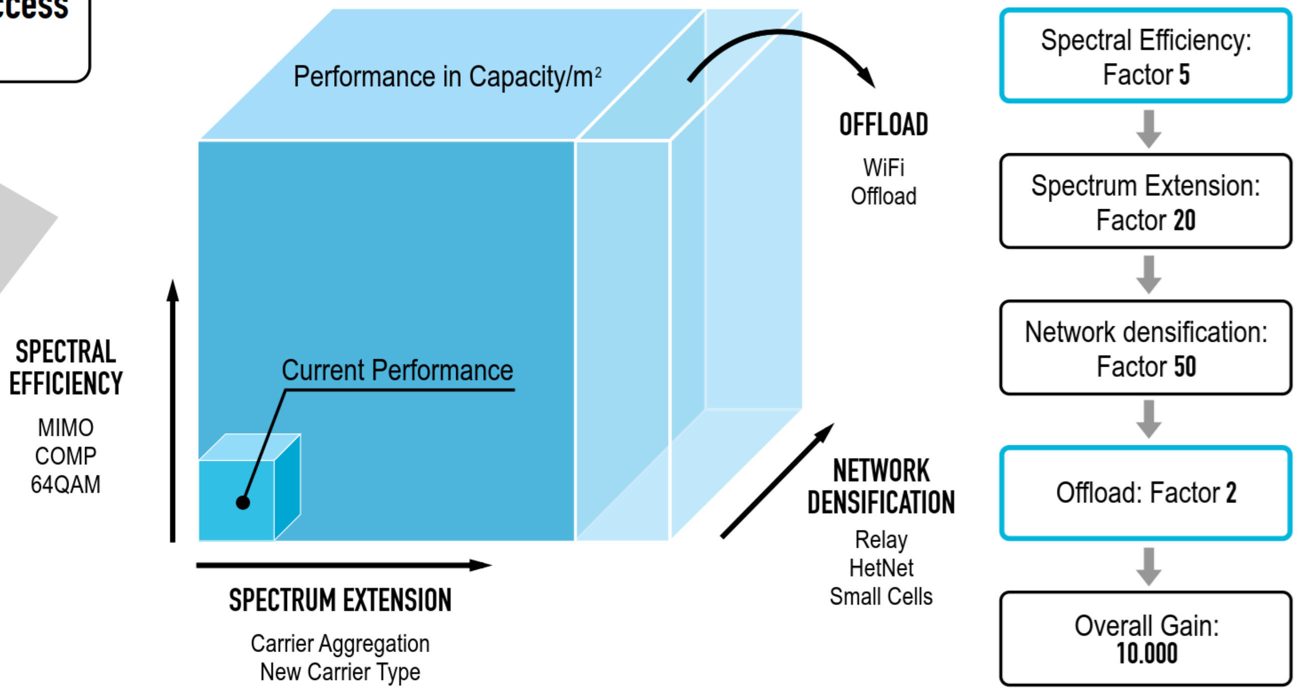




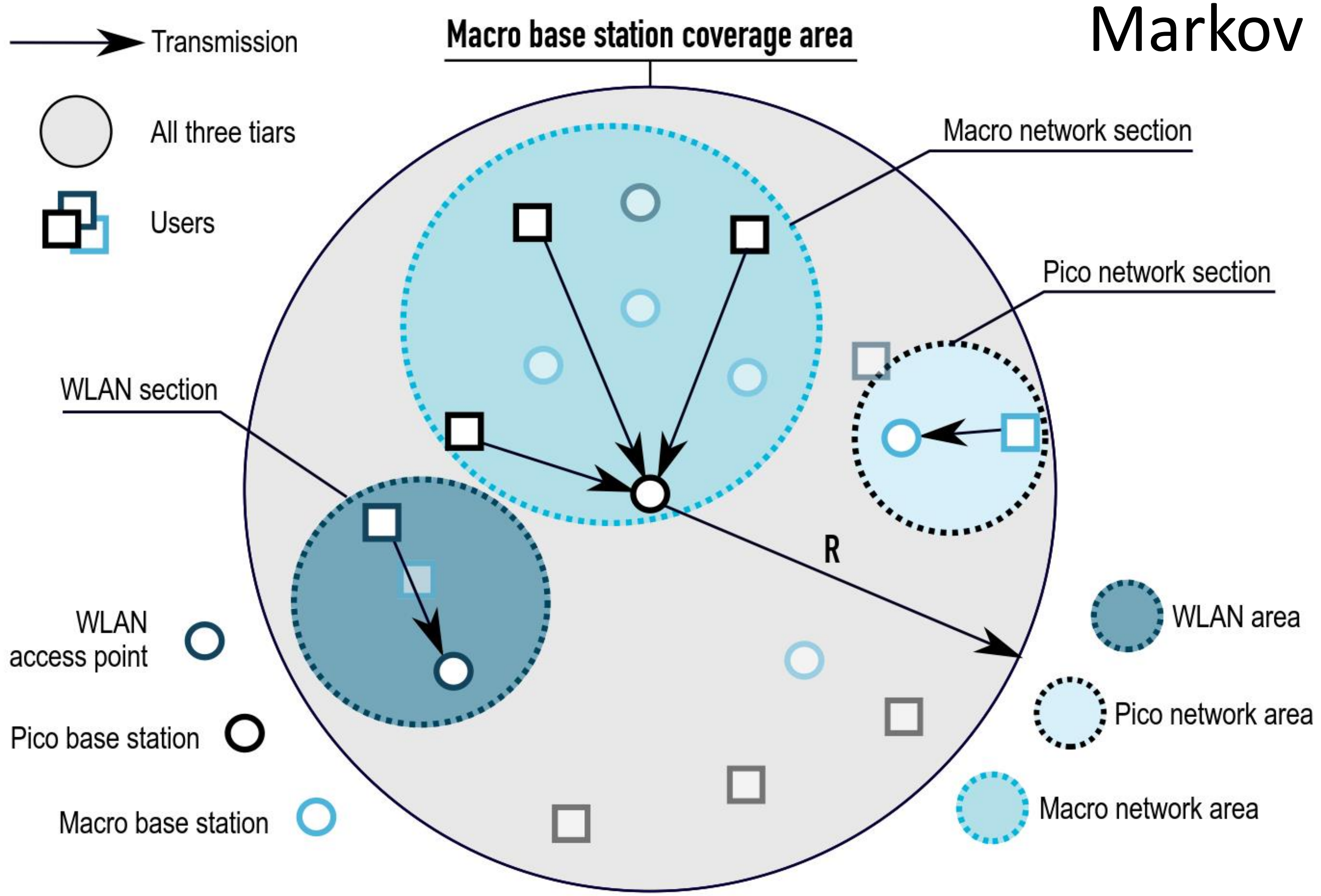
Capacity Scaling in Heterogeneous Networks

- Tighter integration of licensed- and unlicensed-band radios
- Extreme network densification (a.k.a. ultra-densification)

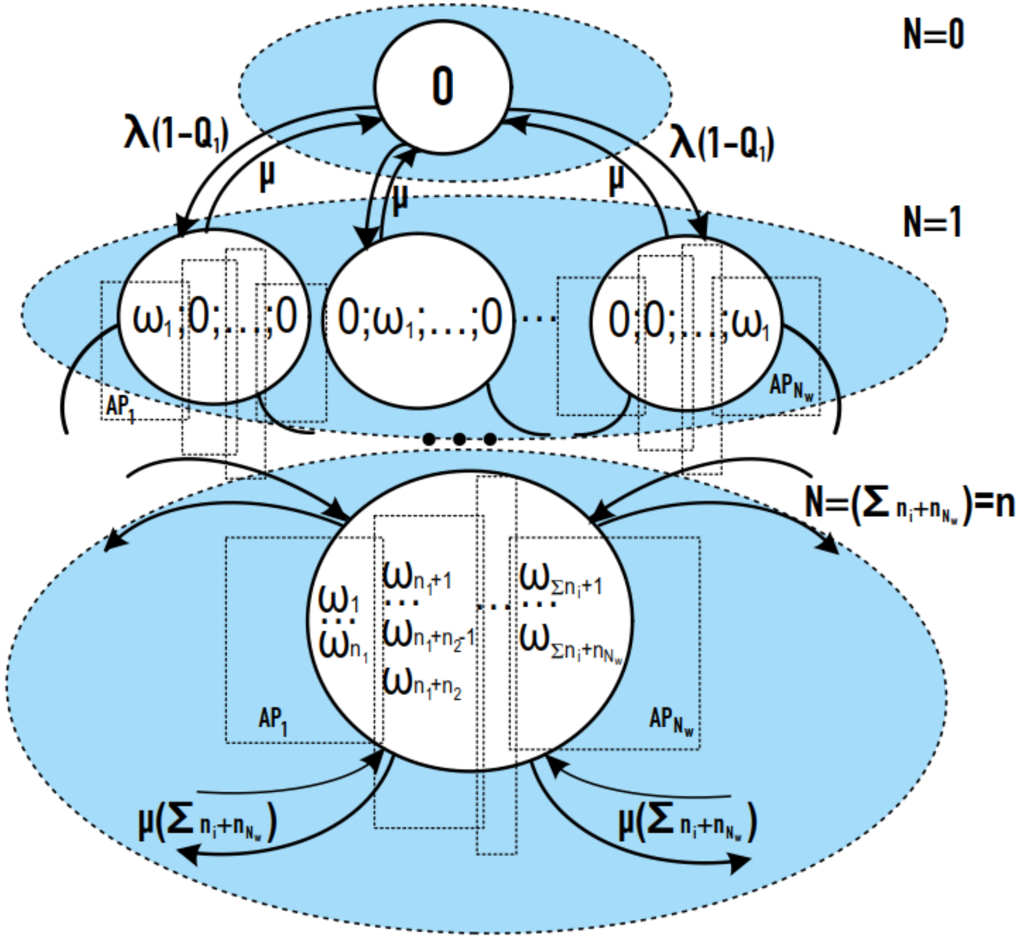




Modeling Multi-Radio Heterogeneous Networks

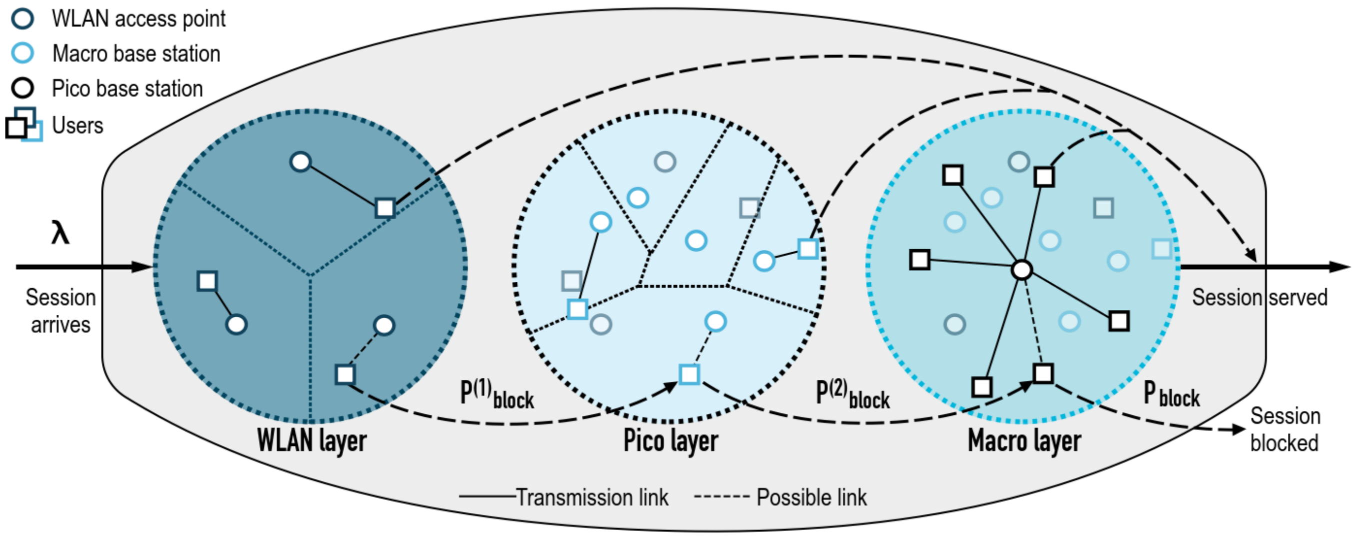


Markov processes with infinite state space



Space-time flow-level modeling methodology

“Cascade” Data Offloading (Steering) Approach



- Calculate probability distribution

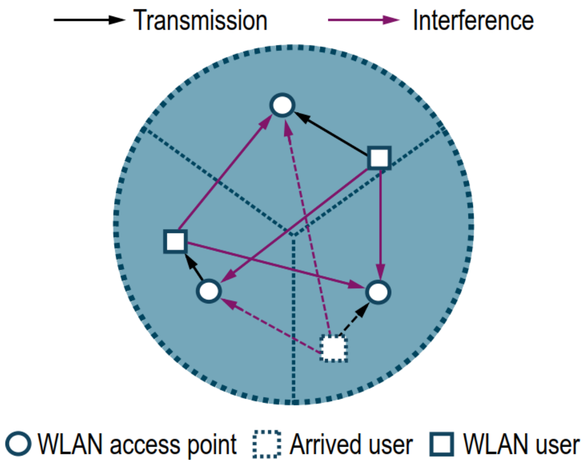
$$\pi_n = \pi_0 \frac{\lambda^n_{m/w/p}}{\mu^n} \frac{\prod_{i=1}^{n}(1-Q_n)}{n!}$$

