Mobile Communications and Orchestration

PART ½ - INTRODUCTION TO THE INTERNET OF THINGS

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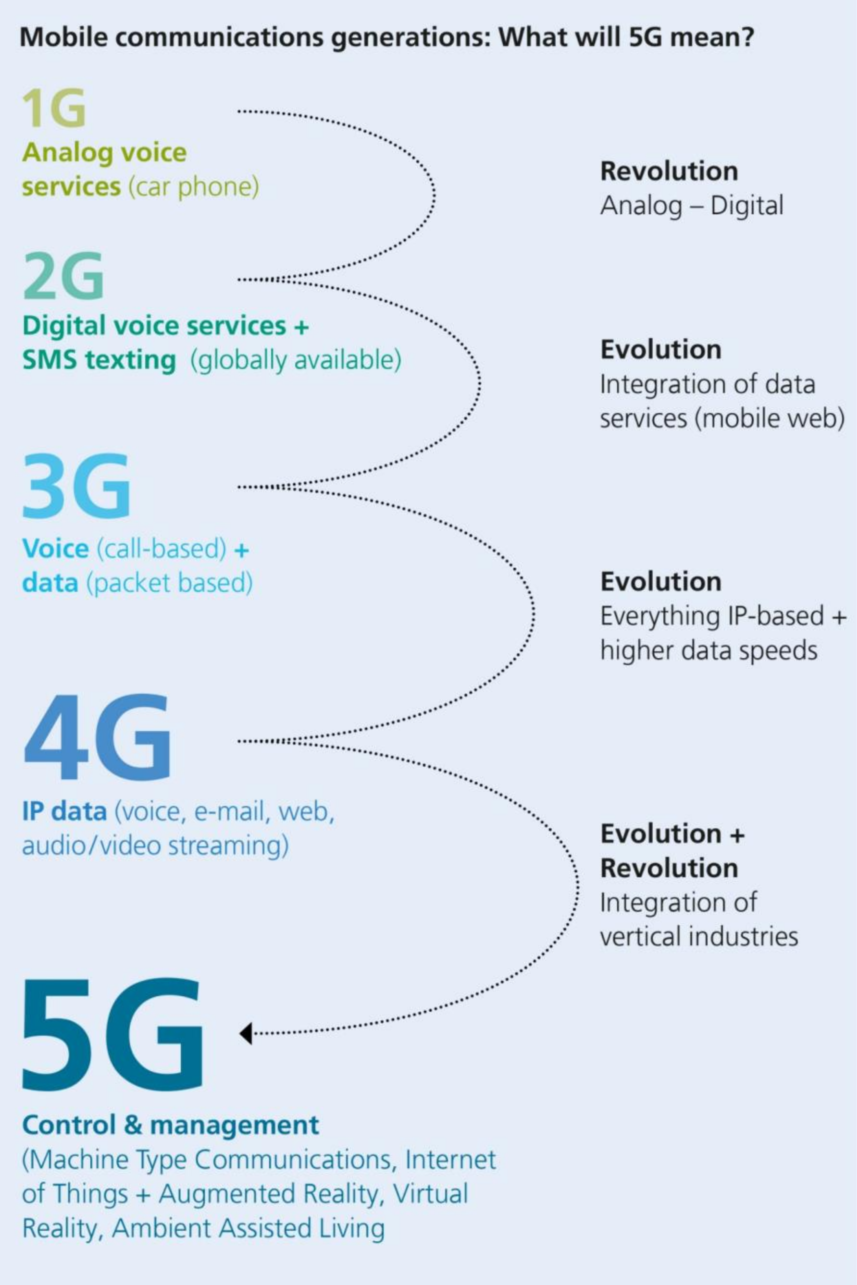
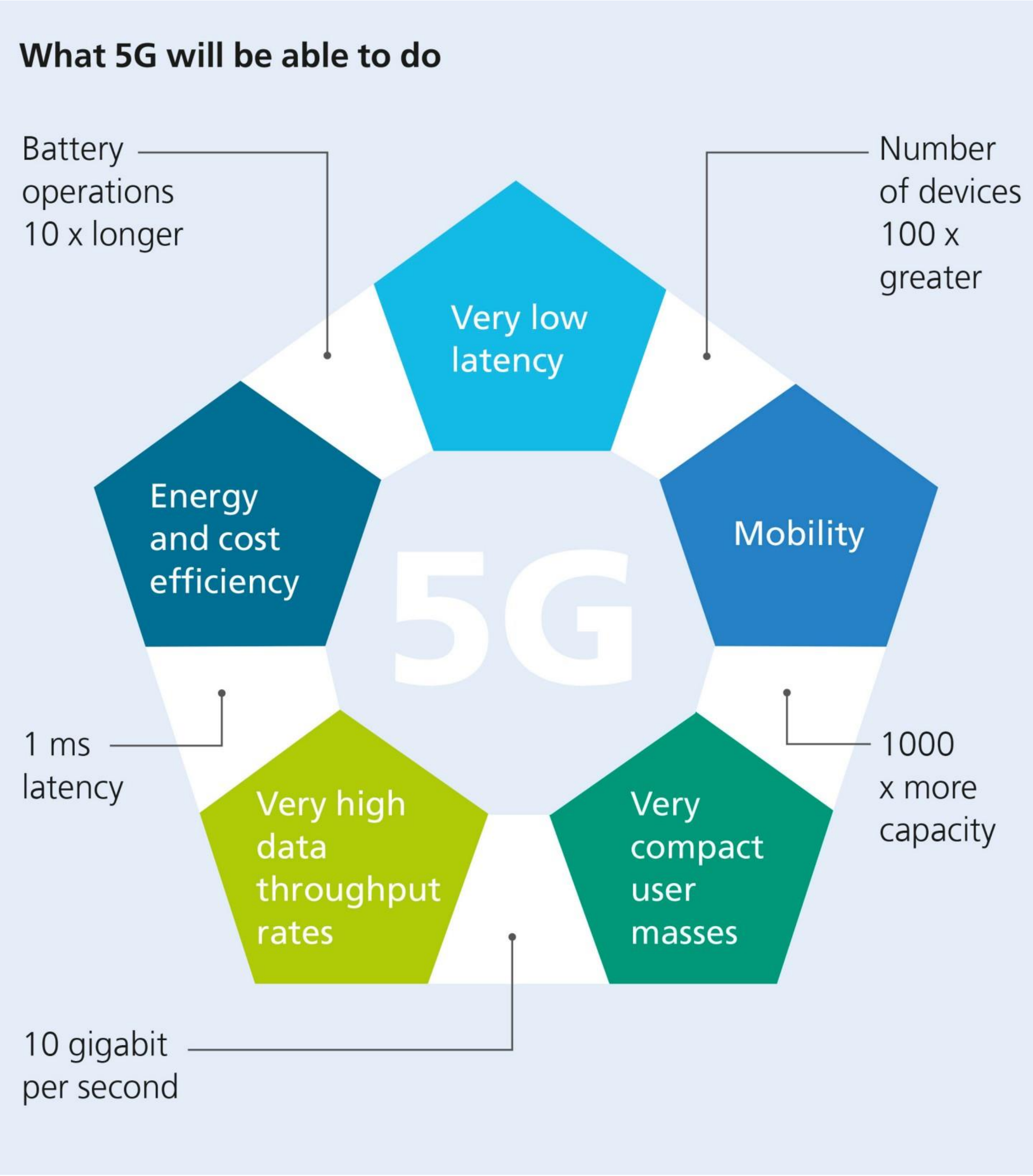
Outline

