4° Congreso internacional del espectro
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Intelligent connectivity enablers for converged heterogeneous 5G-IoT ecosystem

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Major Challenges of Today

- **Increased** mobile data **traffic**, some say 1000x and beyond
- Growth in **connected devices**, up to 50 billion devices
- Diverse **requirements** and **characteristics**

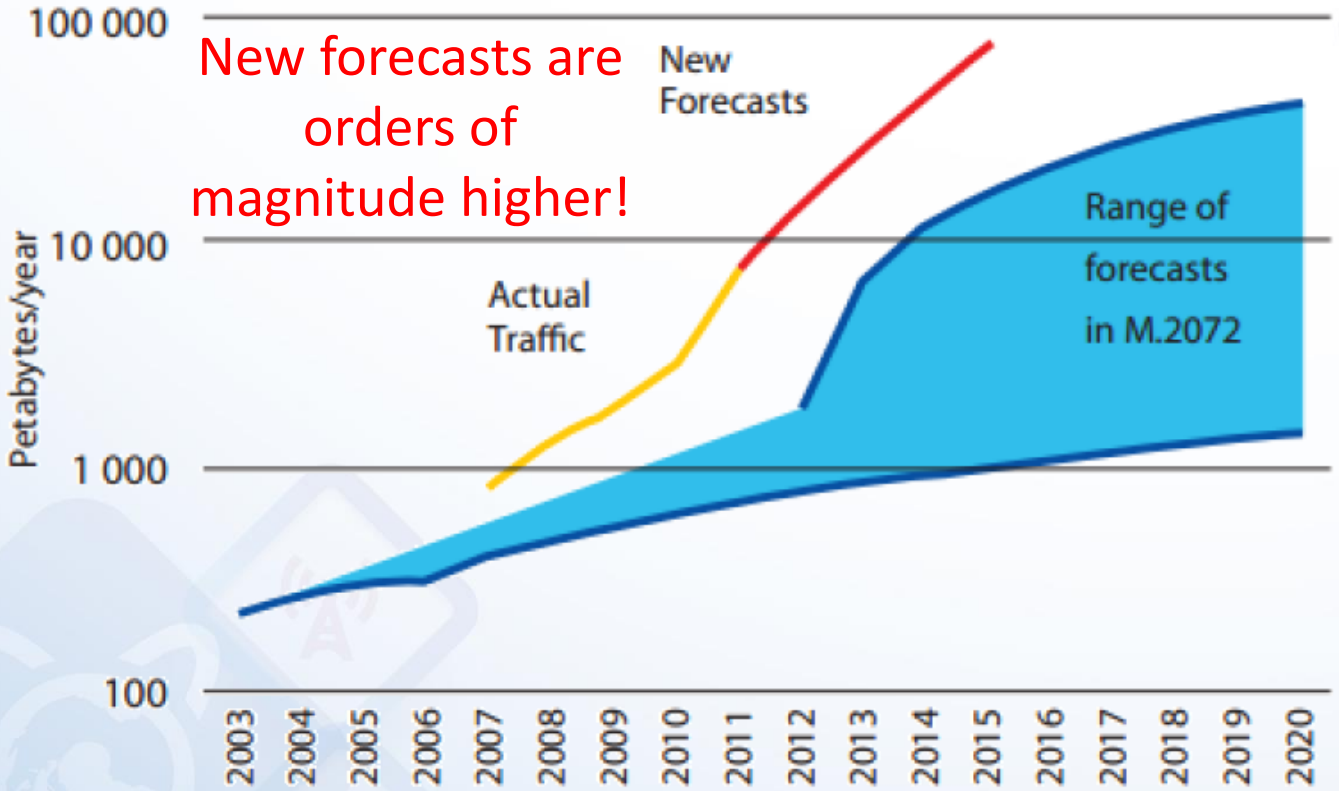
Current mobile networks are likely to face **capacity crunch**

Attention shifts to

what comes **beyond 4G**

(Fifth Generation!)

Wireless Data Traffic



Source: Report ITU-R M.2243

What is on the HORIZON 2020

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

- Given a 10-year cycle for every existing generation, we expect 5G systems sometime **around 2020**
- Whereas there is currently **no** complete definition, 5G may already be understood from the **user** perspective

Human users would like to be **connected at all times**

- regardless of their current **location**
- take advantage of **services** provided

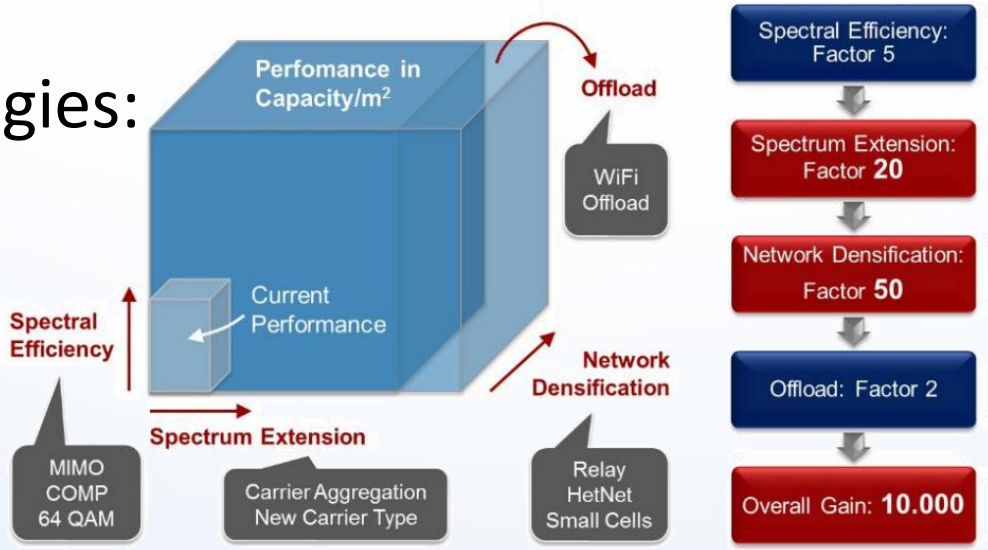
by multimedia-over-wireless networks

A Glimpse of Tomorrow

Main challenge: user's **connectivity experience should** match service rate requirements and **be uniform**

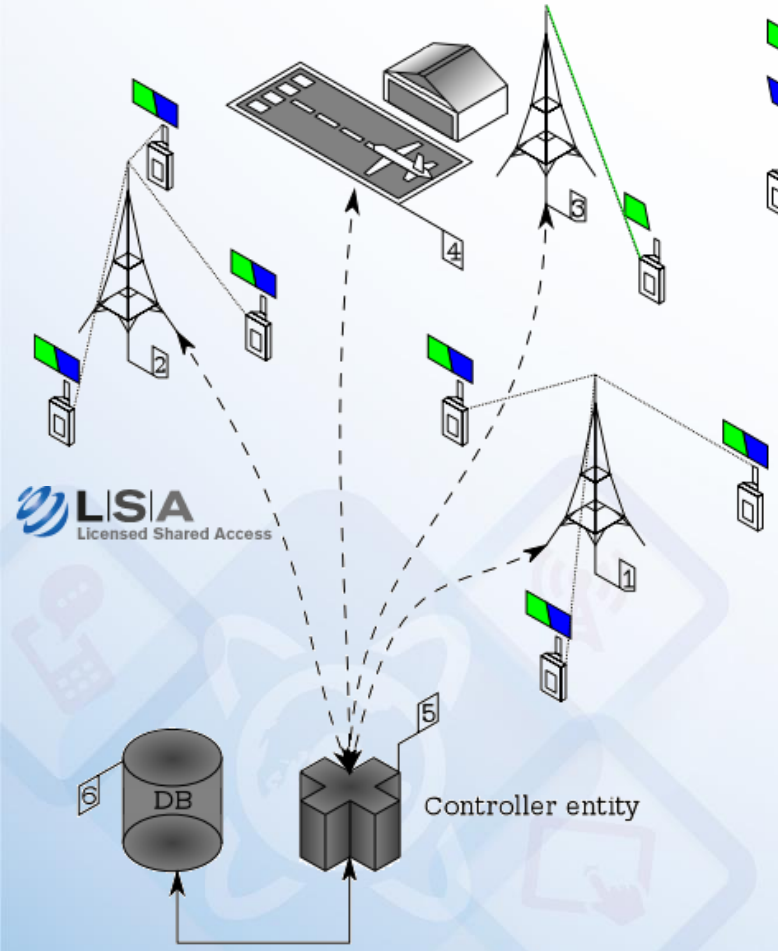
The "Big Three" 5G Technologies:

- ultra-densification
- mmWave radios
- massive MIMO



Source: Intel @ Globecom 2014

Re-Purposing Wireless Spectrum



LSA = Licensed Shared Access

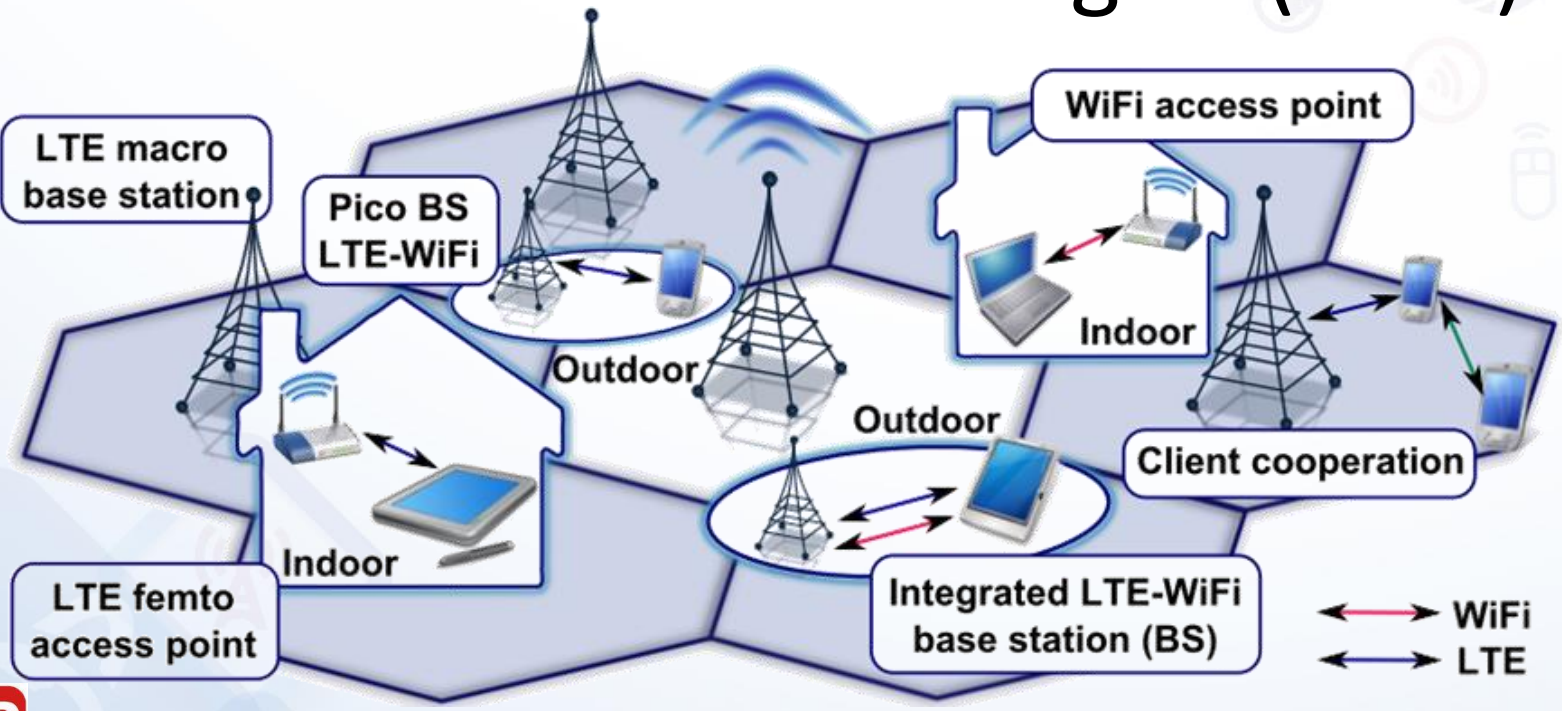
An emerging concept

for spectrum sharing under

an **exclusive** license regime

Intelligent Use of Multiple Radio Access Technologies (RATs)

