

UiO : Faculty of Mathematics and Natural Sciences
University of Oslo

Department of Informatics
Networks and Distributed Systems (ND) group

IN3230/4230

Wireless Communications - III



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Outline

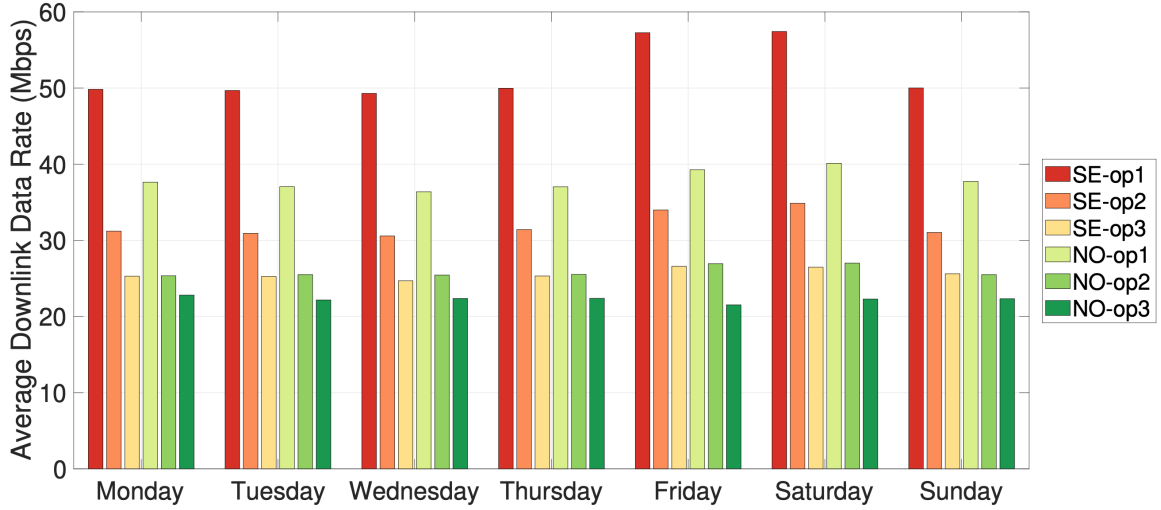
- Mobile Broadband Networks
  - Performance
  - International Roaming
  - Operations
- Massive IoT
  - NB-IoT
  - LORAWAN
- Paving the future
  - 5G and Beyond

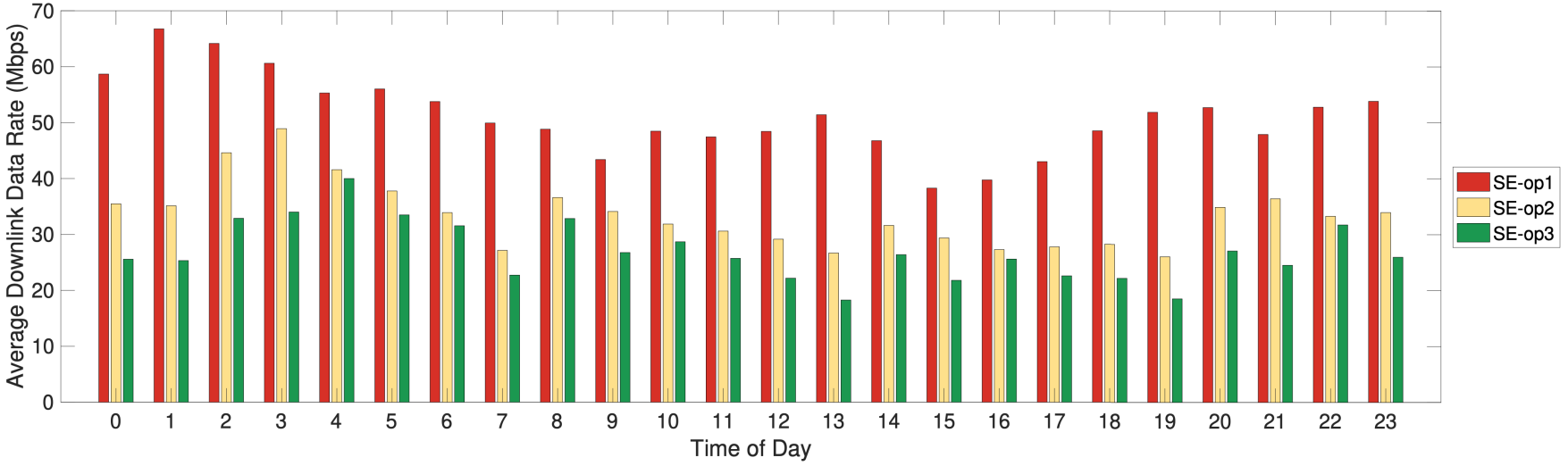
MONROE – Mobile Broadband Measurement Platform

- Coverage in 4 European Countries (Norway, Sweden, Spain, Italy)
- A set of 100 nodes equipped with Ethernet, WiFi and 3G/4G interfaces with commercial MBB subscriptions.
- Under mobility (e.g., on-board of trains or buses) or in stationary scenarios (e.g., in laboratories, or hosted by volunteers in homes).

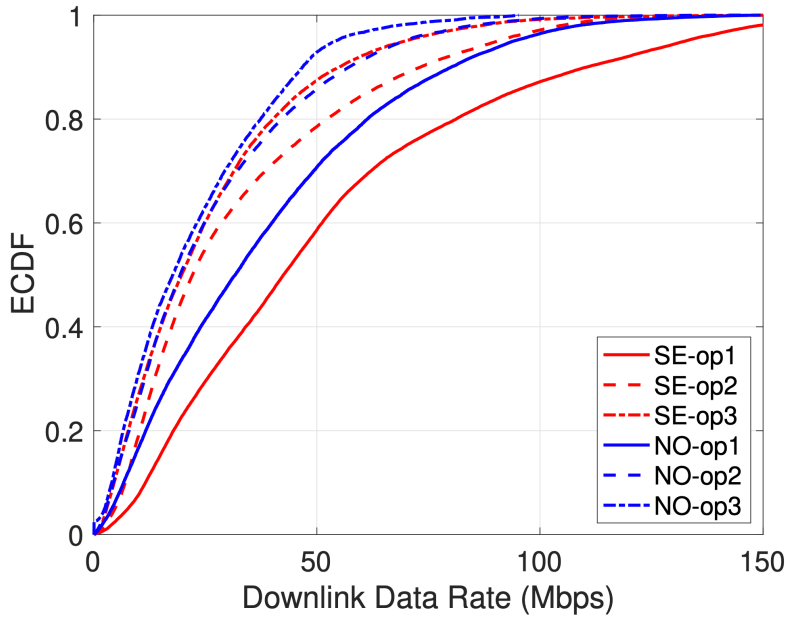


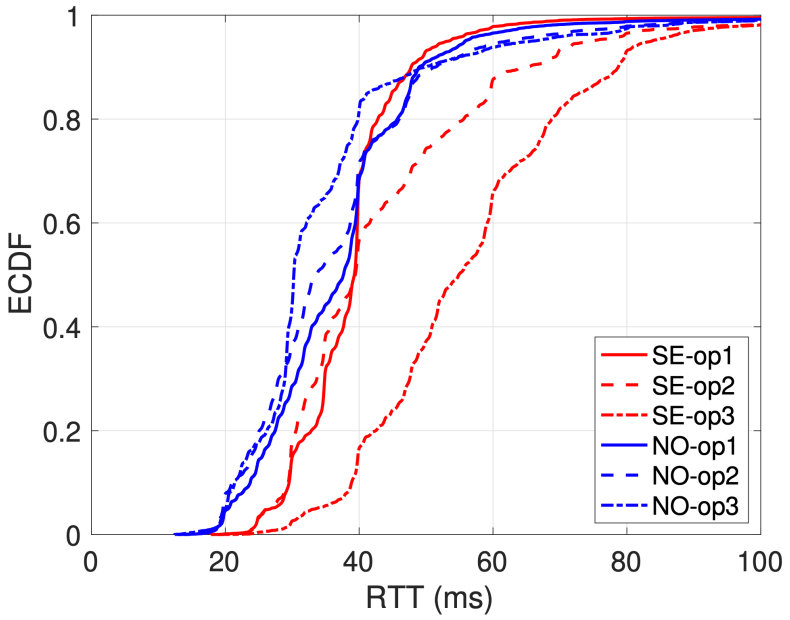
Hourly and Daily Patterns





LTE performance: Data rate and RTT





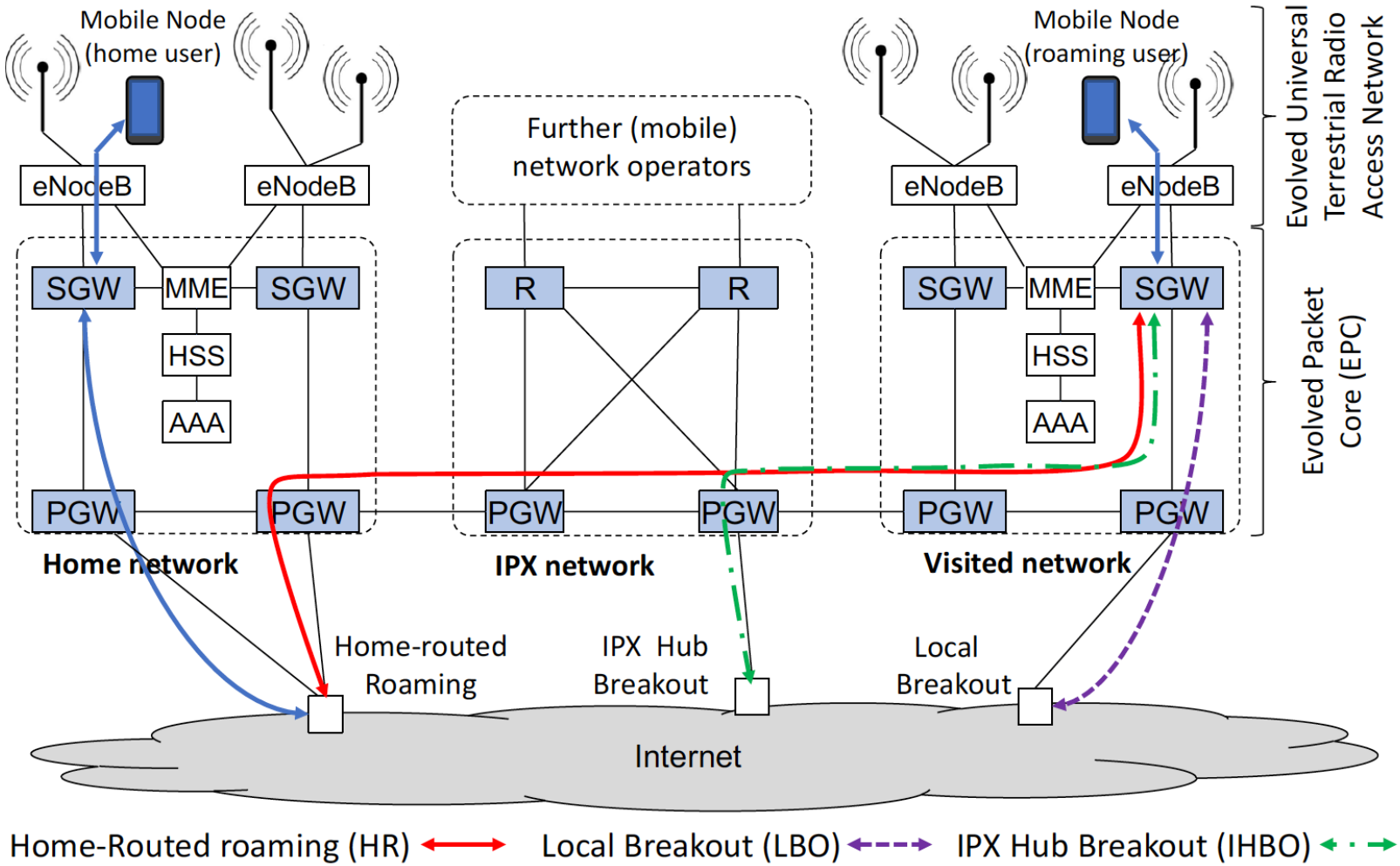
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Free roaming in Europe