Introduction to 5G
- 5G Definition and Characteristics
- 5G Spectrum Plan
- Architecture

5G Features
- Slicing
- Massive MIMO

Network Evolution
- C-RAN
- MEC





https://www.fraunhofer.de/en/research/current-research/tactile-internet.html#:~:text=This%20refers%20to%20Internet%2Dbased,telemedicine%20and%20Car2Car%20communication%20possible.

Why do we need 5G?

Main **enabler** for next-generation IoT applications

- High capacity and density
- Low latency

Pave the way for **massive** IoT deployments

New emerging **use cases** that have increased demands

- High throughput (20+ Mbps)
- Low (< 10ms) or Ultra-low (< 1ms) latency

Virtualisation (decoupling software from hardware) pressures for new software-oriented architecture

- No dedicated hardware → Programmable and reusable hardware

Overcome communication-related **barriers** that limit and slow down application

5G Enablers

Network Function Virtualisation (NFV)

Software-Defined Networking (SDN)

Advancements in signal processing and telecom

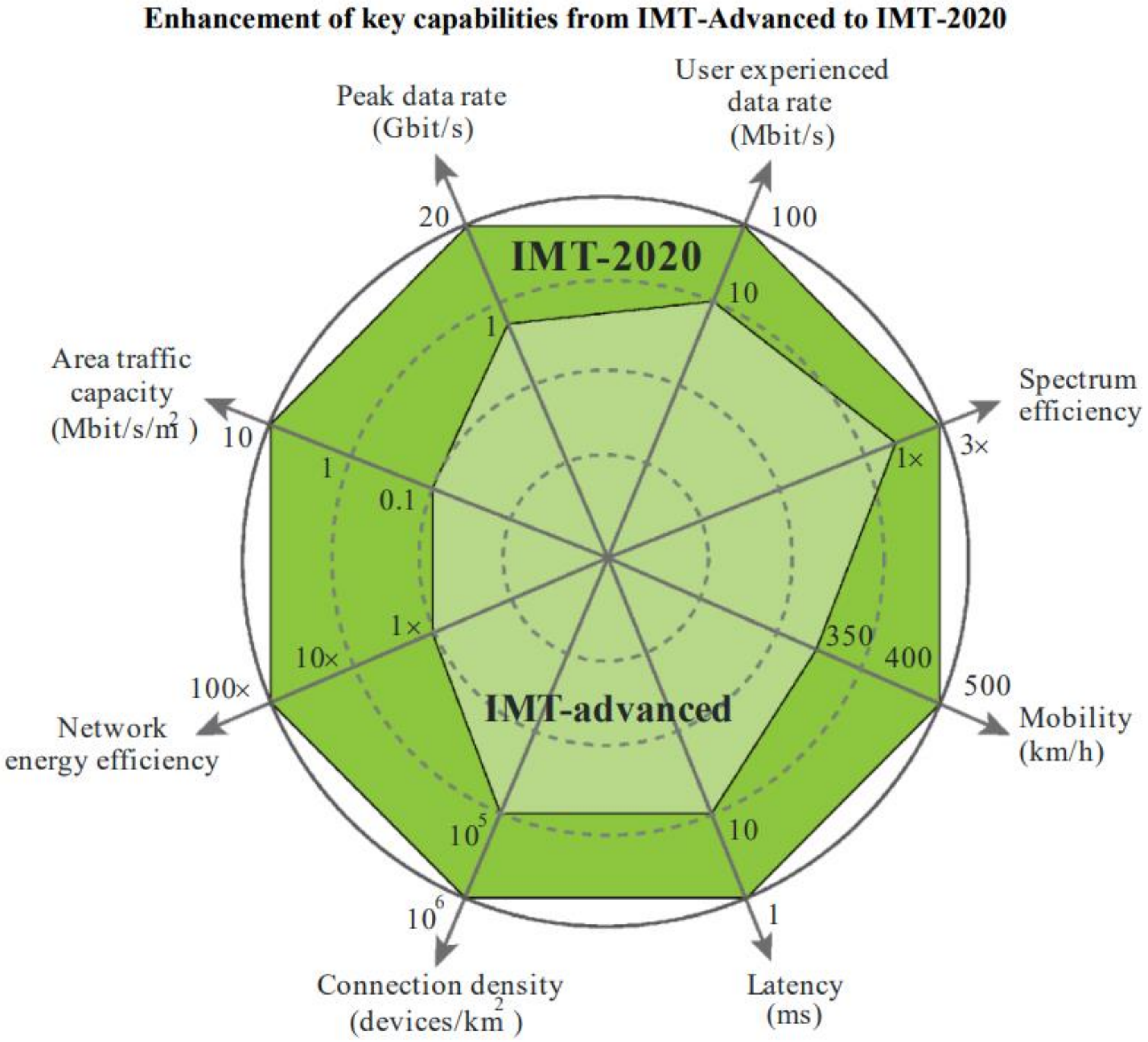
- Massive MIMO
- Beamforming
- Scalable OFDM
- More efficient channel coding – Low-density parity check (LDPC)

5G Definition

A summary of 5G-related key capabilities provided by ITU (International Telecommunication Union)

International Mobile Telecommunications (IMT) Advanced is a set of requirements issued by ITU-R (Radiocommunication sector of ITU) → Known as 4.5G

IMT-2020 are the requirements corresponding to 5G



5G Characteristics

Peak Data Rate: max rate per user under ideal conditions. 10 Gbps for mobiles, **20 Gbps** under certain conditions.