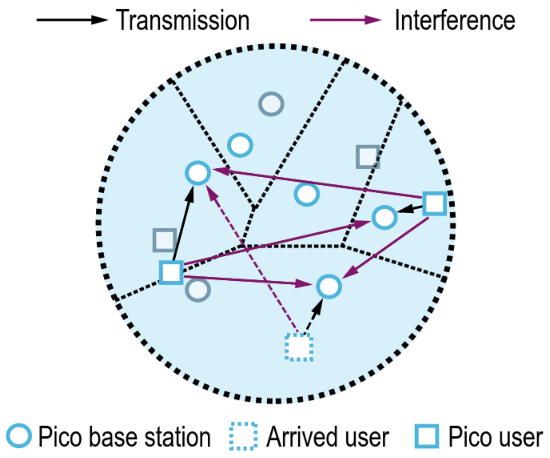
- Establish transition probabilities

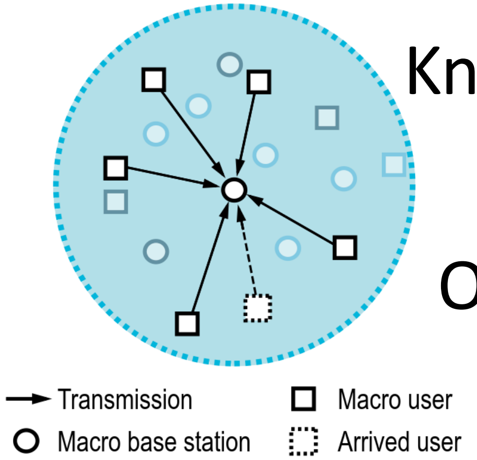
$$\lambda_p(1-Q_{n+1}) = \lambda_p \Pr\left\{A_j^{(n+1)}, j=\overline{1,n+1} \,\middle|\, A_j^{(n)}, j=\overline{1,n}\right\}$$

- Subject to flow admission control

$$A_j^{(n)} = \left\{ r_j^{\max} \geqslant \frac{r_0 n_0}{\delta_p} \text{ и } \gamma_{j,k} p_j \leqslant N_0, k > 1 \right\}$$







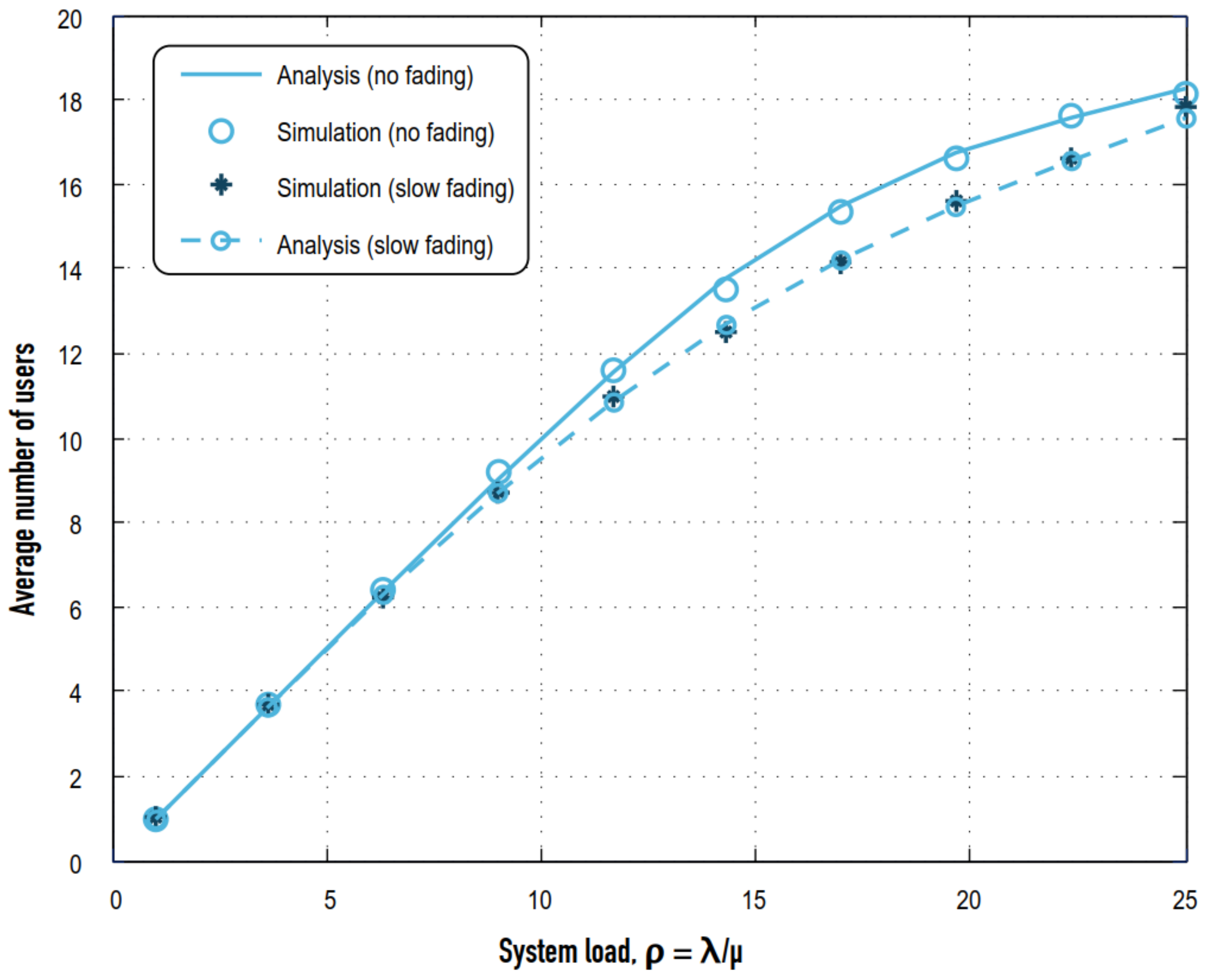
Knowing user transmit power

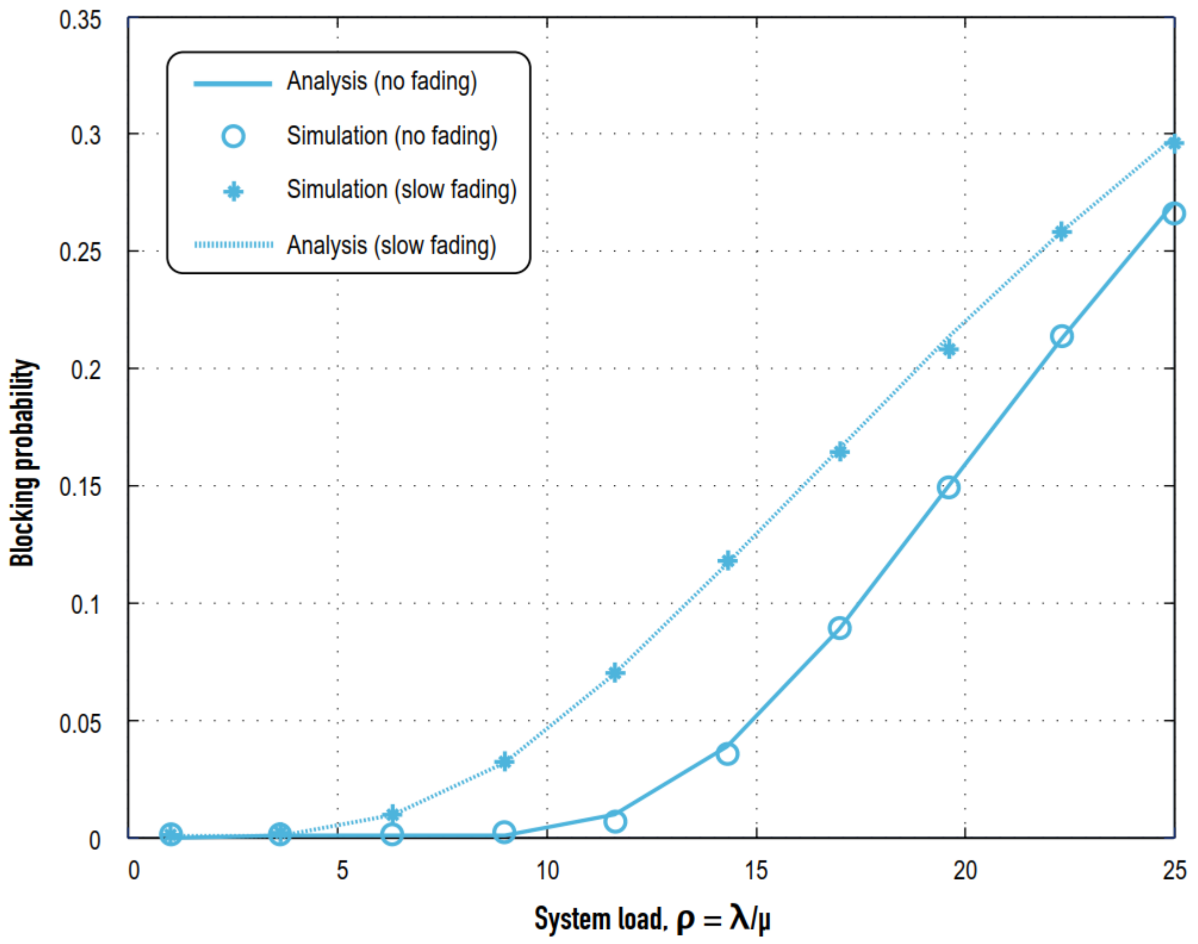
$$p_j = \frac{K N_0}{\eta \gamma_{j,j}} \left(e^{\frac{r_0 n_0}{w \delta_p}} - 1 \right)$$

Obtain performance metrics

$$E[N] = \sum_{n=0}^{\infty} n\pi_n, \quad P_{block} = \sum_{n=0}^{\infty} Q_{n+1}\pi_n.$$