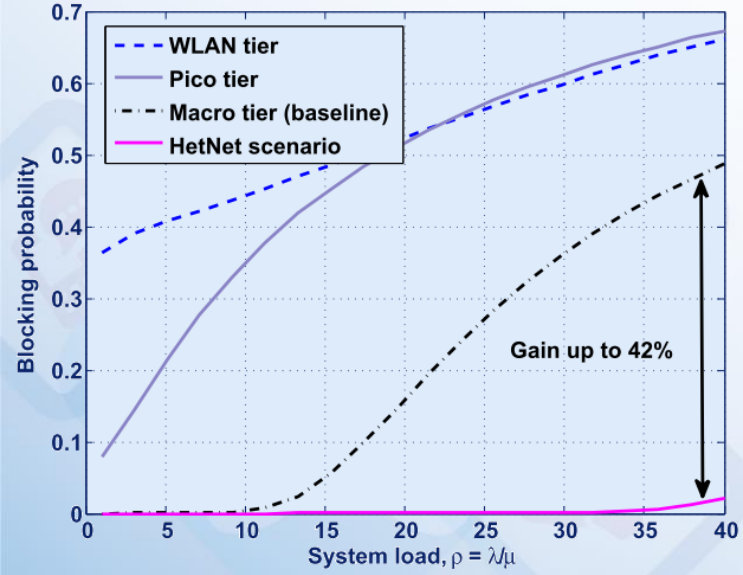
HetNet
=
multi-tier
+
multi-RAT

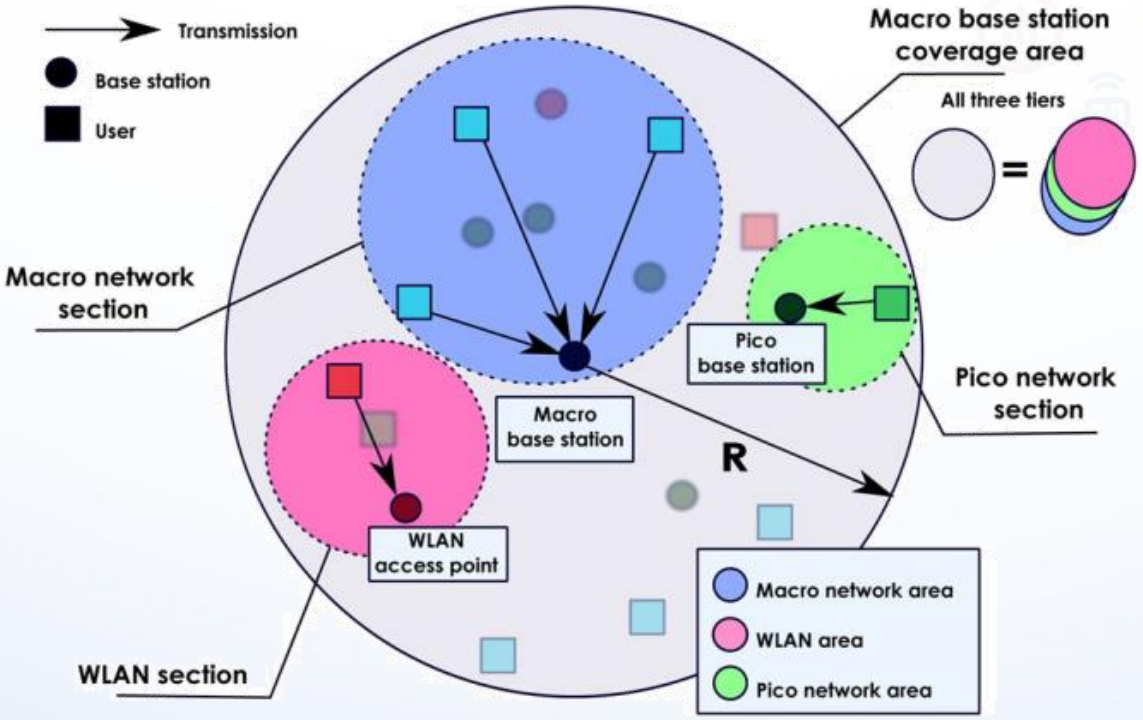


Licensed spectrum continues to be **scarce and expensive**

Radio Access Network (RAN) Selection

The incentive to efficiently **coordinate** between the **alternative** *radio access technologies* is growing stronger

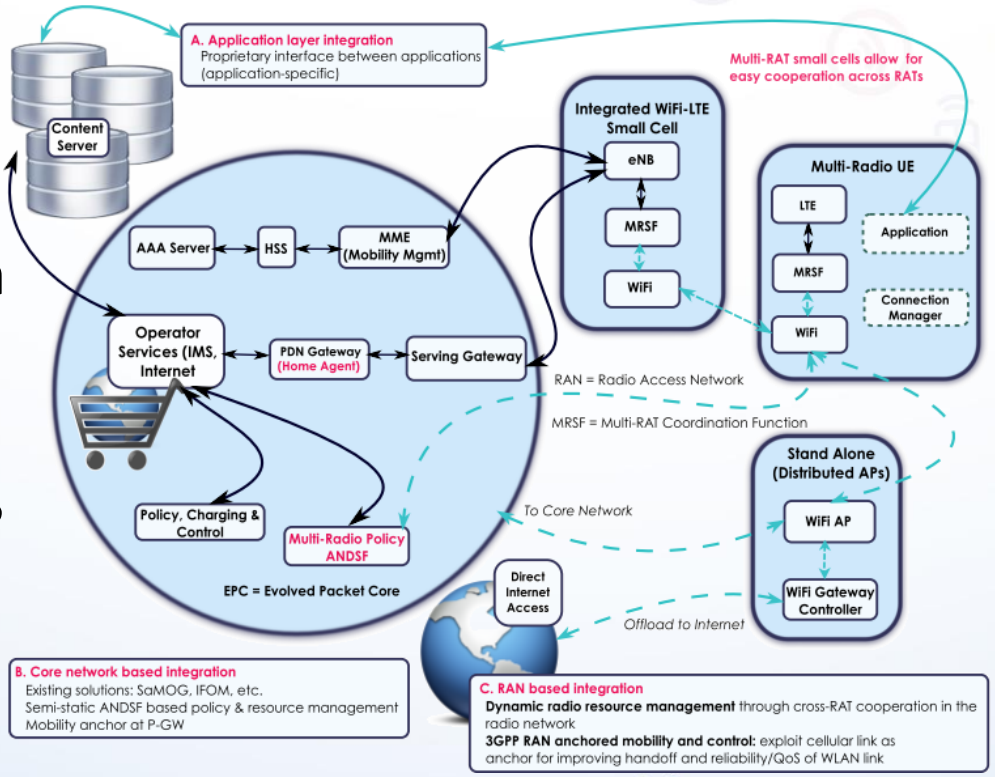




3GPP/WLAN Integration Options

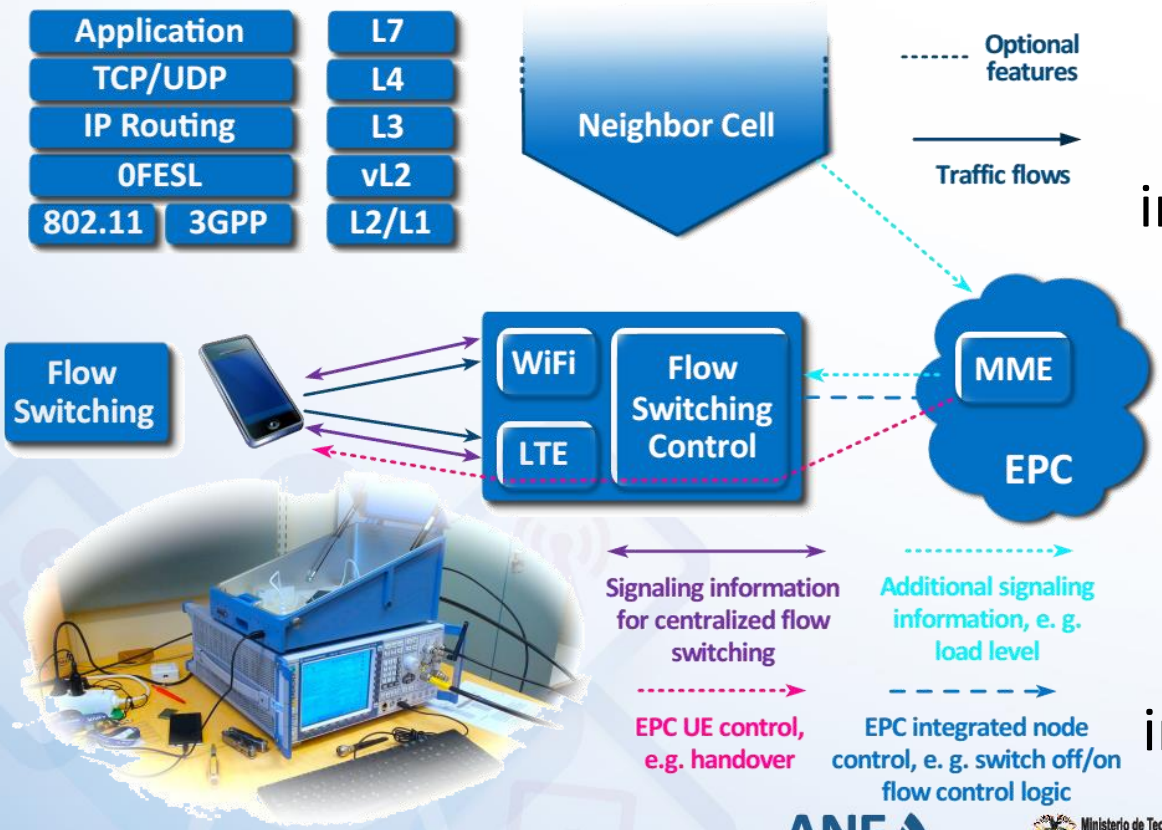
WLAN becomes an **integral part** of wireless landscape

- **Application** layer integration
- **Core network** based integration (e.g., ANDSF): LTE Release 11
- **RAN** based integration: LTE Release 12, contd. in Release 13



Friends or Foes ?