User experienced Data Rate: 95% Rate across the coverage area per user. **100 Mbps** in urban/suburban areas. 1 Gbps hotspot.

Latency: Radio contribution to latency between send and receive

Mobility: Max speed at which seamless handover and QoS is guaranteed

Connection Density: Devices per km2

Energy Efficiency: Network bits/Joule, User bits/Joule

Spectrum Efficiency: Throughput per Hz per cell

Area Traffic Capacity: Throughput per m2

5G Characteristics

Spectrum and Bandwidth Flexibility: Ability to operate at different frequencies and channel bandwidths

Reliability: High availability

Resilience: Continue working in face of disasters

Security and Privacy: Confidentiality, Integrity, Authentication, Protection against hacking, denial of service, man-in-the-middle attacks

Operational Lifetime: Long battery life for IoT devices

5G Applications

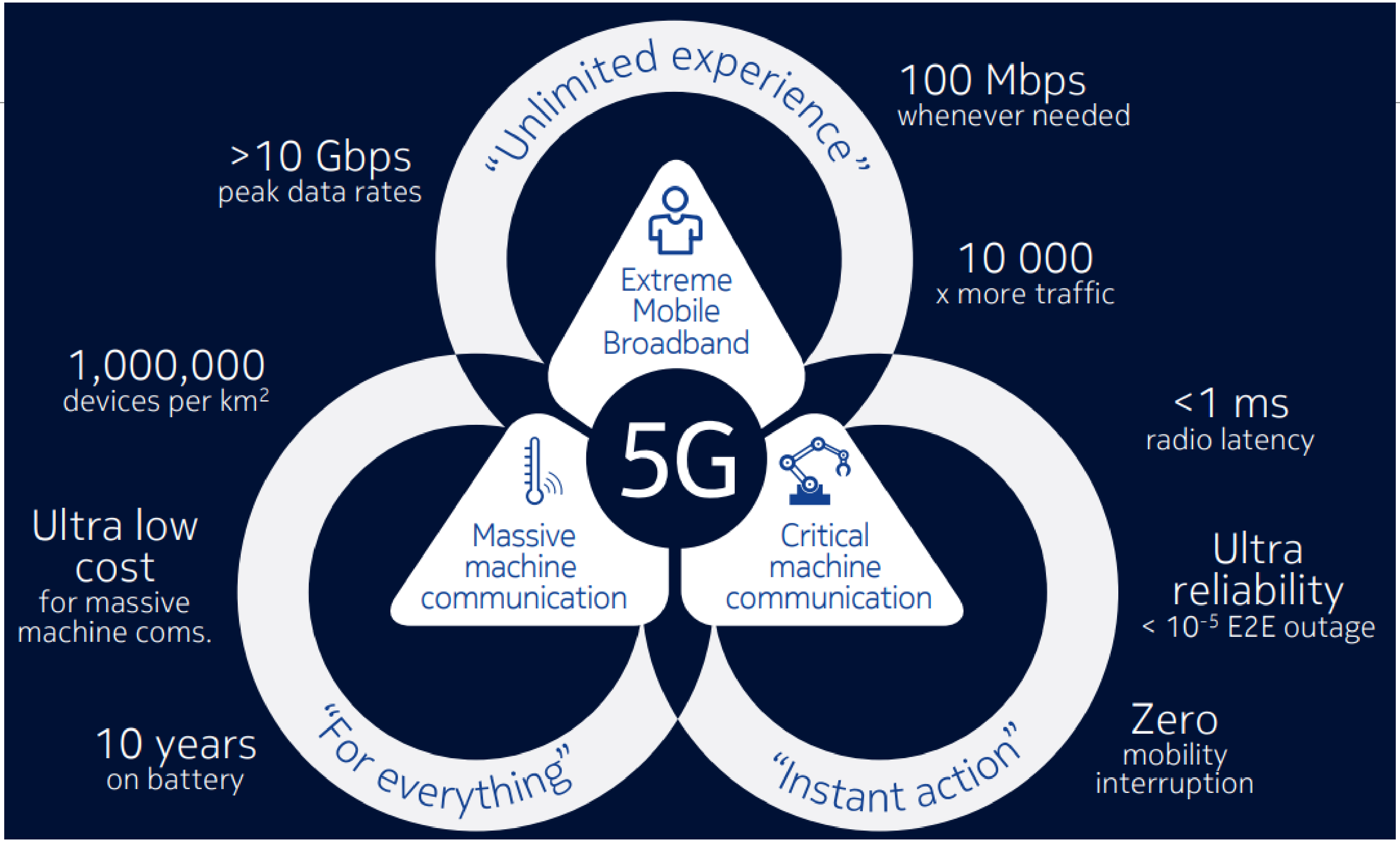
Three Key Application Areas:

Enhanced Mobile Broadband (eMBB): Better cell phones and hot spots. High data rates, high user density. Human centric communications

Ultra-Reliable and Low-Latency Communications (URLLC): Vehicle-to-Vehicle communication, Industrial IoT, 3D Gaming. Human and Machine centric communication

Massive Machine Type Communications (mMTC): Very large number of devices, low data rate, low power. IoT with long battery lifetime. Addition to LoRa, Zigbee, etc. Machine-centric communication.

