

UiO : Faculty of Mathematics and Natural Sciences
University of Oslo

Department of Informatics
Networks and Distributed Systems (ND) group

IN3230/4230

Wireless Communications - III

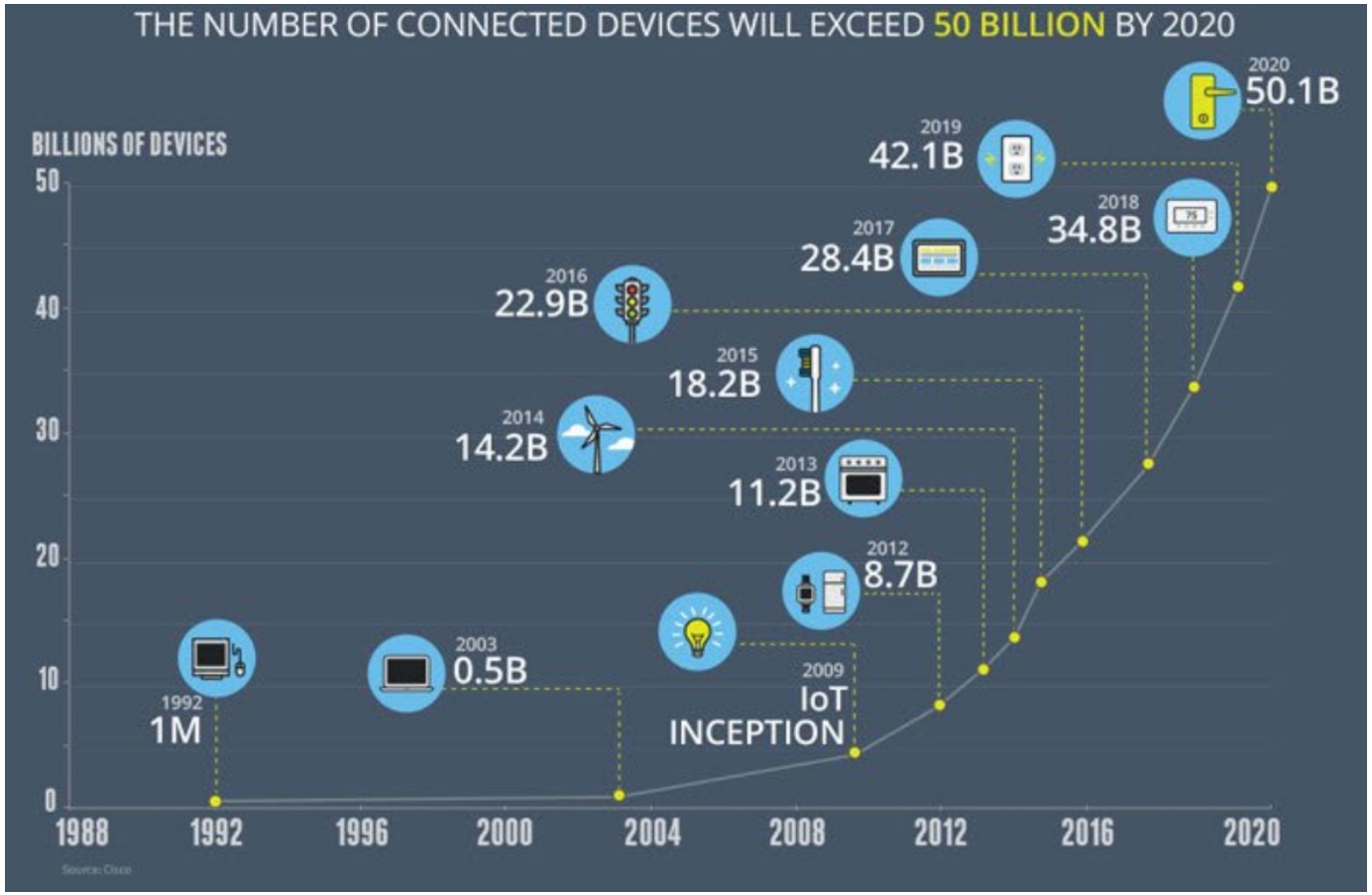


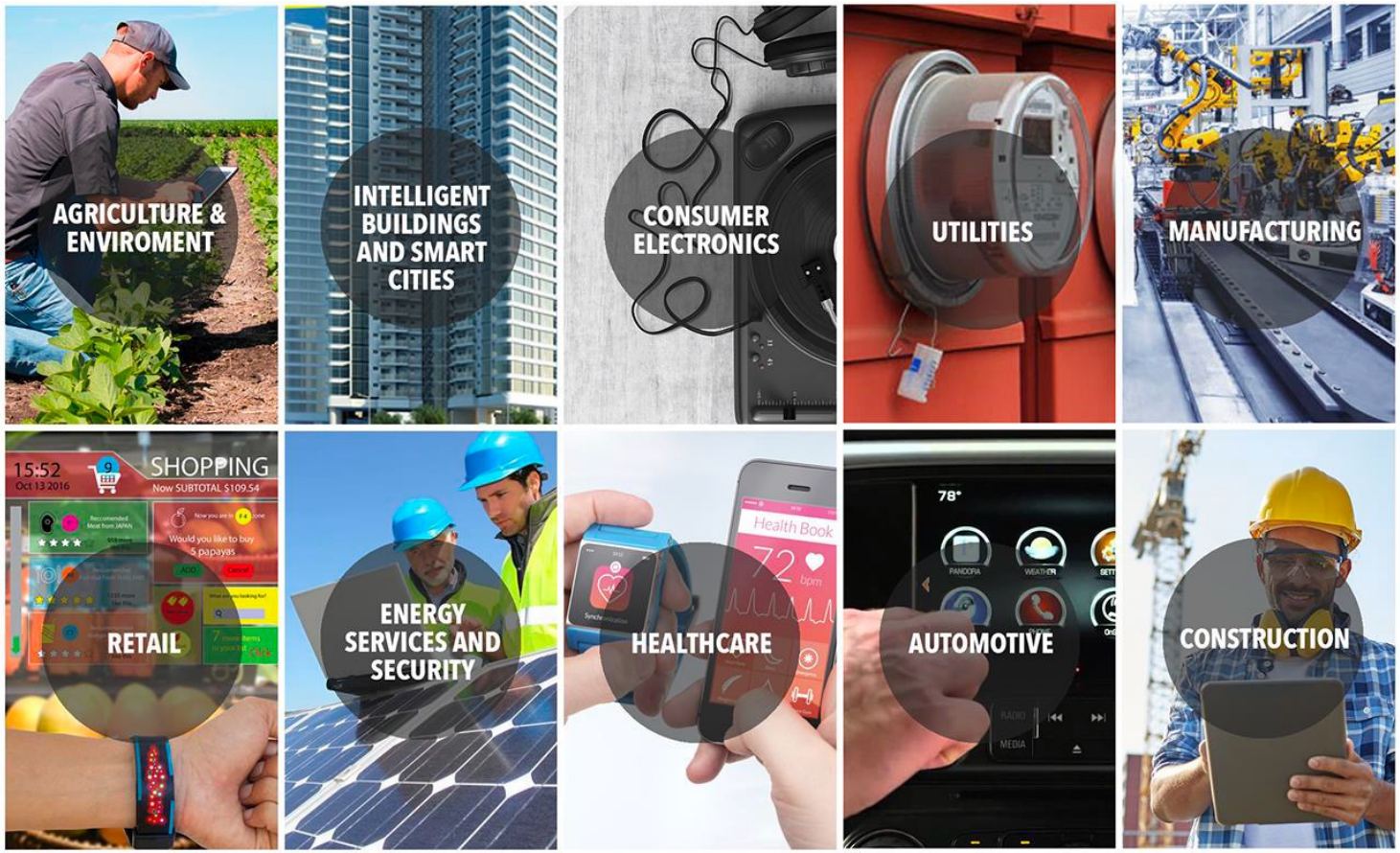
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Outline