Roaming Infrastructure



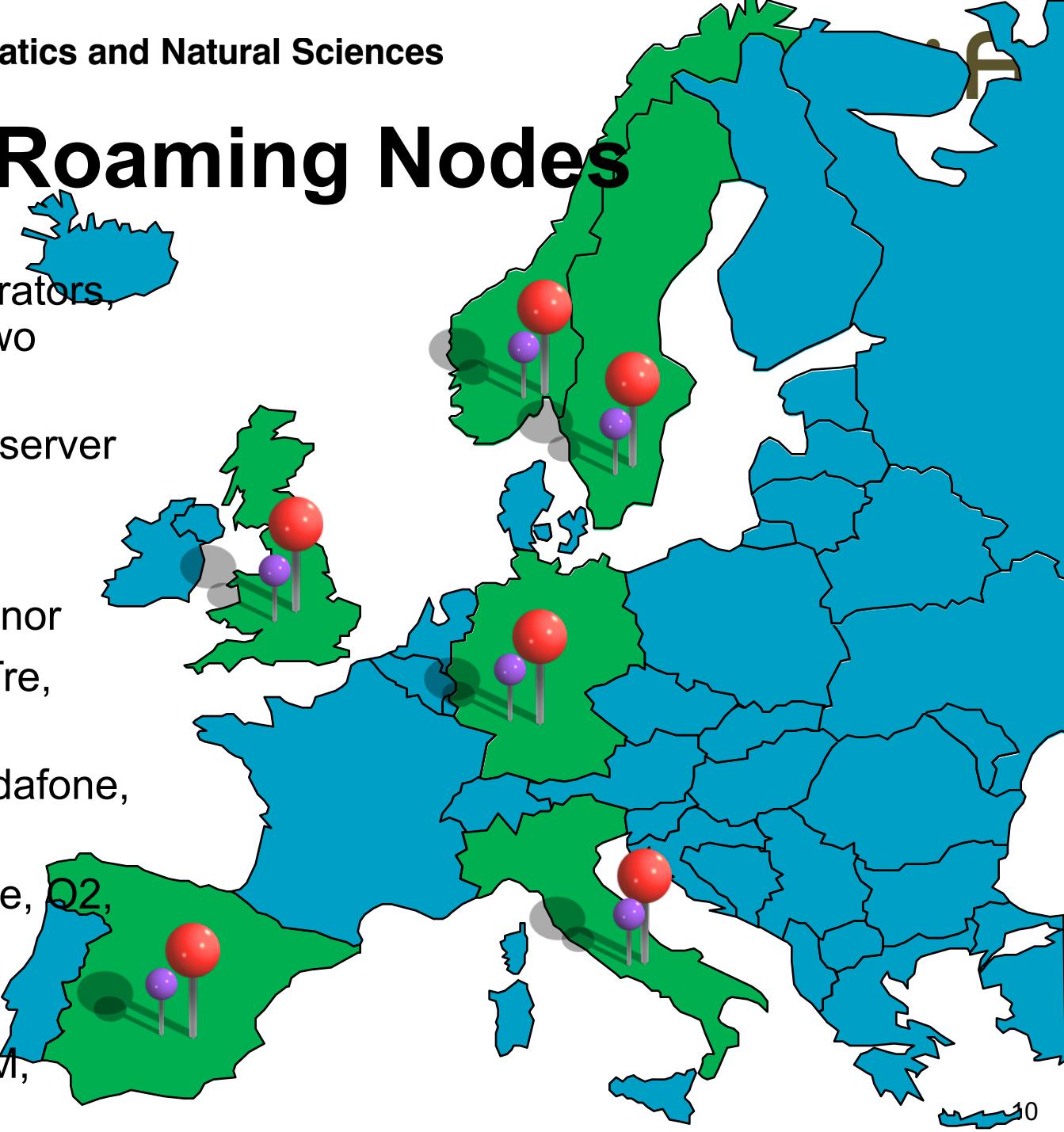
Internet access options for a mobile node at home (left) and when roaming (right).

Roaming Models

- Home Routed (HR):
  - The IP address of the roaming user is provided by the home network.
  - All traffic to and from the mobile user is routed through the home network, for which a GTP tunnel is set up between the SGW of the visited network and the PGW of the home network (red path in the figure).
- Local BreakOut (LBO):
  - When LBO is used, the IP address of the roaming user is provided by the visited network.
  - The GTP tunnel is terminated at the PGW of the visited network and IP-based services can be accessed directly from there (purple path in the figure).
- IPX Hub Breakout (IHBO):
  - The IP address of the roaming user is provided by the IPX network. The GTP tunnel from the SGW in the visited network terminates at a PGW in the IPX network (green path in the figure).
  - There may be multiple PGWs so that latency and resource usage can be reduced by selecting one geographically close to the visited network.

MONROE-Roaming Nodes

- 6 countries, 16 operators, each country has two nodes
- One measurement server per country



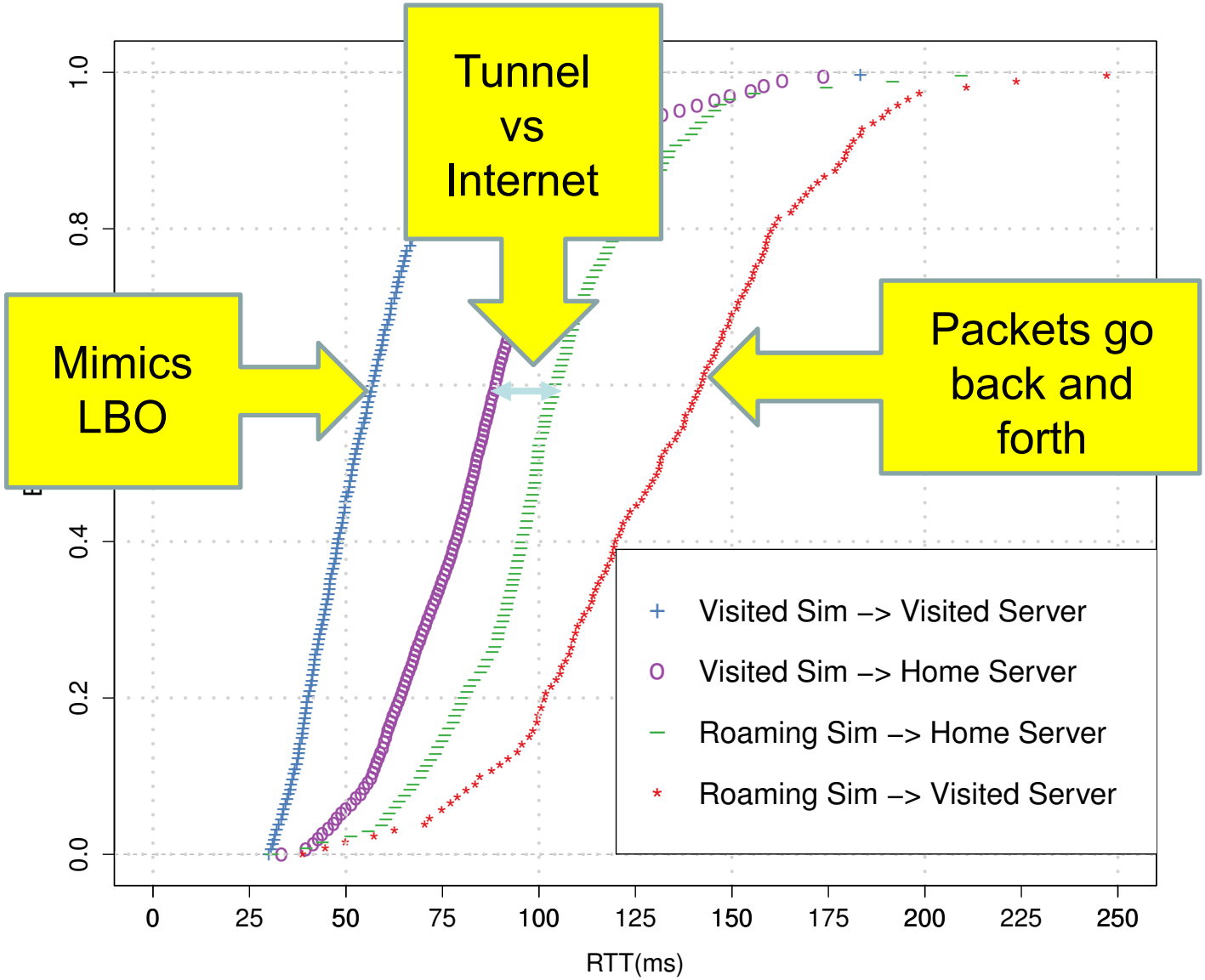
- **Norway**: Telia, Telenor
- **Sweden**: Telenor, Tre, Telia
- **Spain**: Orange, Vodafone, Movistar
- **Germany**: Vodafone, O2, T-Mobile
- **UK**: Vodafone, EE
- **Italy**: Vodafone, TIM, WIND

Roaming Configuration

- Home Routed (HR) Roaming was used by all 16 MNOs!

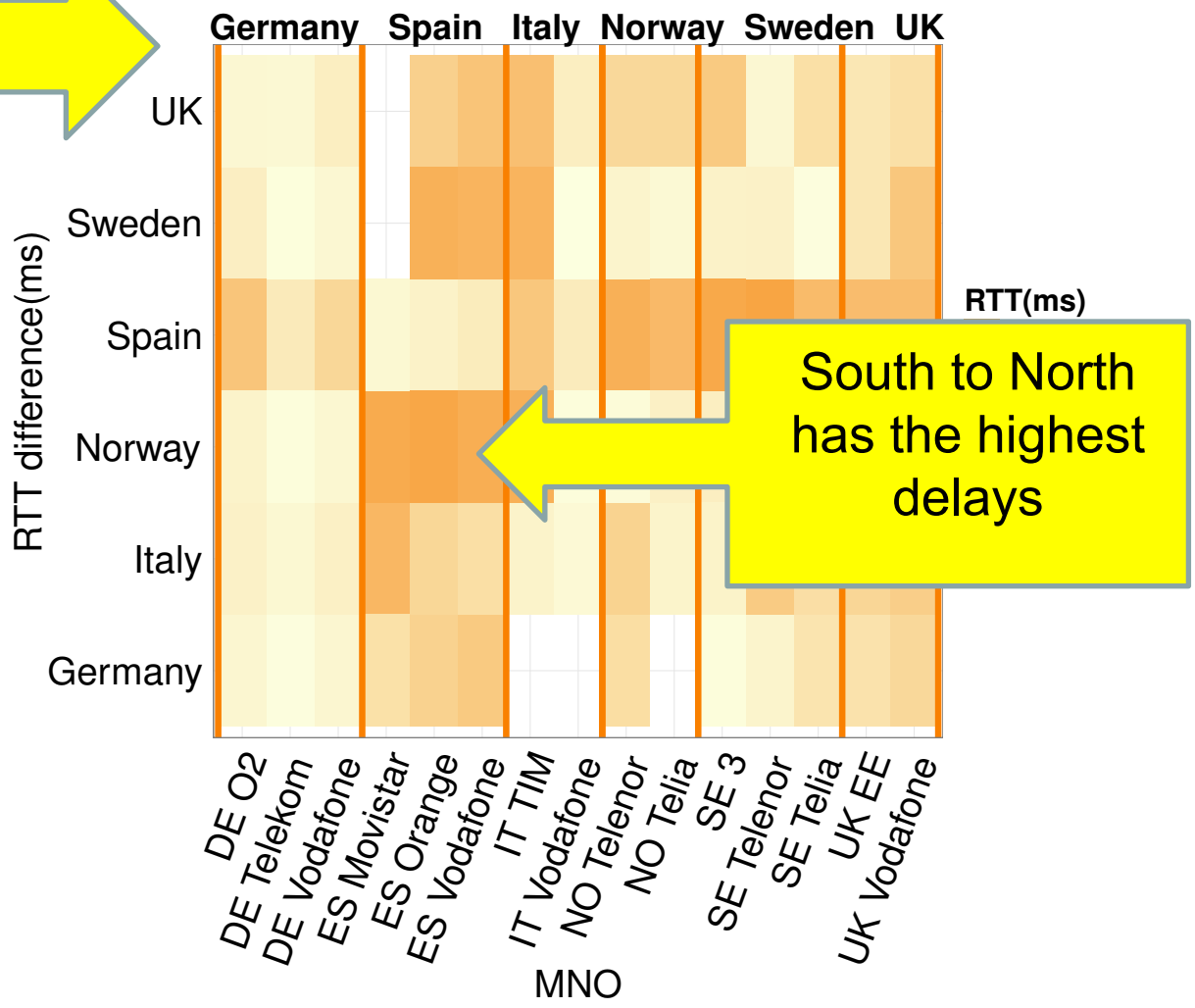
- Why all traffic is sent back to home network?
  - HR provides the home operators with all the accounting and billing information
  - Operators want to have near real-time view of the customer traffic for accounting reasons
  - More complex debugging if HR is not used, who is responsible if there is a problem?

Delay penalty of home-routed roaming



Dela of home-routed roaming geog

Germany is in a good position being in central Europe



RTT difference between the roaming SIM and the visited SIM

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Mobile Virtual Network Operators (MVNO)

- MVNO is an entity that offers mobile network services to end-users, but does not own nor operate fully a cellular network. MVNOs lack of ownership of radio spectrum resources.
- In order to operate, an MVNO needs to have agreements in place to access the network of at least one MNO.