5G Applications and KPIs



https://www.itu.int/en/ITU-D/Regional-Presence/Europe/Documents/Events/2017/Spectrum%20Management/Ulrich Nokia 5G in%20700w.pdf

5G Requirements

Parameter	Minimum Requirement
Peak Data Rate	20 Gbps DL, 10 Gbps UL
Peak Spectral Efficiency	30 bps/Hz DL, 10 bps/Hz UL
User Experienced Data Rate	100 Mbps DL, 50 Mbps UL
User Spectral Efficiency	3× 4G
Area Traffic Capacity	10 Mbps/m2 (Indoor hot spot)
User Plane Latency	4 ms for eMBB, 1 ms for URLLC
Control Plane Latency	20 ms
Connection Density	1 M devices/km2
Reliability	99.999% in Urban macro cell edge for URLLC
Mobility	1.5 × 4G
Mobility Interruption time	0 ms
Bandwidth	At least 100 MHz and up to 1 GHz in higher bands. Scalable bandwidth support required.

3G vs. 4G vs. 5G

Feature	3G	4G	5G
Download waveform	CDMA	OFDMA	OFDMA, SCFDMA
Upload waveform	CDMA	SCFDMA	OFDMA, SCFDMA
Channel coding	Turbo	Turbo	LFPC (Data)/Polar (Control)
Beamforming	No	Data only	Full support
Spectrum	0.8 – 2.1 GHz	0.4 – 6 GHz	0.4 – 52.6 GHz
Network Slicing	No	No	Yes
QoS	Bearer based	Bearer based	Flow based
Small Packet Support	No	No	Connectionless
Cloud Support	No	No	Yes

5G Use Cases

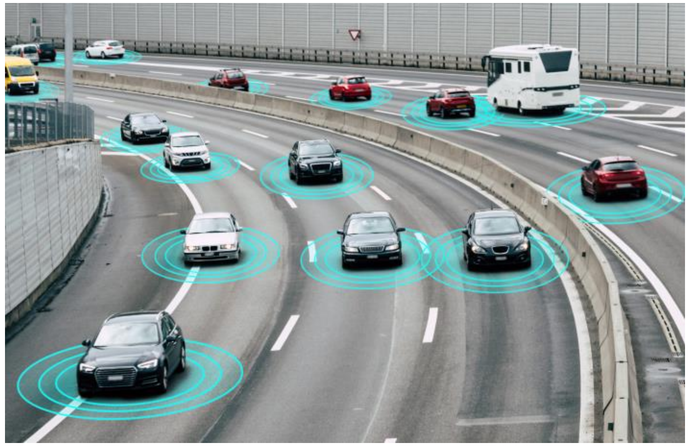
Broadband-like Mobile Services

Autonomous Vehicles

Augmented Reality / Virtual Reality

Critical Infrastructures

- Smart grids and time-critical scenarios
- Video surveillance with drones



5G Spectrum Plan

https://www.itu.int/en/ITU-D/Regional-Presence/Europe/Documents/Events/2017/Spectrum%20Management/Ulrich__Nokia__5G_in%20700w.pdf

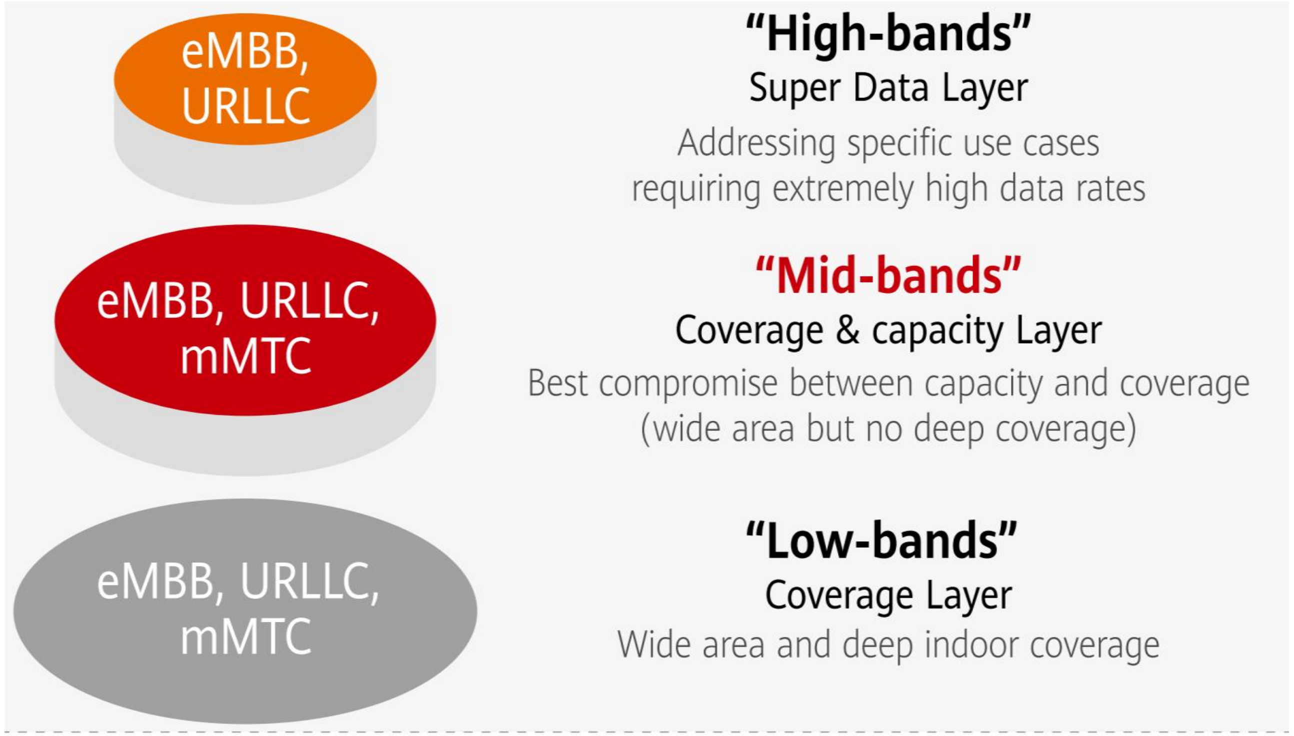
Aim: Globally harmonized spectrum plan for maximum compatibility

Three main frequency bands:

- Sub-GHz band (< 1 GHz)
- Mid-band (1 – 6 GHz)
- mm-wave (> 6 GHz)

5G Europe Spectrum:

- 700 MHz
- 3.4 – 3.8 GHz
- 26 GHz



Source: Huawei

5G European Bands

700 MHz layer with 1 ms latency

- Large area coverage
- Outdoor to indoor penetration
- mMTC and URLLC support
- Moderate invest on existing 800/900 MHz grids