Proof-of-Concept Demonstration

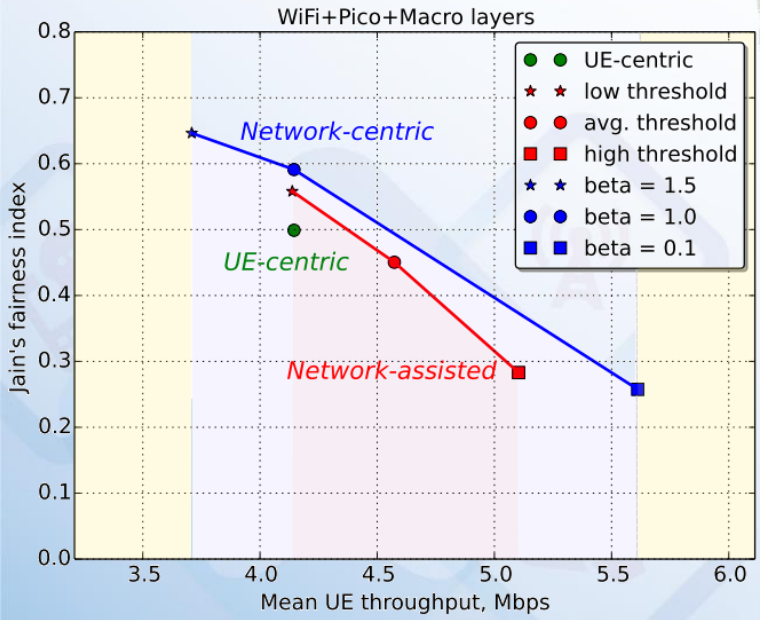


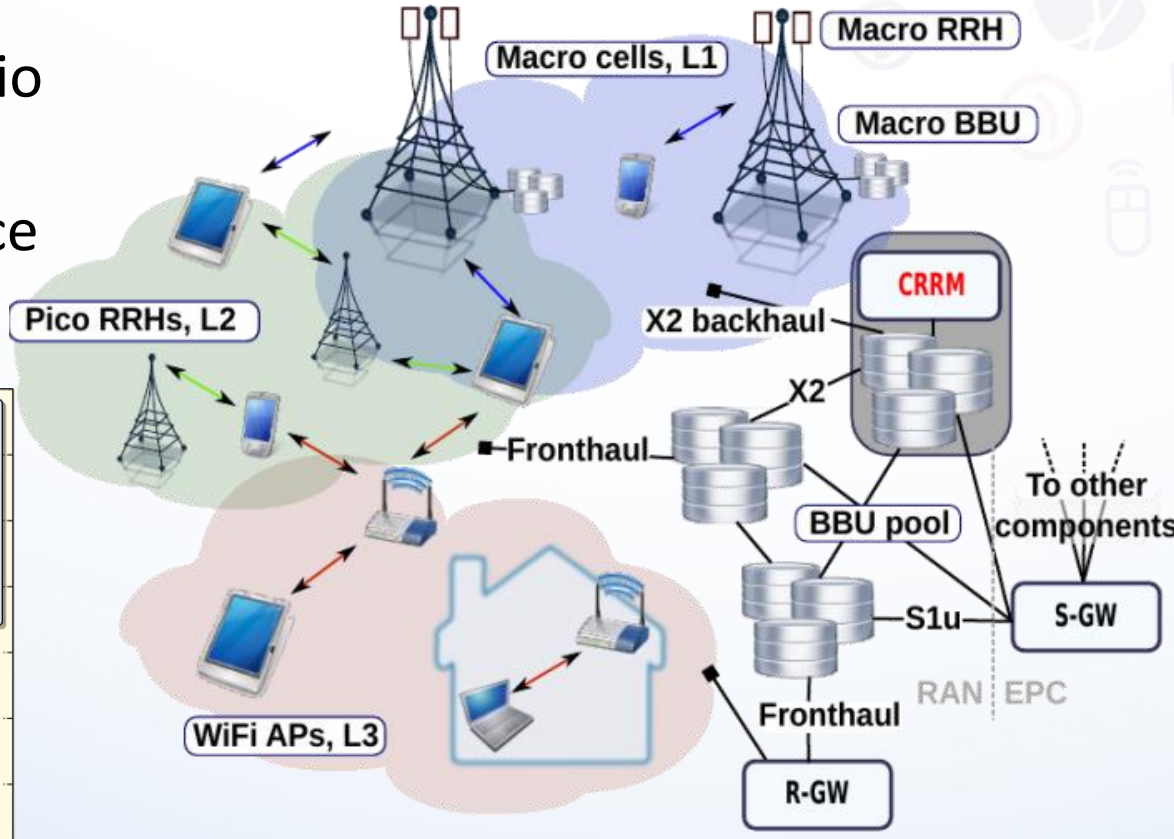
RAN-assisted link selection creates significant improvement in **mobile user experience** by enabling dynamic traffic-aware transmission

An important extension is **link aggregation** for integrated WLAN/3GPP cells

Coordinated Radio Resource Management

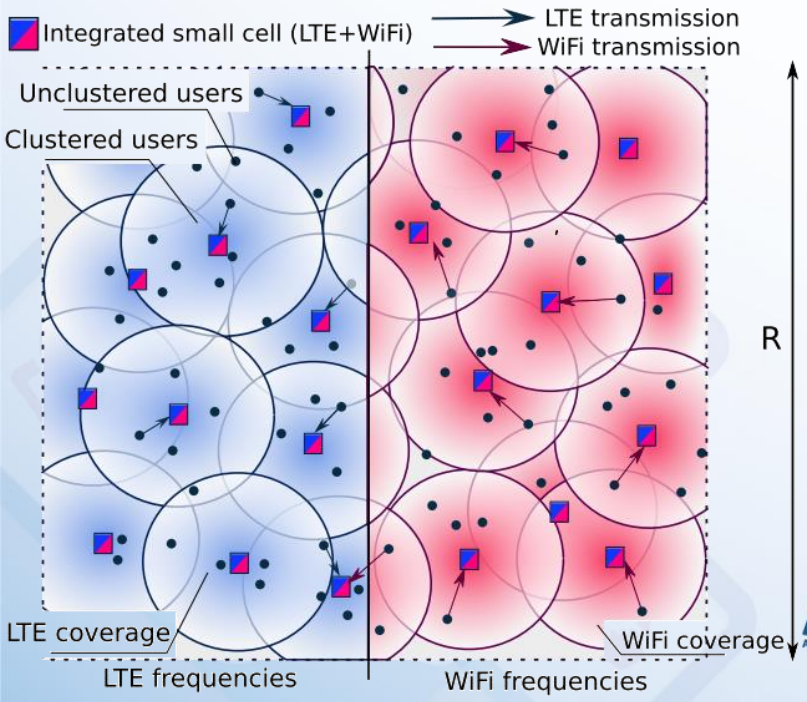
Heterogeneous cloud radio access networks *enable* **cooperative** radio resource management

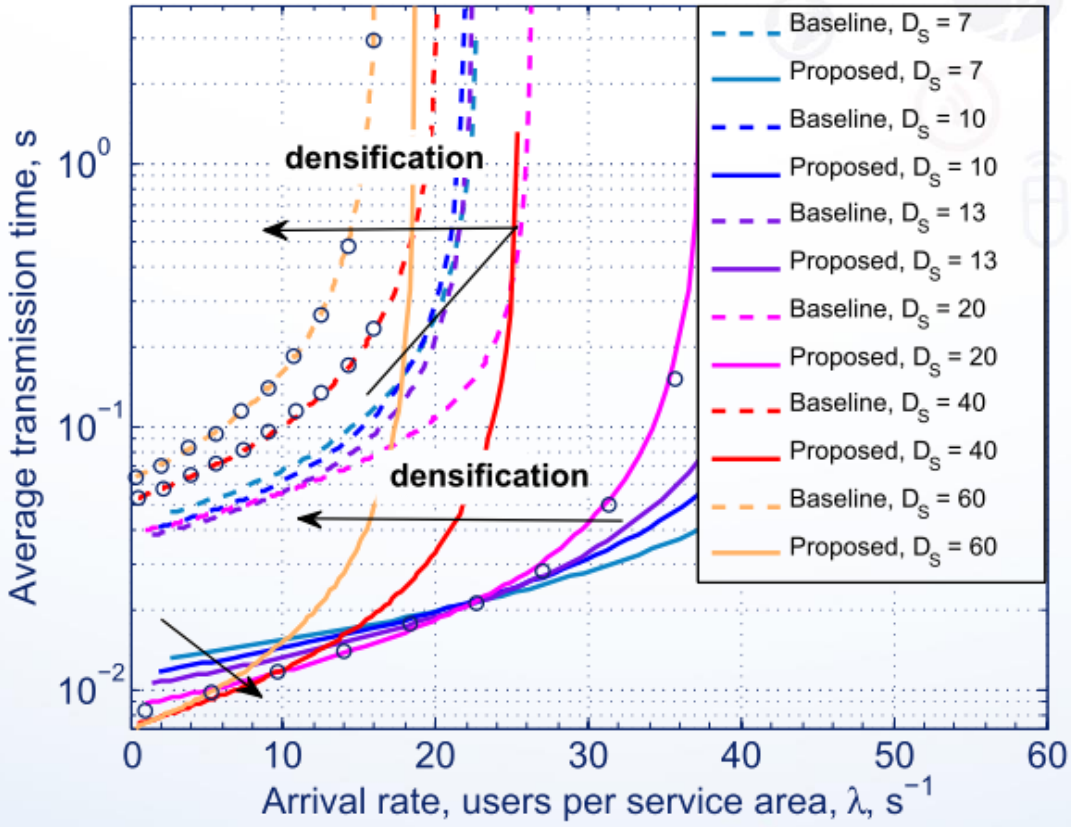




Towards Extreme Network Densification

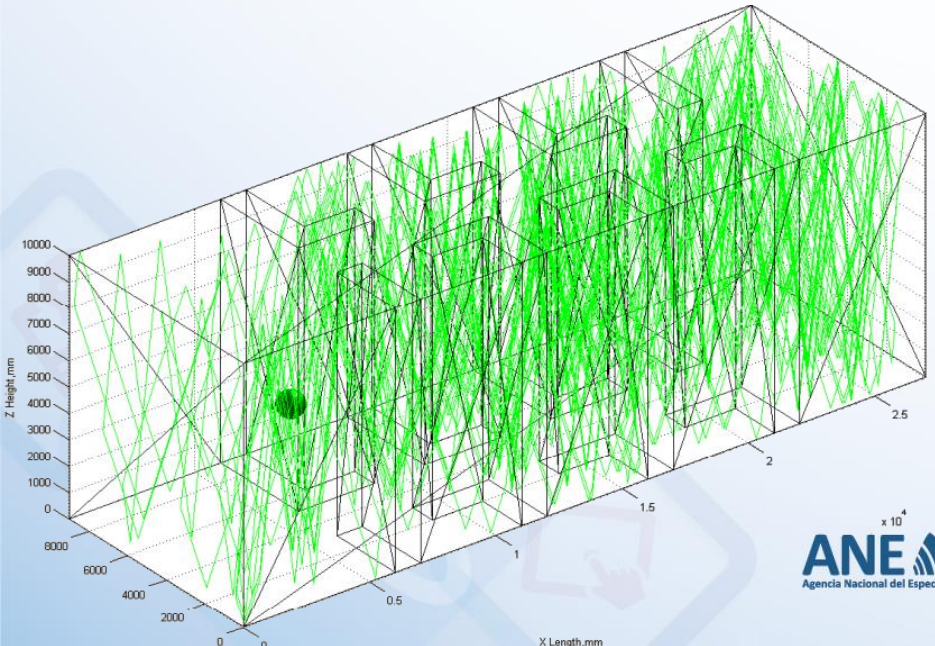
Integrated ultra-dense HetNet is an **unprecedented** paradigm shift