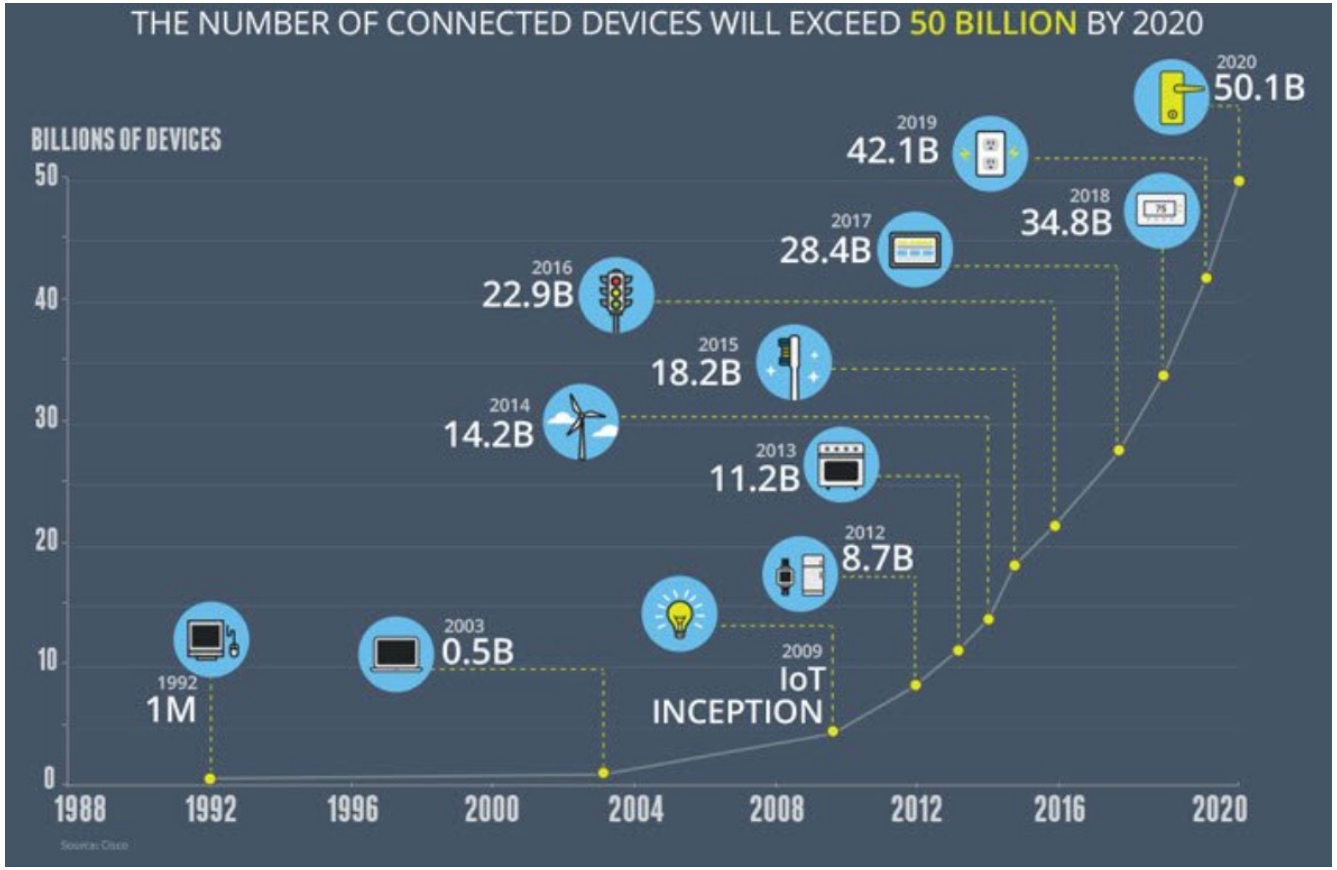
MVNO Models

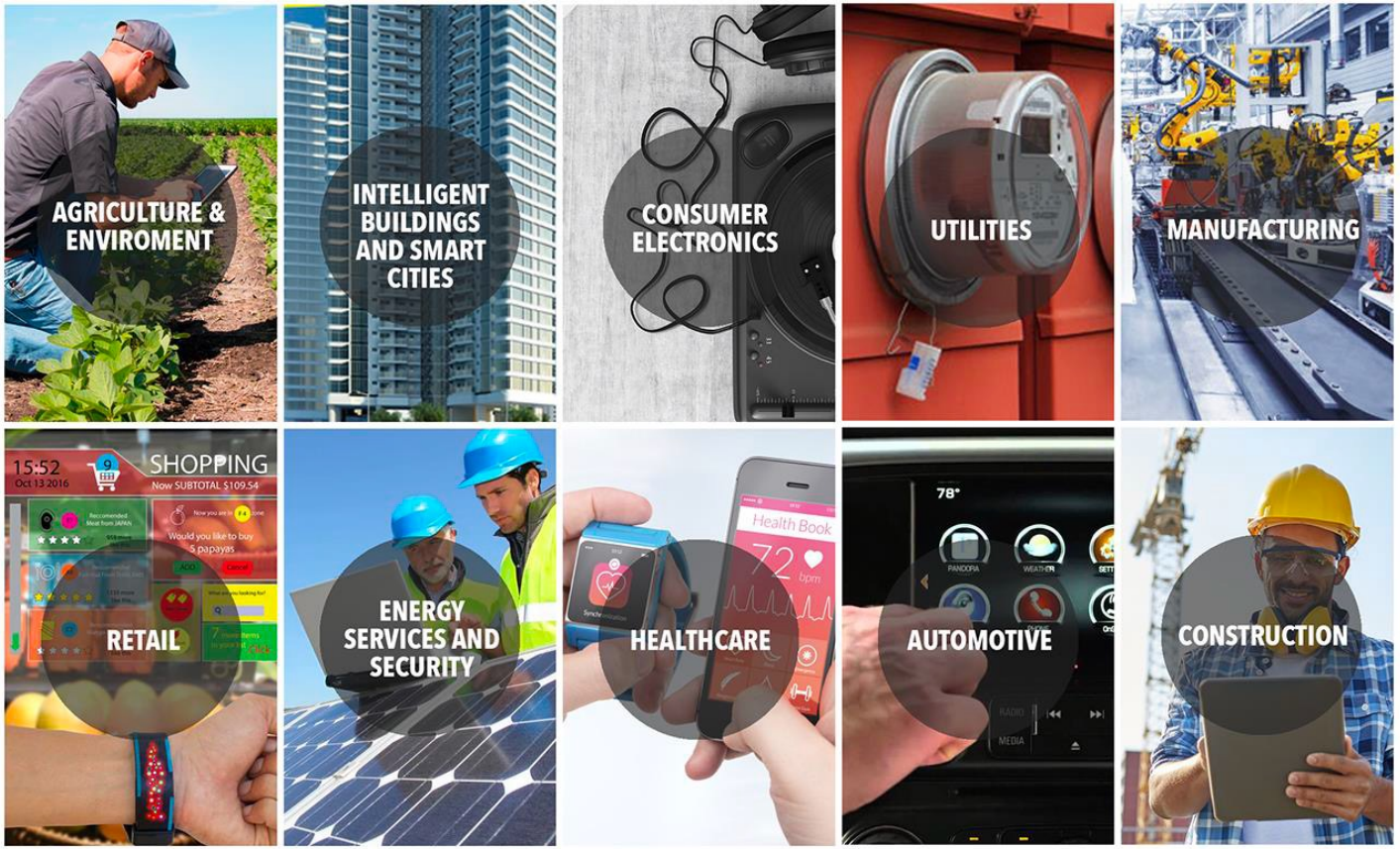
- A "light" MVNO is a service provider that has its own customer support, marketing, sales and distribution operations, and has the ability to set its tariffs independently from the retail prices set by the host MNO.
- The “full” MVNO have a core network implementation operating essentially the same technology as a mobile network operator, only missing their own radio network. They run their own core network and rely on at least one host MNO who can offer access to the radio resources.
- Mobile Network Aggregator (MNA): Some full MVNOs exploit more than one single MNO, establishing the MNA operating model. Aggregating multiple MNOs allows the MNA's customers to dynamically change the MNO they are attached to based on the different factors, such as policy, coverage, performance, etc.

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Growth in the number of connected devices

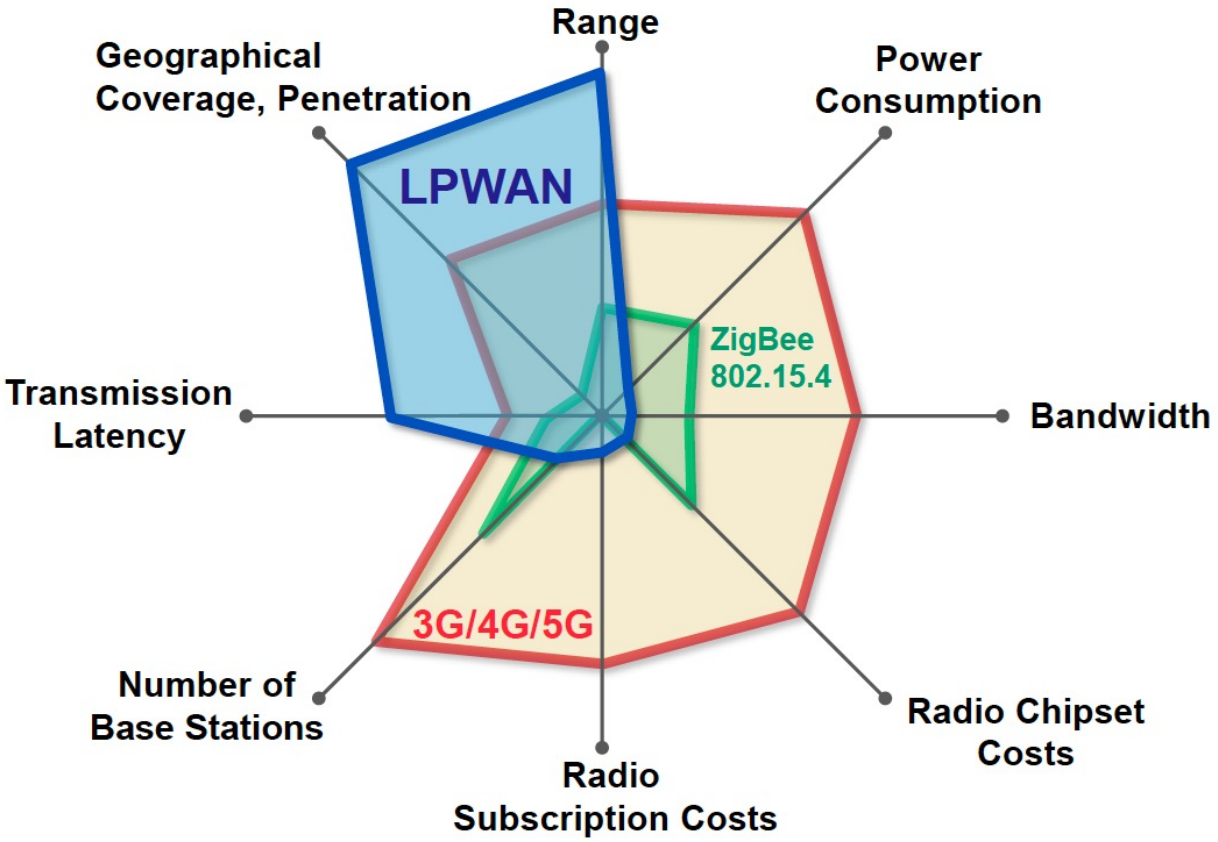



AGRICULTURE & ENVIROMENT
INTELLIGENT BUILDINGS AND SMART CITIES
CONSUMER ELECTRONICS
UTILITIES
MANUFACTURING
15:52
Oct 13 2016
SHOPPING
Now SUBTOTAL $109.54
RETAIL
ENERGY SERVICES AND SECURITY
Health Book
HEALTHCARE
78°
AUTOMOTIVE
CONSTRUCTION

Key Challenges for Massive IoT

- **Battery life** – many IoT devices will be battery-powered, and often the cost of replacing batteries in the field is not viable. (Battery life time of 10 years)
- **Coverage and Range** – deep indoor connectivity is a requirement for many applications in the utility area. Regional (or even national or global) coverage is a prerequisite for many use cases, especially within the transport area. (5 –40 km in the open field)
- **Quality of Service** – providing a certain low bitrate reliably is important for many applications while latency is not that critical. (Typically a few hundred bit/s or less)
- **Deployment and device cost** – clearly a key enabler for high-volume, mass-market applications, enabling many of the use cases. Moreover, in order to enable a Massive IoT market, networks need to scale efficiently. (Device cost of a few Euros)

Low Power Wide Area Networks (LPWAN)



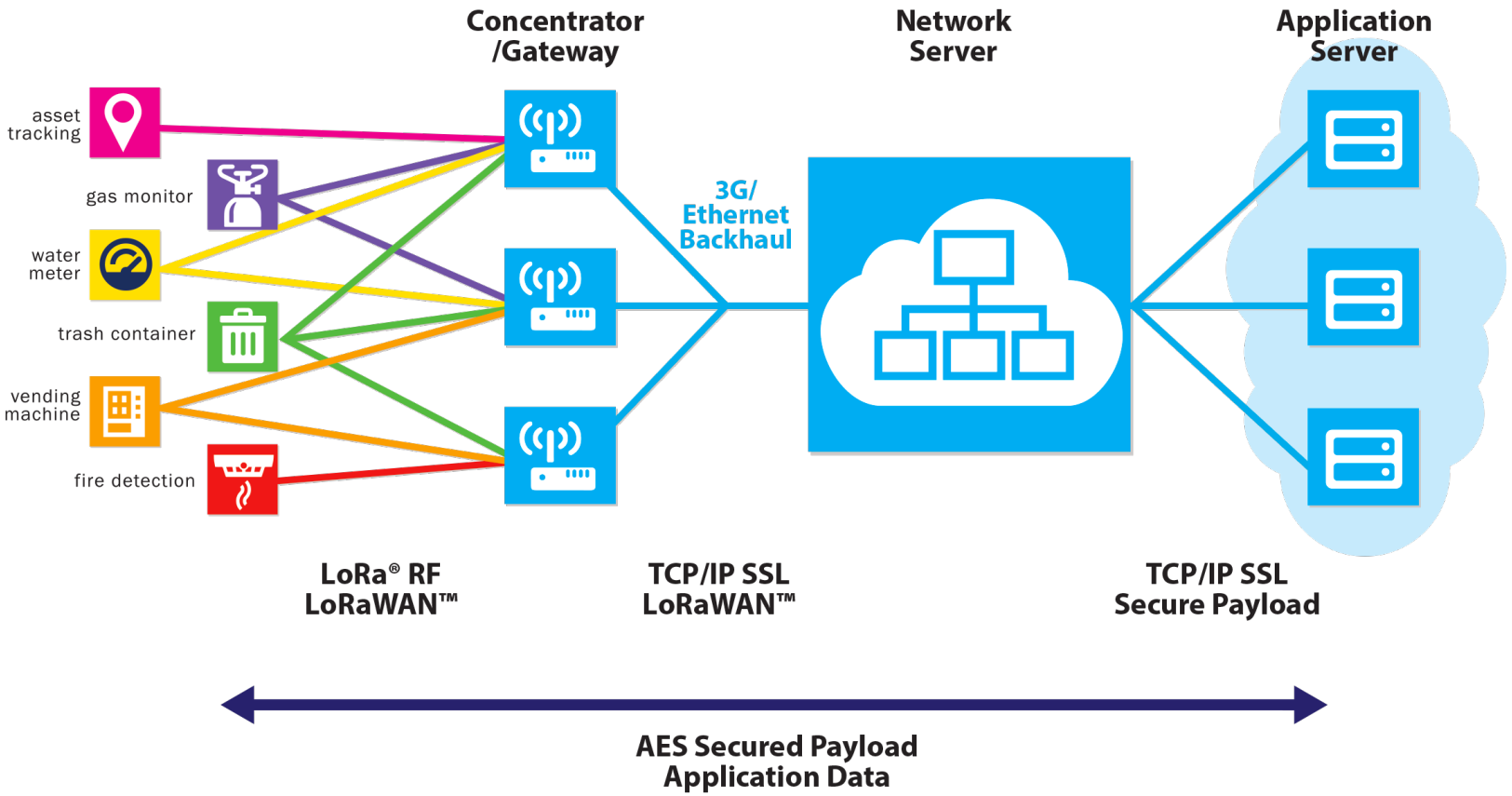
What is LORAWAN?