3.4 – 3.8 GHz with ~1 Gbps and 1 ms latency

- Dense urban coverage, including airport, stadium and public transport
- Limited eMMB support

26 GHz layer with ~10 Gbps and 1 ms latency

- Coverage in selected hot spots (airport, stadium, press centre)
- Full eMMB support

3GPP 5G Architecture (release 15, aka 5G phase #1)

The 3GPP 5G system architecture is service based → Architectural elements are **network functions** integrated in a **virtualised** environment

5G = 5G RAN + 5G Core

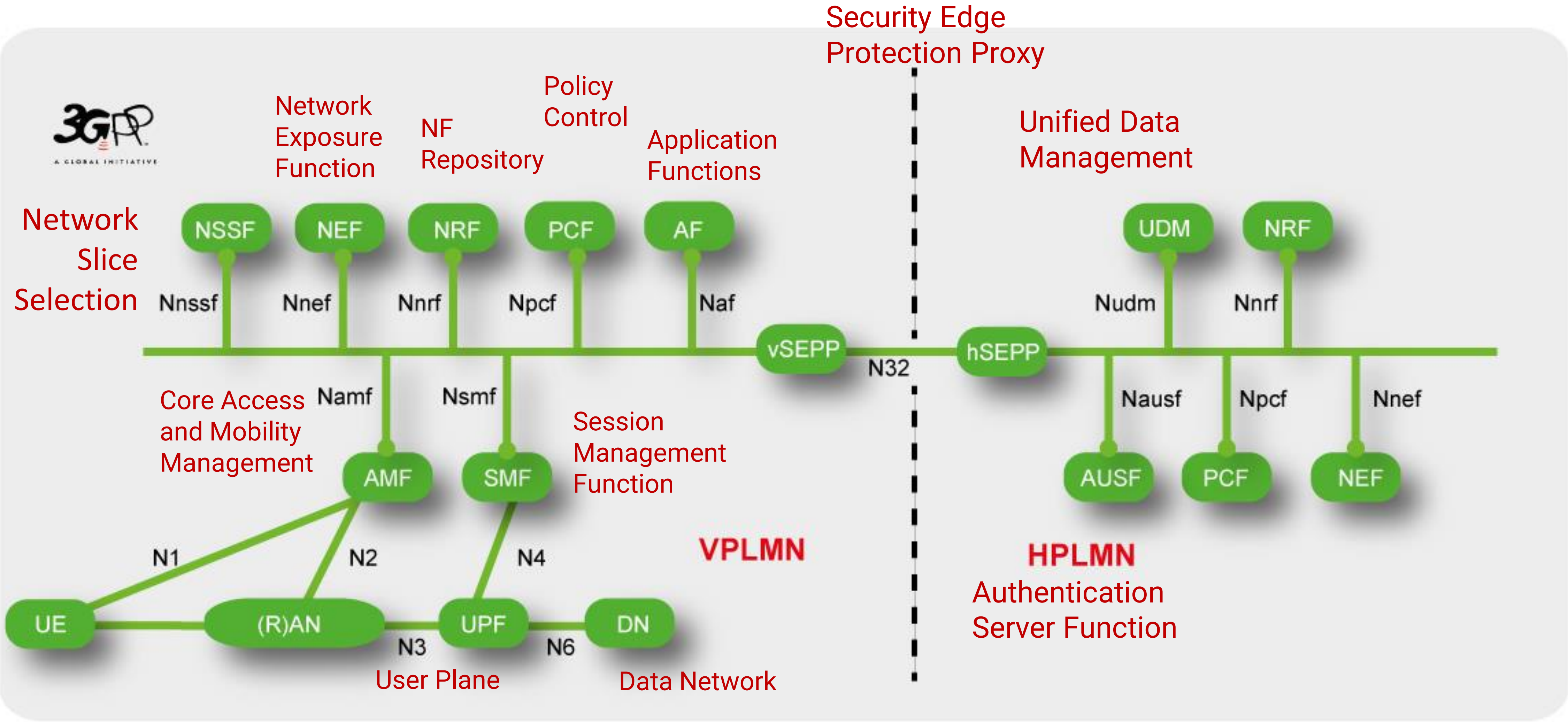
- RAN = Radio Access Network
- Core is responsible for non-radio functions: authentication, roaming, handoffs, end-to-end connections

Two deployment methods

- **Non-Standalone** (NSA): Use legacy EPC core with 5G RAN to accelerate 5G NR deployments
- **Standalone** (SA): Full 5G RAN + 5G Core

Each core service is a function, and several functions can be implemented in a physical node or Virtual Machine https://www.mpirical.com/glossary