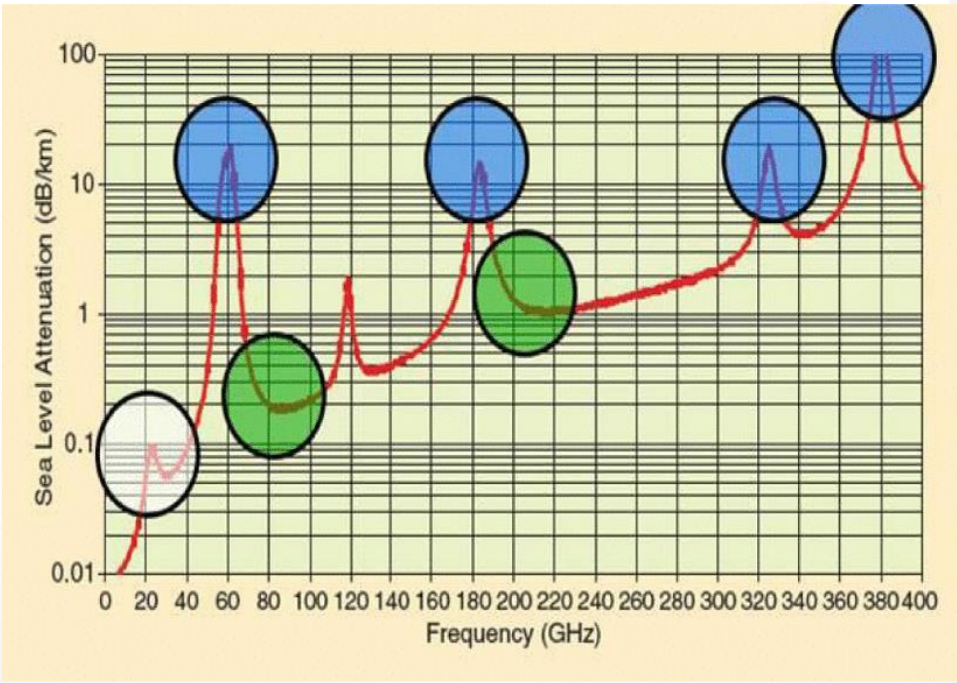




Harnessing Very High Frequencies

mmWave spectrum should be 10–100 × **cheaper per Hz** than the 3G and 4G spectrum below 3 GHz

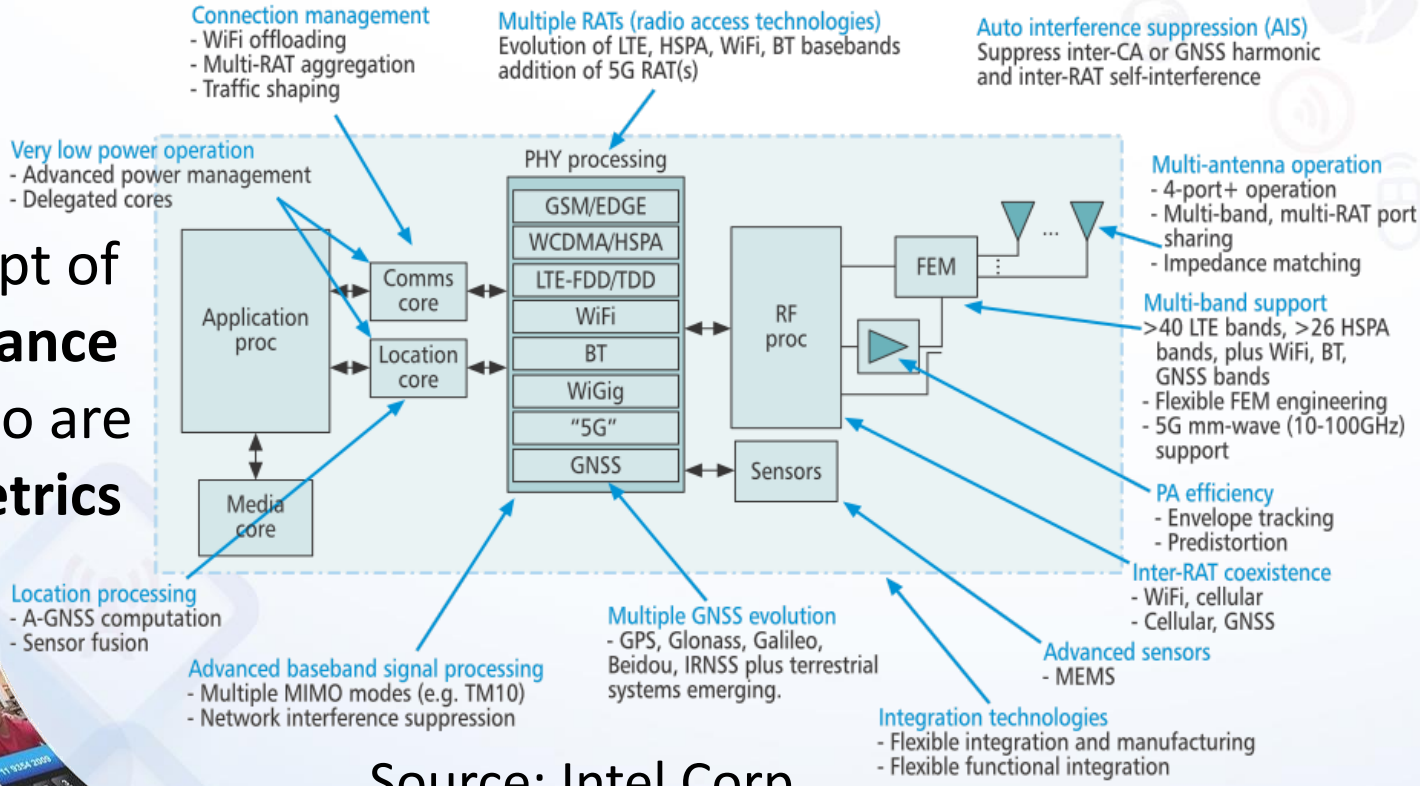




Source: NYU-Poly

Capable Mobile Devices

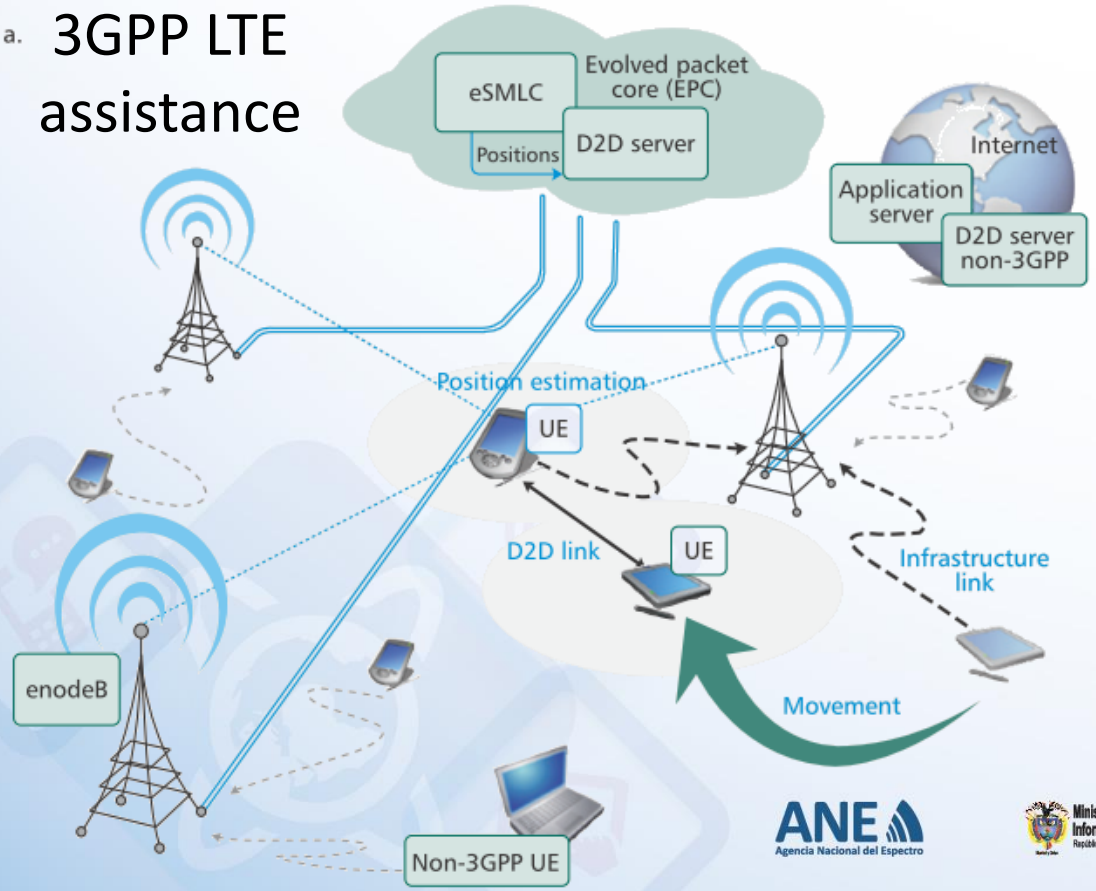
Industry's concept of **mobile performance** is evolving, and so are performance **metrics**



Source: Intel Corp.