- Low Power, Wide Area (LPWA) networking protocol for IoT
- Provides bi-directional communication, end-to-end security, mobility and localization services
- Open source standard
- Unlicensed band (EU 868)
- LORA Alliance (400+ industry partner)
- The Things Network (TTN)*: *“a global, crowdsourced, open, free and decentralized LoRaWAN IoT platform”*

THE THINGS NETWORK

*https://www.thethingsnetwork.org/

LoRaWAN Architecture



LoRaWAN Specification

Spectrum	***Unlicenced*** 863-870 MHz frequency bands (in Europe) 125/250 KHz channels
Modulation and Access	LoRa modulation (***Chirp Spread Spectrum (CSS))*** LORAWAN MAC (Aloha)
Data rate	250bps-50kbps
UE Max Tx Power	14 dBm
Range	5 km (urban), 20 km (rural)
Energy Efficiency	***Adaptive Data Rate (ADR)***

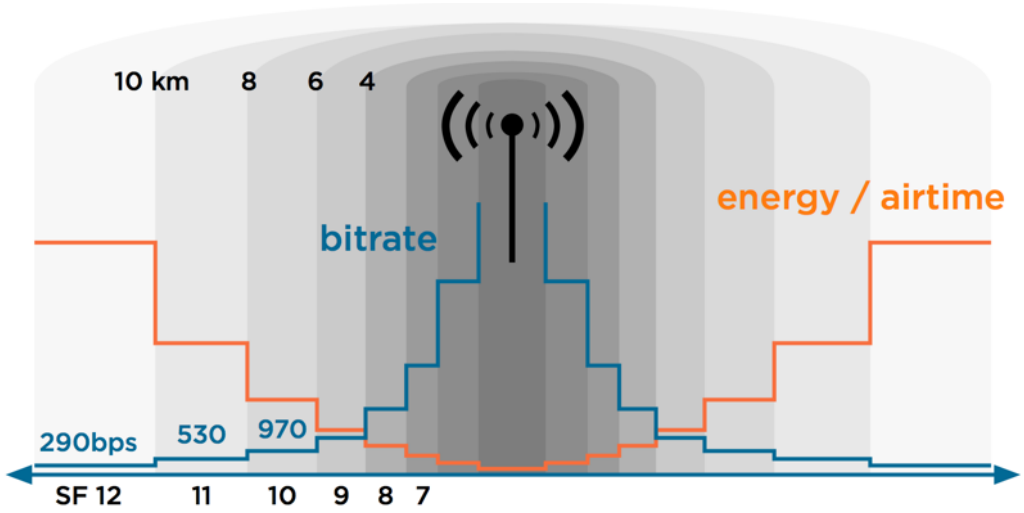
Adaptive Data Rate (ADR)

- Adaptive Data Rate (ADR) is a mechanism for optimizing data rates, airtime and energy consumption in the network.
- Spreading Factor (SF): is the duration of the chirp. **LoRa** operates with **spread factors** from 7 to 12. SF7 is the shortest time on air, SF12 will be the longest.

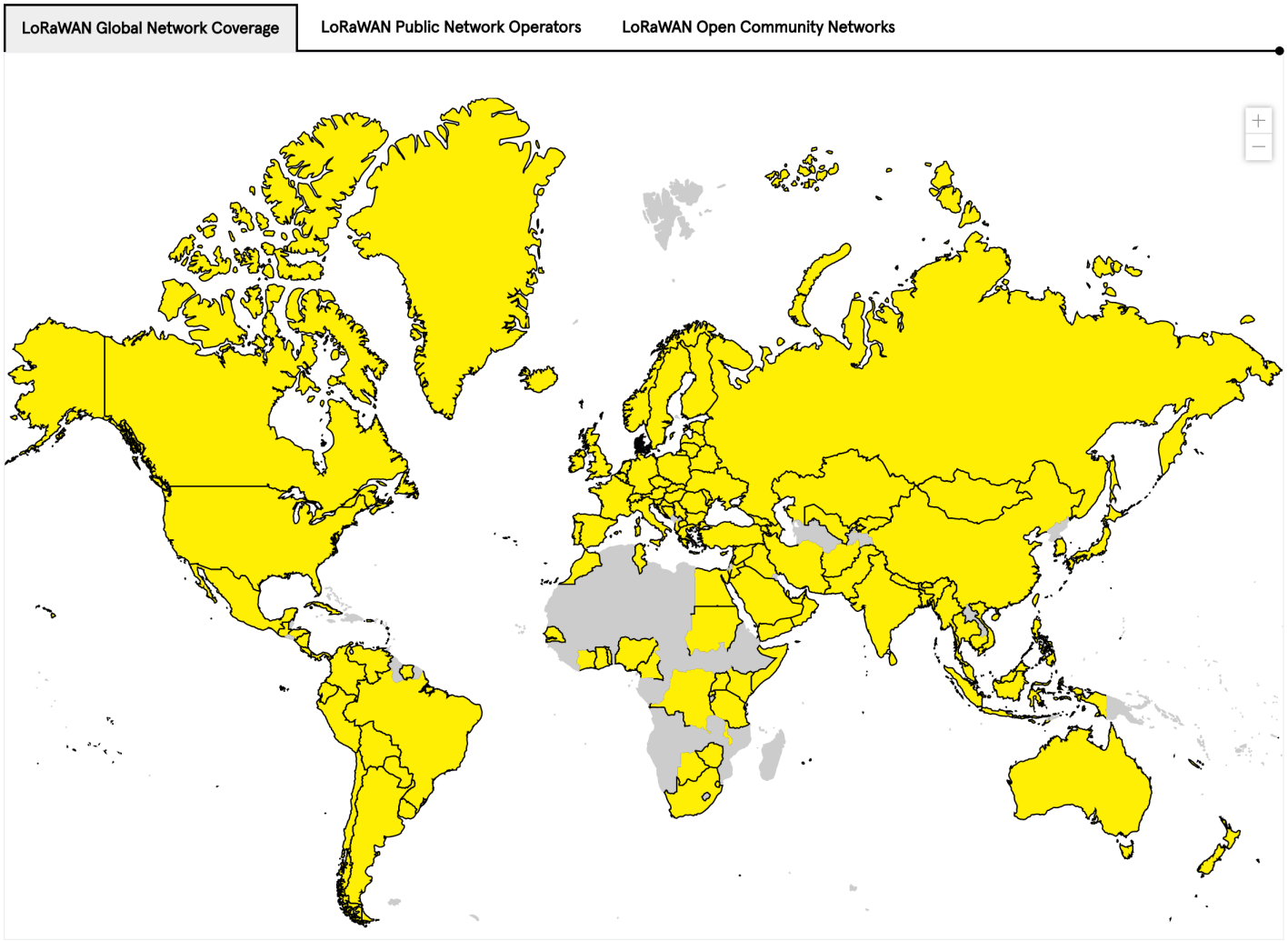
ADR triggers:

I. SF increase (device-side): Improves message delivery in harsh radio conditions

II. SF decrease (network-side): Improves data rate and power consumption



LORAWAN Network Coverage

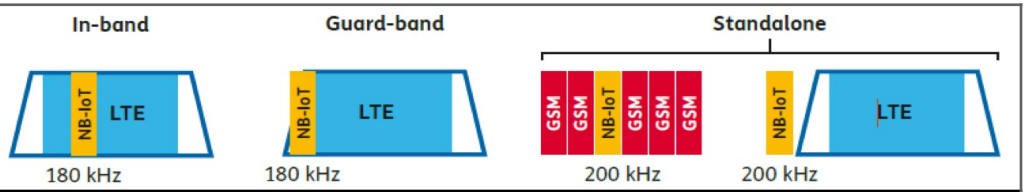


What is NB-IoT?

- LPWAN radio technology standard developed by 3GPP to meet IoT application requirements
- Builds on the LTE ecosystem, and can be deployed as a simple addition of new software to existing LTE infrastructure
  - leading to fast development, scalibility, and global roaming
- Includes state-of-the-art LTE security
  - Identity management
  - Authentication and authorization (embedded SIM)
  - End to end encription of device data and signalling
- Future feature growth for MBB and NB-IoT use cases

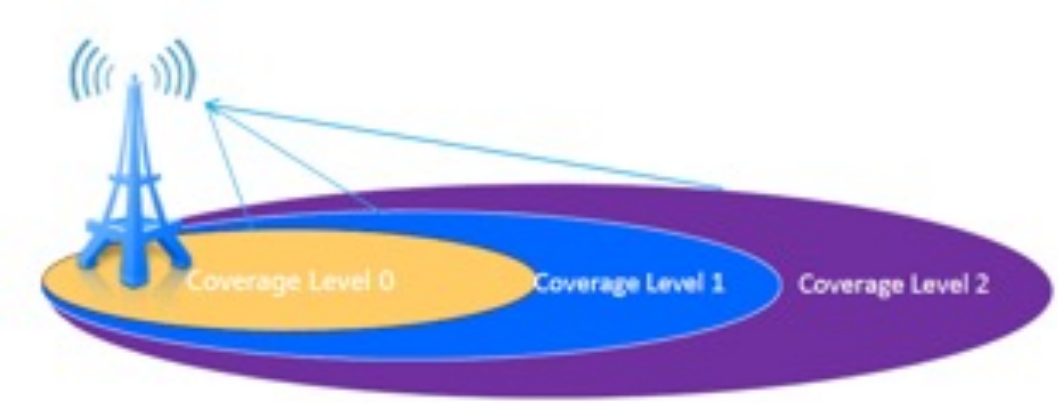
NB-IoT Specification

Rel-13

Spectrum Deployment	
Modulation and Access	Modulation: BPSK/QPSK MAC: DL: OFDMA, UL: SC-FDMA
Peak data rate	DL: 250 kbps UL: 20 kbps
UE Max Tx Power	23 dBm
Coverage enhancements	***Power Spectral Density boost*** ***Repetitions***
Range	1 km (urban), 10 km (rural)
Energy Efficiency	***Power Saving Mode (PSM)*** ***extended Discontinuous Reception (eDRx)***

NB-IoT Coverage

- **Coverage Enhancement (CE) Techniques (w.r.t. LTE)**
  - Power Spectral Density boost: Tx power focused on smaller bands
  - Repetitions: messages can be repeated up to 128 times

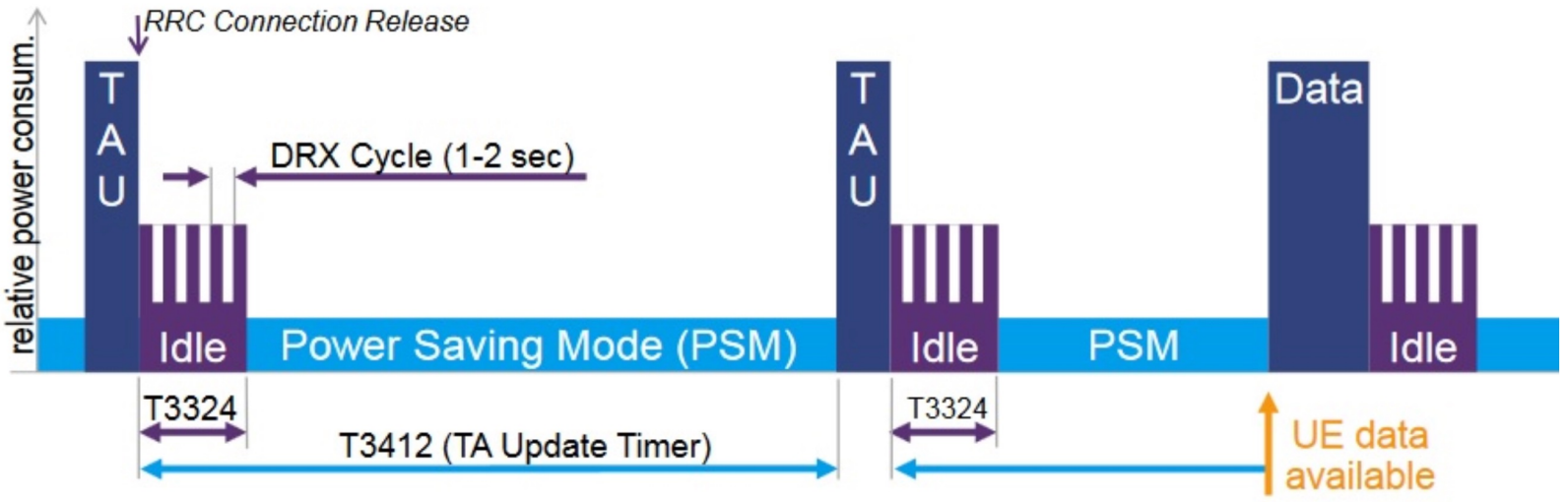


CE Level (CL)	# Repetitions
0	[0-2]
1	[4-16]
2	[32-128]