- Massive IoT
  - NB-IoT
  - LORAWAN
- Paving the future
  - 5G and Beyond

Growth in the number of connected devices

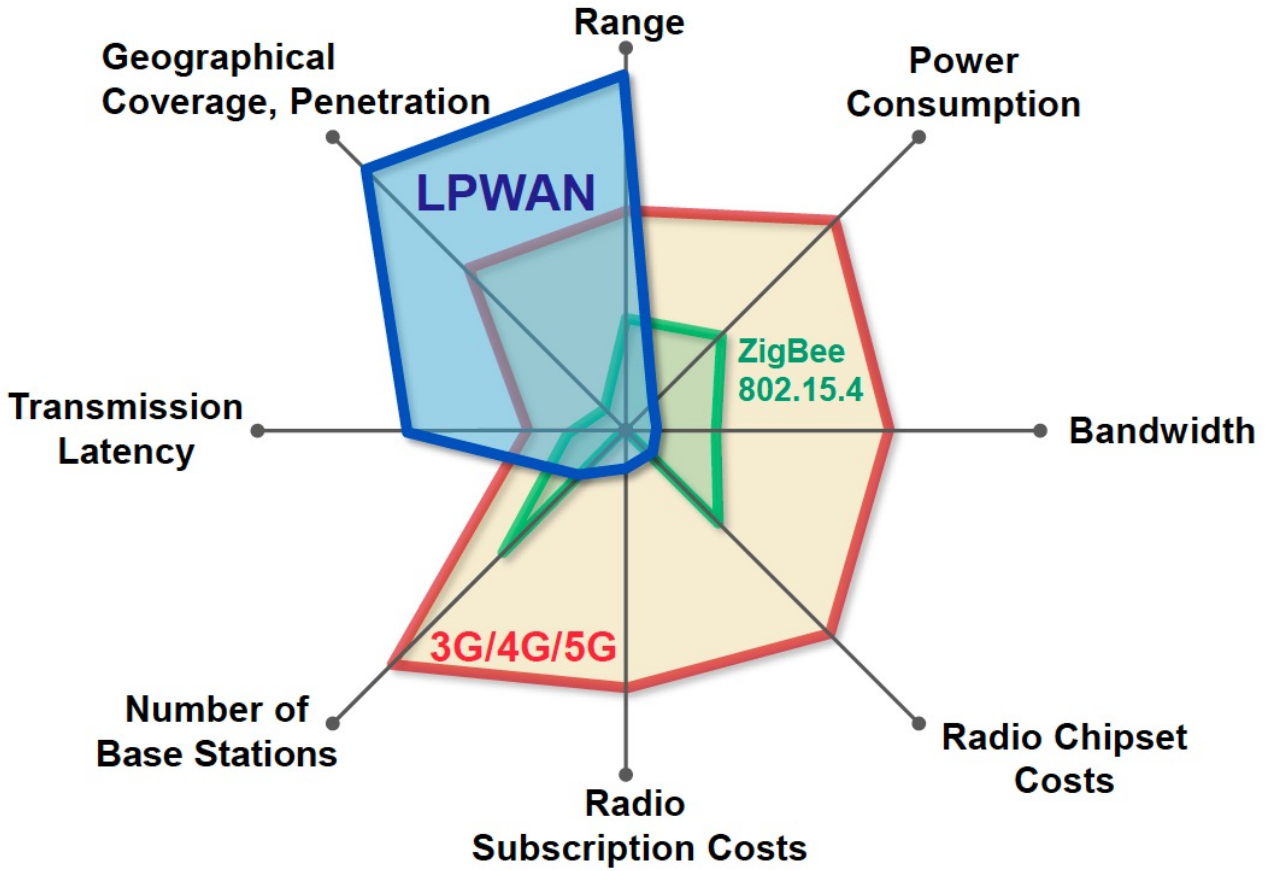



AGRICULTURE & ENVIROMENT
INTELLIGENT BUILDINGS AND SMART CITIES
CONSUMER ELECTRONICS
UTILITIES
MANUFACTURING
RETAIL
ENERGY SERVICES AND SECURITY
HEALTHCARE
AUTOMOTIVE
CONSTRUCTION

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)



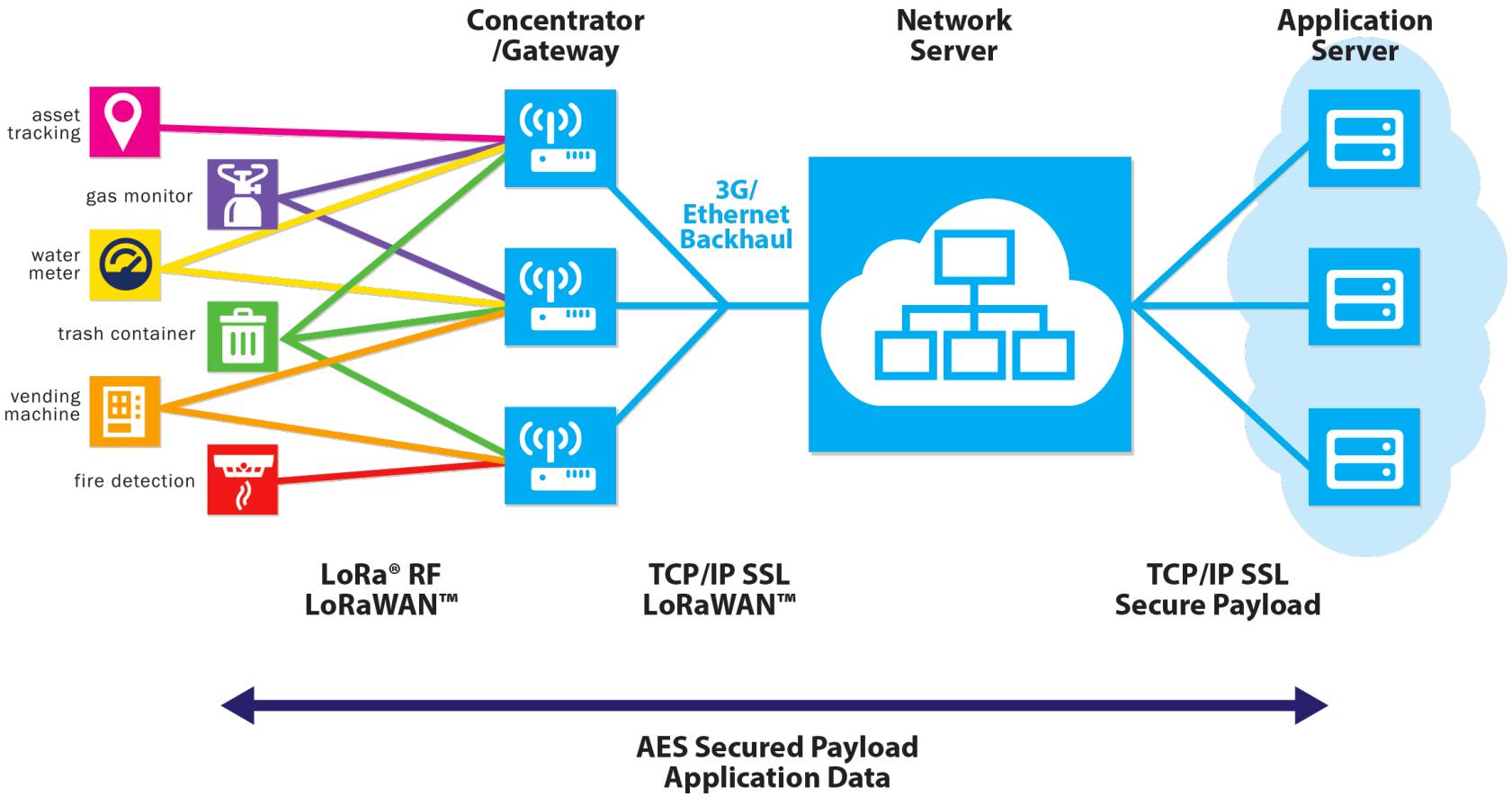
What is LORAWAN?

- 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)***

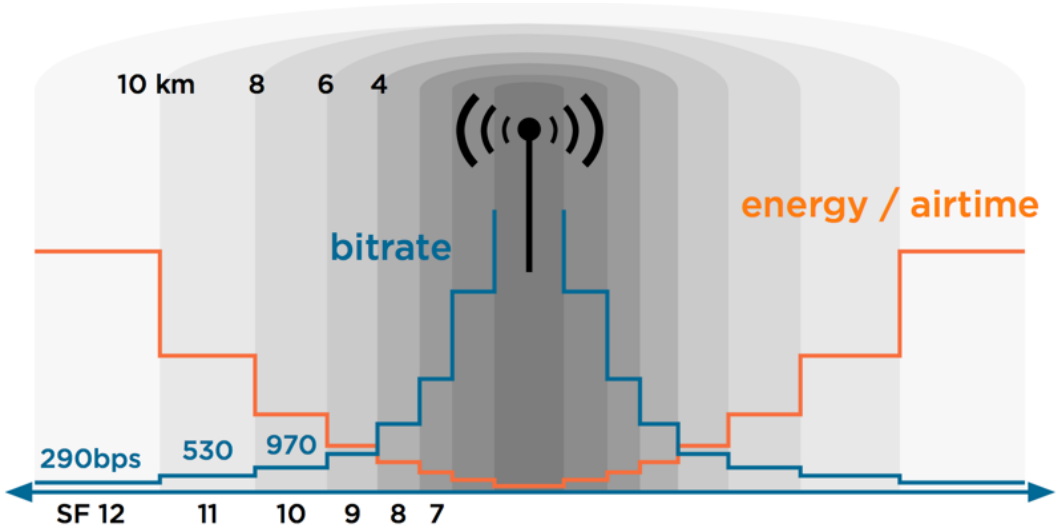
Adaptive Data Rate (ADR)

- 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.

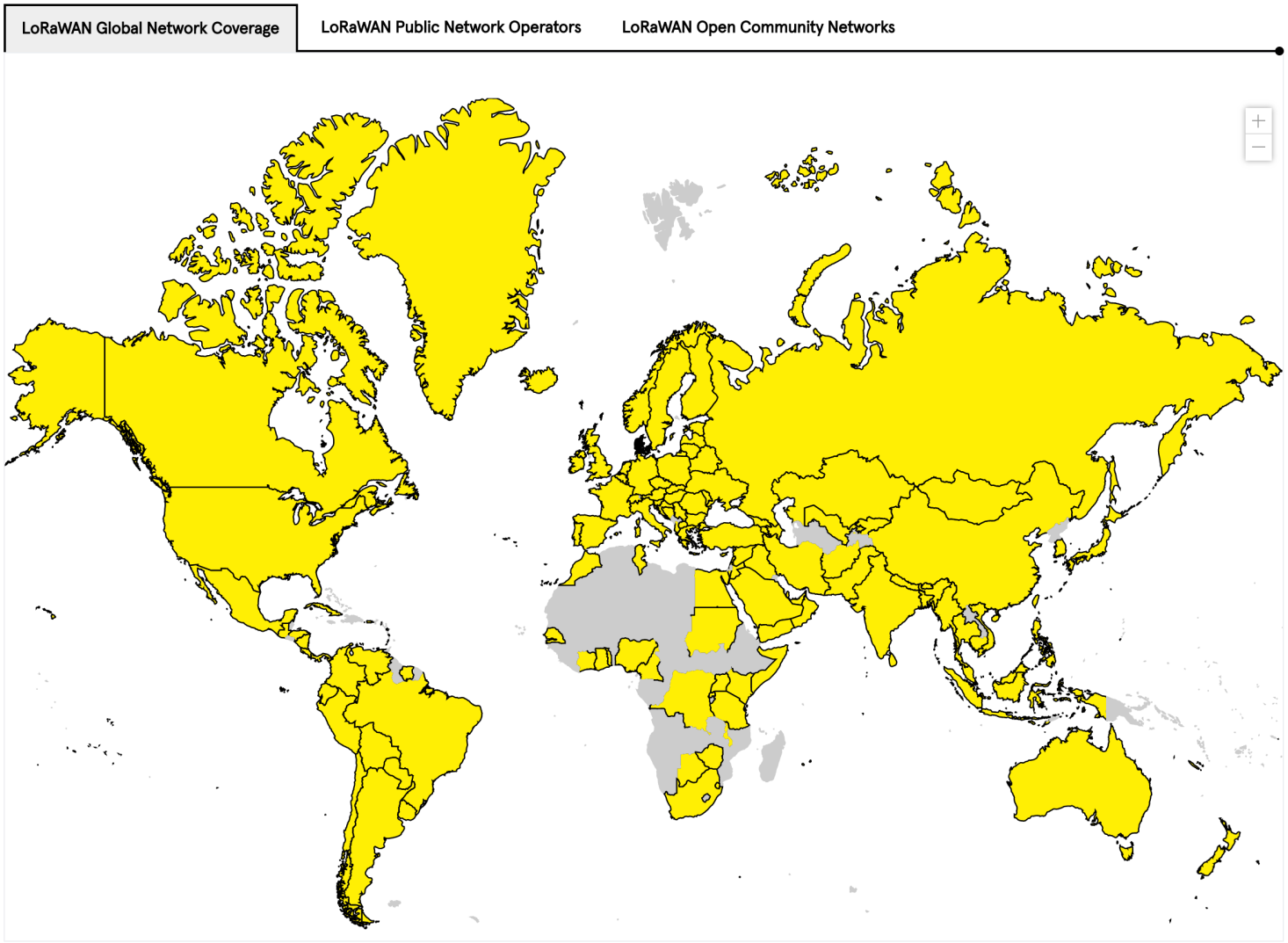
ADR triggers:

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

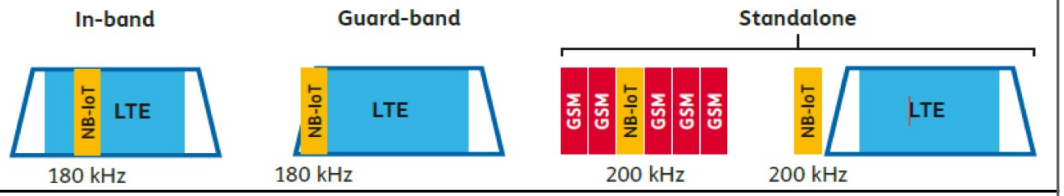


What is NB-IoT?

- 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

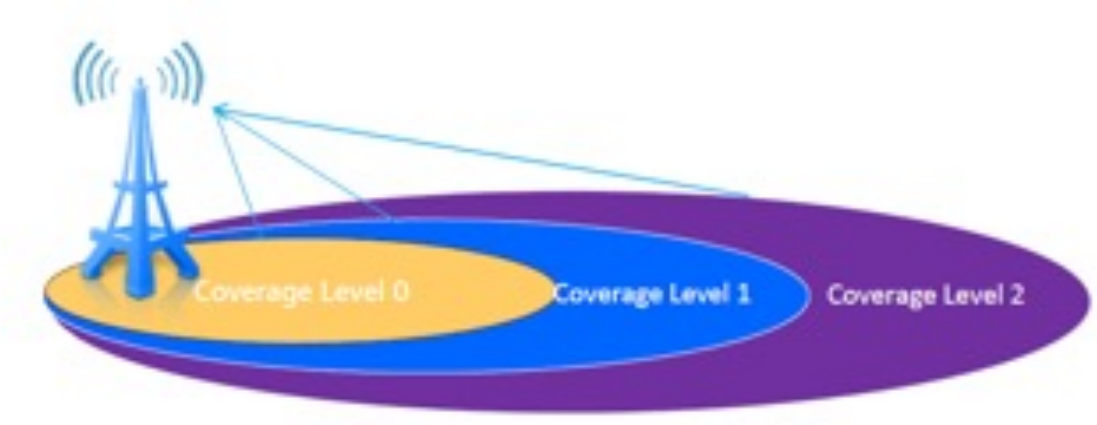
NB-IoT Specification

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

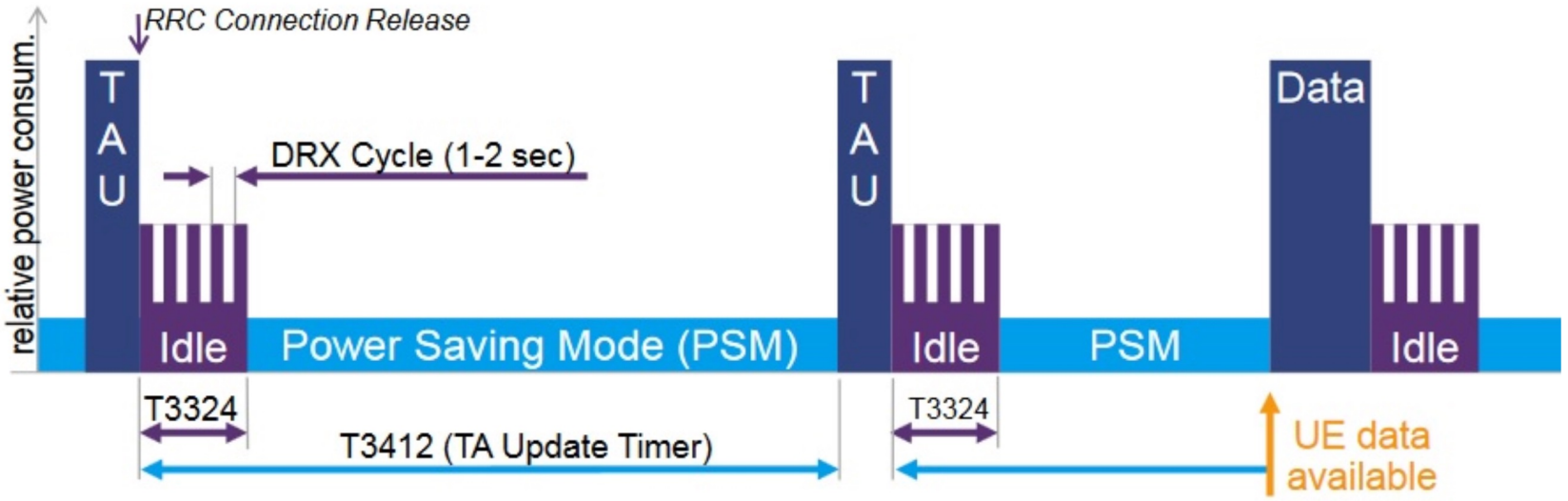


CE Level (CL)	# Repetitions
0	[0-2]
1	[4-16]
2	[32-128]

CL0 = LTE coverage

NB-IoT Power Savings

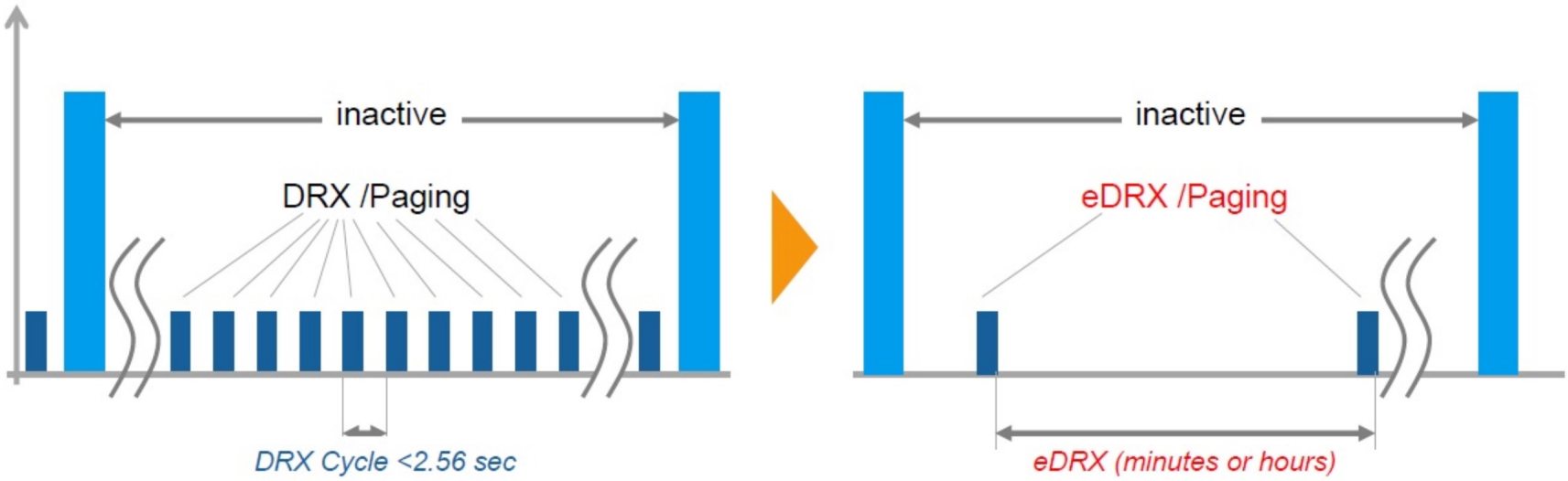
- **Power Saving Mode (PSM)** is a power-off mode, in which the device nevertheless remains registered on the network