Device-to-Device (D2D) Communications

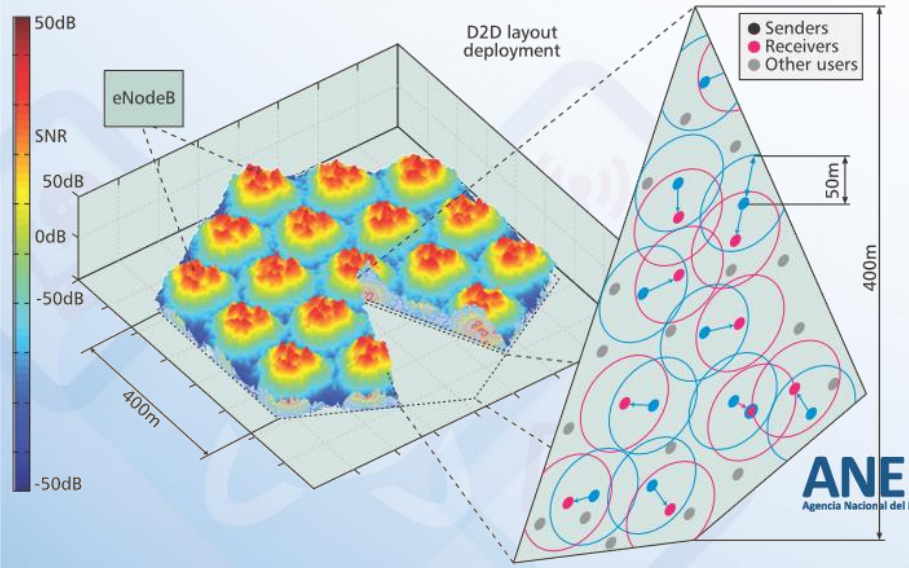
a. 3GPP LTE assistance

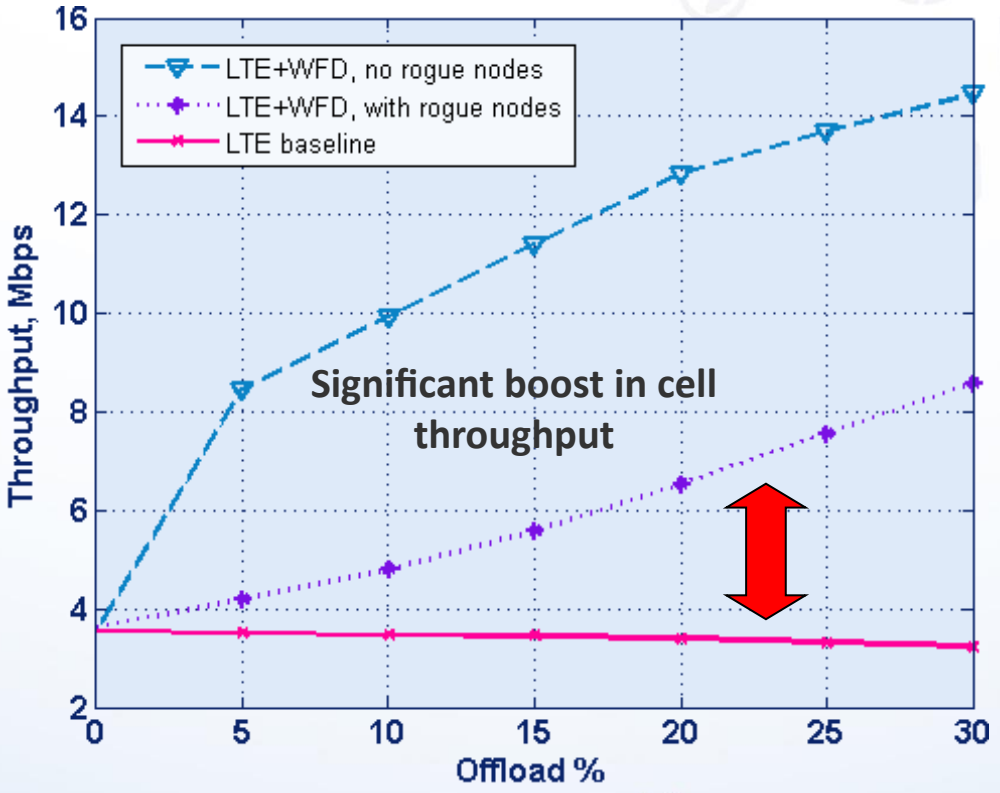


Significant operator and end user **benefits** by enabling a new generation of **proximity services**

LTE-Assisted WiFi-Direct

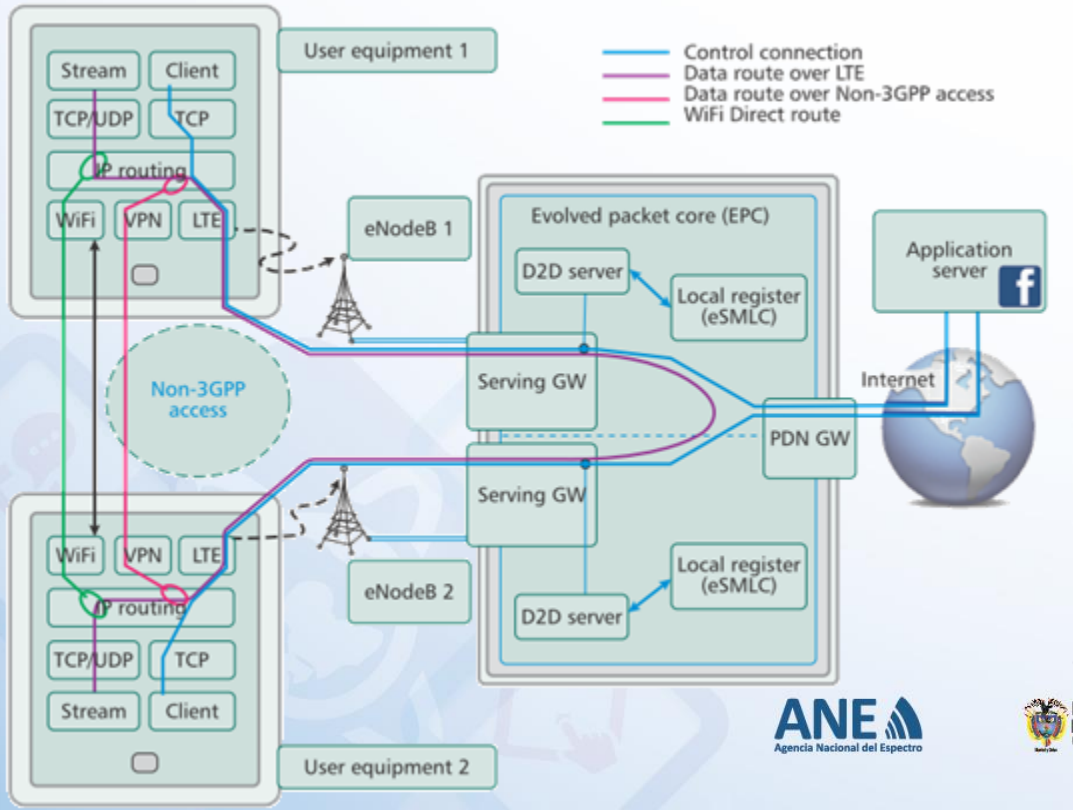
Improved D2D **connection** establishment, battery efficiency, and **service** continuity on the system-wide scale





Production-Ready D2D Prototype

Automated, continuous, and efficient **assistance** with secure discovery of devices & services



Devices **receive help** from the network during device discovery and D2D connection establishment

Test 3GPP LTE deployment:

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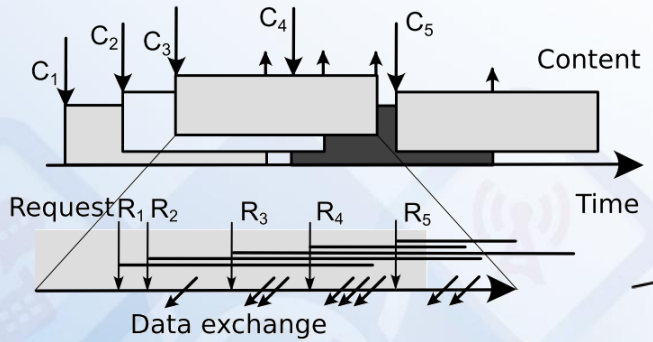
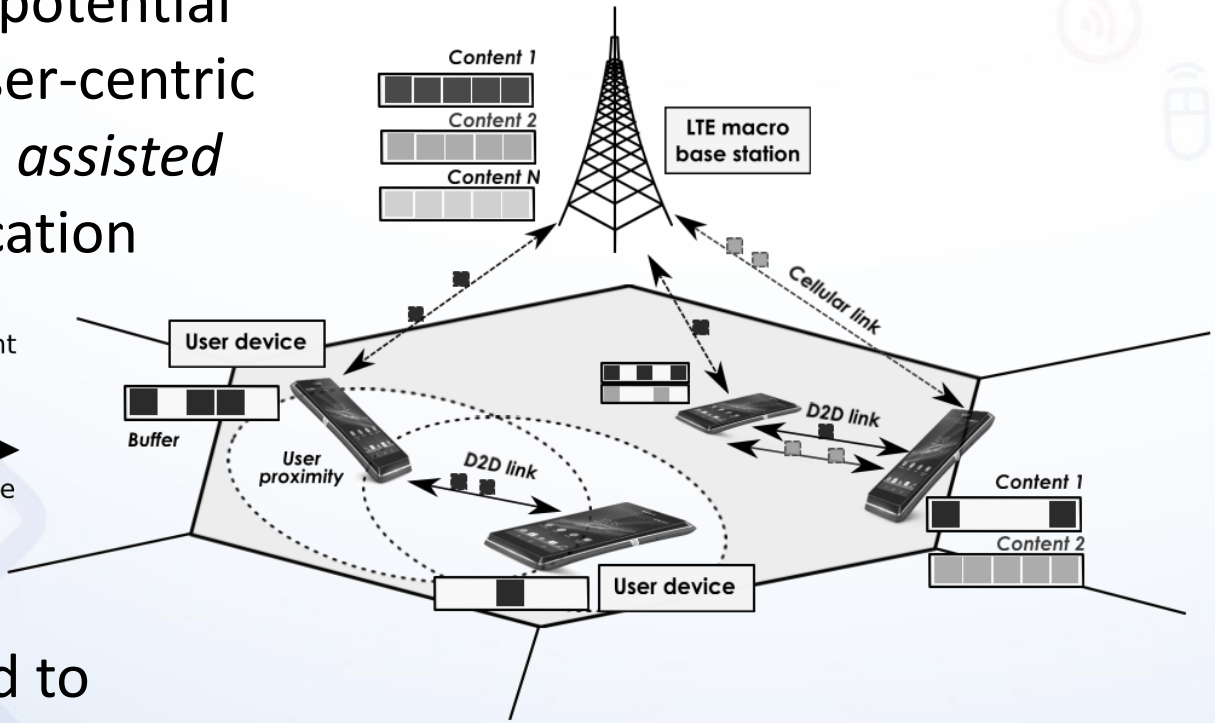
D2D-based Coding and Caching

Need to understand the potential of **network coding** and user-centric **data caching** to upgrade *assisted* proximate communication