CL0 = LTE coverage

NB-IoT Power Savings

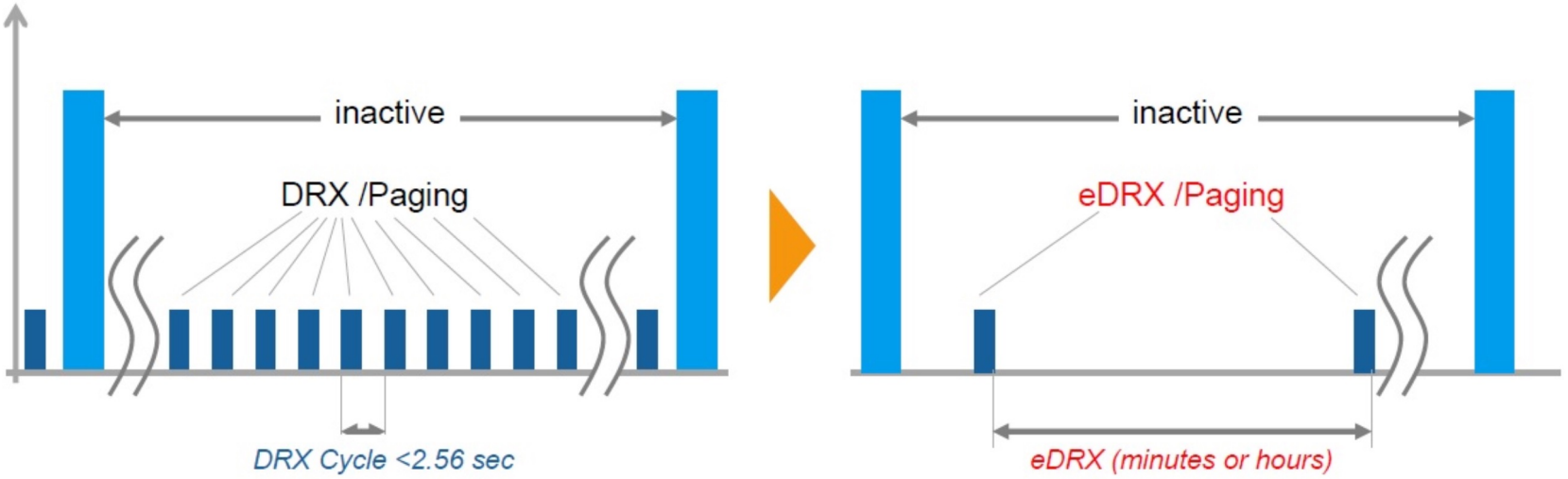
- **Power Saving Mode (PSM)** is a power-off mode, in which the device nevertheless remains registered on the network



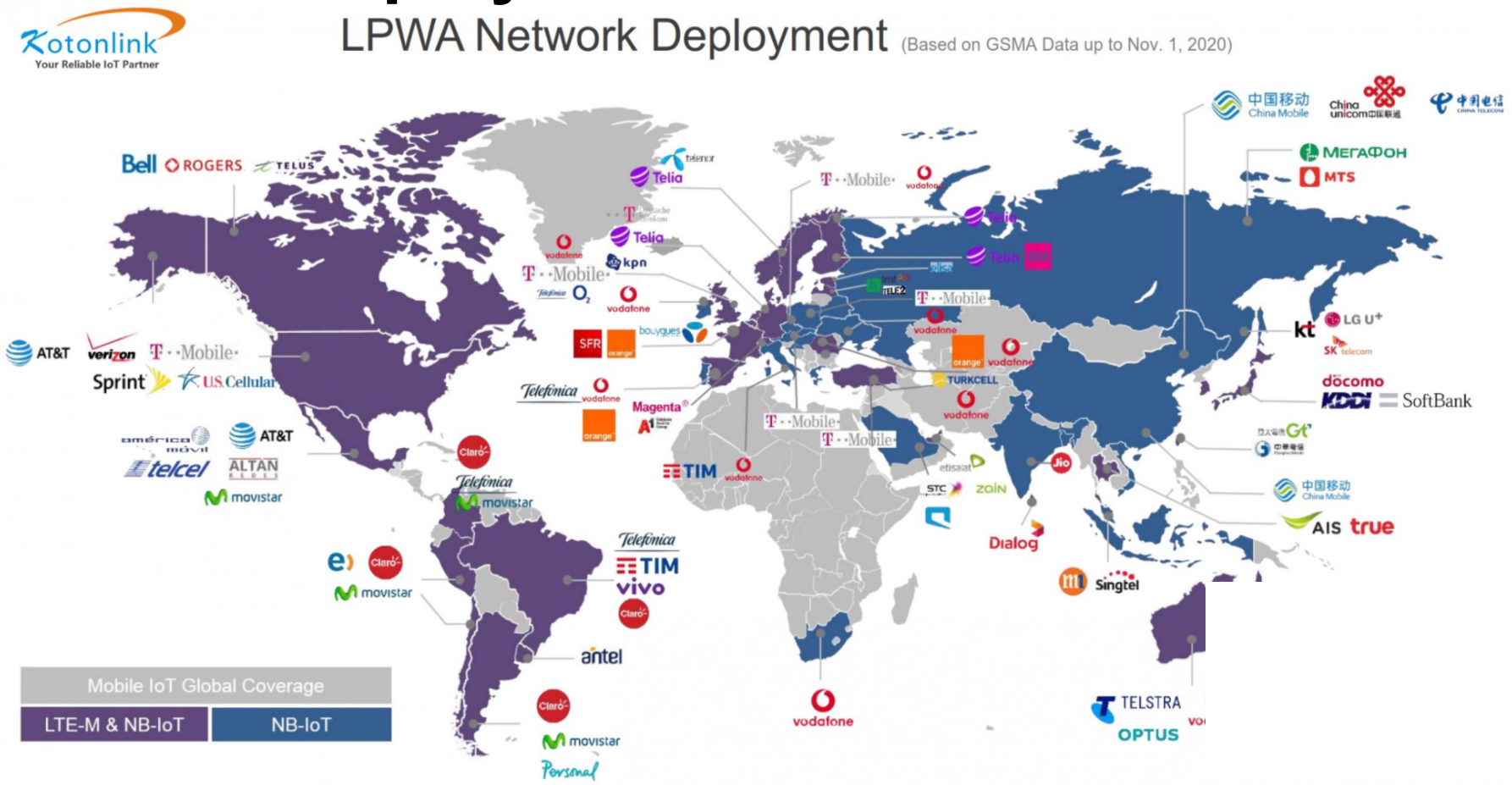
TAU: Tracking Area Update
RRC: Radio Resource Control
DRX: Discontinuous Reception

NB-IoT Power Savings

- **extended Discontinuous Reception (eDRx)** mode allows you to significantly increase the period of time when the receiving path of the device is turned off.



NB-IoT Deployment

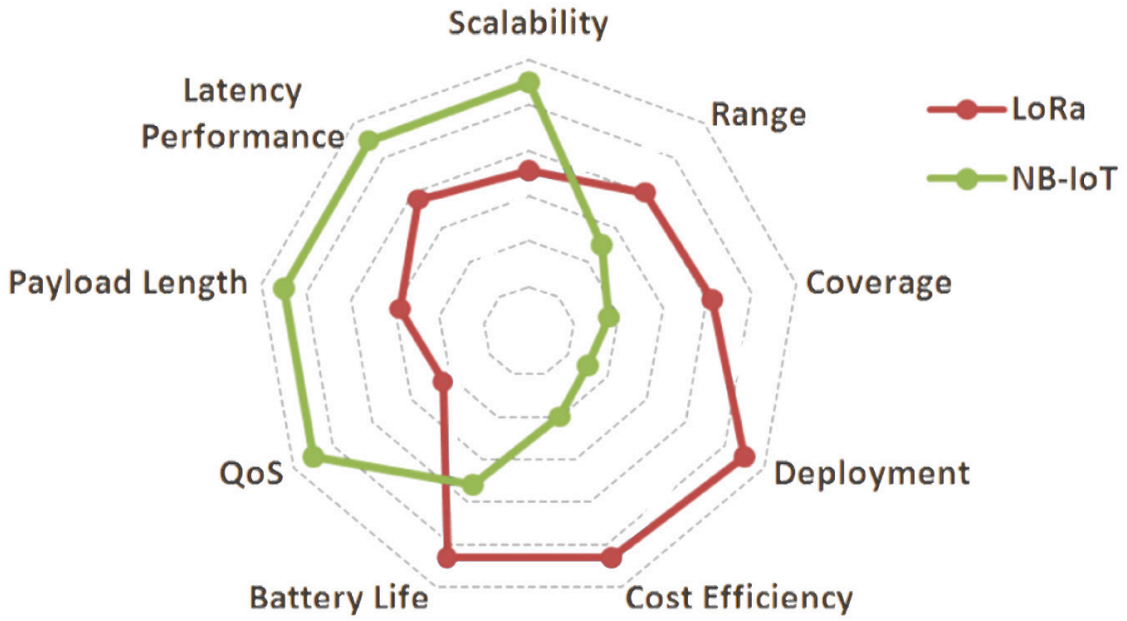


*Source: https://www.kotonlink.com/NewsDetail/2434022.html

LORAWAN vs NB-IoT

- Range and Penetration
- Battery
- Cost (deployment, spectrum, device)

Overall LORAWAN vs NB-IoT



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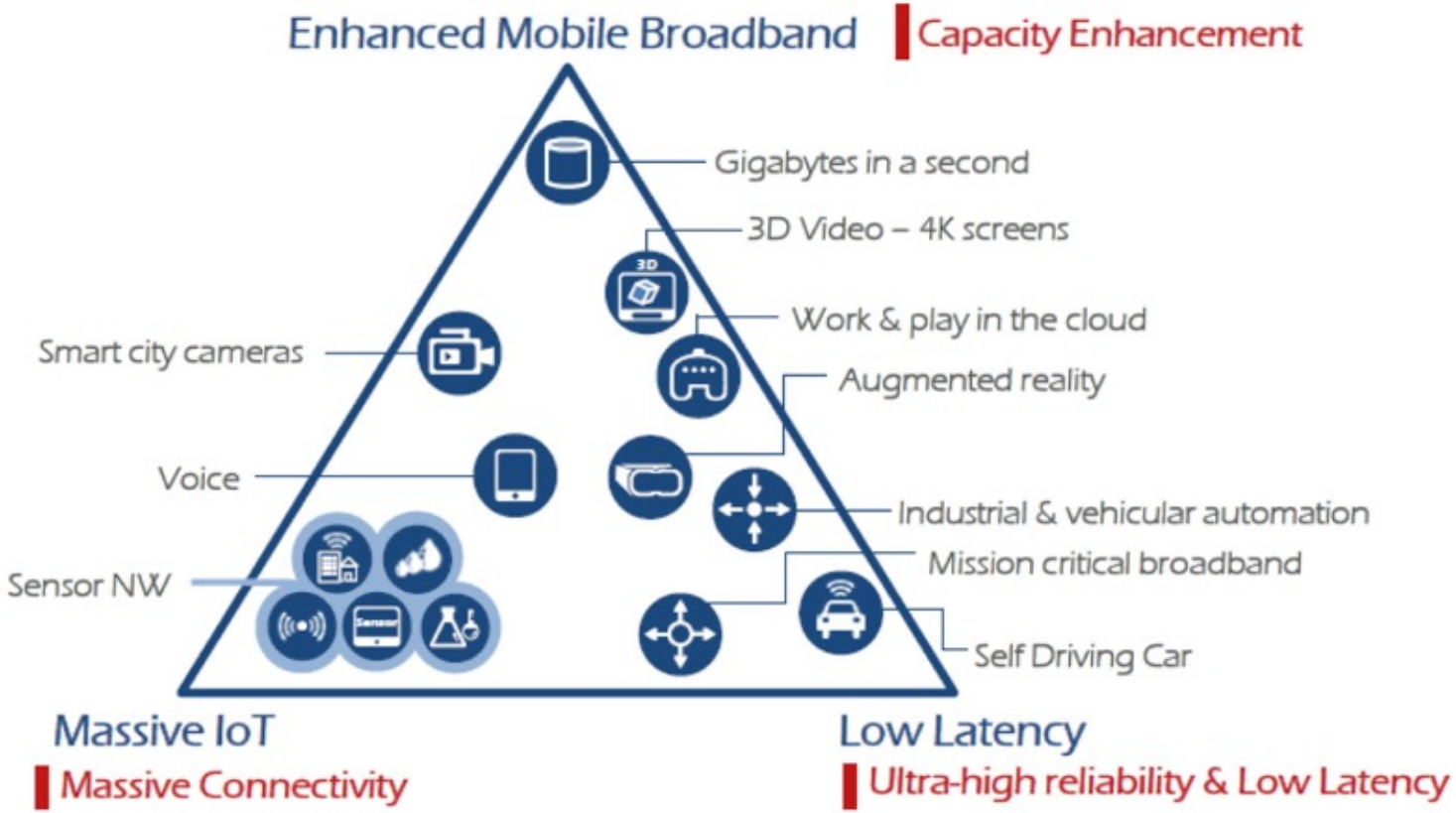
What is 5G?