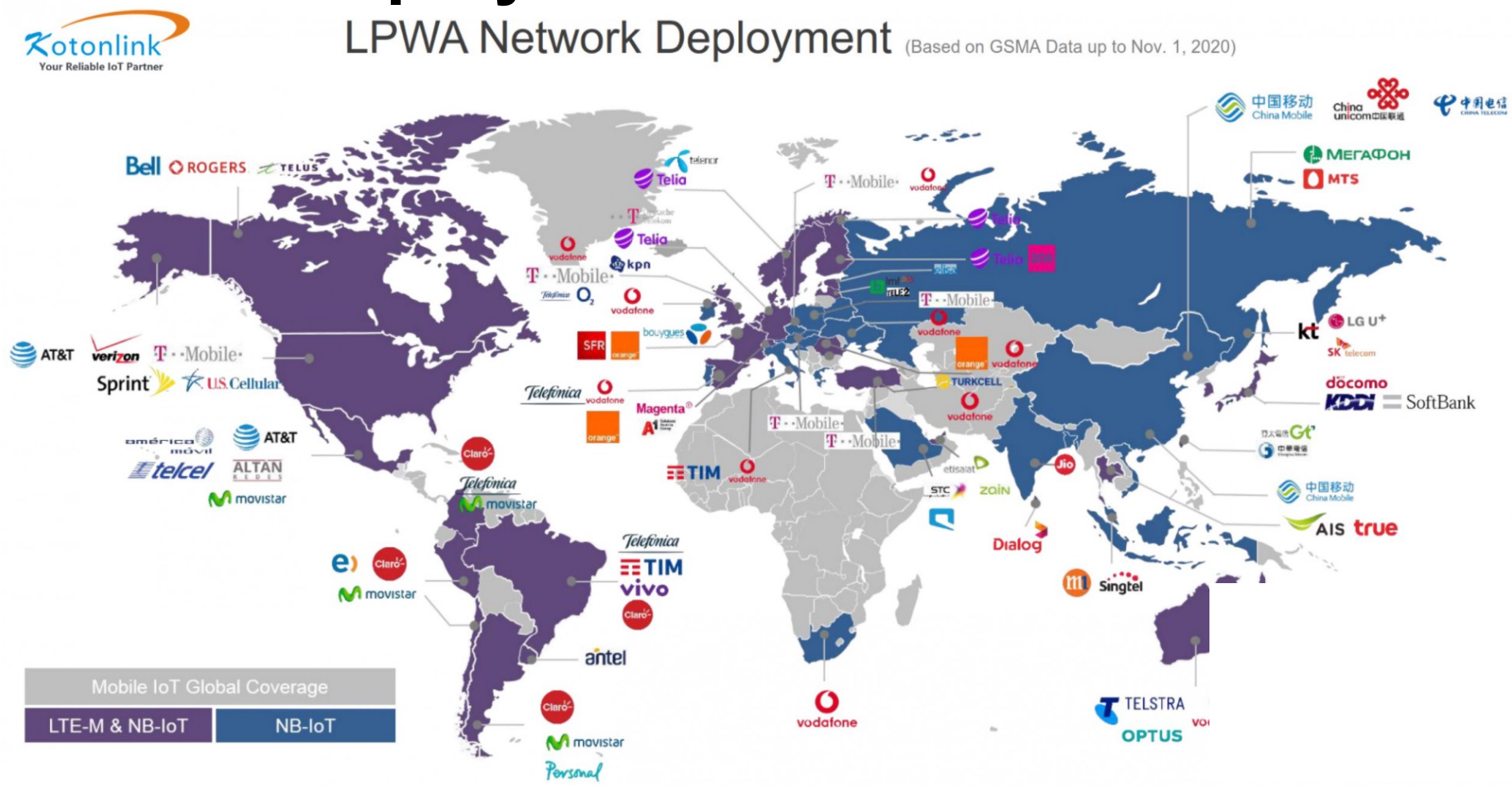
TAU: Tracking Area Update
RRC: Radio Resource Control
DRX: Discontinuous Reception

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

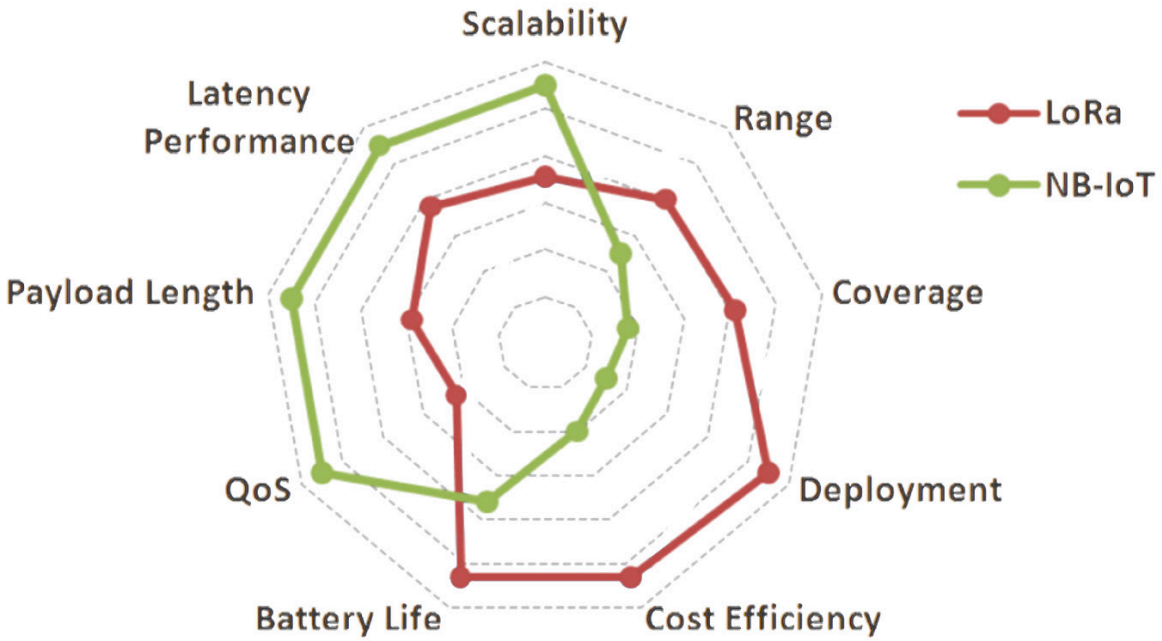


*Source: https://www.kotonlink.com/NewsDetail/2434022.html

LORAWAN vs NB-IoT

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

Overall LORAWAN vs NB-IoT



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- Massive IoT
  - NB-IoT
  - LORAWAN
- Paving the future
  - 5G and Beyond

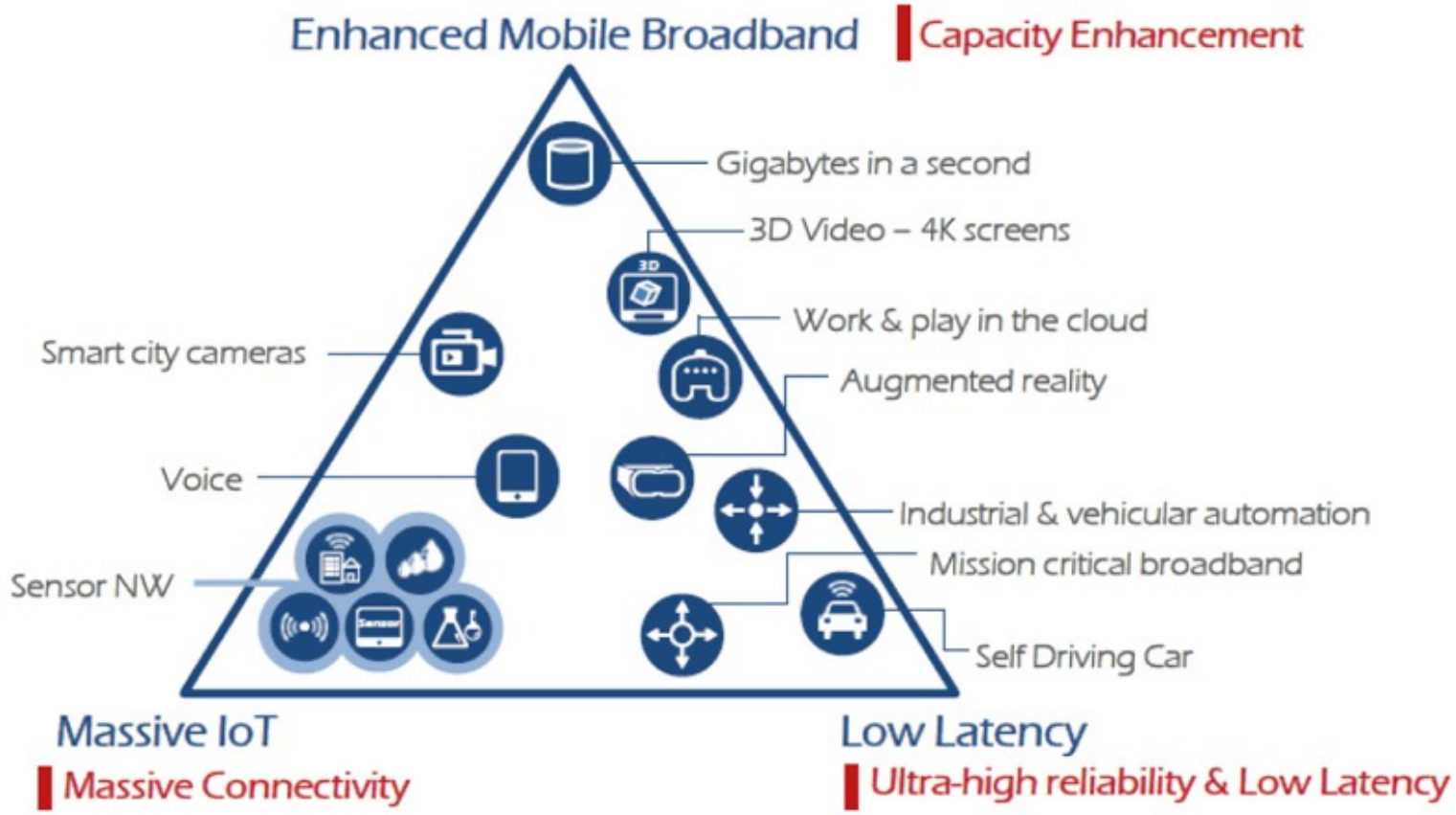
What is 5G?