Number of Sessions and Blocking Probability

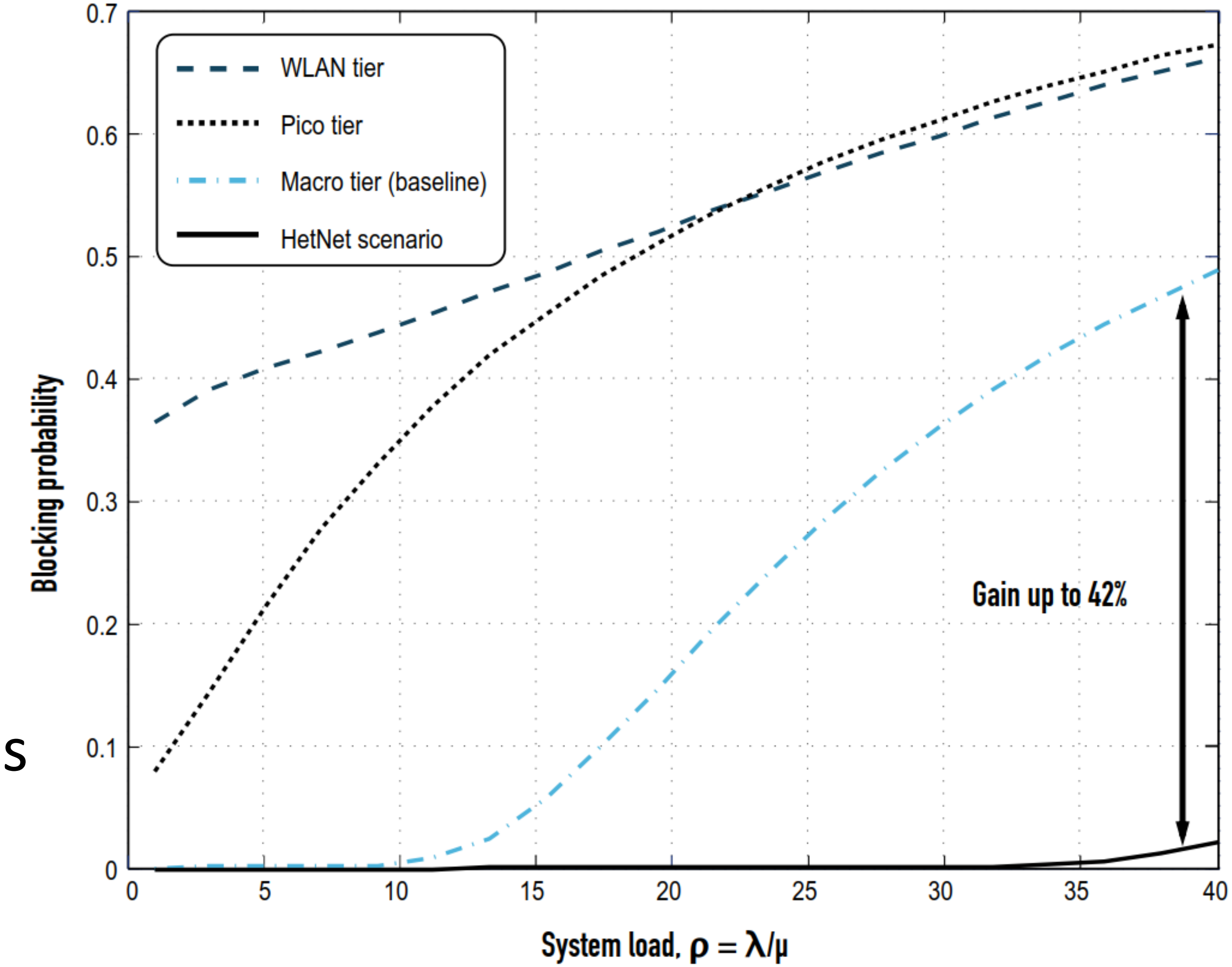




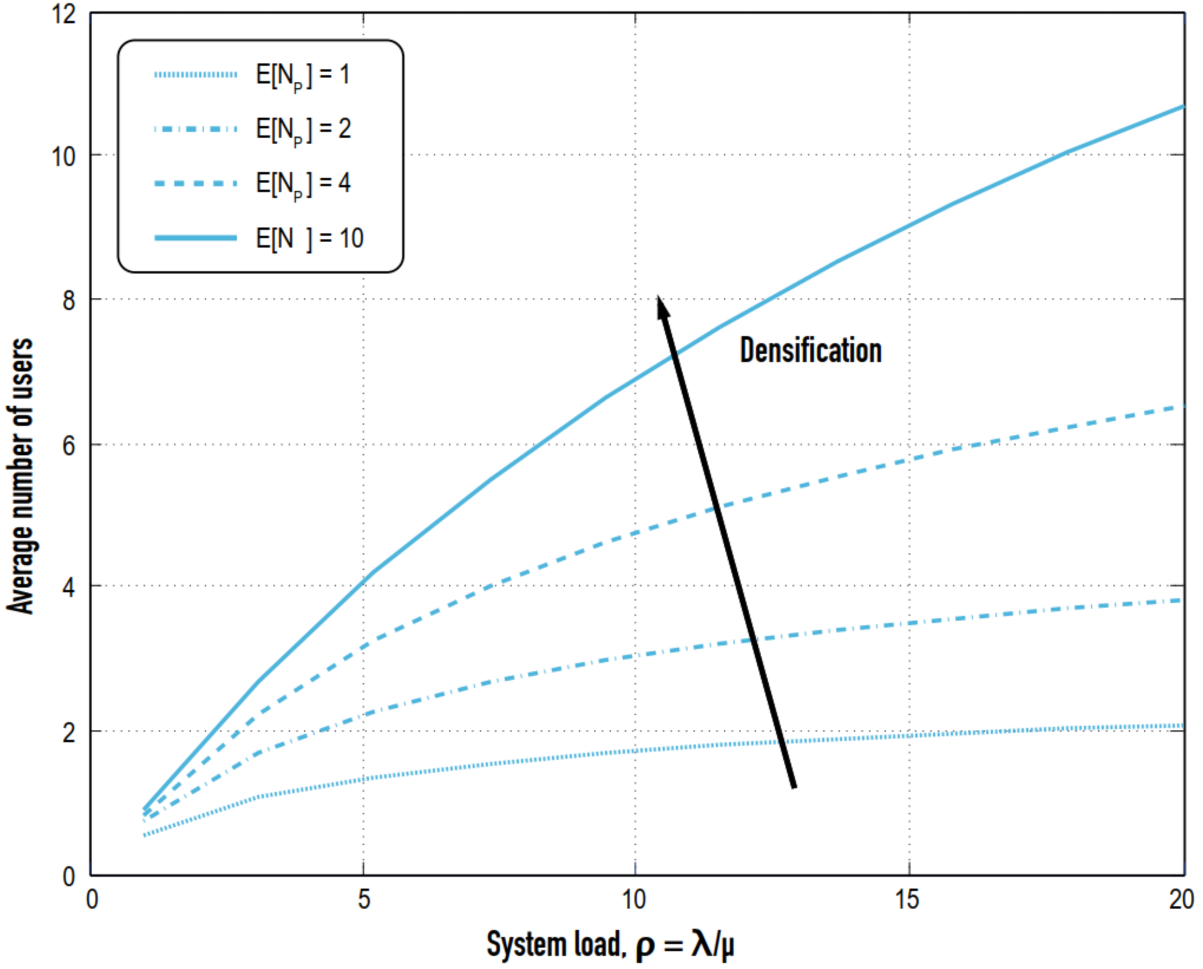
Analysis of Blocking in Multi-Radio HetNets

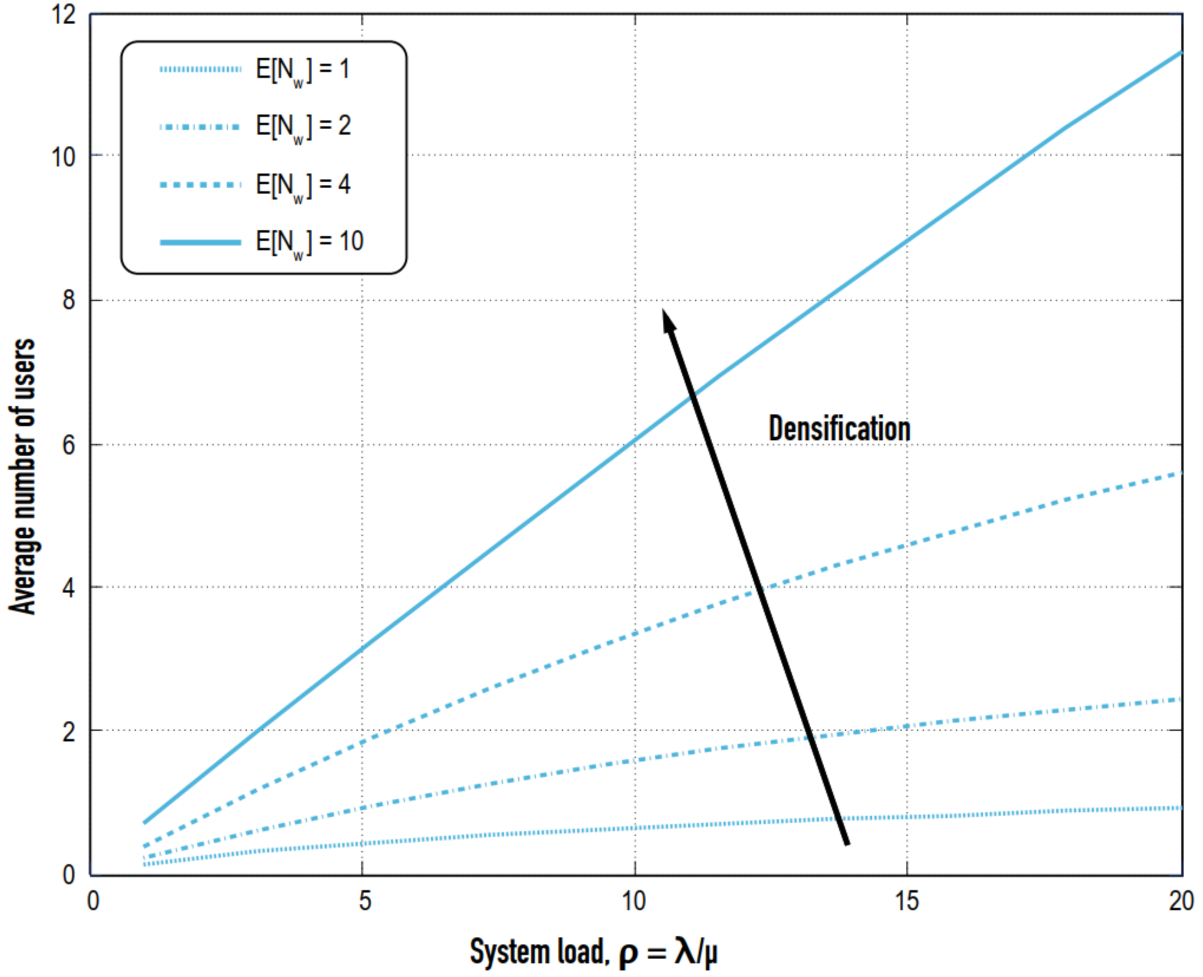
More detailed assessment of **session blocking probability**:

- Considers three HetNet tiers, both together and separately
- Quantifies system-level performance improvements with added network tiers
- Compares against baseline macro-only case to show gains