5G is the 5th generation of mobile networks

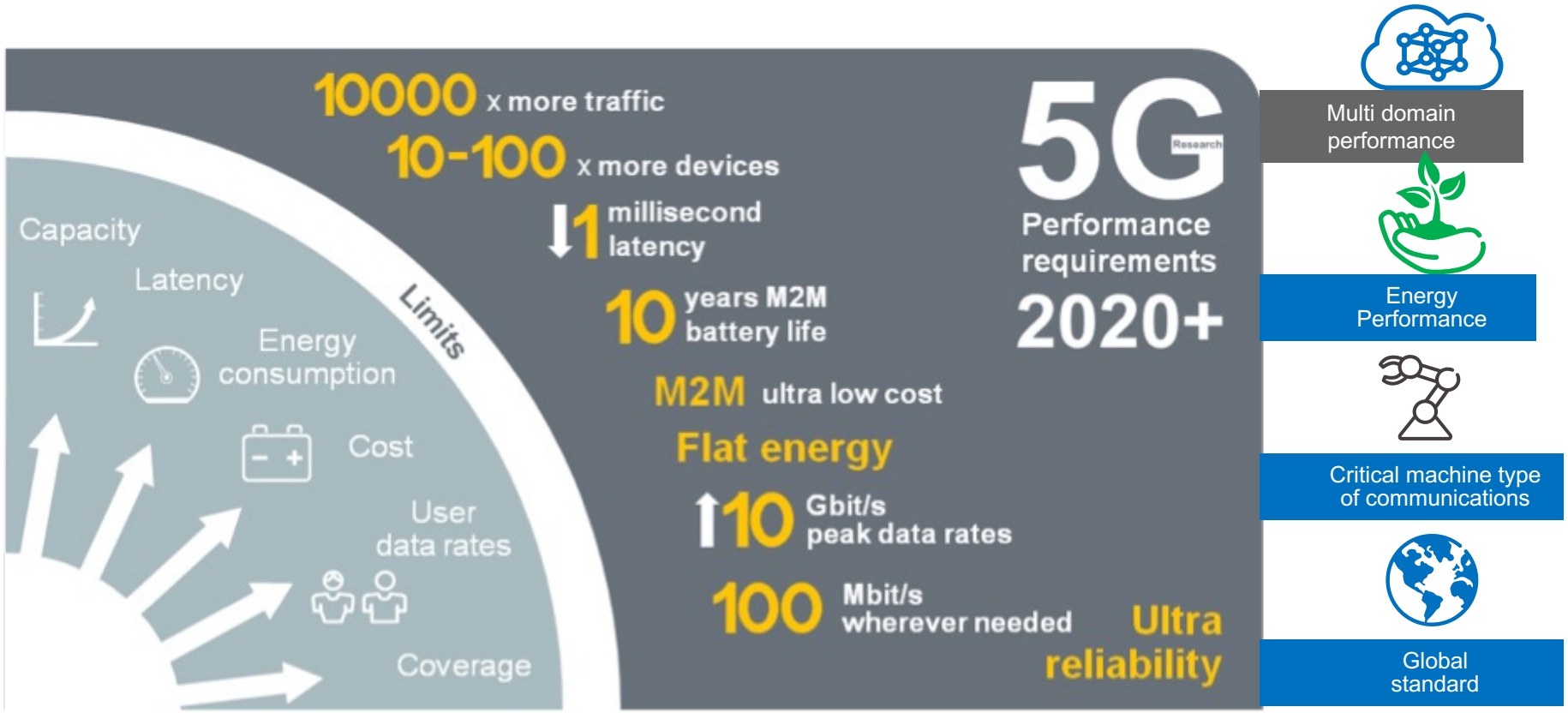


1G	2G	3G	4G	5G
1980s	1990s	2000s	2010s	2020
Analogue	Digital SMS	Multimedia Video Calling Mobile internet	Mobile Broadband Enhanced Video	Mobile Connected World Enhanced Mobile Broadband Low latency applications Internet of Things Augmented and Virtual Reality (AR & VR)

Different requirements for 5G applications and services



5G Mobile Network Expected Performance

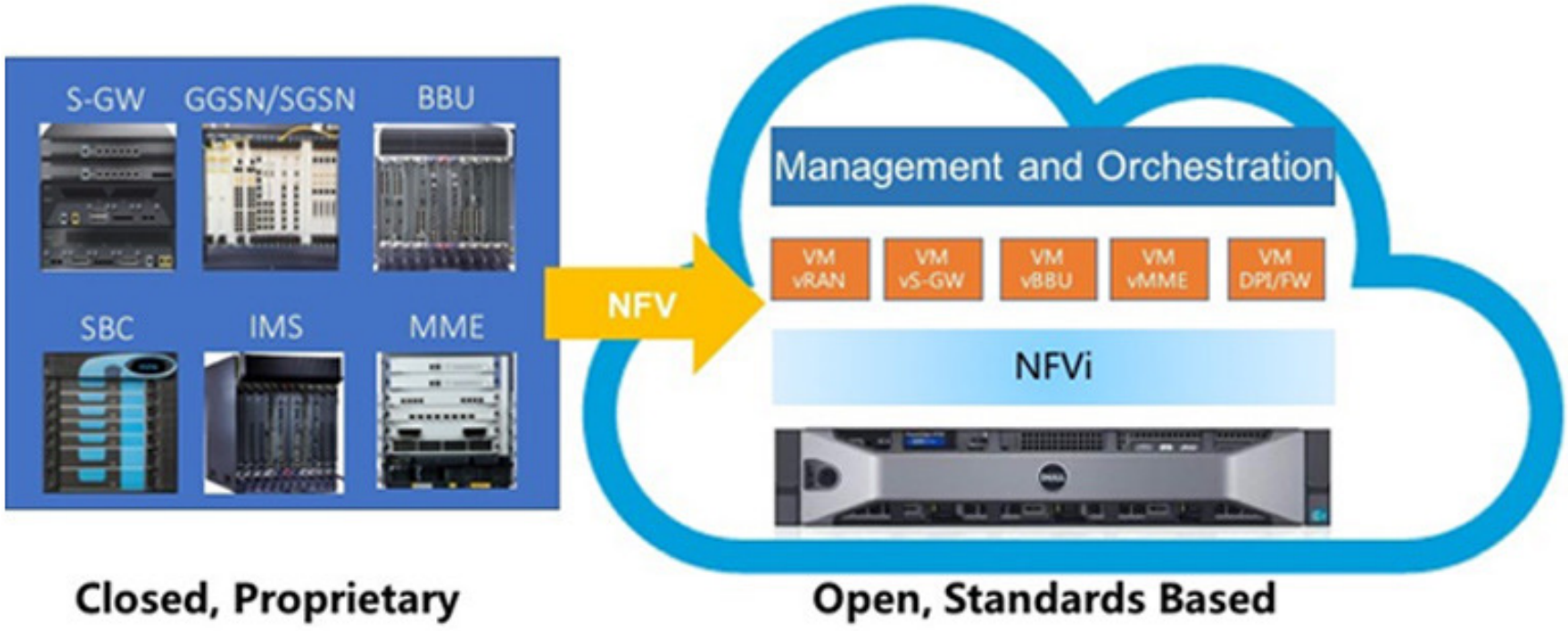


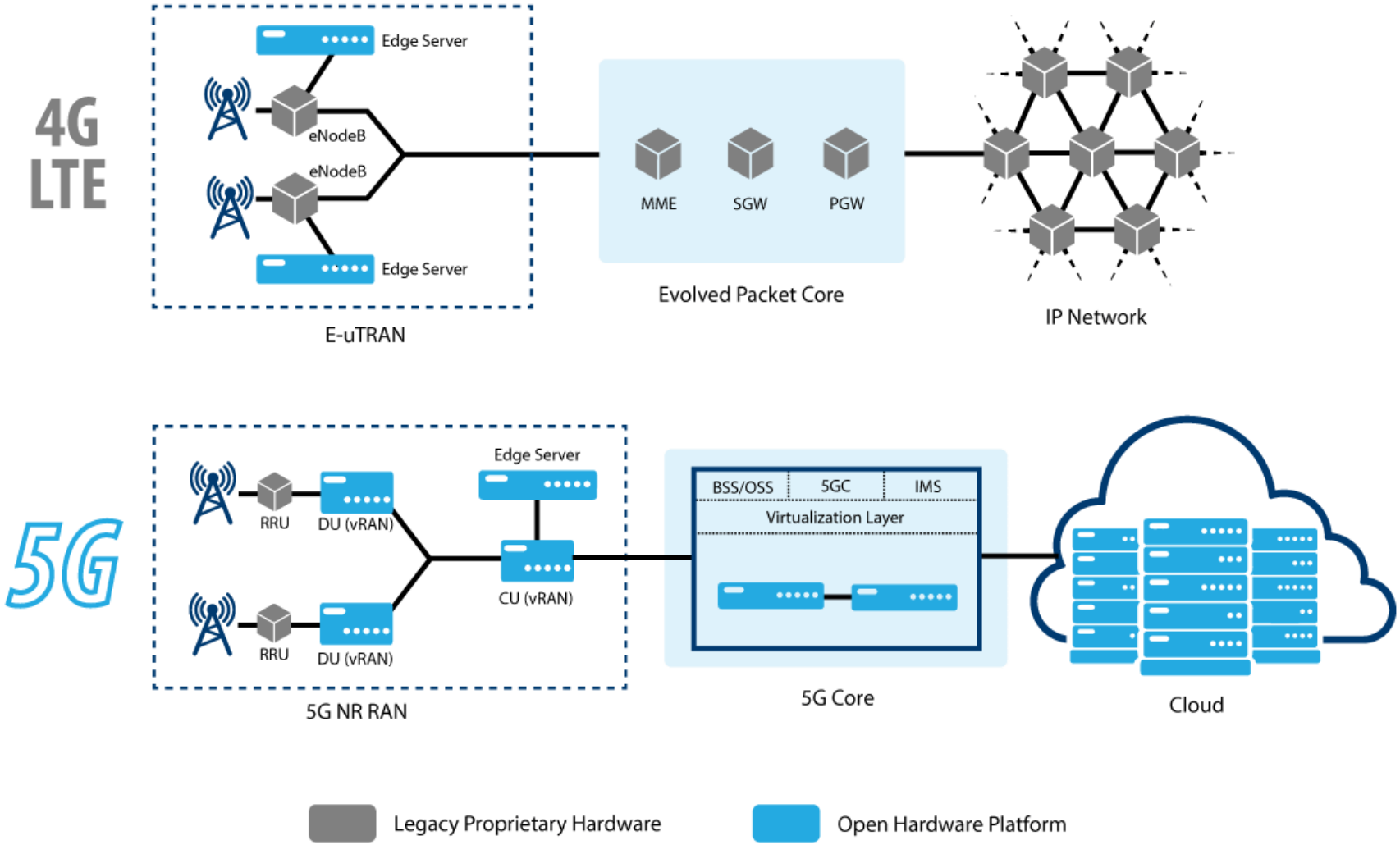
Back in the day…

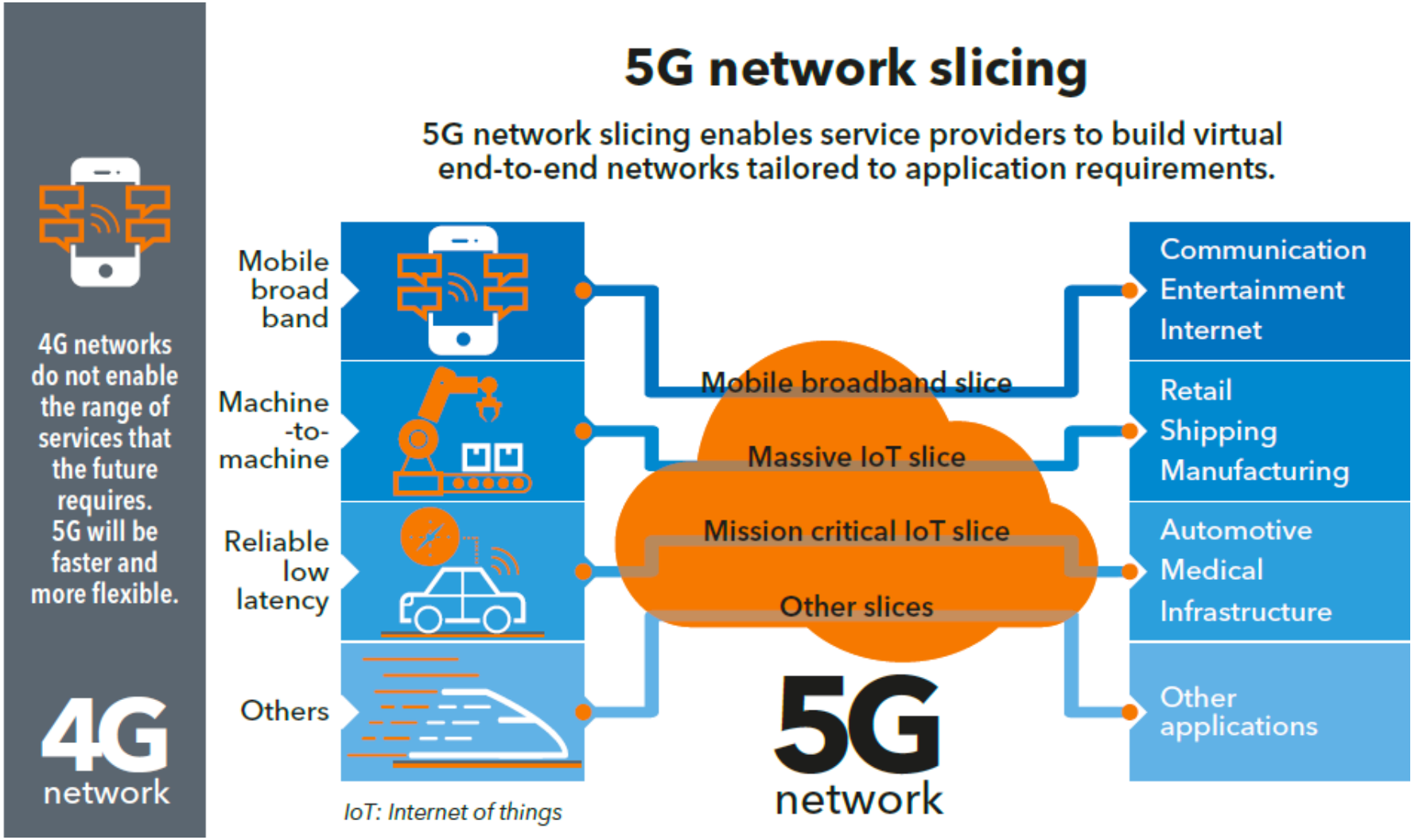
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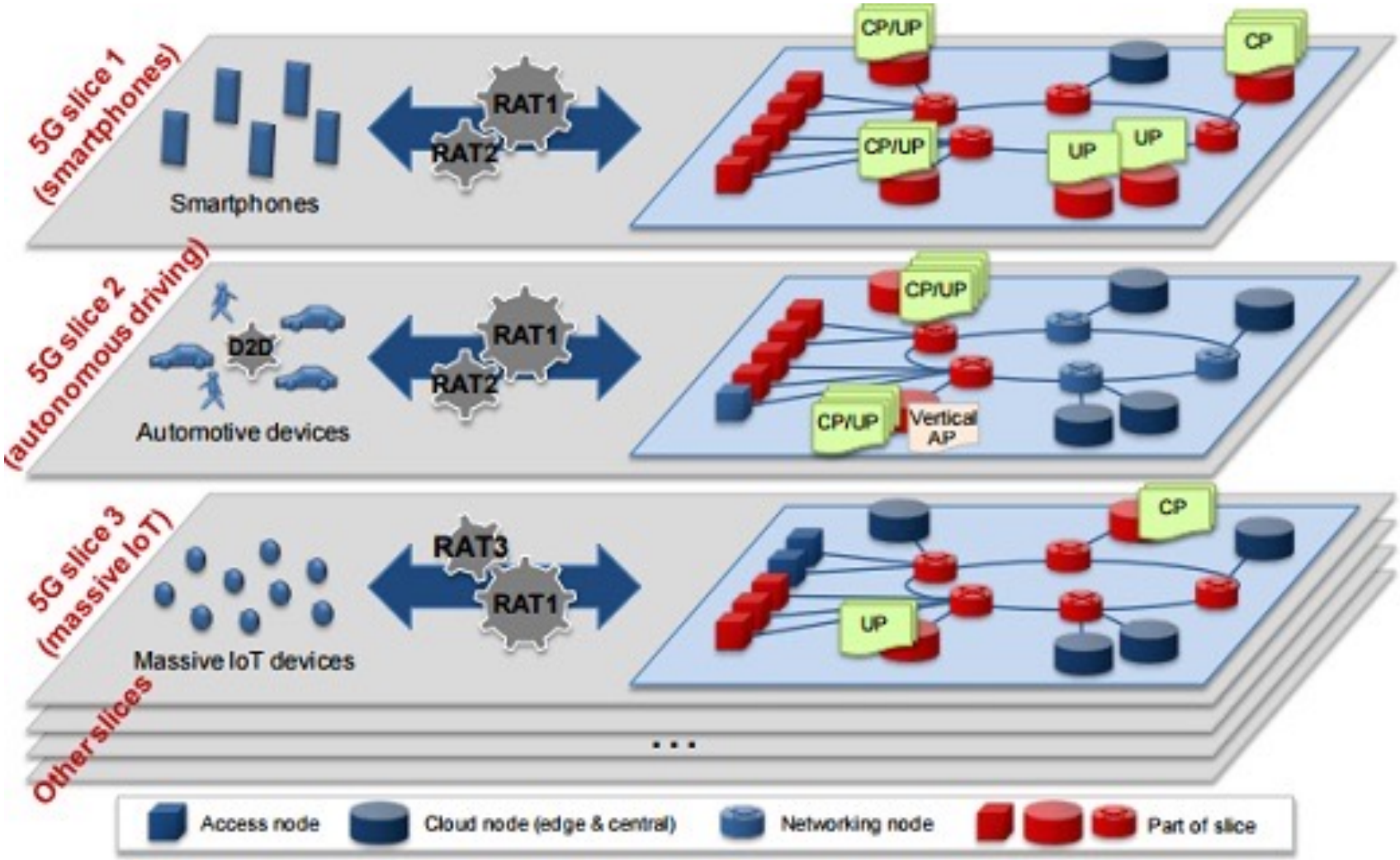
Network Flexibility: Virtualization