5G is the 5th generation of mobile networks

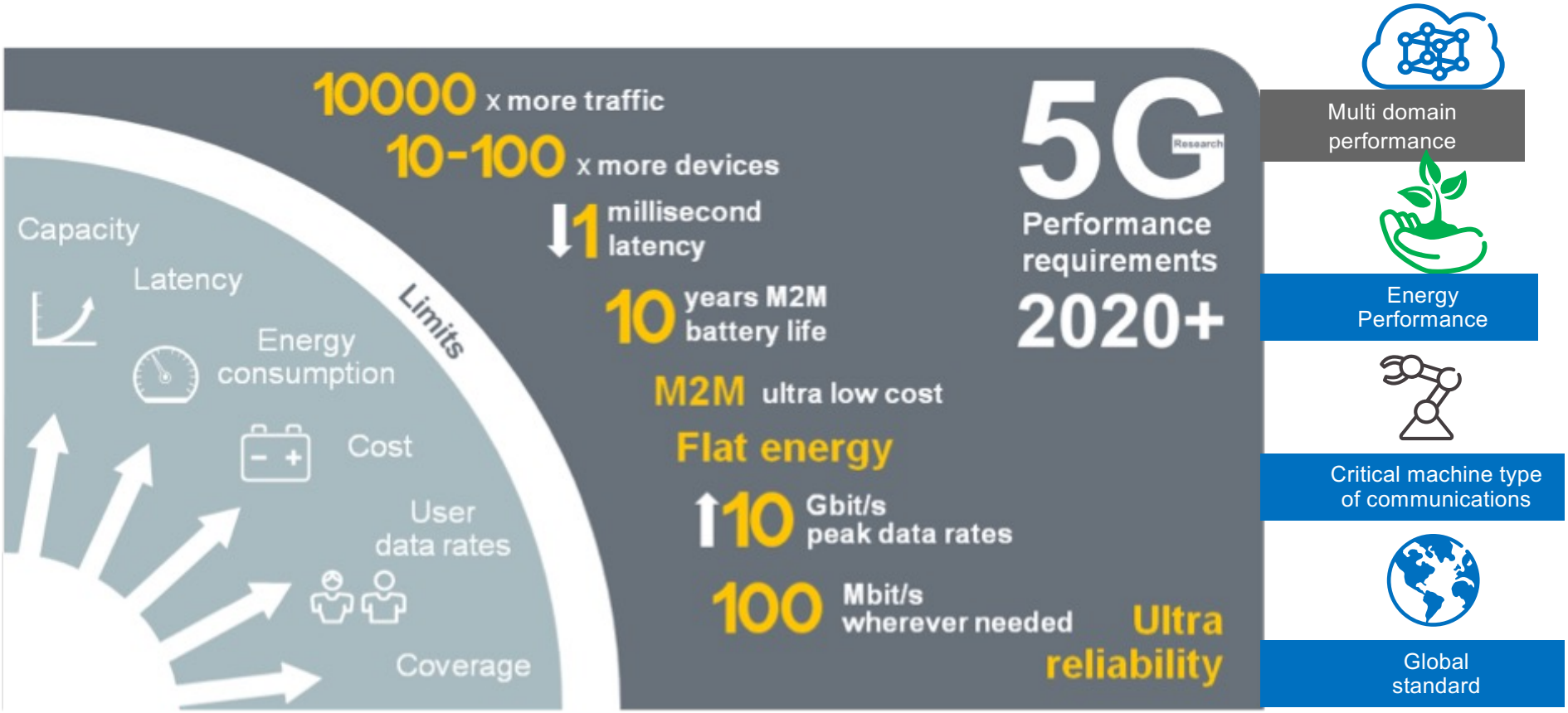


1G	2G	3G	4G	5G
1980s	1990s	2000s	2010s	2020
Analogue	Digital SMS	Multimedia Video Calling Mobile internet	Mobile Broadband Enhanced Video	Mobile Connected World Enhanced Mobile Broadband Low latency applications Internet of Things Augmented and Virtual Reality (AR & VR)