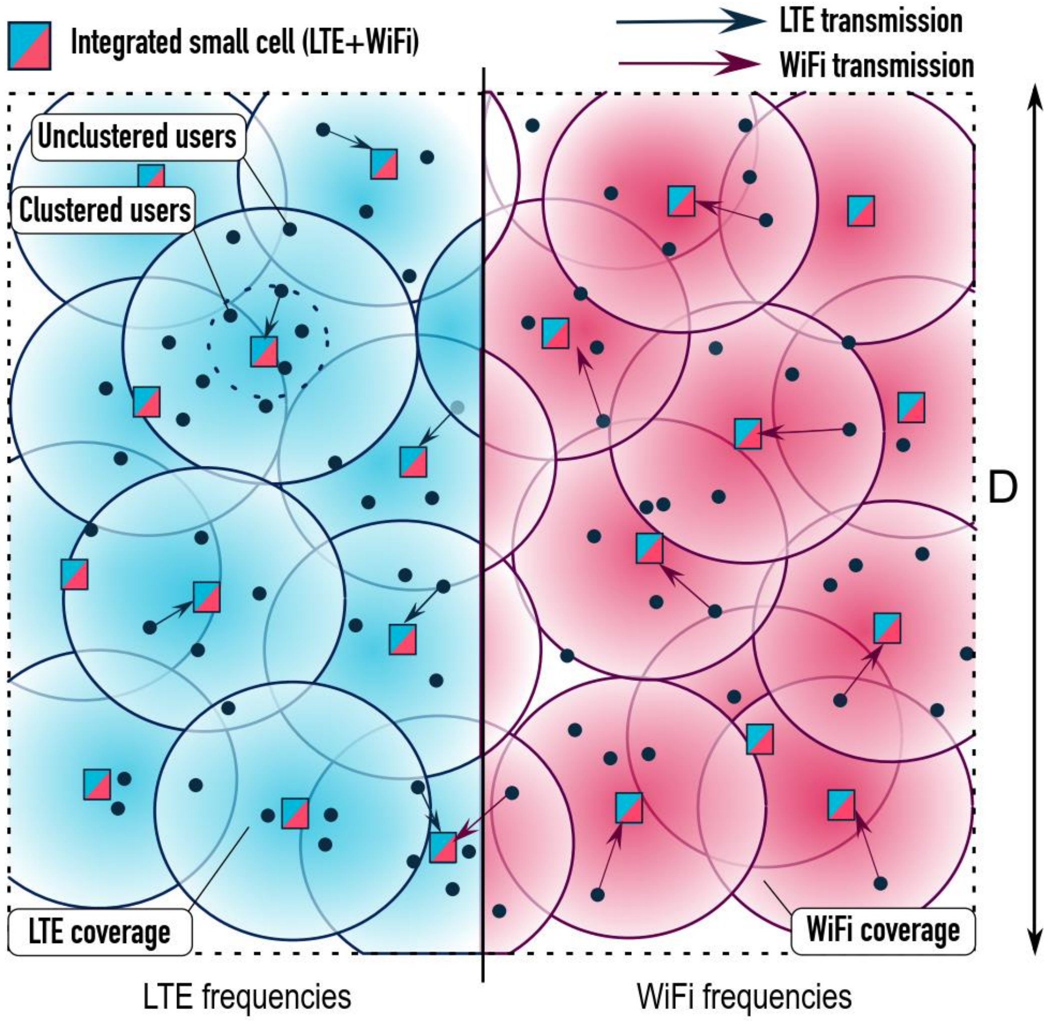


Densification Effects in Multi-Radio HetNets

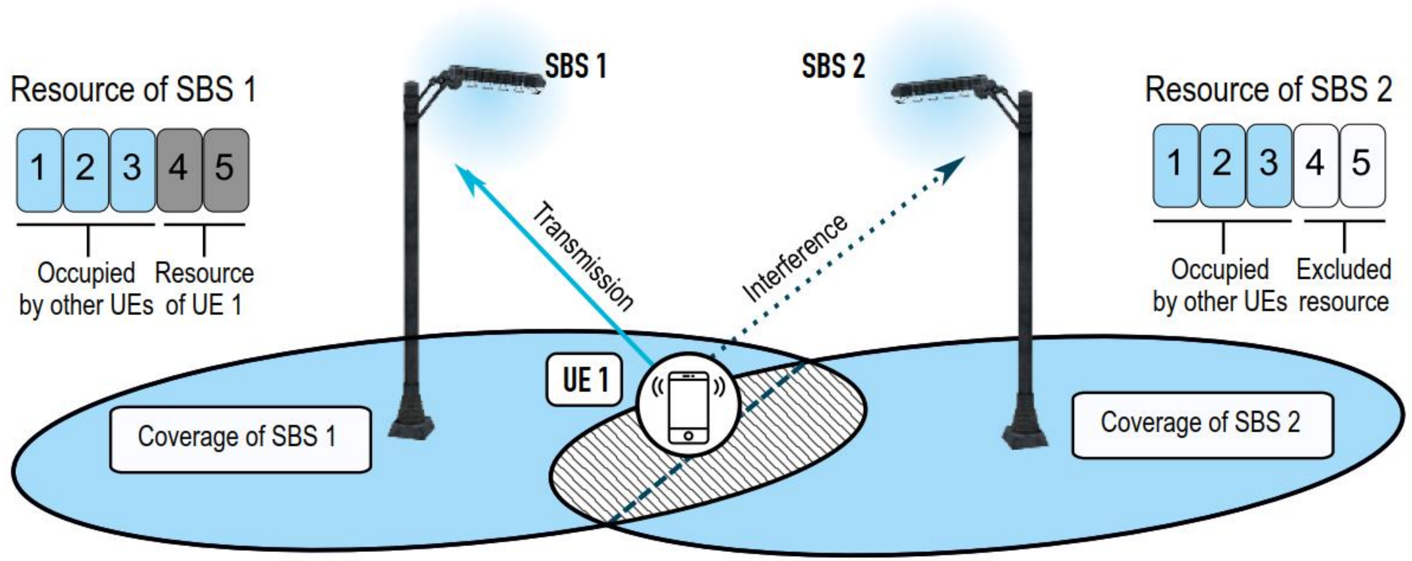




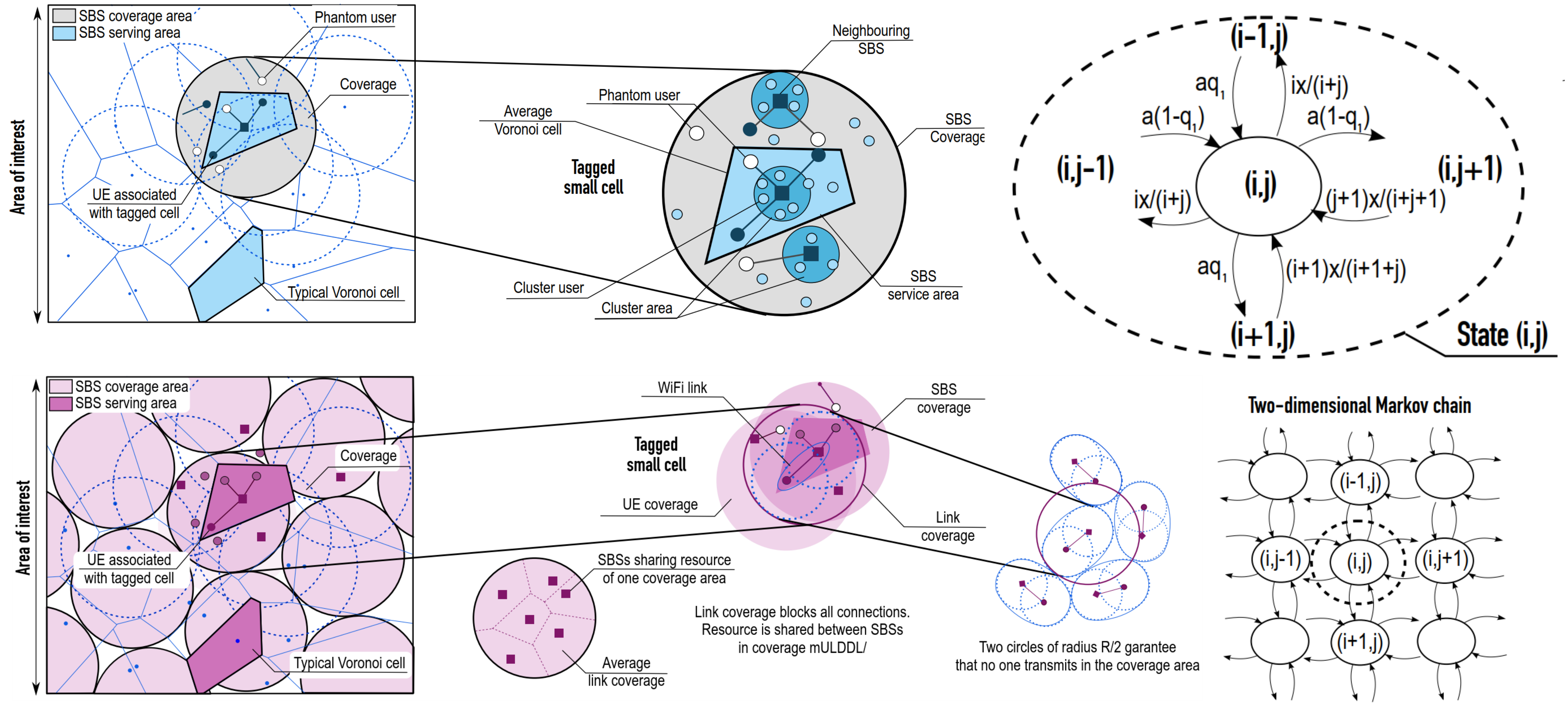
Converged Ultra-Dense Multi-Radio HetNets



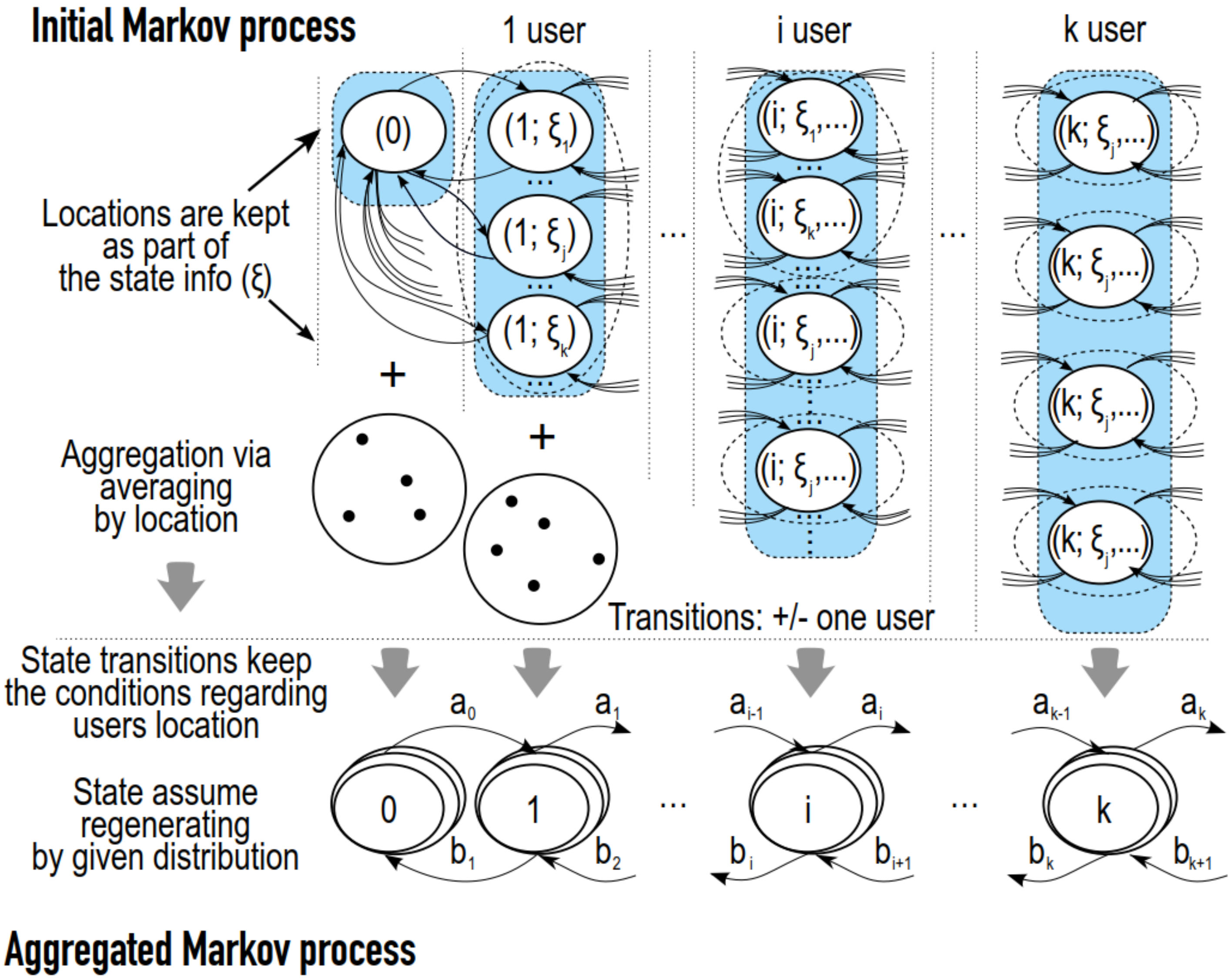
- Fully-integrated LTE+WiFi HetNet layouts
- Cells are deployed "on every lamppost"
- Offer improved system capacity scaling
- Suffer from increased interference levels



Our Proposed Concept of “Phantom” Users



Space-Time Modeling of Ultra-Dense HetNets



- Probability distribution is

$$\pi_n = \pi_0 \prod_{i=1}^{n} \frac{a_{i-1}}{b_i}$$

- Transition rates are given as

$$a_i = \lambda \frac{S_s}{D^2}$$

$$b_i = \tilde{\delta}_{w/l} \left[\int_0^\infty x \left(\int_{r_R}^{r_{\lim}} \frac{r}{\theta} e^{-\frac{r}{\theta}x} f_r(r) dr - C \frac{r_{\lim}}{\theta} e^{-\frac{r_{\lim} x}{\theta}} \right) dx \right]^{-1},$$

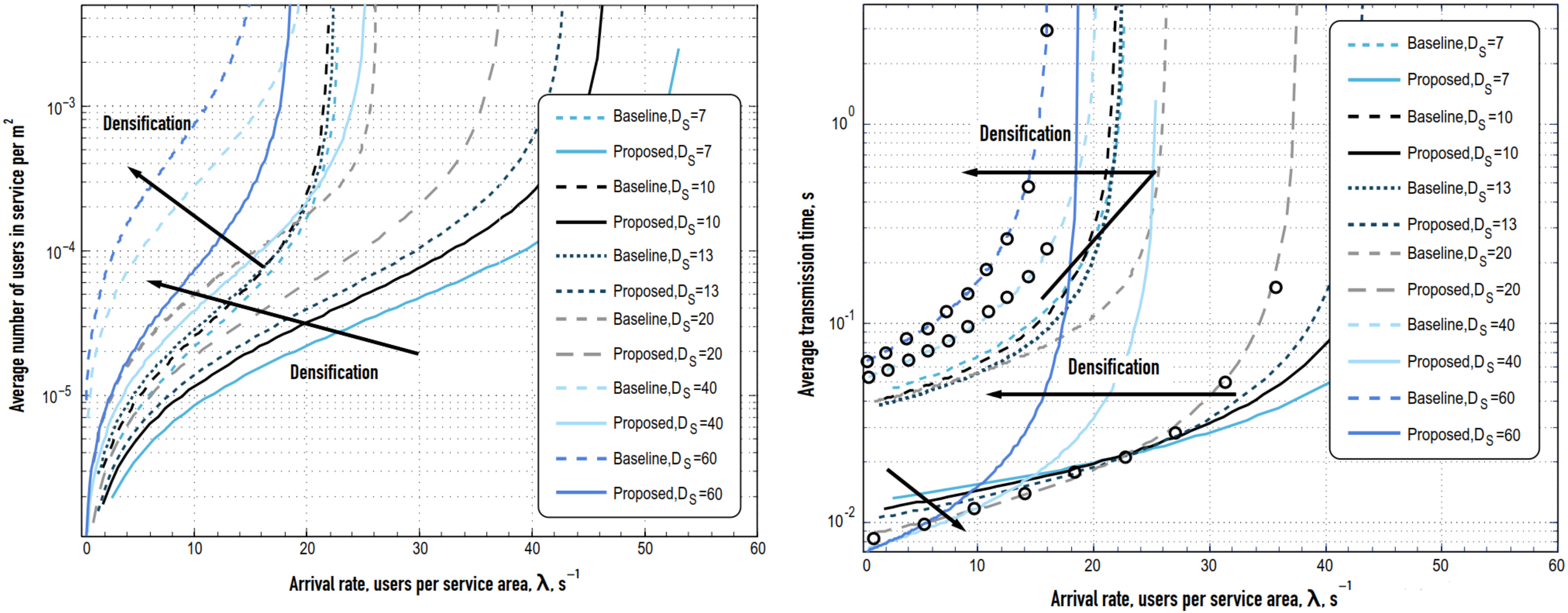
where

$$C = \int_{r_R}^{r_{\lim}} f_r(r) dr, \; \tilde{\delta}_{w/l} \leqslant \delta_{w/l} \leqslant 1$$

- Metrics of interest are then

$$E_t[n] = \sum_{i=0}^{\infty} i\pi_i, \quad E_t[T] = \frac{E[n] D^2}{\lambda S_s}, \quad E_t[r] = E_s[r] \frac{\sum_{i=0}^{\infty} \frac{1}{i}\pi_i}{1 - \pi_0}$$