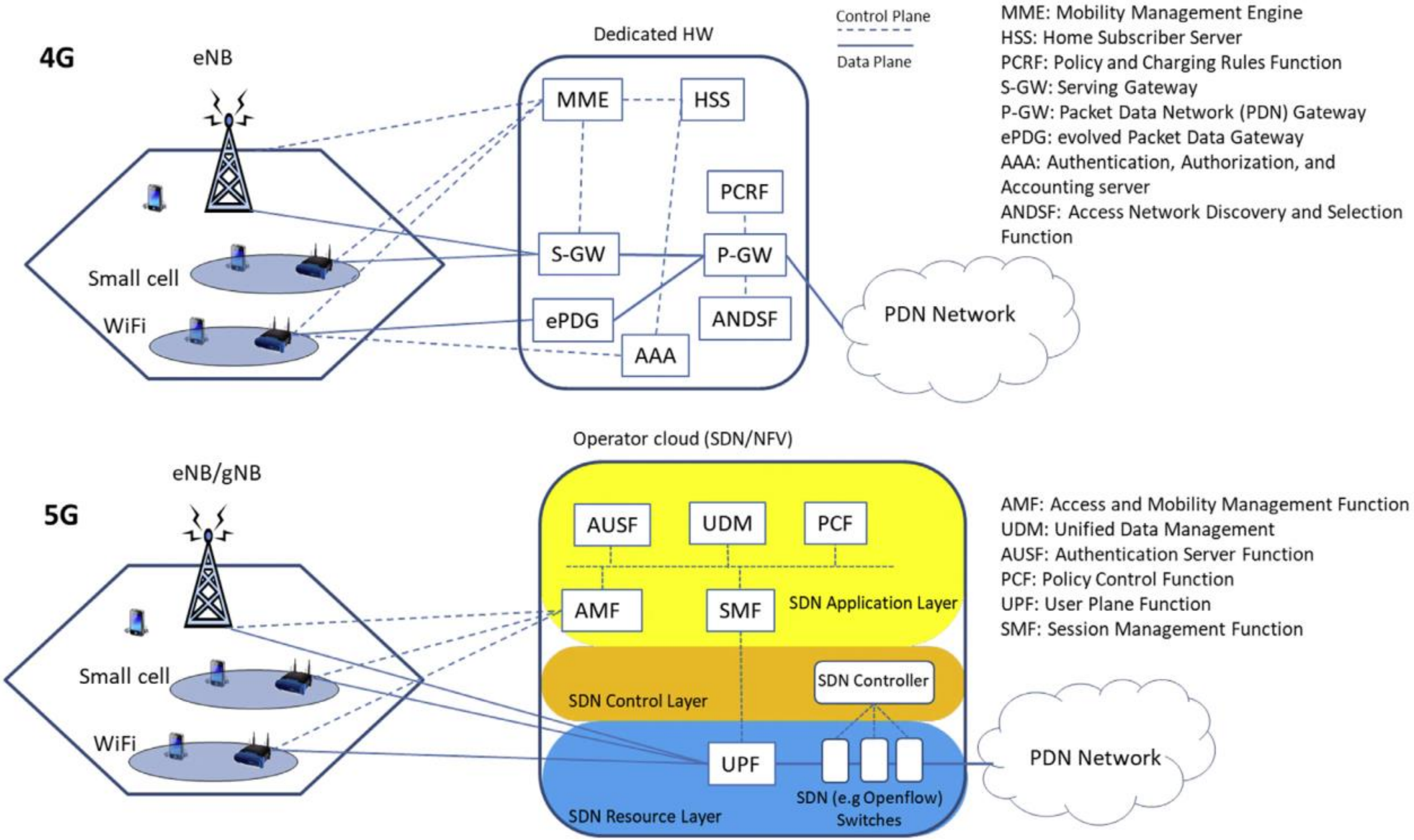
3GPP 5G Architecture – Roaming with local breakout example



VPLMN = Visited Public Land Mobile Network

HPLMN = Home PLMN

4G vs 5G



4G
eNB
Dedicated HW
Control Plane
Data Plane
MME
HSS
PCRF
S-GW
P-GW
ePDG
ANDSF
AAA
Small cell
WiFi
PDN Network
MME: Mobility Management Engine
HSS: Home Subscriber Server
PCRF: Policy and Charging Rules Function
S-GW: Serving Gateway
P-GW: Packet Data Network (PDN) Gateway
ePDG: evolved Packet Data Gateway
AAA: Authentication, Authorization, and Accounting server
ANDSF: Access Network Discovery and Selection Function
5G
eNB/gNB
Operator cloud (SDN/NFV)
AUSF
UDM
PCF
AMF
SMF
SDN Application Layer
SDN Controller
SDN Control Layer
UPF
SDN (e.g Openflow) Switches
SDN Resource Layer
Small cell
WiFi
PDN Network
AMF: Access and Mobility Management Function
UDM: Unified Data Management
AUSF: Authentication Server Function
PCF: Policy Control Function
UPF: User Plane Function
SMF: Session Management Function

Scalable OFDM

$$\Delta f = 15\ \text{kHz} * 2^n$$

Orthogonal Frequency Division Multiplexing is the right candidate for 5G NR

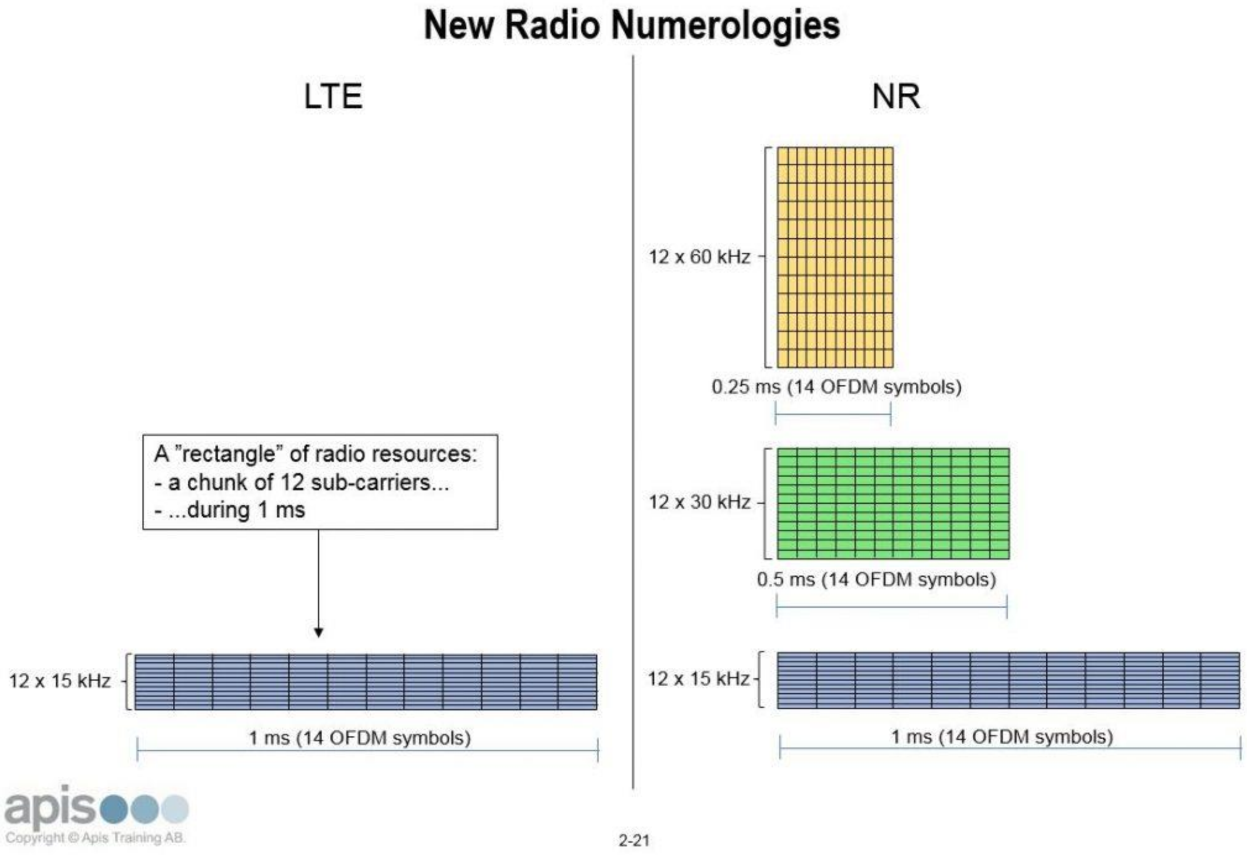
5G innovation is the scalable OFDM multi-tone 2n numerology