Different requirements for 5G applications and services



5G Mobile Network Expected Performance

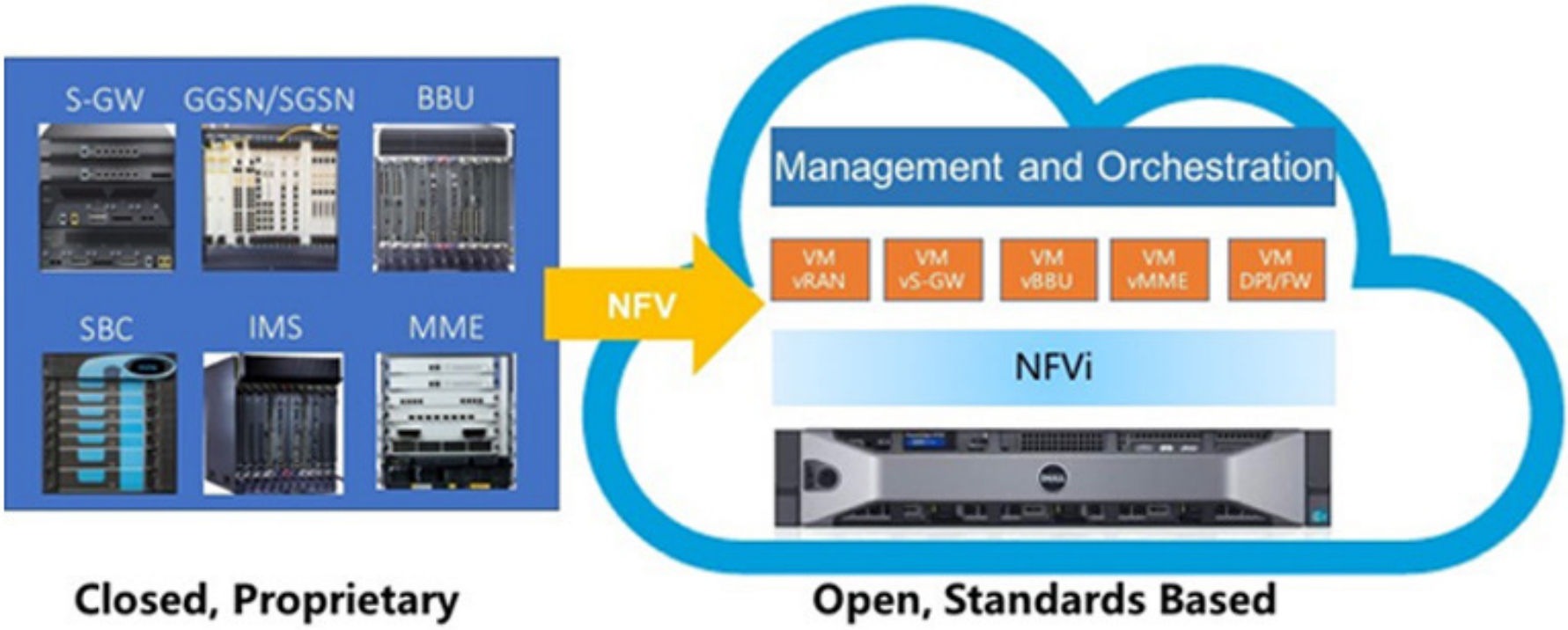


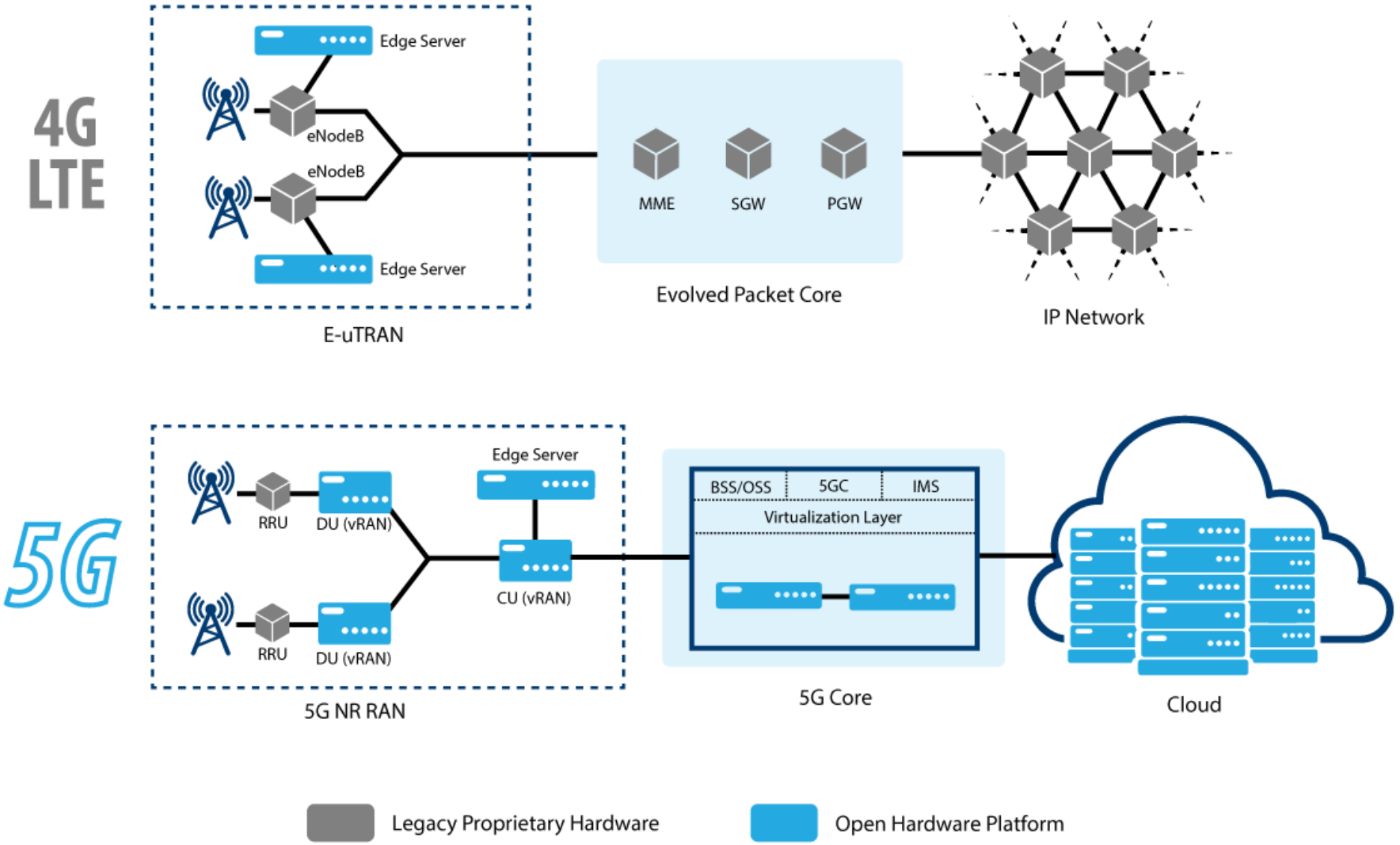
Back in the day…

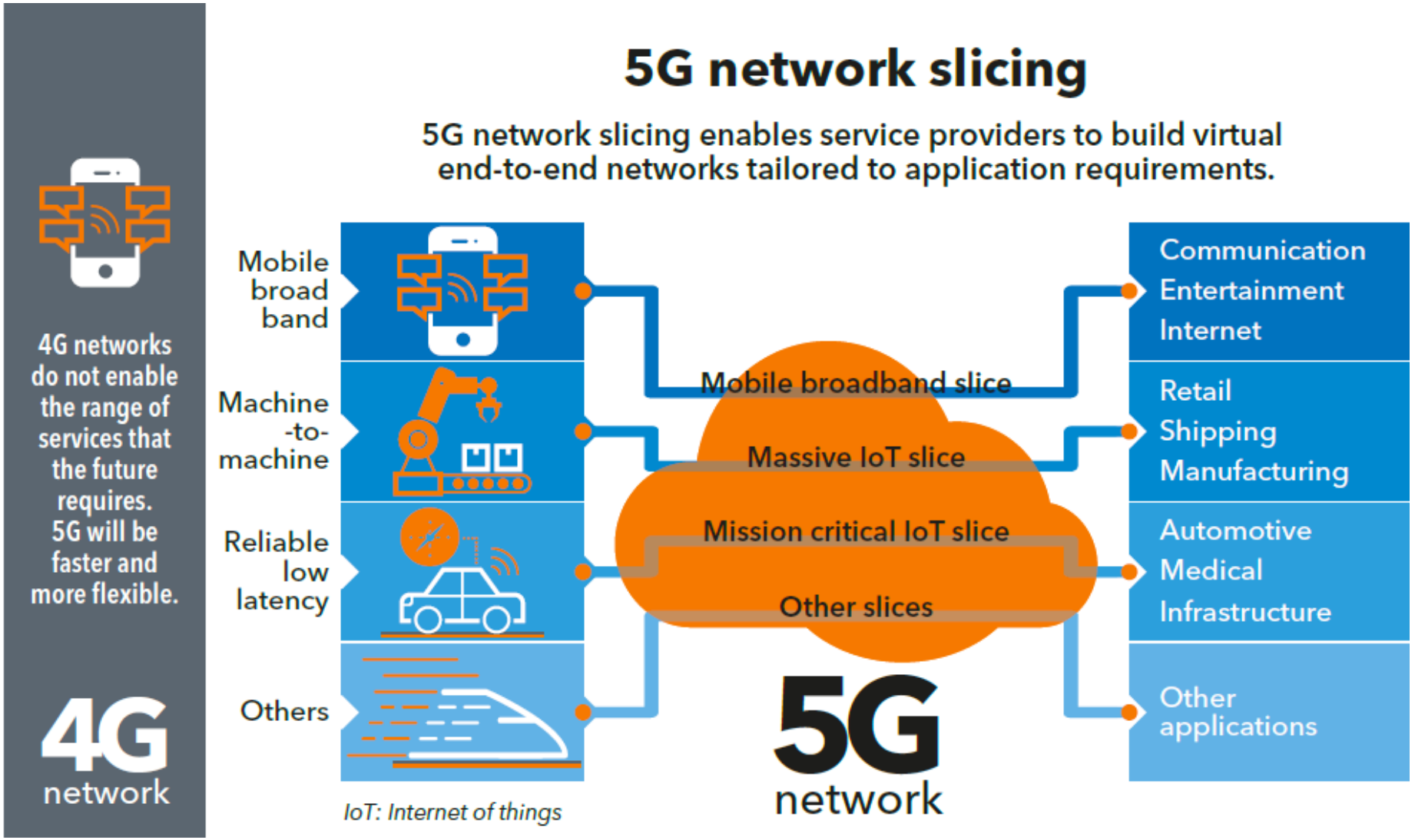
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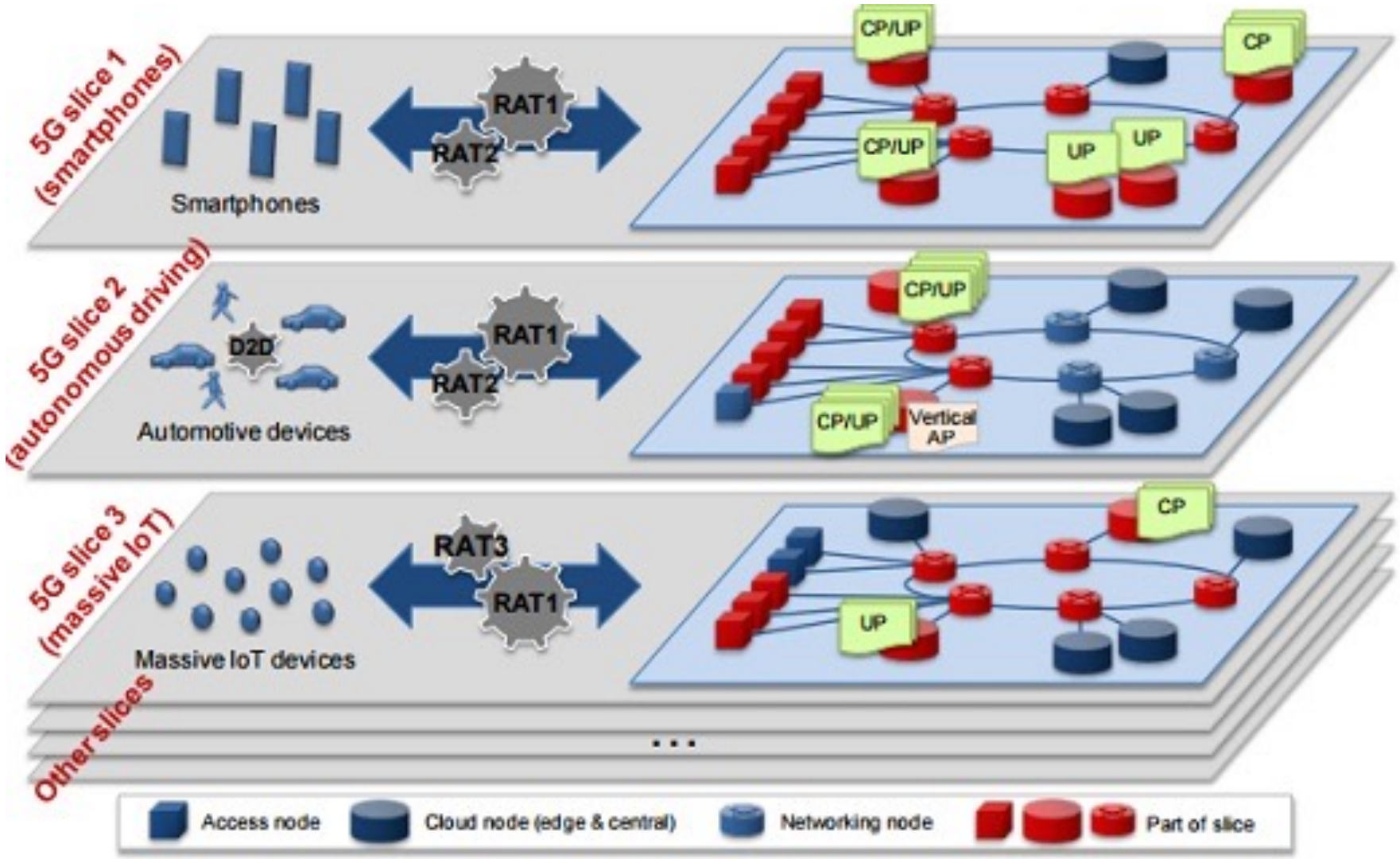
Network Flexibility: Virtualization




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

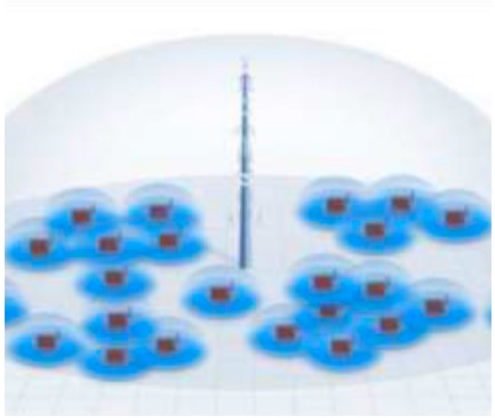

4G networks do not enable the range of services that the future requires. 5G will be faster and more flexible.
4G network
5G network slicing
5G network slicing enables service providers to build virtual end-to-end networks tailored to application requirements.
Mobile broad band
Machine -to- machine
Reliable 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



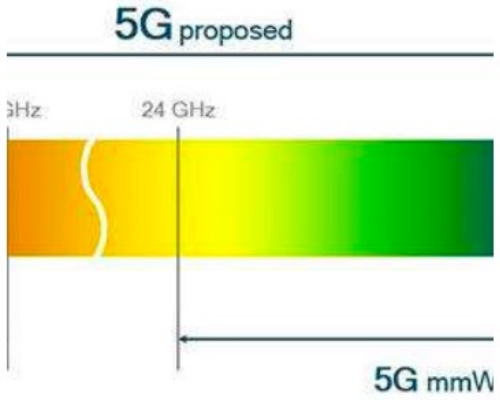
Capacity Enhancements

Densification



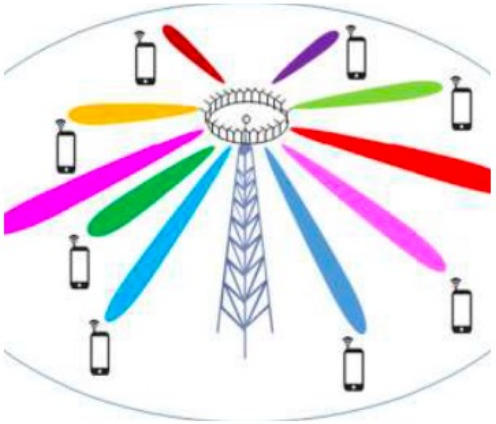
- Small cells, Relays, mobile Relays and Drones