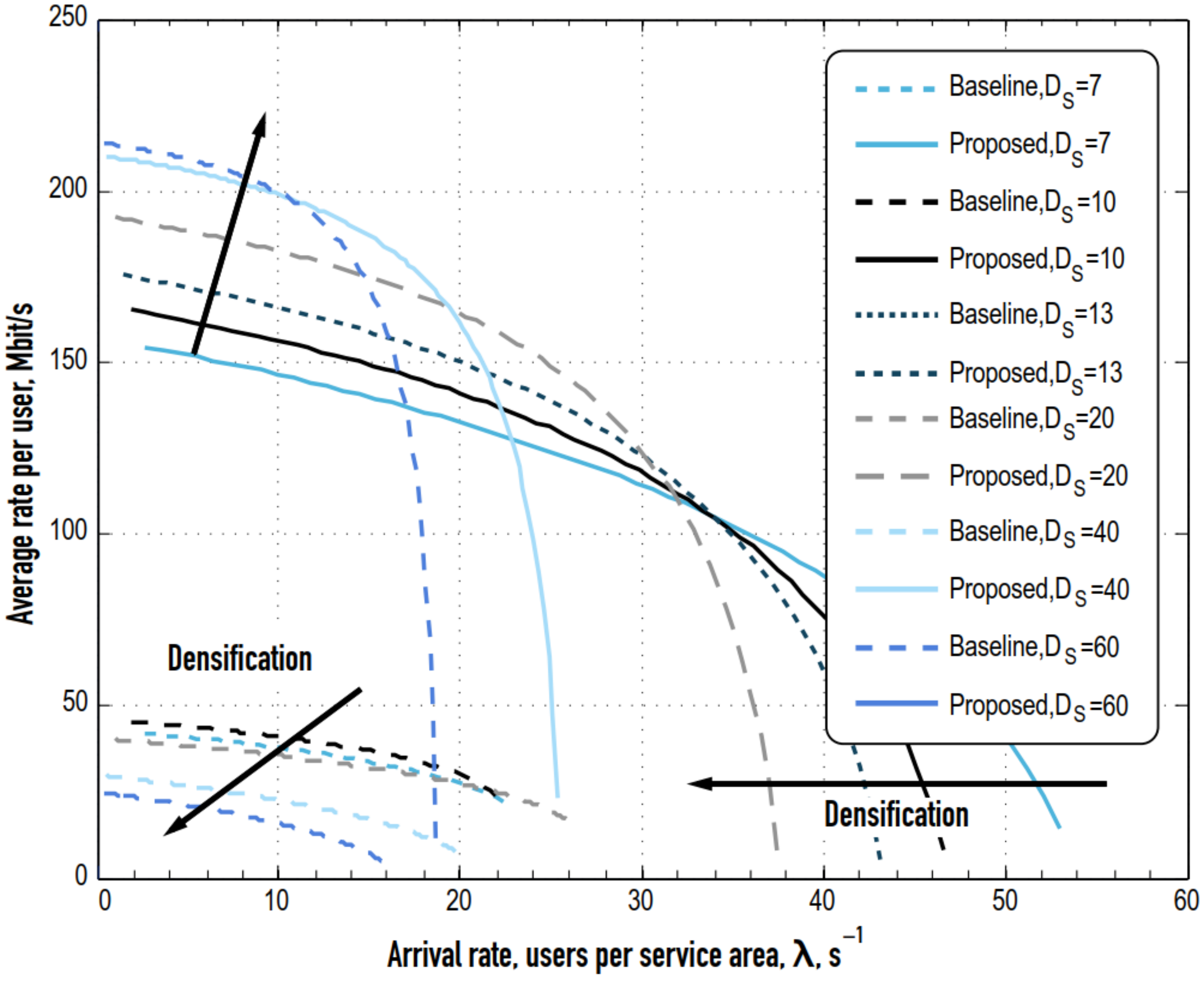
Number of Sessions and Transmission Time



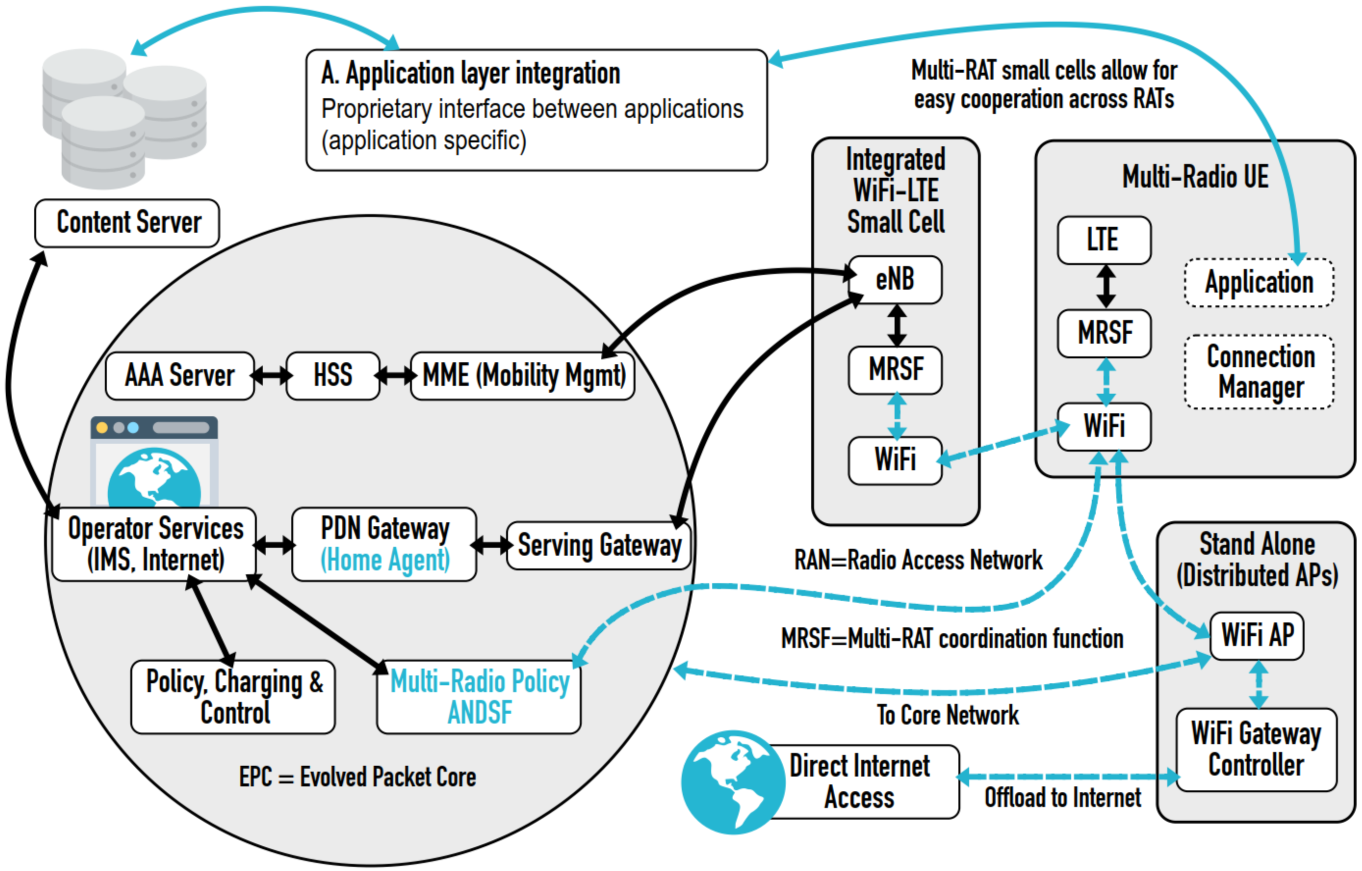
User Data Rate in Converged LTE+WiFi HetNets

More detailed assessment of the **per-user data rate** (throughput):

- Considers two control schemes, preferred RAT vs. dual RAT case
- Baseline scheme does not gain much despite ultra-densification
- Proposed scheme demonstrates consistent benefits under traffic load fluctuations and scales well

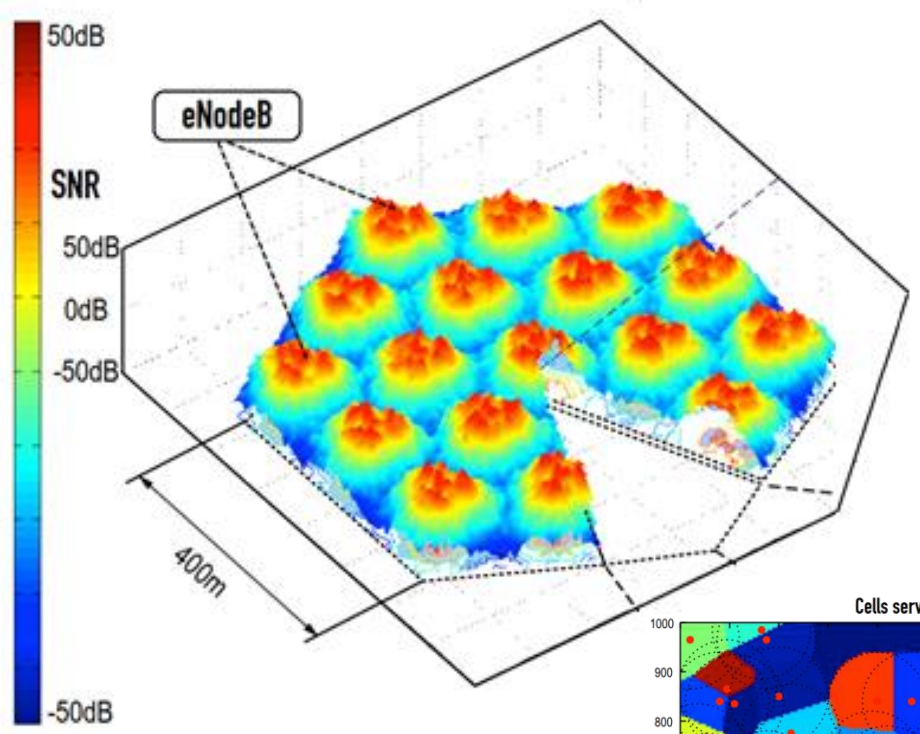


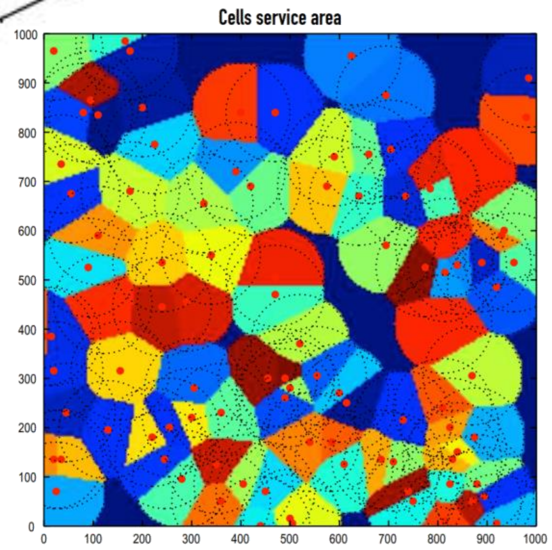
Multi-Radio Integration Options in Real HetNets



B. Core network based integration
Existing solutions: SaMOG, IFOM etc. Semi-static ANDSF based policy & resource management
Mobility anchor at P-GW

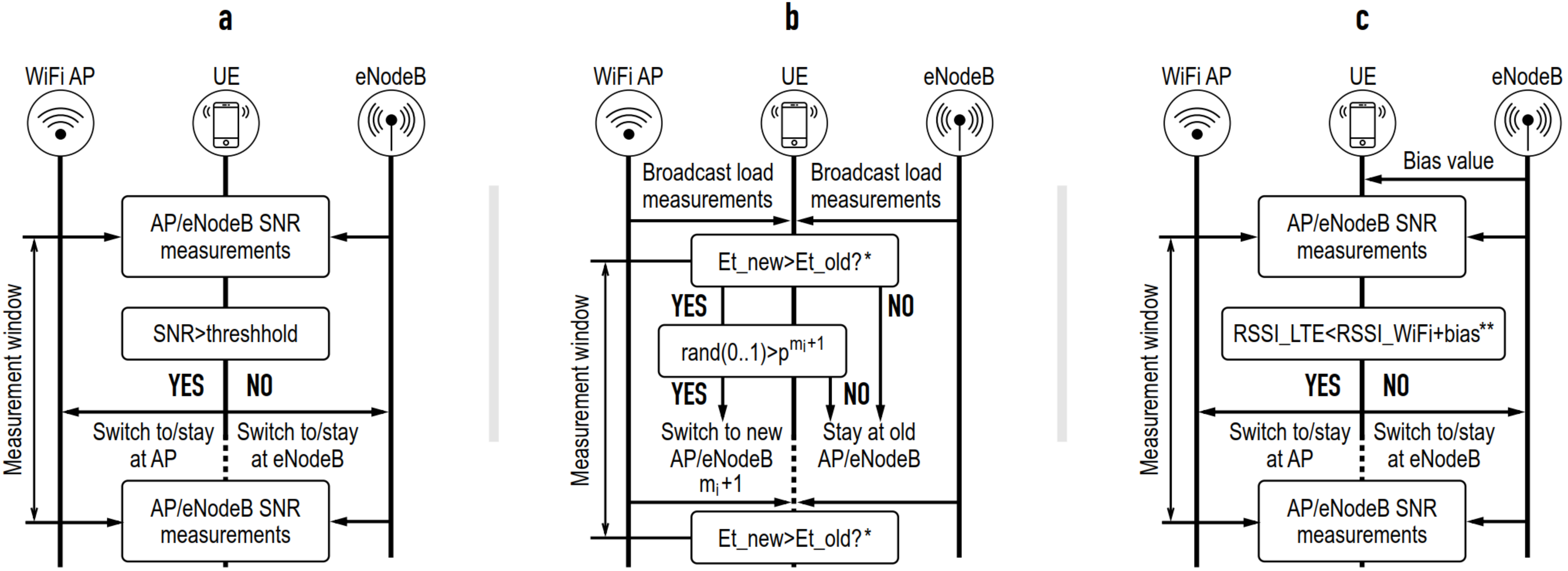
C. RAN based integration
Dynamic radio resource management trough cross-RAT cooperation in the radio network
3GPP RAN anchored mobility and control: exploit cellular link as anchor for improving handoff and reliability/QoS of WLAN link