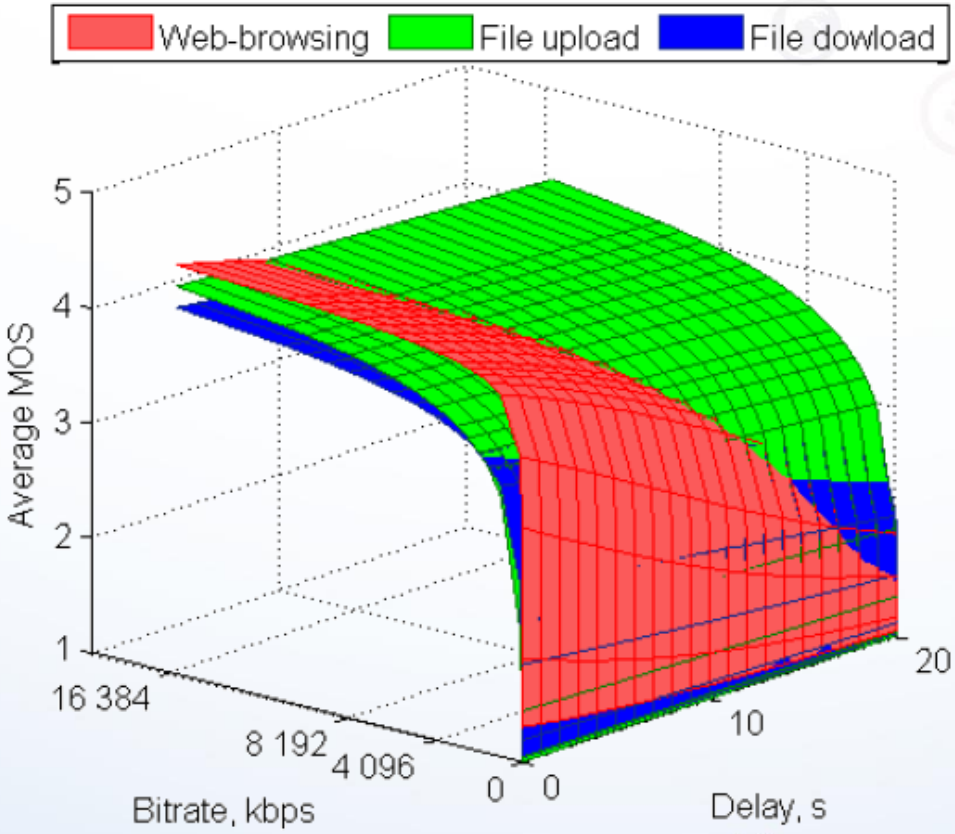


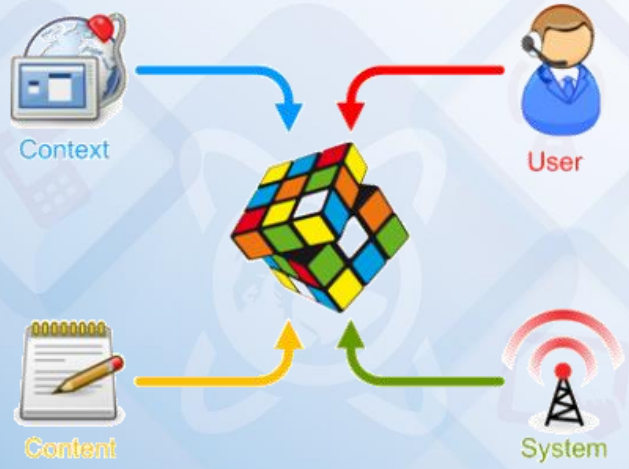


New models are required to investigate **dynamic mobile content** behavior

Mobile User QoS/QoE Estimation

There is a growing demand for **adequate QoE estimation** models accounting for dominant mobile data services (HTTP, YouTube, etc.)

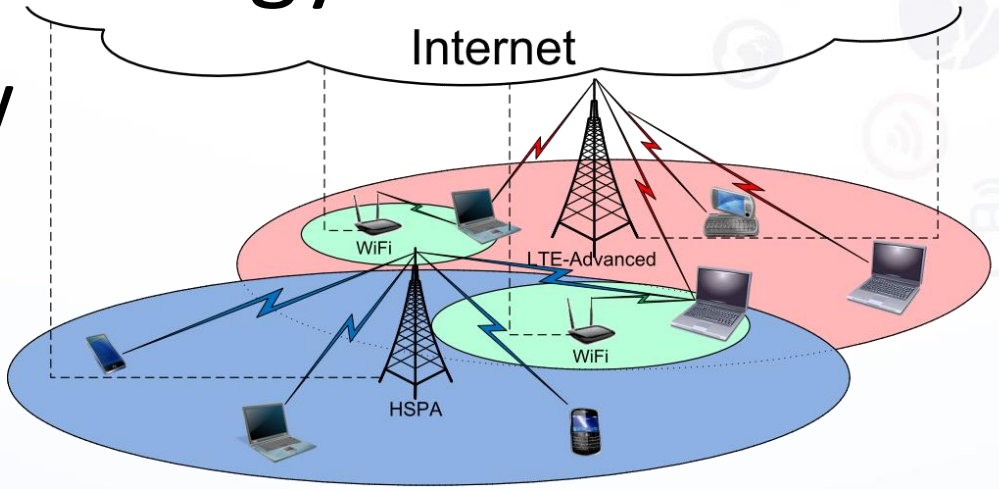


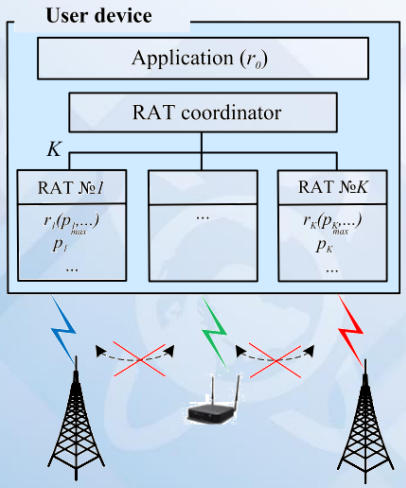


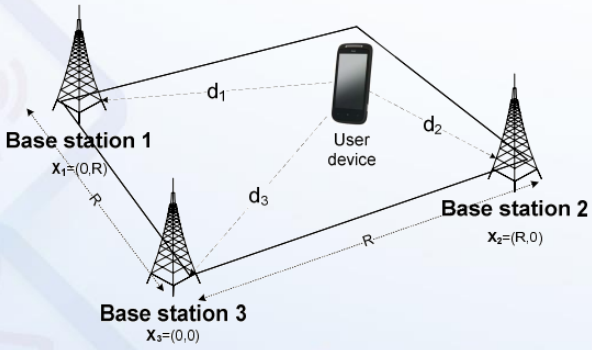
Multi-Radio Energy Awareness

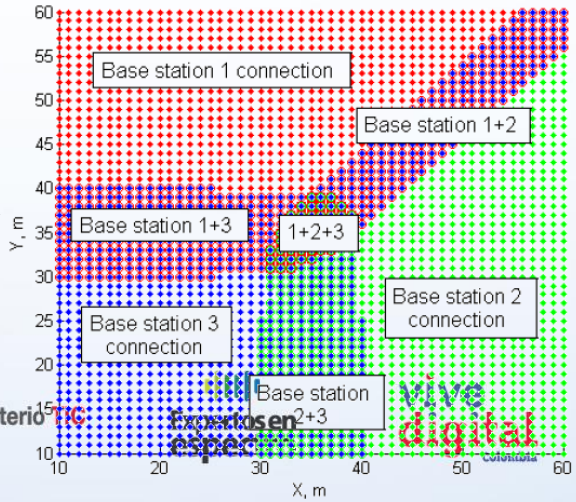
Concentrate attention on **energy efficiency** of a mobile device:

- Optimize Tx power per radio
- Recommend when each RAT should be used

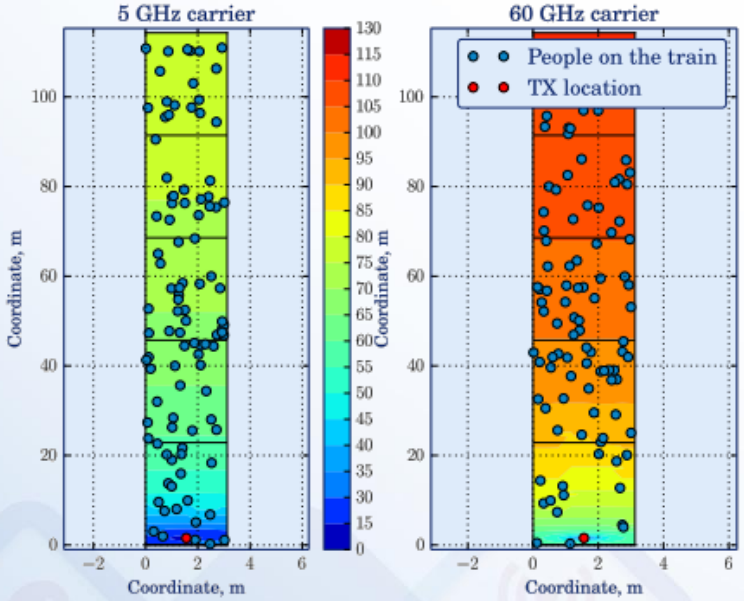




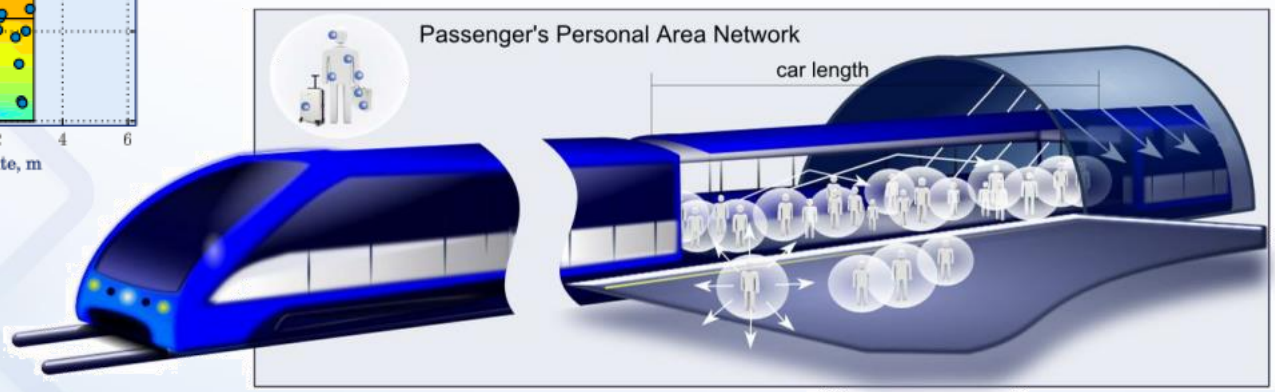




Wearable Communication Technology



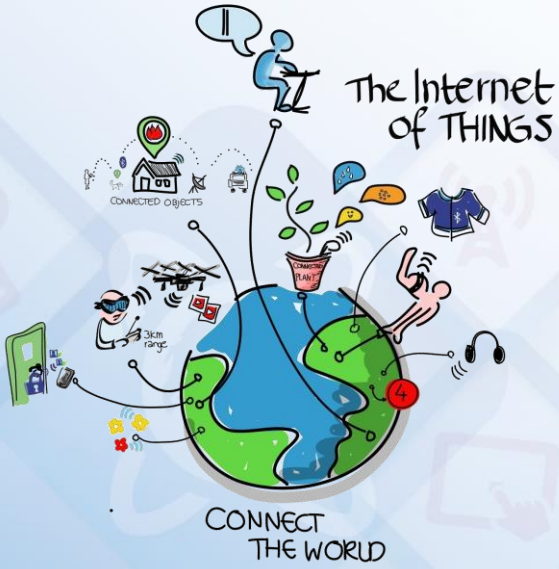
Wearable wireless **devices** are very likely to soon **move into the mainstream** of our society, led by the rapidly expanding multibillion dollar health and fitness markets