More bandwidth



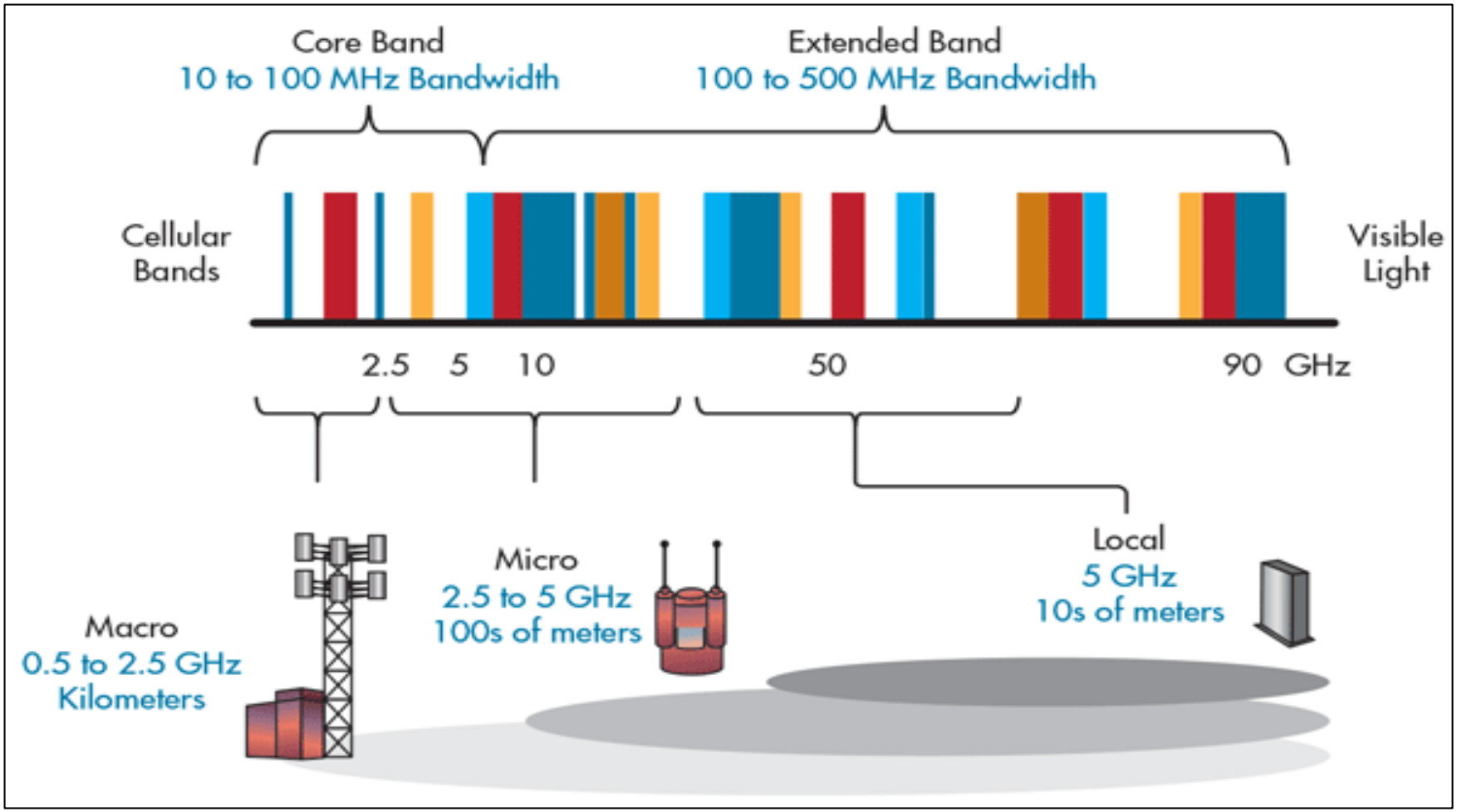
- new spectrum @ higher frequencies (above 6 GHz)