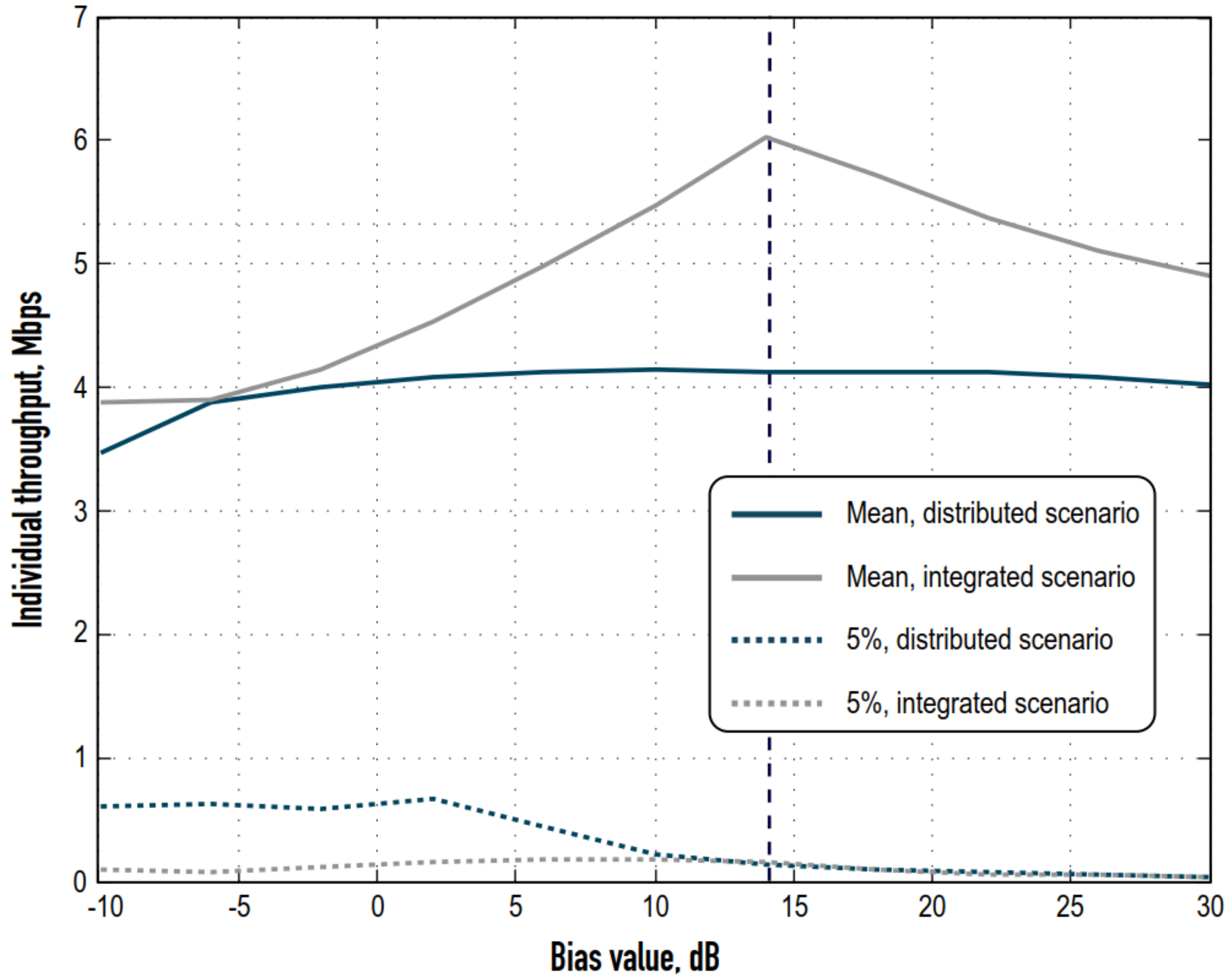
Our in-house system-level simulation software

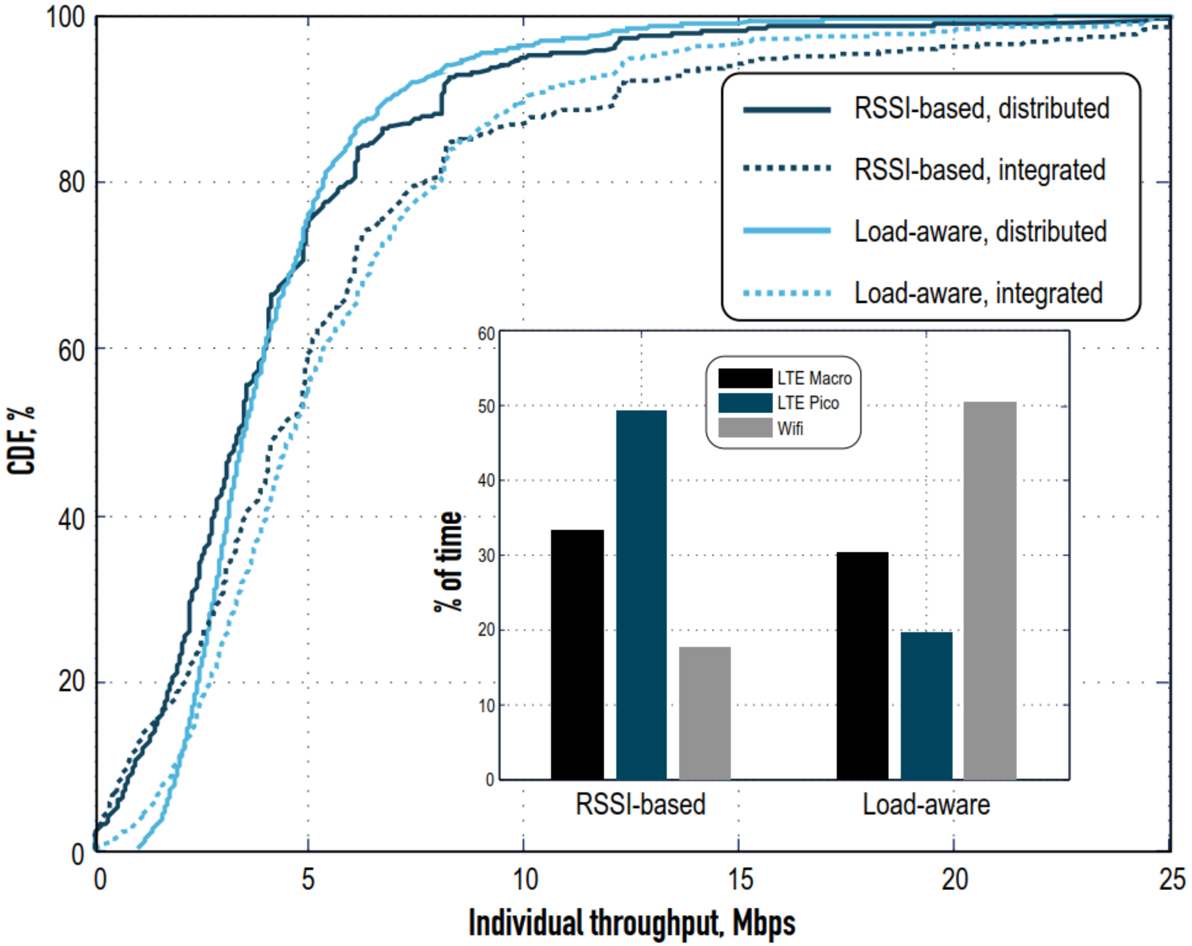
Practical Traffic Steering (Offloading) Algorithms



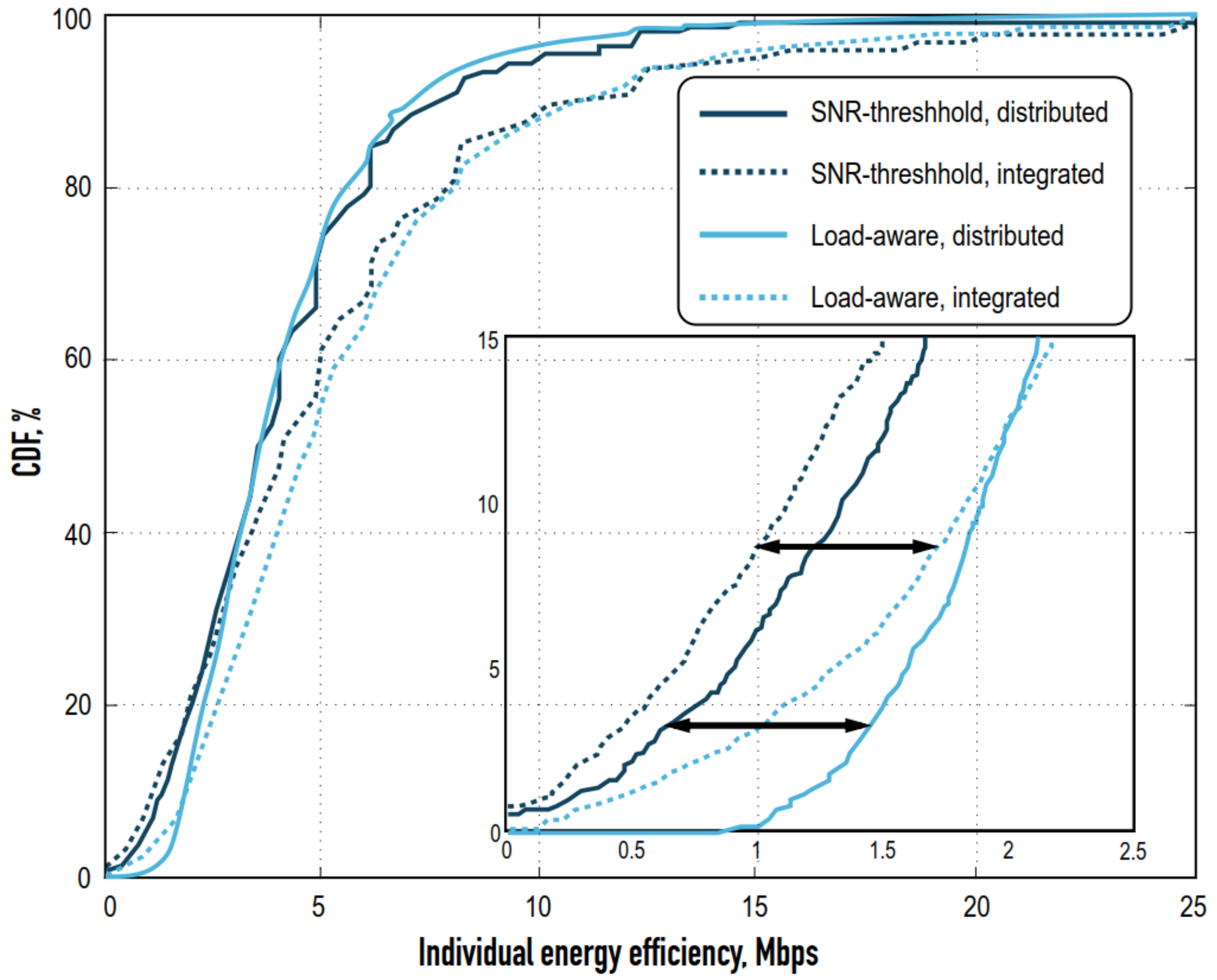
User-centric (a), RAN-assisted (b), and RAN-controlled (c) algorithms

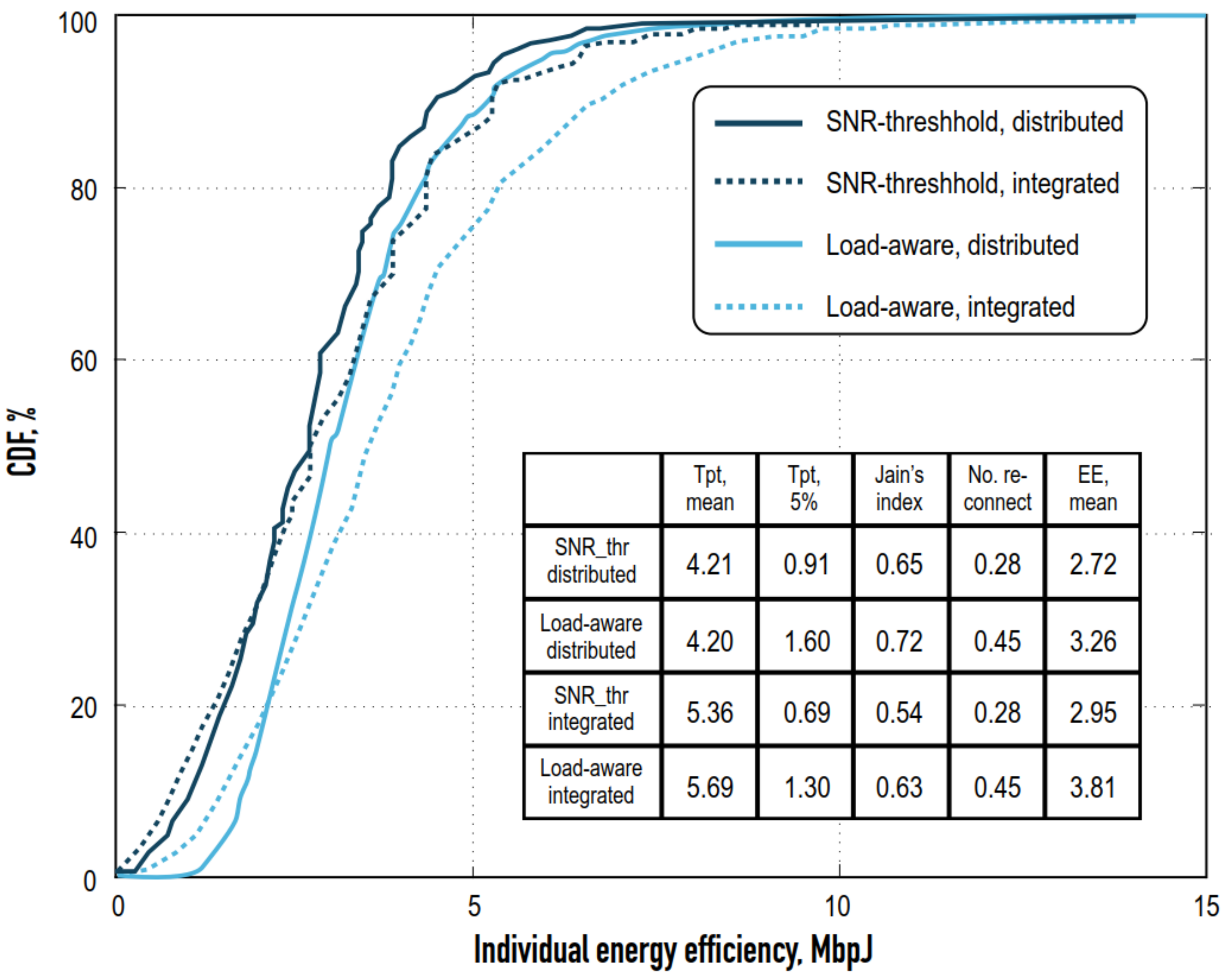
Per-User Throughput in Multi-Radio HetNets