4G
LTE
Edge Server
eNodeB
eNodeB
Edge Server
E-uTRAN
MME
SGW
PGW
Evolved Packet Core
IP Network
5G
Edge Server
RRU
DU (vRAN)
RRU
DU (vRAN)
CU (vRAN)
5G NR RAN
BSS/OSS
5GC
IMS
Virtualization Layer
5G Core
Cloud
Legacy Proprietary Hardware
Open Hardware Platform

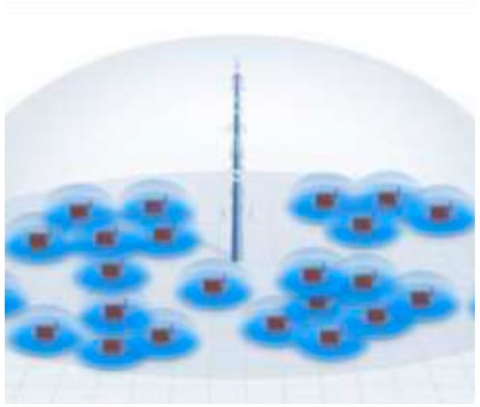

4G networks do not enable the range of services that the future requires. 5G will be faster and more flexible.
4G network
5G network slicing
5G network slicing enables service providers to build virtual end-to-end networks tailored to application requirements.
Mobile broad band
Machine -to- machine
Reliable low latency
Others
Mobile broadband slice
Massive IoT slice
Mission critical IoT slice
Other slices
5G network
Communication Entertainment Internet
Retail Shipping Manufacturing
Automotive Medical Infrastructure
Other applications
IoT: Internet of things

Network Slicing for diverse requirements



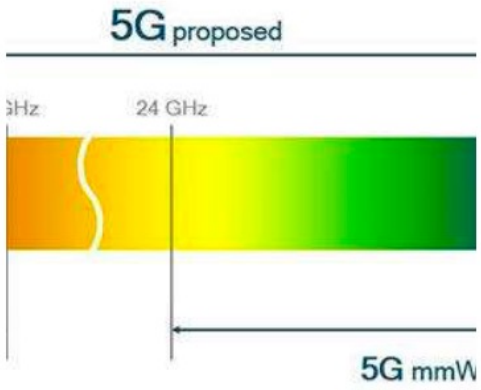
Capacity Enhancements

Densification



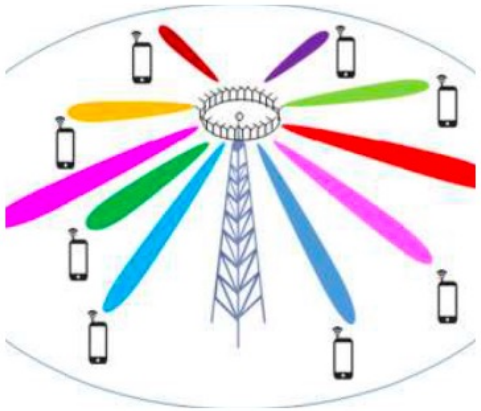
- Small cells, Relays, mobile Relays and Drones

More bandwidth



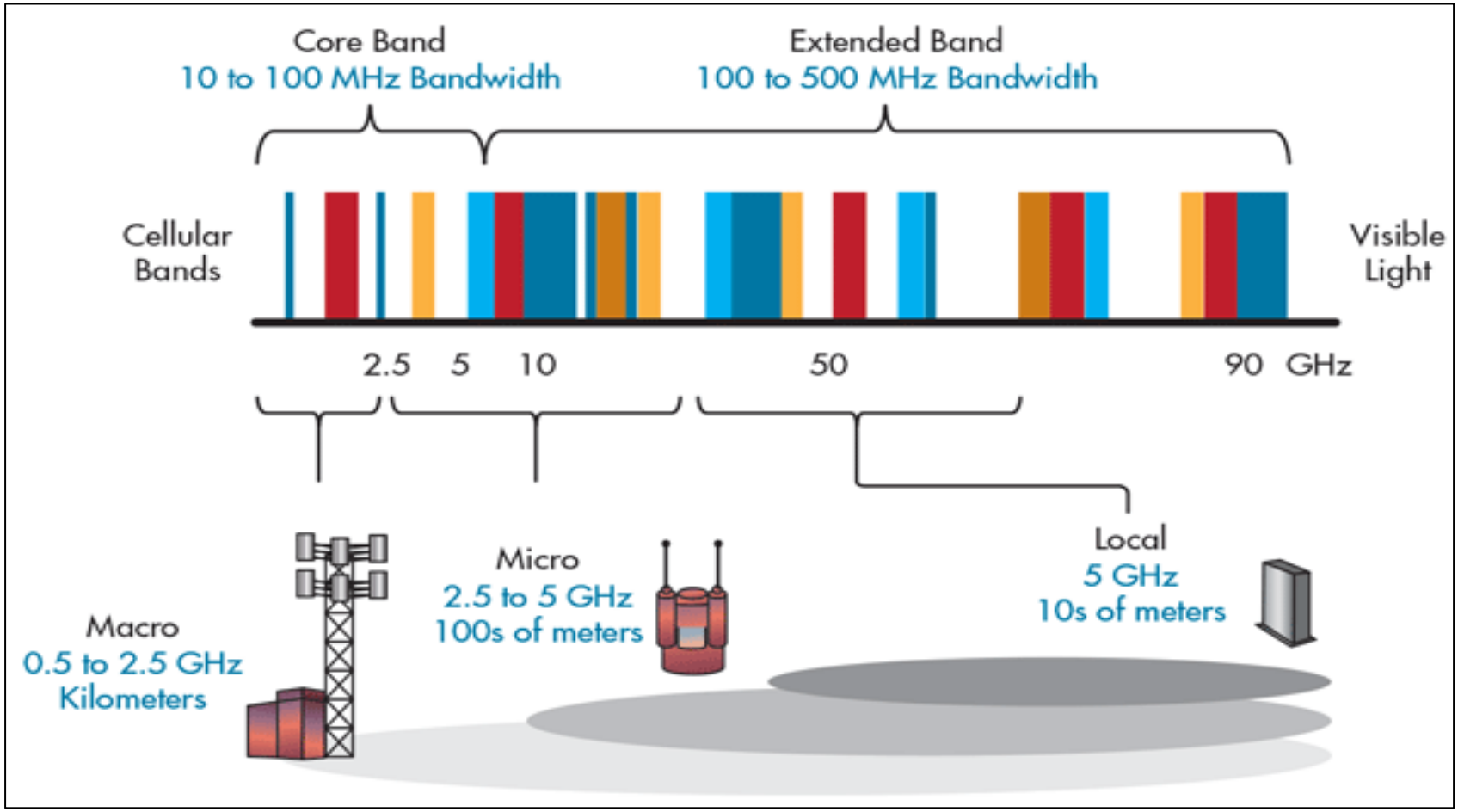
- new spectrum @ higher frequencies (above 6 GHz)