- LTE supports carrier bandwidths up to 20 MHz – Fixed OFDM sub-carrier spacing of 15 KHz

5G supports scalable OFDM numerology, meaning smaller OFDM symbol duration and doubled subcarrier spacing when required

Smaller symbol duration means more flexible resource allocation and increased speeds

High frequencies introduce increased phase noise → Larger subcarrier spacing required



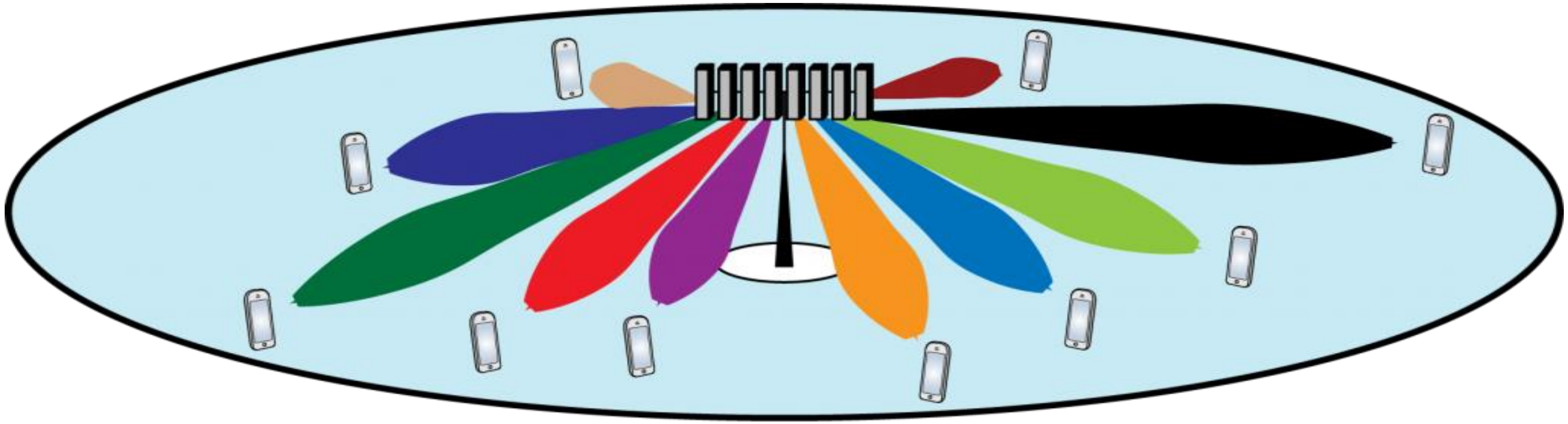
https://apistraining.com/news/5g-numerology/

Massive MIMO

Sub-6 GHz wireless access technology

Base stations are equipped with arrays of many (→ massive) antennas that serve multiple users at the same time-frequency resource

Whilst standard MIMO uses 2-4 antennas, massive MIMO uses as many as 96 to 128 antennas

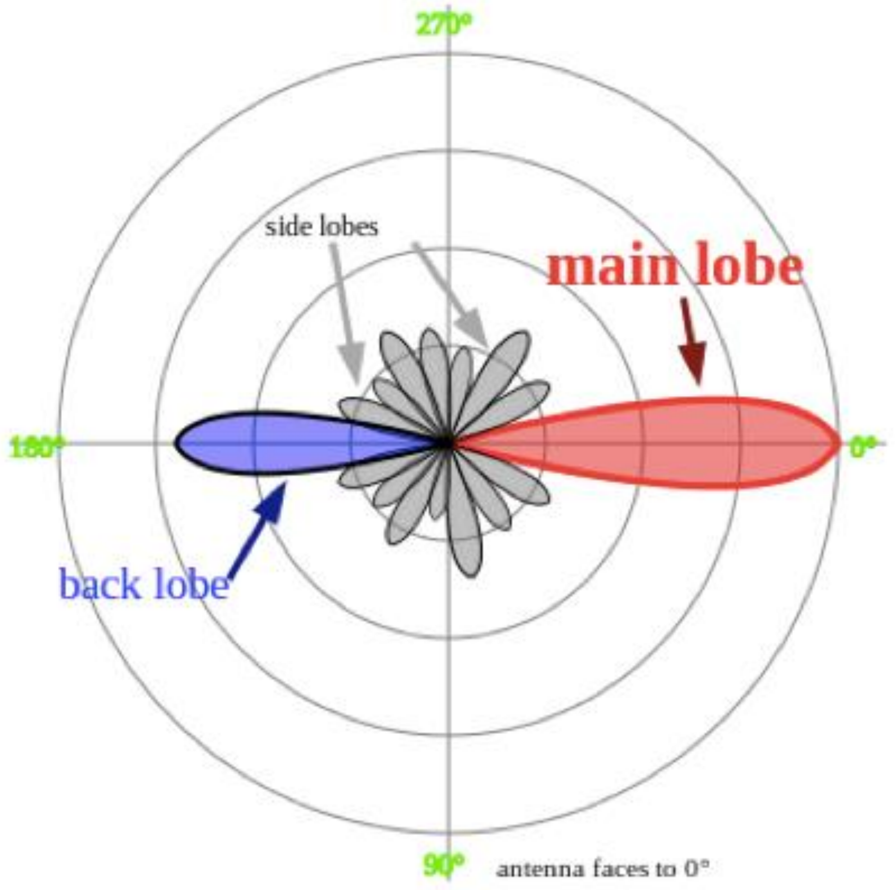


Massive MIMO / Beamforming

The capacity is multiplied without requiring more spectrum

Leverages beamforming to focus wireless signal towards a specific receiving device
- Beamforming is utilised by 802.11ax (WiFi 6)