User Energy Efficiency in Multi-Radio HetNets

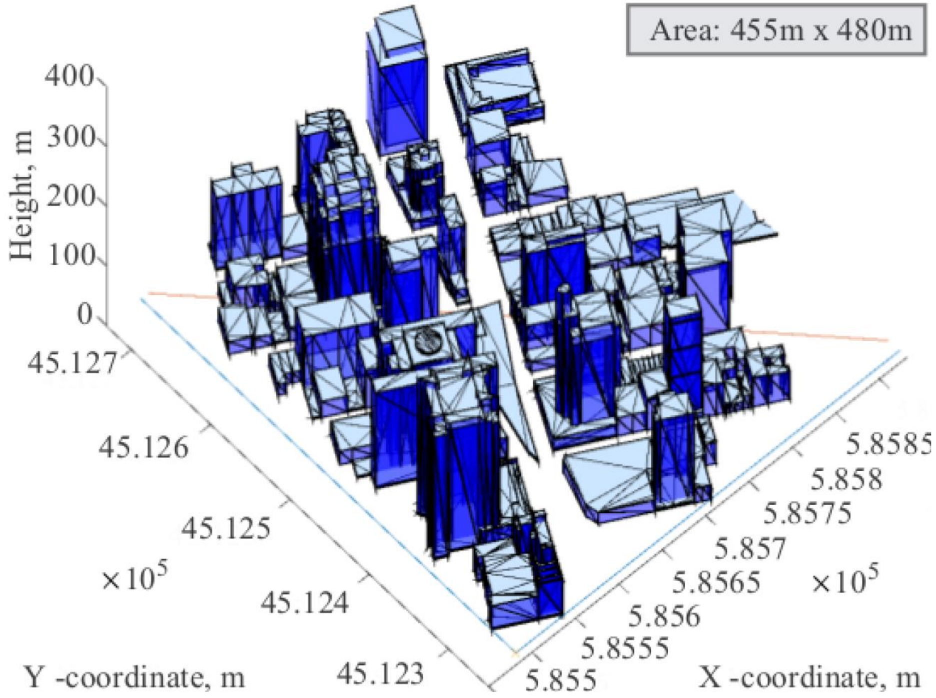


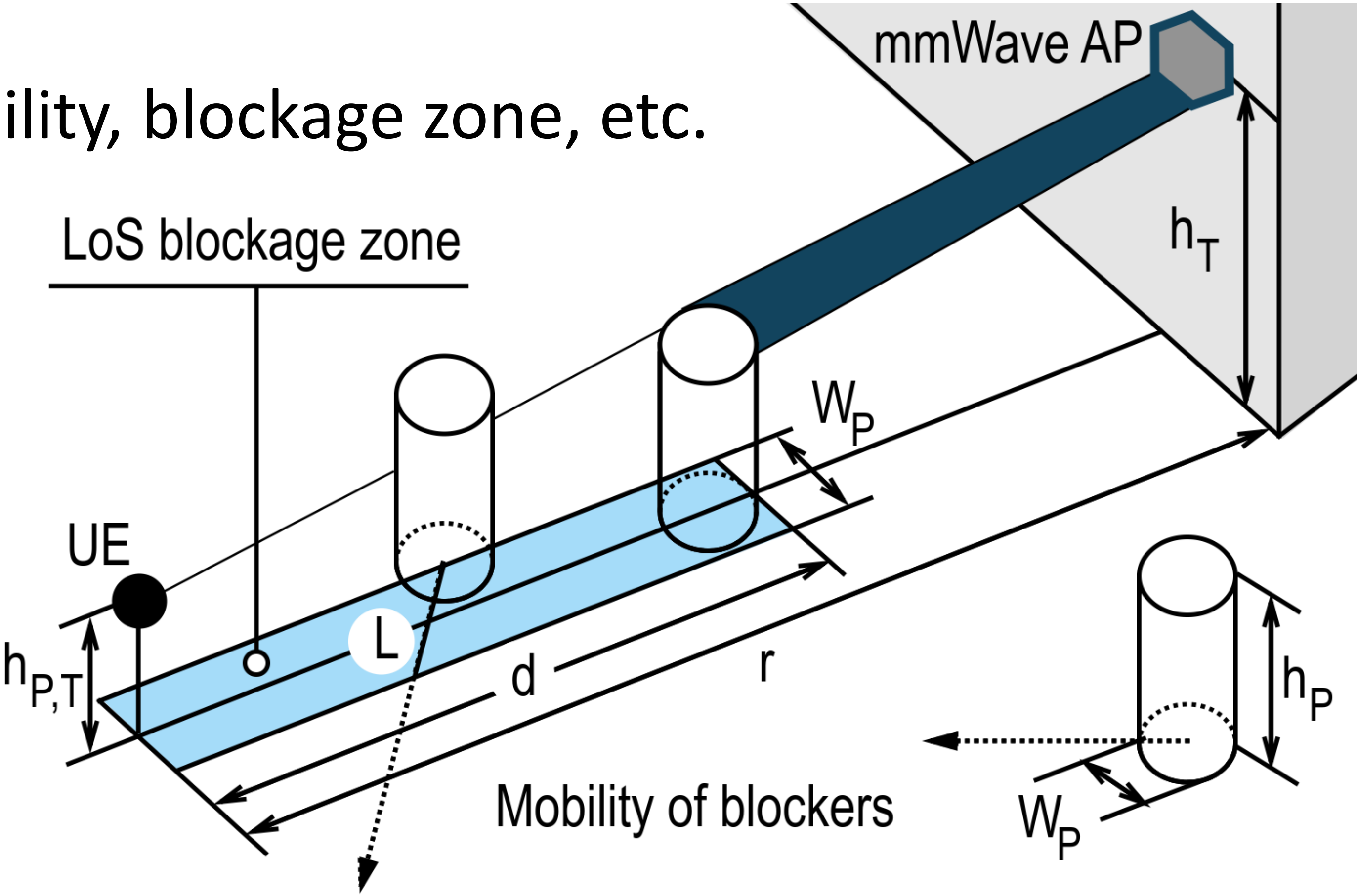


	Tpt, mean	Tpt, 5%	Jain's index	No. re-connect	EE, mean
SNR_thr distributed	4.21	0.91	0.65	0.28	2.72
Load-aware distributed	4.20	1.60	0.72	0.45	3.26
SNR_thr integrated	5.36	0.69	0.54	0.28	2.95
Load-aware integrated	5.69	1.30	0.63	0.45	3.81

New Challenges for 3GPP's New Radio

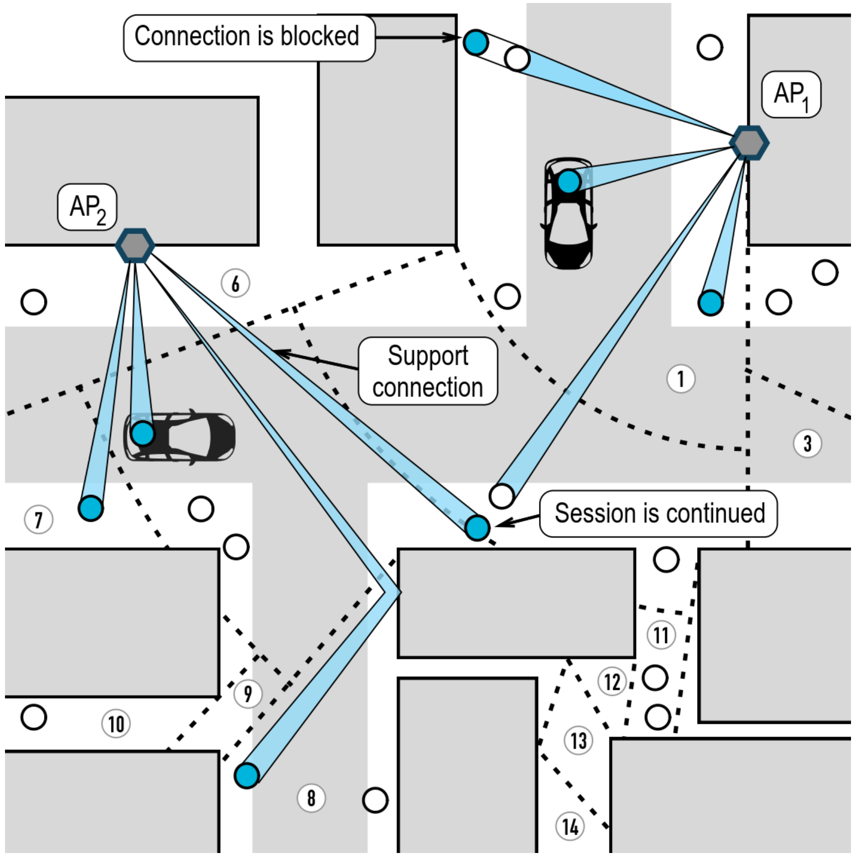
- Obstacles introduce blockage of the line-of-sight radio propagation path
  - They can large (e.g., buildings) and small (e.g., human bodies)
  - They can also be static or dynamic
- Need to introduce blockage probability, blockage zone, etc.

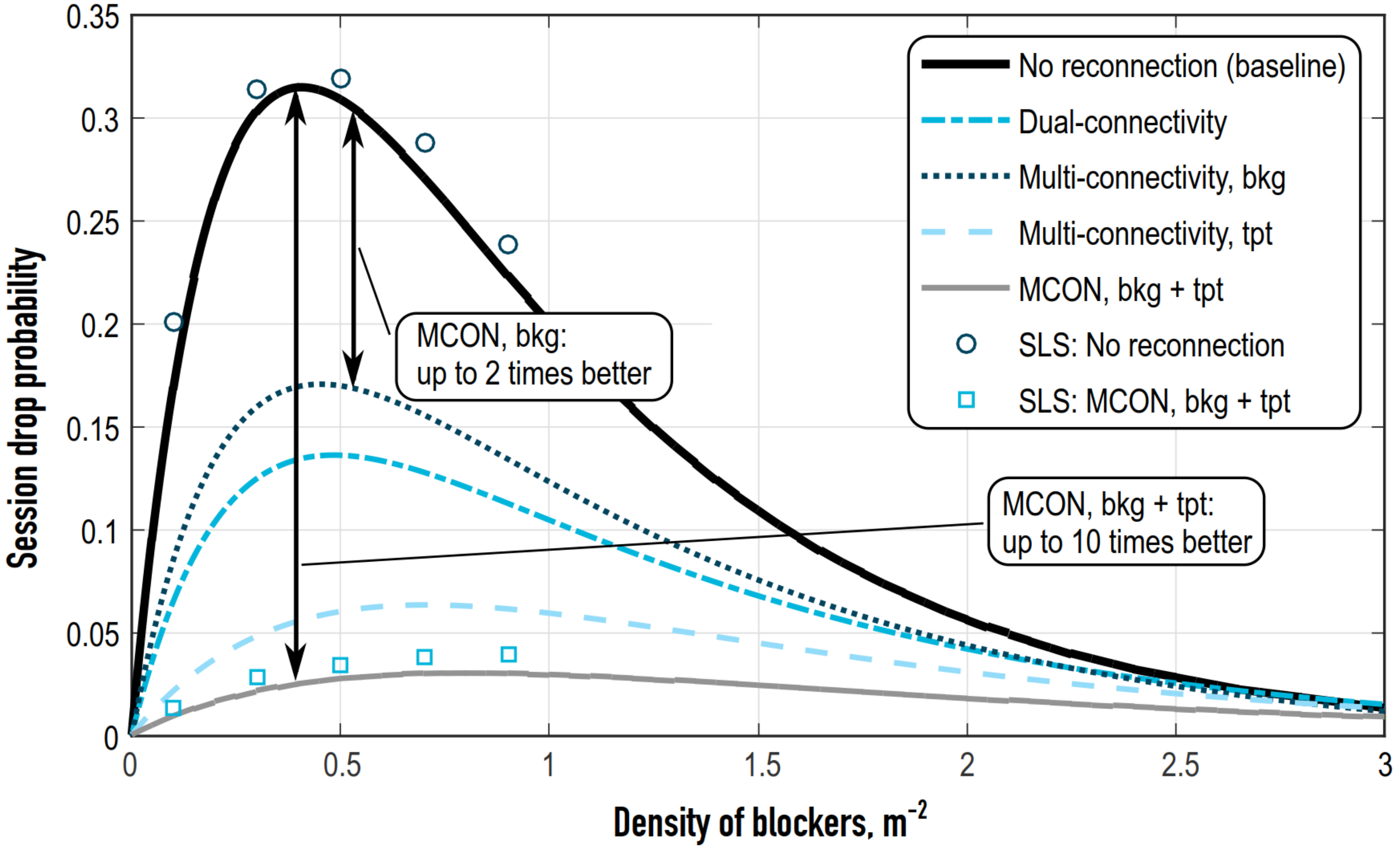




Mitigating Blockage at mmWave Frequencies

Blockage can be mitigated by connecting to several base stations **simultaneously**





Various **multi-connectivity** strategies may be coined mindful of proximity, blockage probability, etc.