More antennas

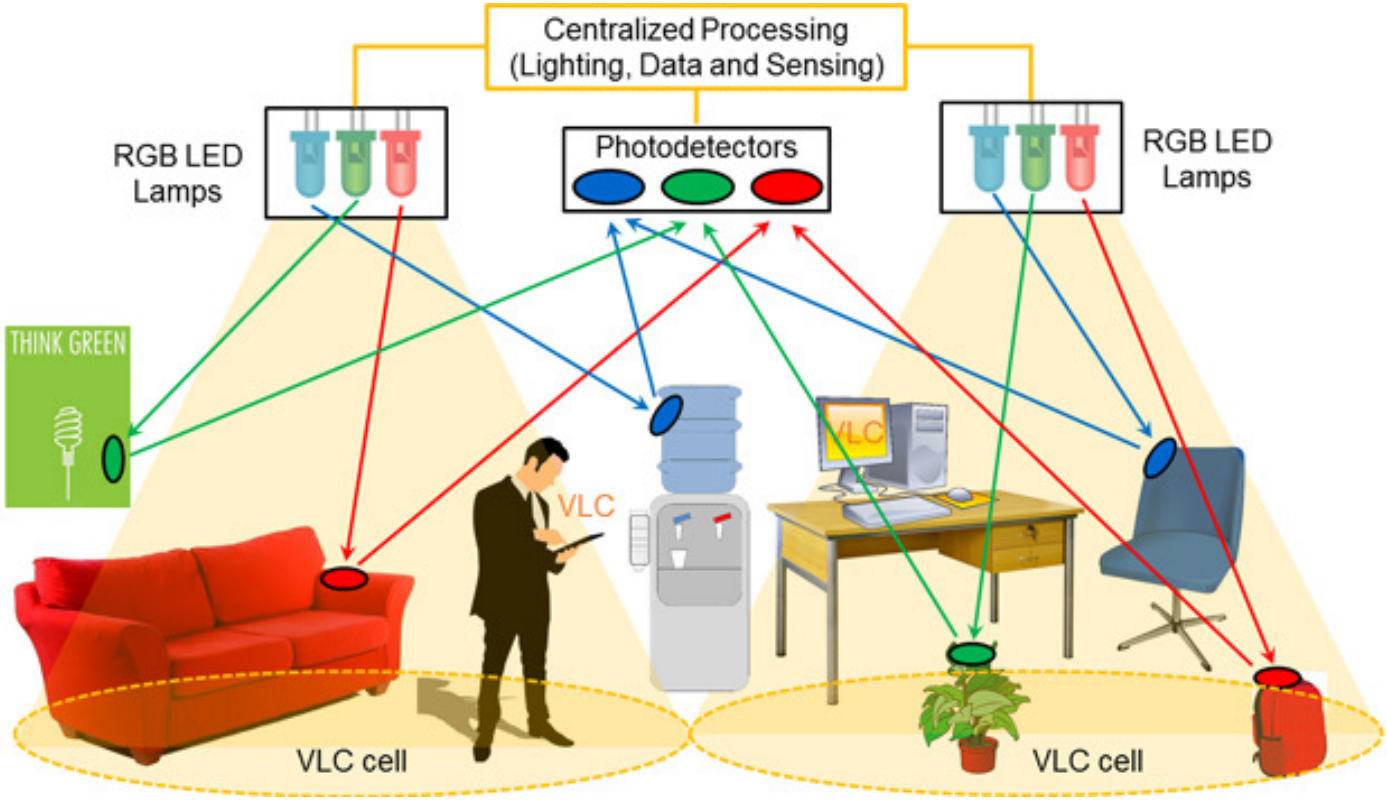


- Massive MIMO
- Spectrum sharing

5G Bands and its impact on Cell size

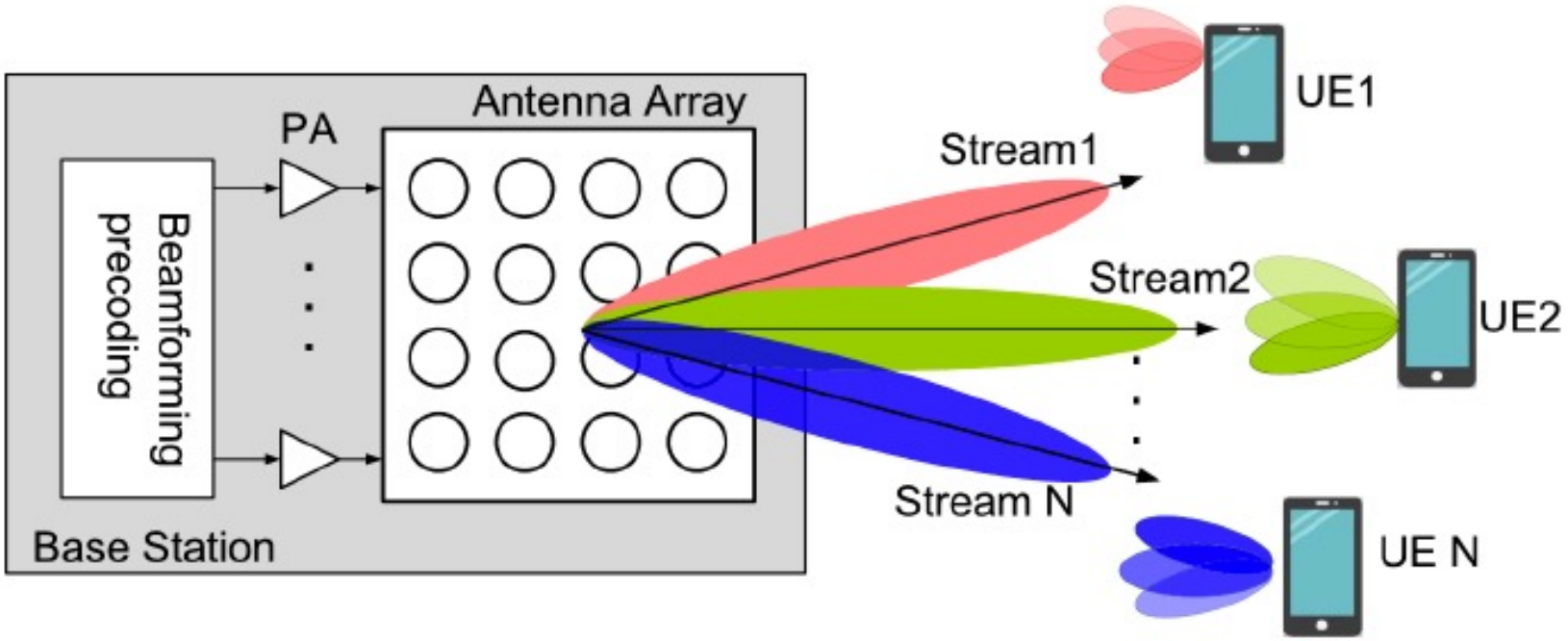


Visible Light Communications



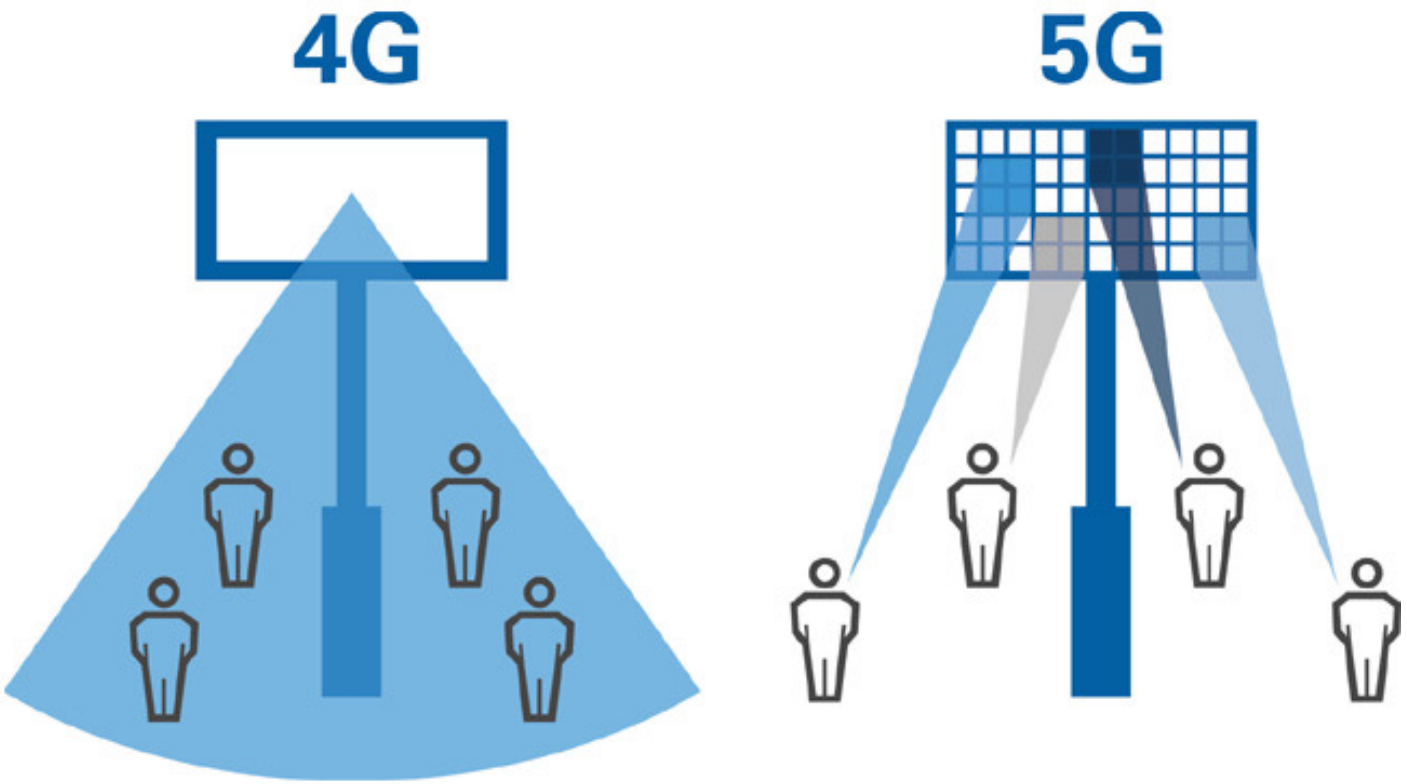
https://attract-eu.com/showroom/project/vladimir/

Millimeter Wave Massive MIMO



B. Yang, Z. Yu, Y. Dong, J. Zhou and W. Hong, "Compact Tapered Slot Antenna Array for 5G Millimeter-Wave Massive MIMO Systems," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 12, pp. 6721–6727, Dec. 2017.

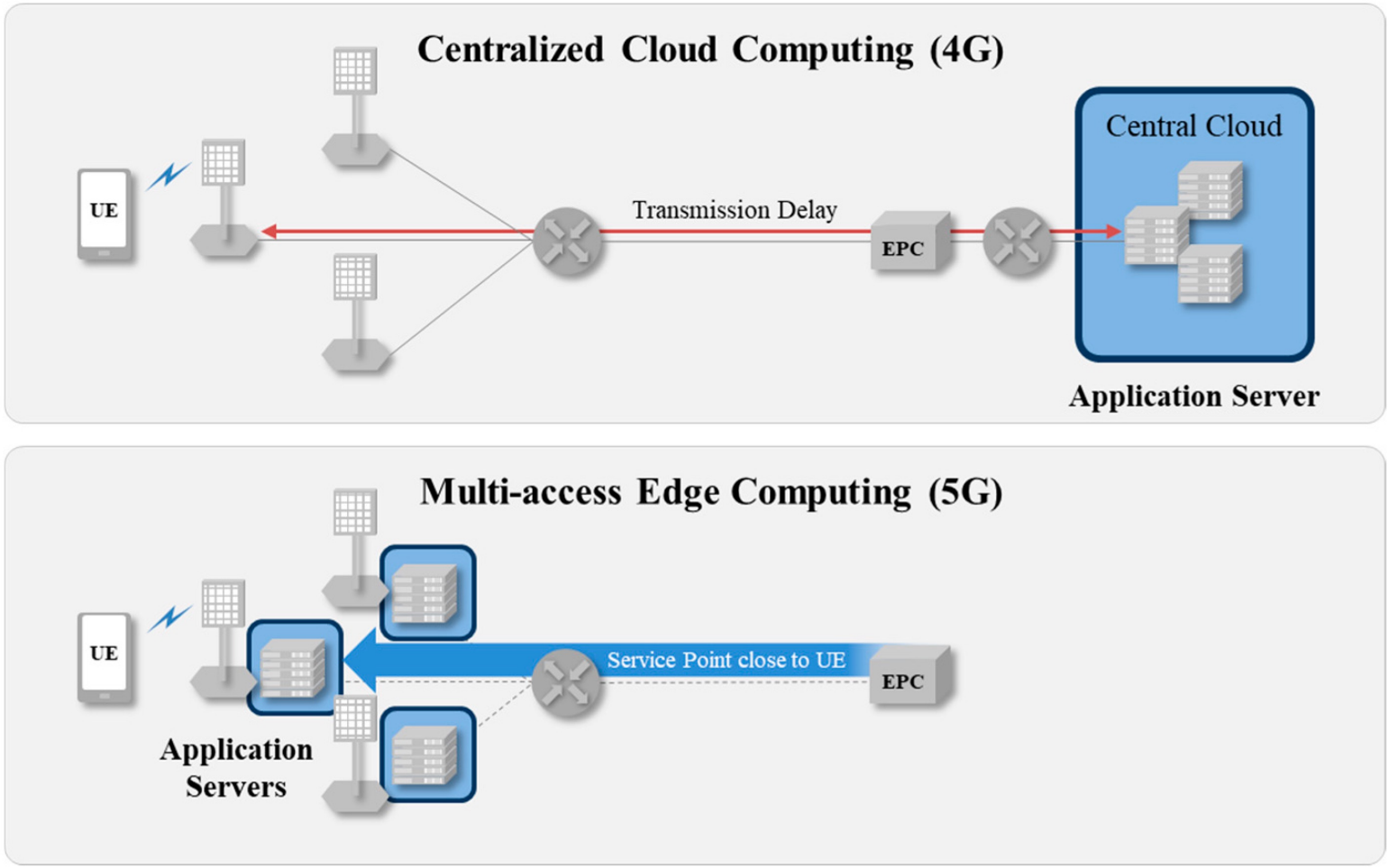
Multi-User MIMO Beamforming



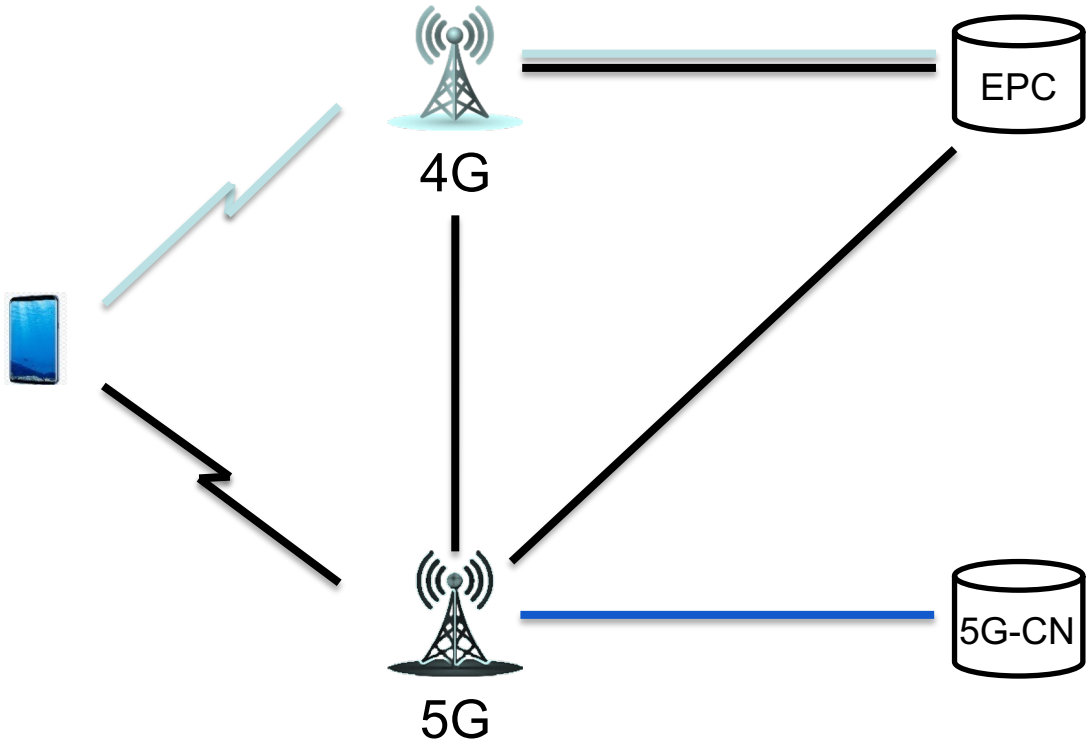
Spectrum Sharing: Multi-connectivity



Ultra high reliability and Low Latency



From 4G to 5G Transition



Today – 4G Access
Device attaches to LTE/4G radio and Evolved Packet Core (EPC)

Early 5G – Non-Standalone
Device attaches to 5G-NR, which routes either via 4G Base Station to EPC, or direct to EPC
4G acts as control plane

5G Standalone
Device attaches to 5G-NR and 5G Core Network.