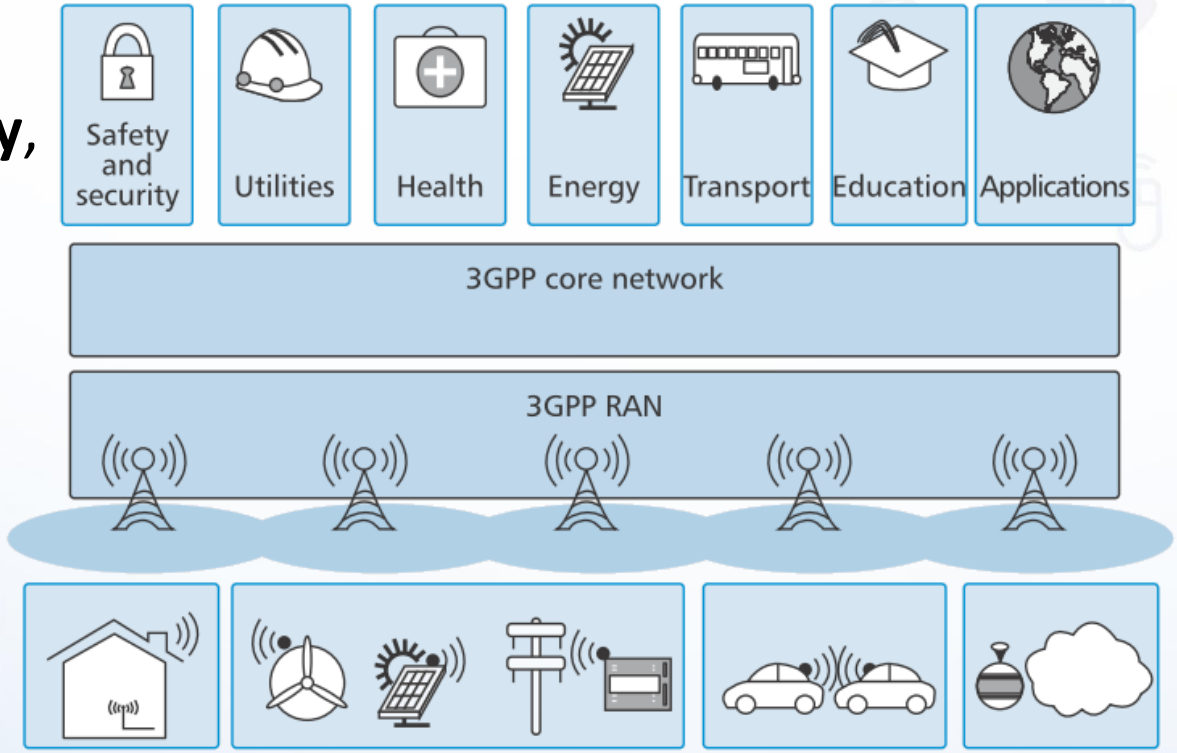


High-density **mobile wearable** scenario: a commuter train

Diversity of IoT Applications and Services

The world is developing toward a **networked society**, where *all kinds* of devices interact and share information





Source: Ericsson Research

The IoT Vision

Smart car parking,
H2H + M2M,
Automation,

Wearables,
D2D for M2M,
Vehicular,
Smart home,

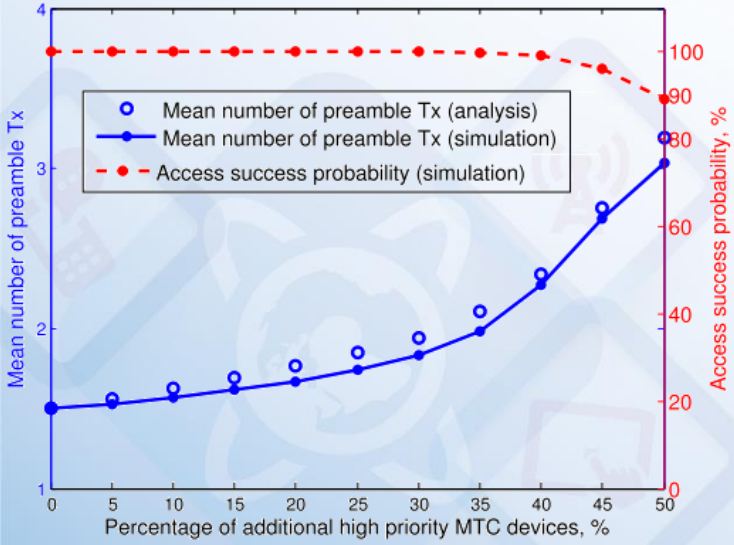
Small data,
Smart factory,
Overload control,
Smart grid,
Massive M2M,
Smart agriculture

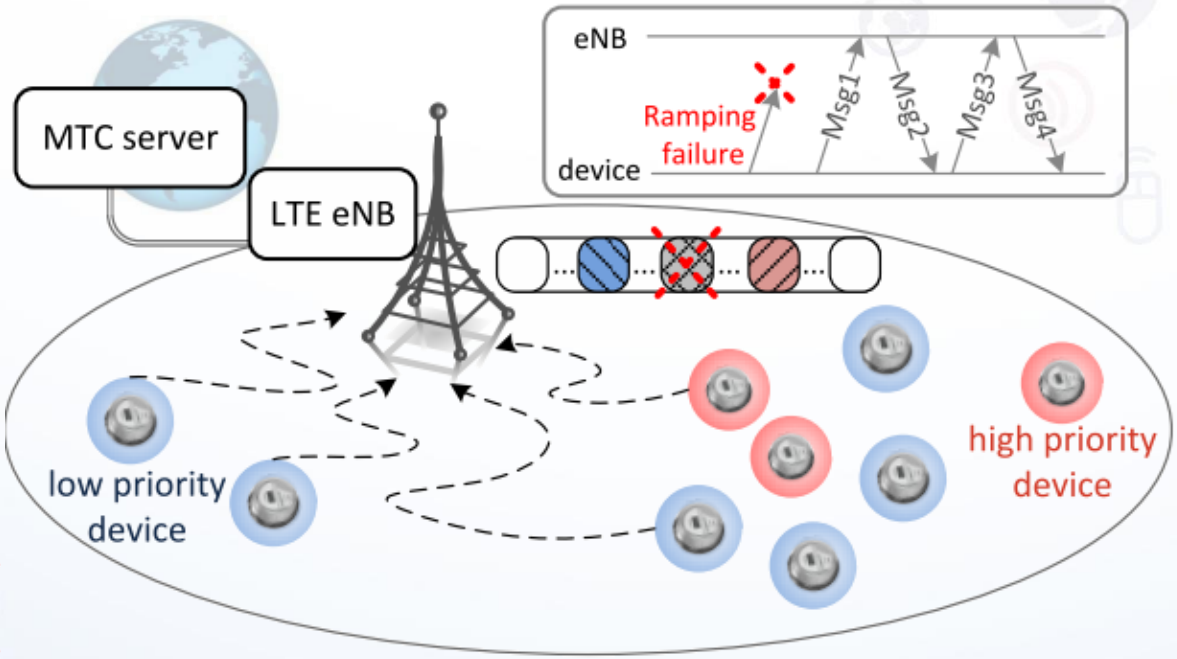
Rural deployment,

Coverage extension,
Commuter train

Long-Range Radio Technologies for MTC

Recent efforts focused on improving **3GPP LTE support of MTC:** overload control, small-data access, coverage extension, etc.

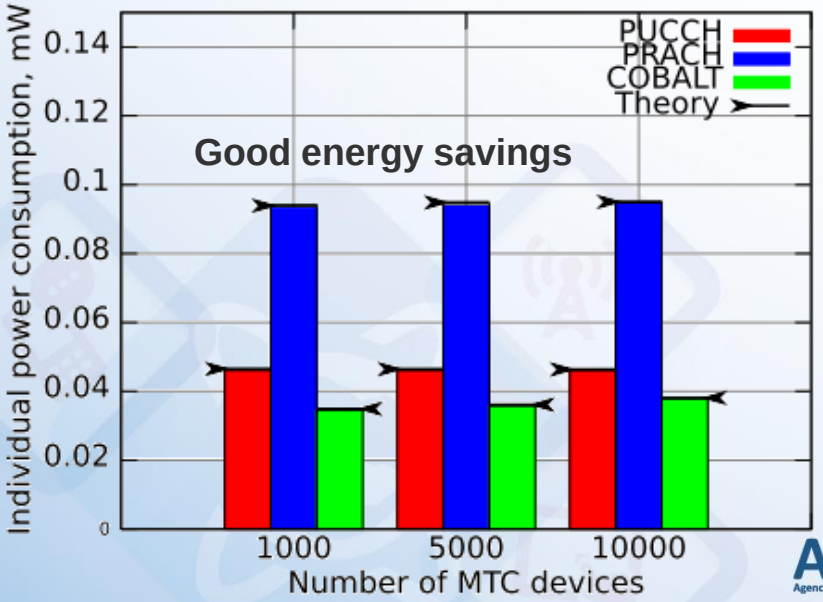


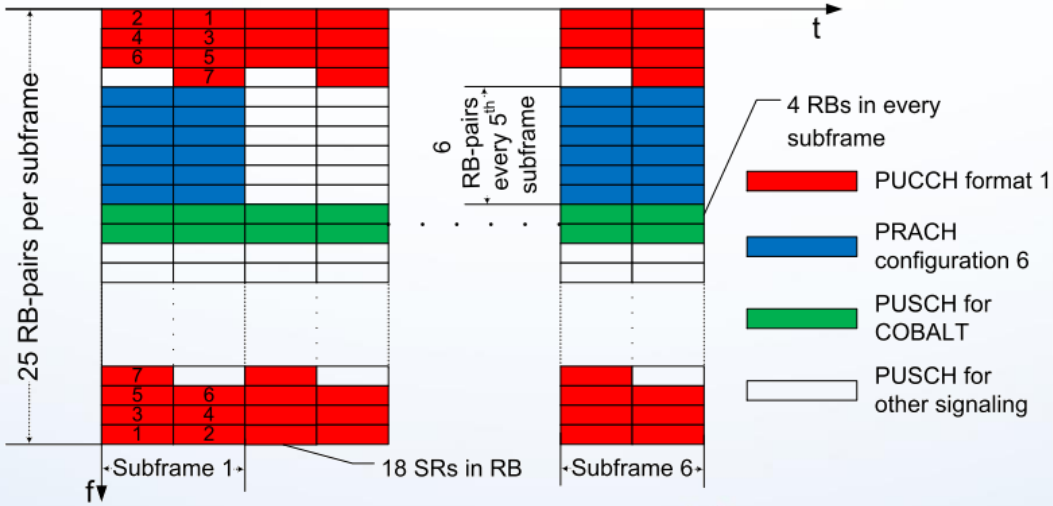


Network has to *reliably* support **very large** numbers of devices with **very low** traffic