Essential Outcomes and Main Conclusions

Space-time modeling of multi-tier, multi-radio heterogeneous networks:

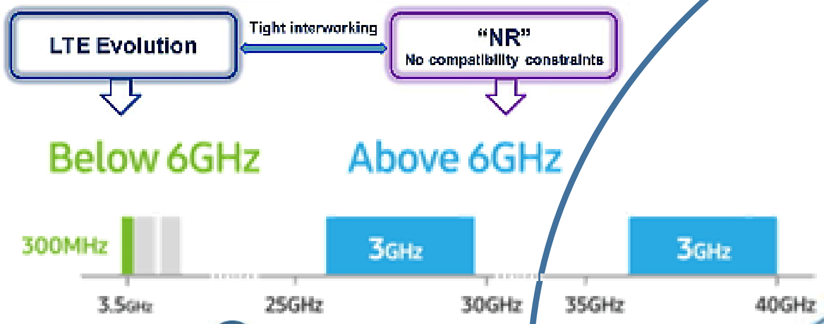
- Combines node layout geometry with uplink user traffic dynamics
- Suitable for flow-level analysis of converged ultra-dense HetNets

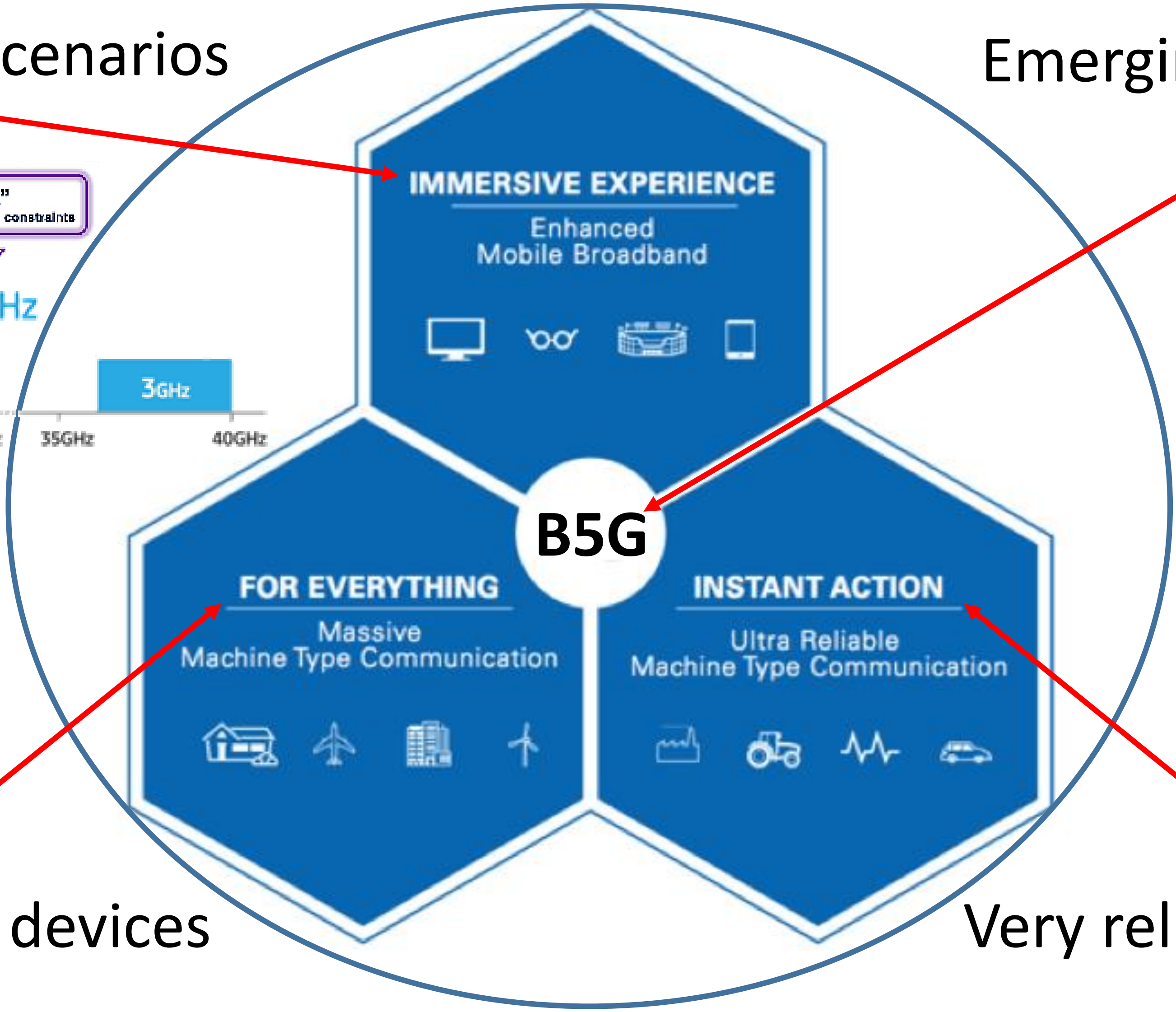
Network-assisted and network-controlled **traffic steering algorithms**:

- Leverage multiple radio access technologies for efficient offloading
- Account for practical multi-radio integration options in 5G cellular

Emerging Research Vision Beyond 5G (B5G)

High-bandwidth scenarios





Emerging area of research for **beyond 5G** case:

High-bandwidth

AND

Large numbers

AND

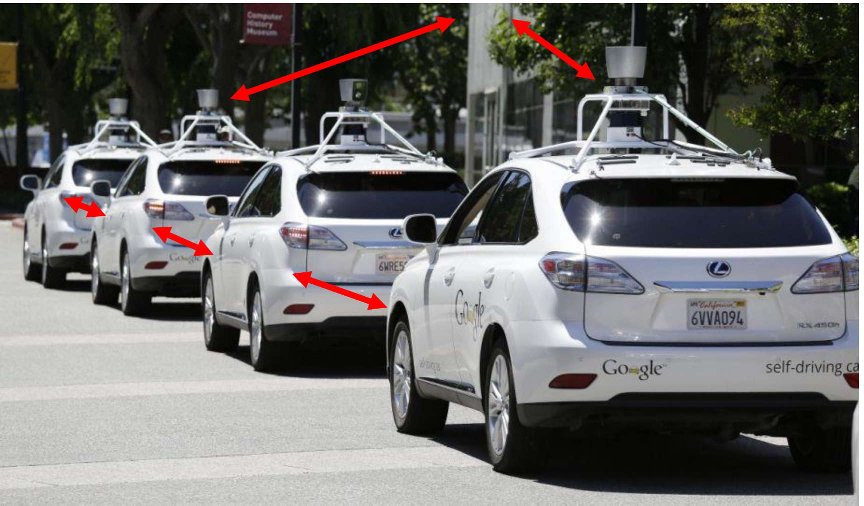
Very reliable

Large numbers of devices

Very reliable device operation

Intelligent **Connected** and **Moving** Machines

1. Massive mobile AR/VR/MR glasses



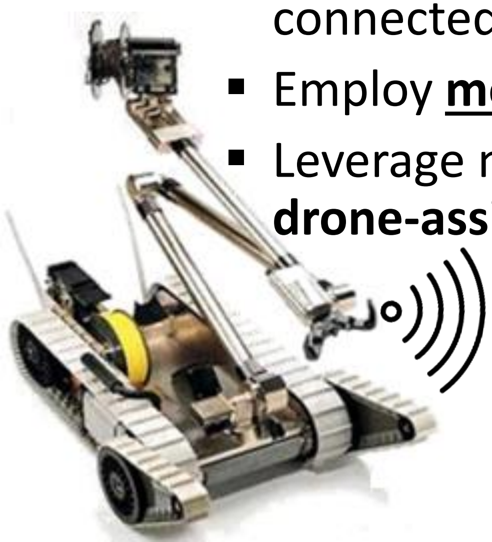
2. Very large fleets of autonomous vehicles

3. Cooperating drone swarms

4. Collaborative moving robots

Research Challenges Beyond 5G

- *Access supply* (i.e., the potential cell capacity) has been well-studied in the past but the implications of *user demand* (i.e., the actual cell traffic) **remain largely unexplored**
- Need to **rethink wireless system design** and content delivery for <u>**better matching**</u> the irregular *user demand* with the network *access supply* in (beyond-)5G systems
- Proposed solution: **dynamic and mobile network infrastructures** that intelligently leverage provisional and personal radio access equipment
  - Offer truly flexible and *on-demand* network architectures by involving operator- and user-owned connected machines without the associated high costs
  - Employ <u>**mobile**</u> **base stations** equipped with high-rate (e.g., mmWave) radio access capabilities
  - Leverage multi-radio uplink, downlink, direct device-to-device (D2D) links, as well as **vehicle- and drone-assisted access**



5G = ‘connectivity for better machines’
5G+ = ‘machines for better connectivity’

This May Happen NOW

Finland has one of the **most liberal policies** for using drones; they may be tested easily:

Unmanned Aerial Online

The largest event for the commercial UAV industry

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Finland Introduces Some of World's 'Most Liberal' UAS Regulations

Posted by Betsy Lillian on October 13, 2015 — No Comments

Categories : Policy & Regulations

Trafi, the transportation safety agency of Finland, has introduced what it says is one of the most liberal aviation regulatory systems in the world in regards to the use of unmanned aircraft systems (UAS).

The level of regulation depends on how the device is used: The requirements for model aircraft used for recreational purposes are significantly lighter than those for UAS used professionally. On the other hand, professional operators may legally carry out such tasks that are not allowed for recreational flyers.

Truly emerging human-aware technology for the benefit of people and the environment

Ericsson and China Mobile conduct world's first 5G drone prototype field trial

Up next — What is 5G? — Autoplay

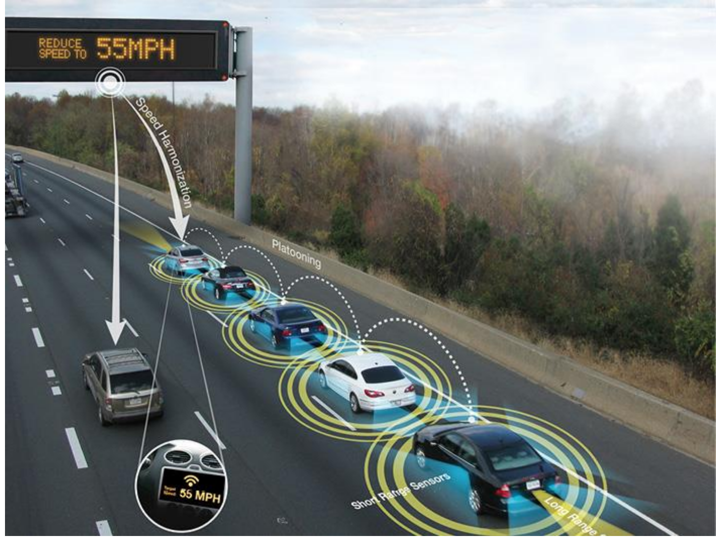
A **dramatic departure** from conventional cellular system design that for past **40 years** relied on *static* and rigid radio access infrastructures!

Wi-Fi on Wheels drives coverage anywhere

2016-05-16 Categories: Industry Technology

At Ericsson we're used to rolling out industry-leading innovation – and this time we're taking it literally.

Expected Impact: TIME TO ACT!



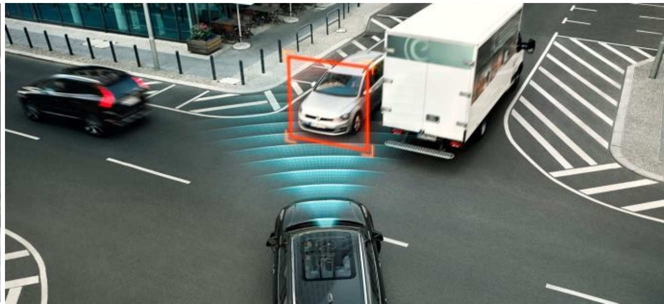
- <u>Breakthrough goal</u>: **reliable people-aware connectivity** where space-time supply and demand may be shaped *opportunistically*
- User-owned machines (high-end wearables, cars, drones, etc.) take a more active role in **5G+ service provisioning** (especially in *partial coverage* situations)
  - Functional disparity between the network and the user equipment is rapidly becoming blurred
- <u>Theoretical benefits</u>: orders of magnitude better **network capacity scaling**
  - Number of base stations: ***K***
  - Min number of antennas: *n*
  - Available bandwidth: *W*

Network capacity ≈ $\boldsymbol{K} \times n \times W \times \log(\mathrm{SNR})$

Fundamental improvement!

- <u>Practical benefits</u>: clearly noticeable more stable and smoother **user connectivity experience**
- This research accentuates the **importance of people** as an integral component of beyond-5G system infrastructure with multiple impacts in *industry*, *education*, and *community outreach*



A Vision Whose Day Has Come:
dynamic network infrastructure and tight user involvement