More antennas

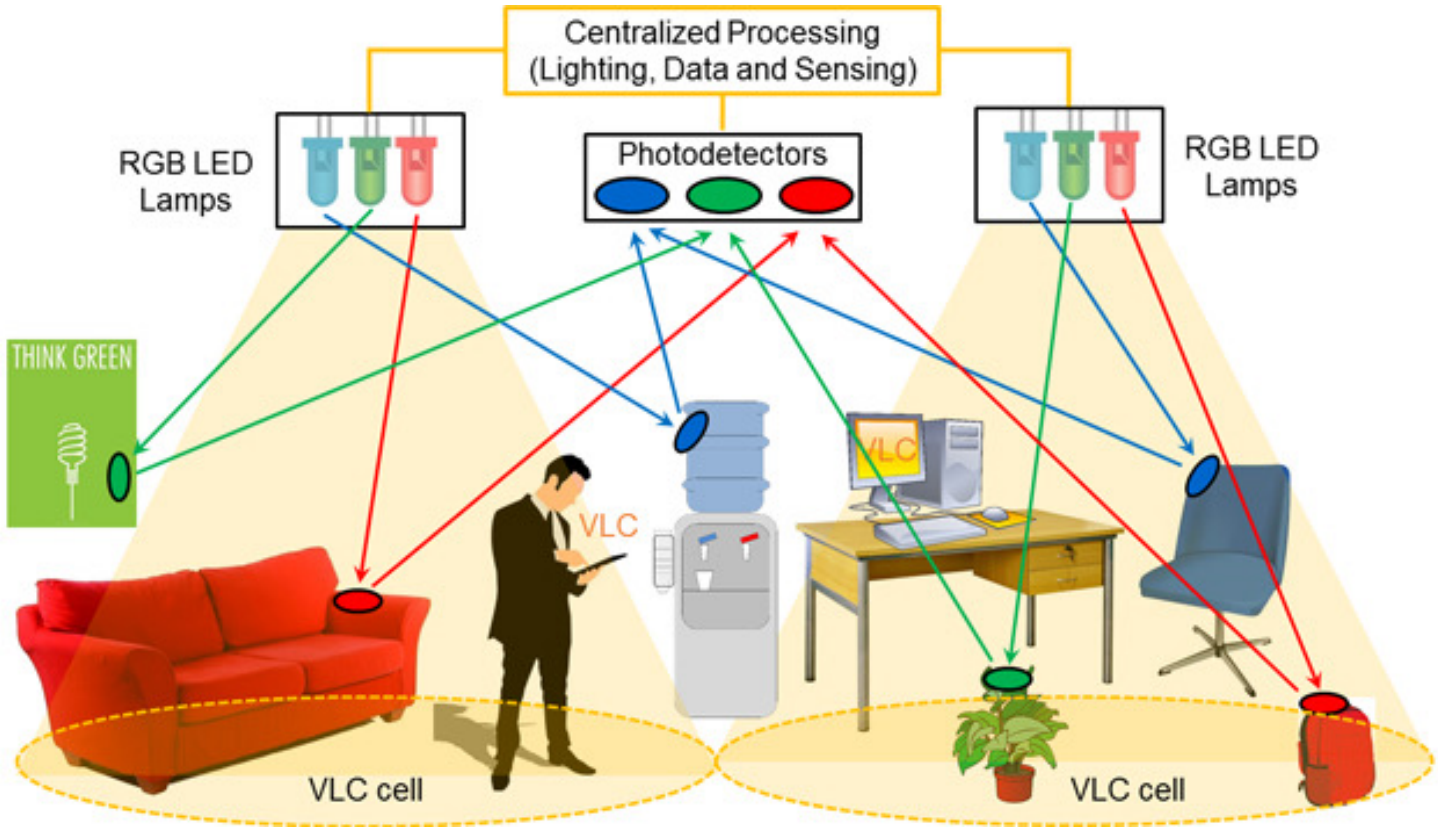


- Massive MIMO
- Spectrum sharing

5G Bands and its impact on Cell size

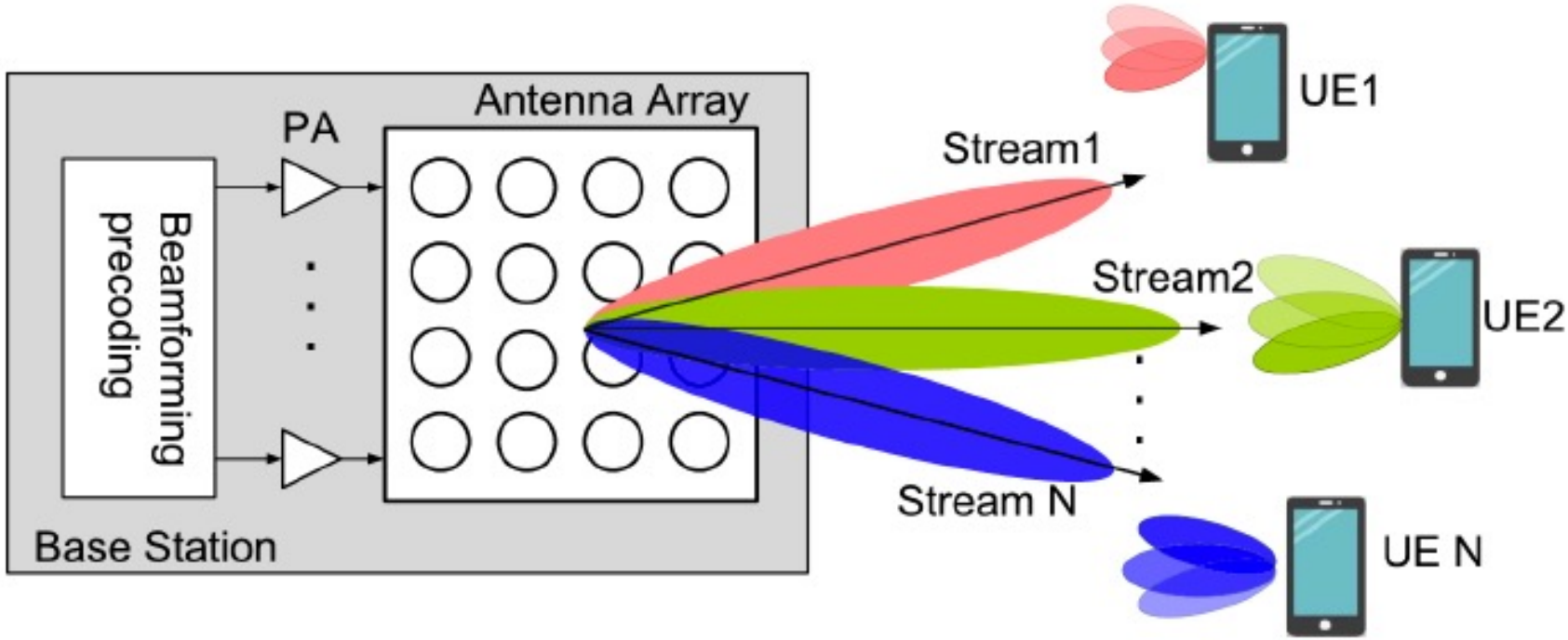


Visible Light Communications



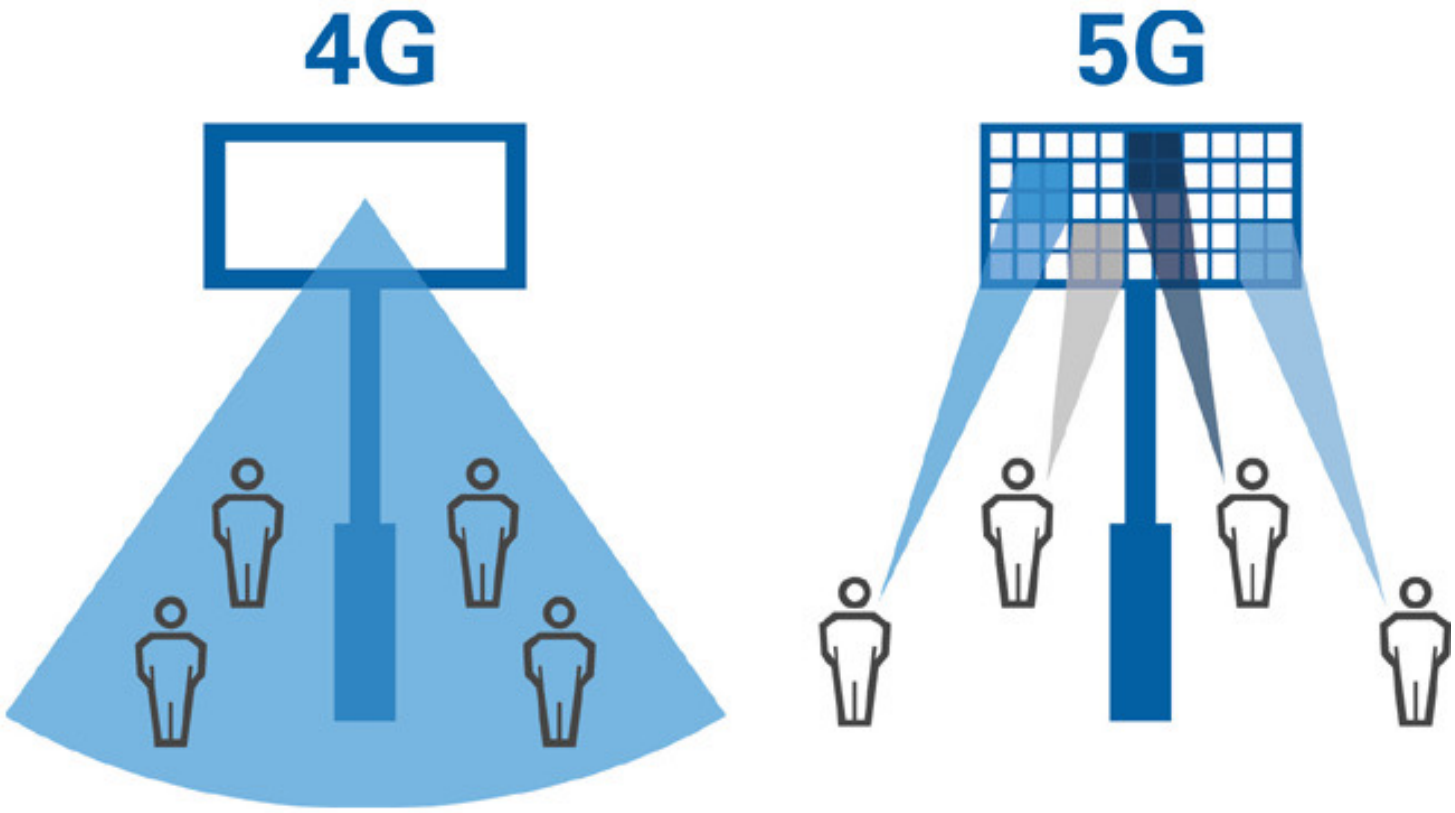
https://attract-eu.com/showroom/project/vladimir/

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.

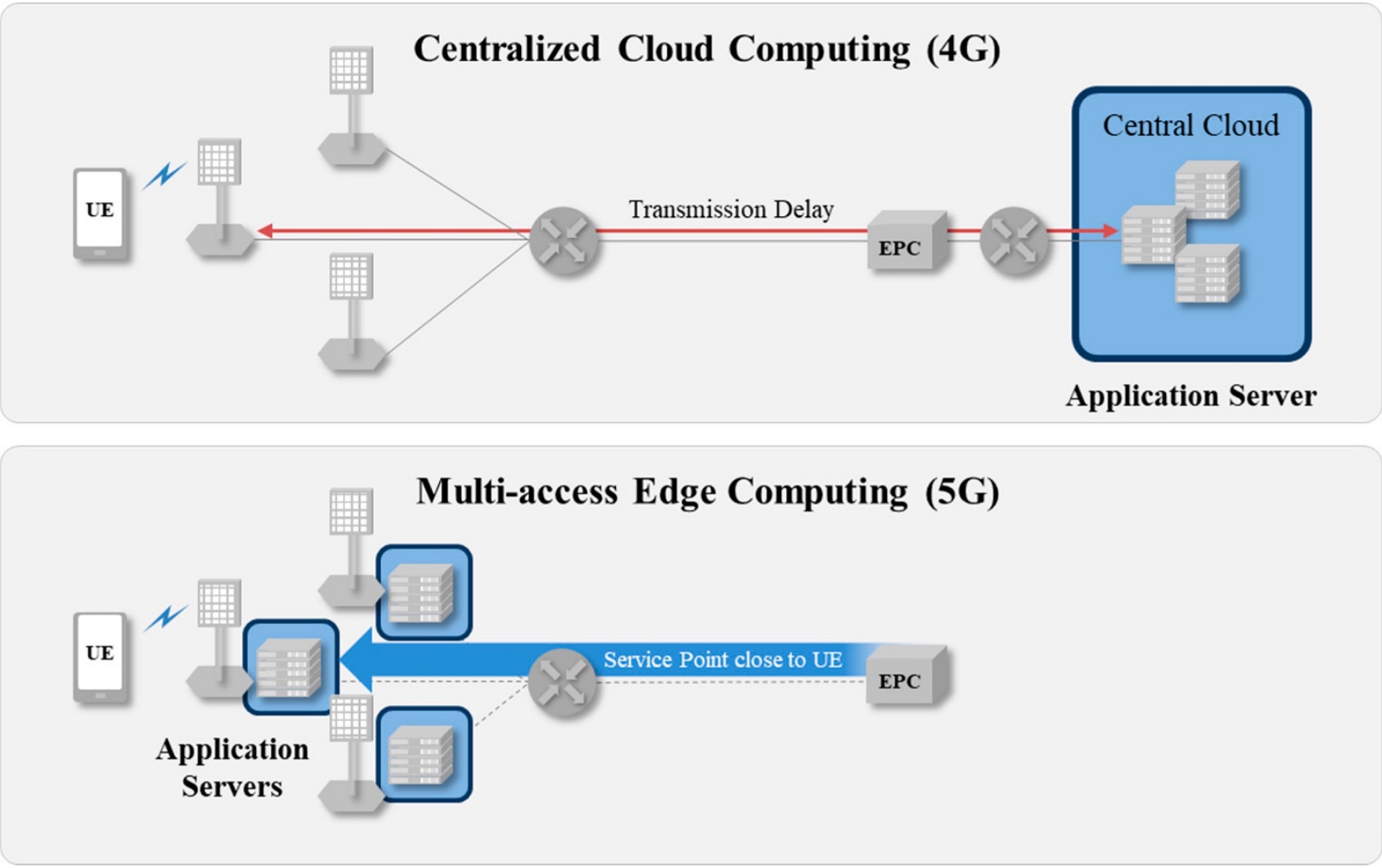
Multi-User MIMO Beamforming



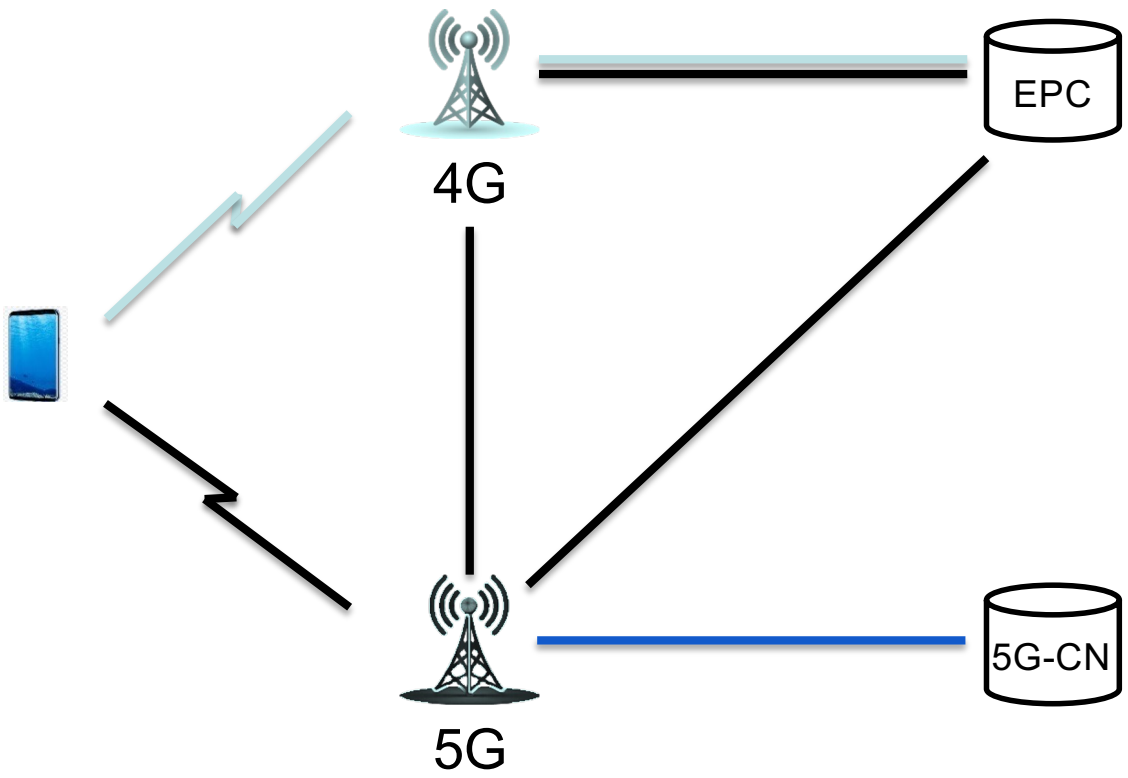
Spectrum Sharing: Multi-connectivity



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.