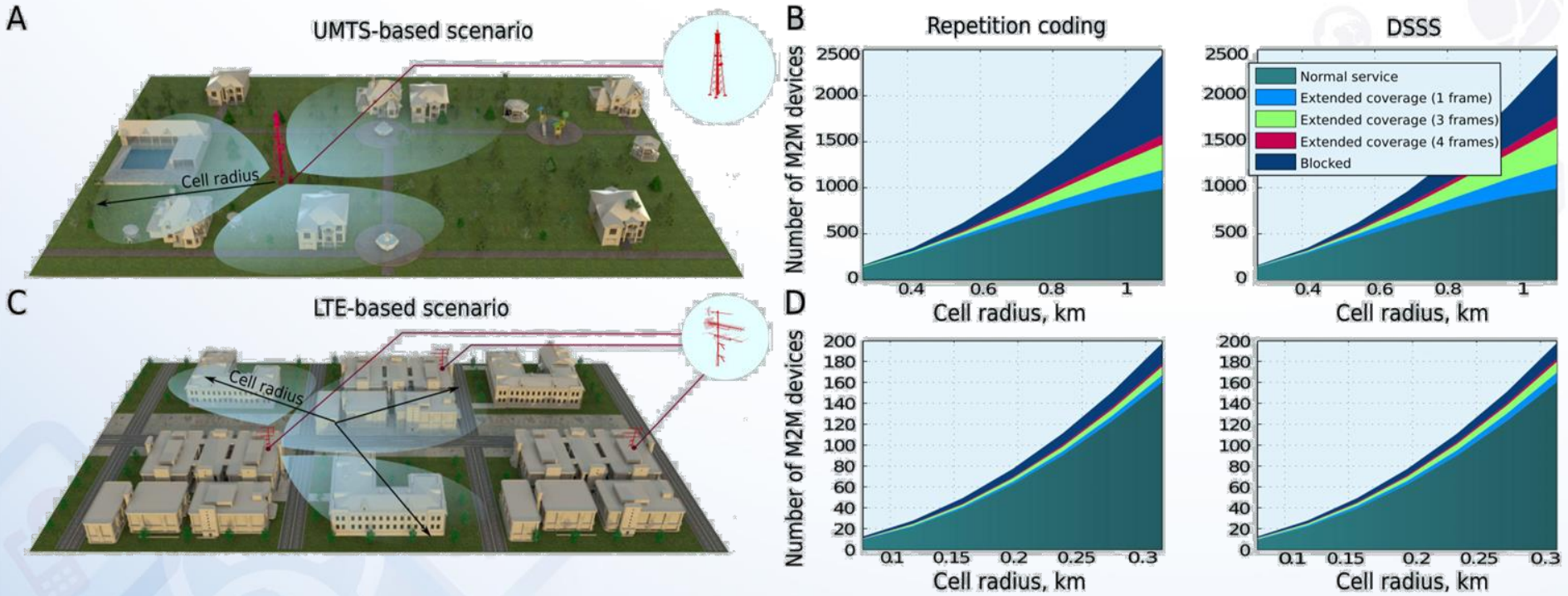
Novel Small-Data Access Mechanisms

Additional **data access channels** are necessary in 3GPP LTE to enable *massive* MTC deployments with *stringent* performance requirements, in both idle and connected modes





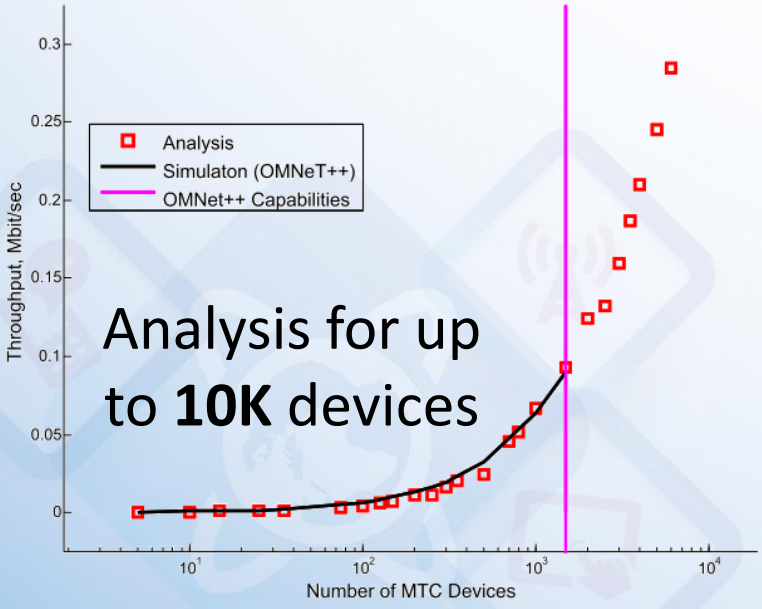
3GPP LTE Coverage Enhancements



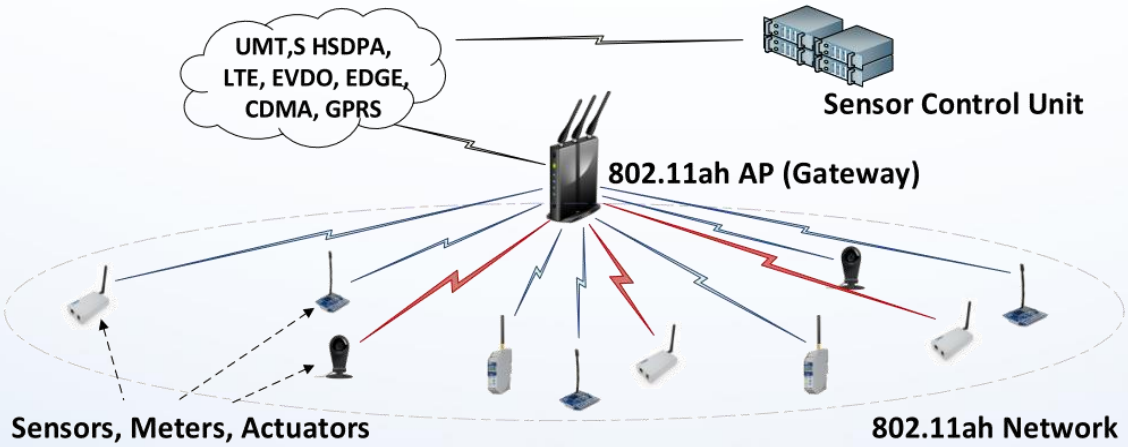
Reaching certain locations such as *basements* may be difficult and thus **coverage enhancement** features have been proposed for LTE

Other Radio Technologies for MTC

IEEE 802.11ah technology is currently being developed to empower *low-cost* and *large-scale* connectivity across **massive MTC deployments** with high spectral and energy efficiencies



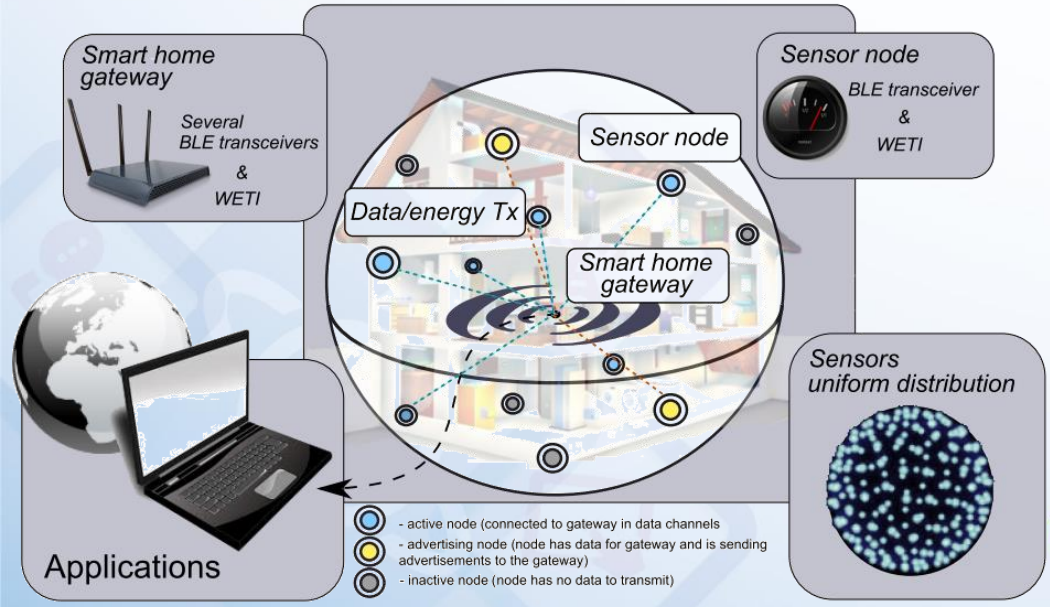
Analysis for up to **10K** devices

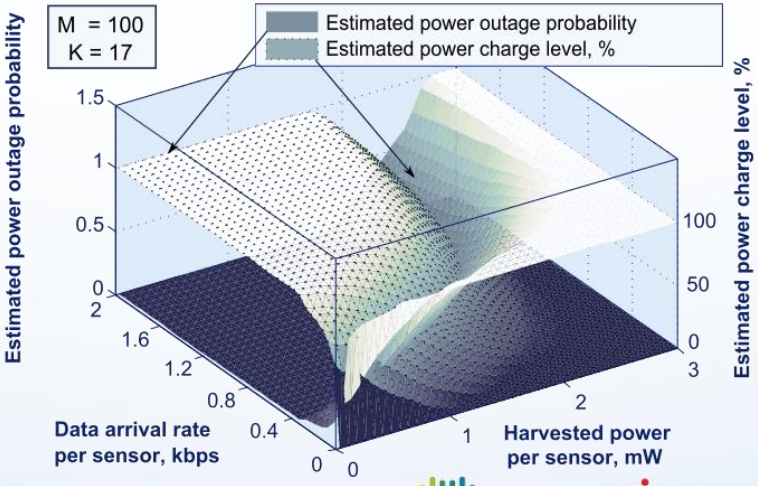


Potential of (Wireless) Energy Harvesting

As **IoT devices** are *small-scale* and *battery-powered*, the key challenge is to **extend their lifetime** without recharging/replacing batteries

Hence, device may **harvest RF energy** transmitted from the source *wirelessly* via a dedicated radio interface





5G Research Roadmap by W.I.N.T.E.R.

Network-assisted device-to-device connectivity & Wearable communications technology

Multi-radio connectivity & Power efficiency

Short-range technologies for low-power MTC deployments

Integrated heterogeneous networks & Ultra-dense networks

Indoor mmWave access technology

Large-scale industry-grade machine-type deployments

Some of Our Recent Publications

1. S. Andreev, et al., Analyzing Assisted Offloading of Cellular User Sessions onto D2D Links in Unlicensed Bands // **IEEE Journal on Selected Areas in Communications: D2D Communications in Cellular Networks,** 2015.
2. A. Pyattaev, et al., Communication Challenges in High-Density Deployments of Wearable Wireless Devices // **IEEE Wireless Communications: Mobile Wearable Communications**, 2015.
3. A. Pyattaev, et al.,Understanding Practical Limitations of Network Coding for Assisted Proximate Communication // **IEEE Journal on Selected Areas in Communications: Fundamental Approaches to Network Coding in Wireless Communication Systems**, 2015.
4. M. Gerasimenko, et al., Cooperative Radio Resource Management in Heterogeneous Cloud Radio Access Networks // **IEEE Access**, 2015.
5. O. Galinina, et al., 5G Multi-RAT LTE-WiFi Ultra-Dense Small Cells: Performance Dynamics, Architecture, and Trends // **IEEE Journal on Selected Areas in Communications: Recent Advances in Heterogeneous Cellular Networks**, 2015.
6. S. Andreev, et al., Intelligent Access Network Selection in Converged Multi-Radio Heterogeneous Networks // **IEEE Wireless Communications: Mobile Converged Networks**, 2014.
7. O. Galinina, et al., Capturing Spatial Randomness of Heterogeneous Cellular/WLAN Deployments With Dynamic Traffic // **IEEE Journal on Selected Areas in Communications: 5G Wireless Communication Systems**, 2014.
8. S. Andreev, et al., Cellular traffic offloading onto network-assisted device-to-device connections // **IEEE Communications Magazine: Smart Device-to-Smart Device Communications**, 2014.
9. O. Galinina, et al., Optimizing energy efficiency of a multi-radio mobile device in heterogeneous beyond-4G networks // **Elsevier Performance Evaluation**, 2014.
10. M. Gerasimenko, et al., Impact of MTC on Energy and Delay Performance of Random-Access Channel in LTE-Advanced // **Transactions on Emerging Telecommunications Technologies**, 2013.