Benefits of massive MIMO
- Increased network capacity
- Improved coverage
- User experience



5G Slicing

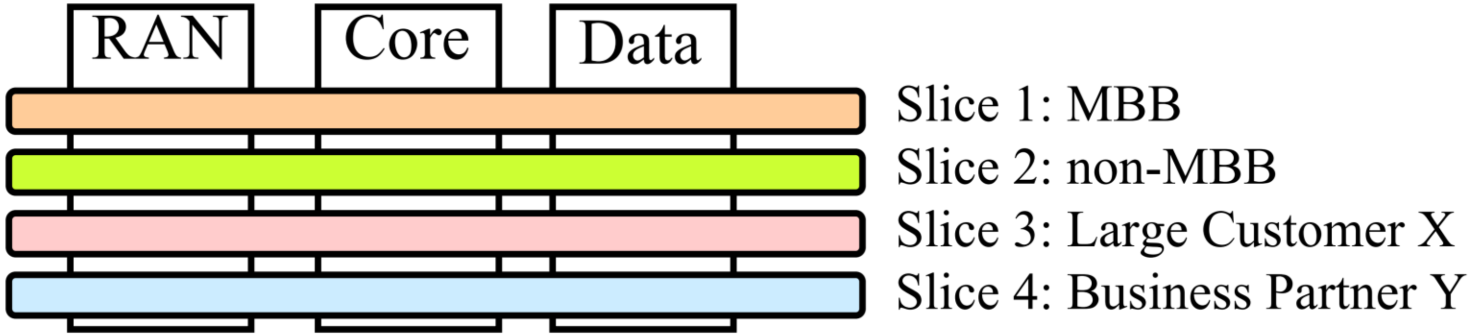
Slice: A logical network serving a particular application, business partner, or customer

Like Virtual Machines (VMs) on a computer

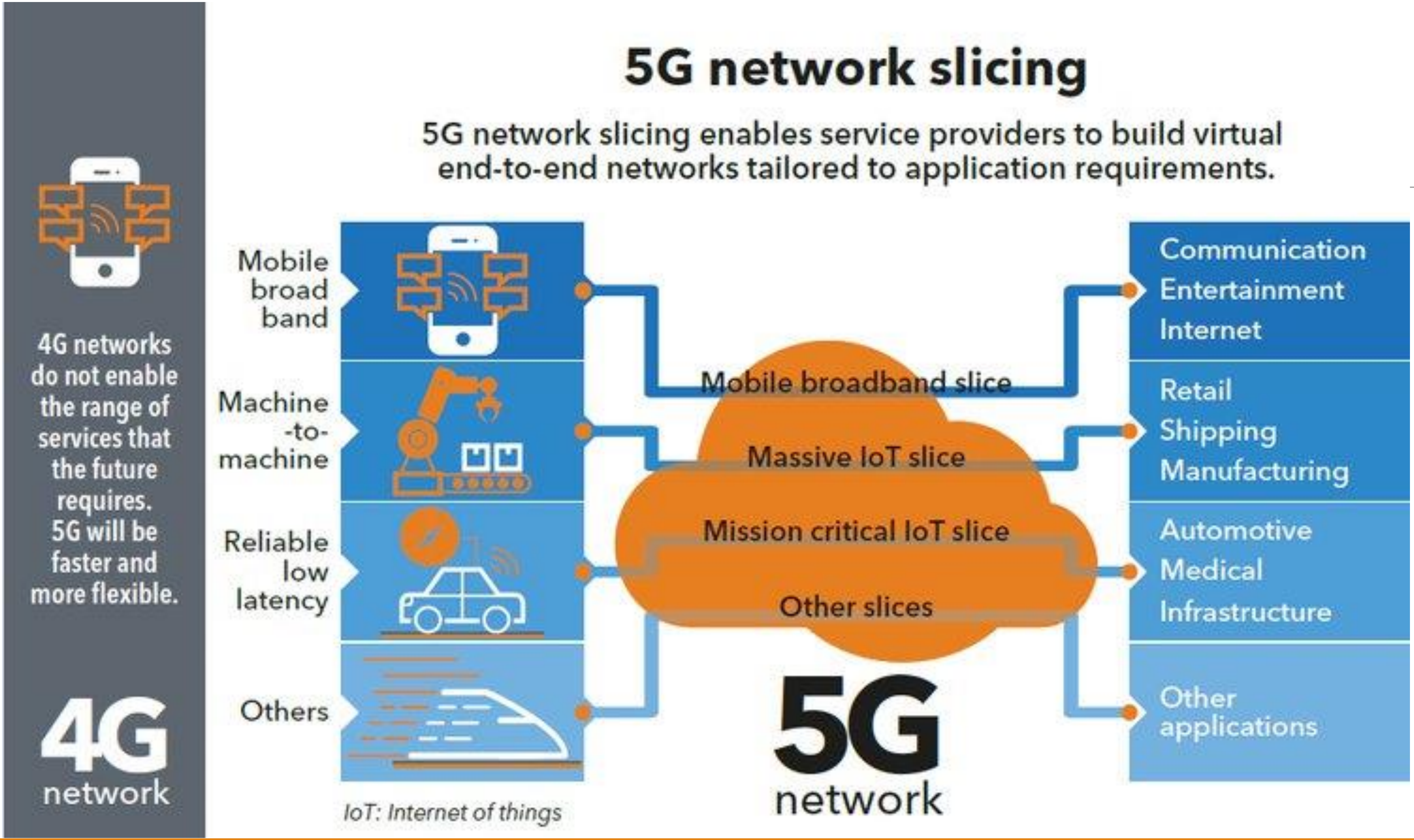
A network can be divided into many slices

Each slice looks to the user as a separate network with reserved resources

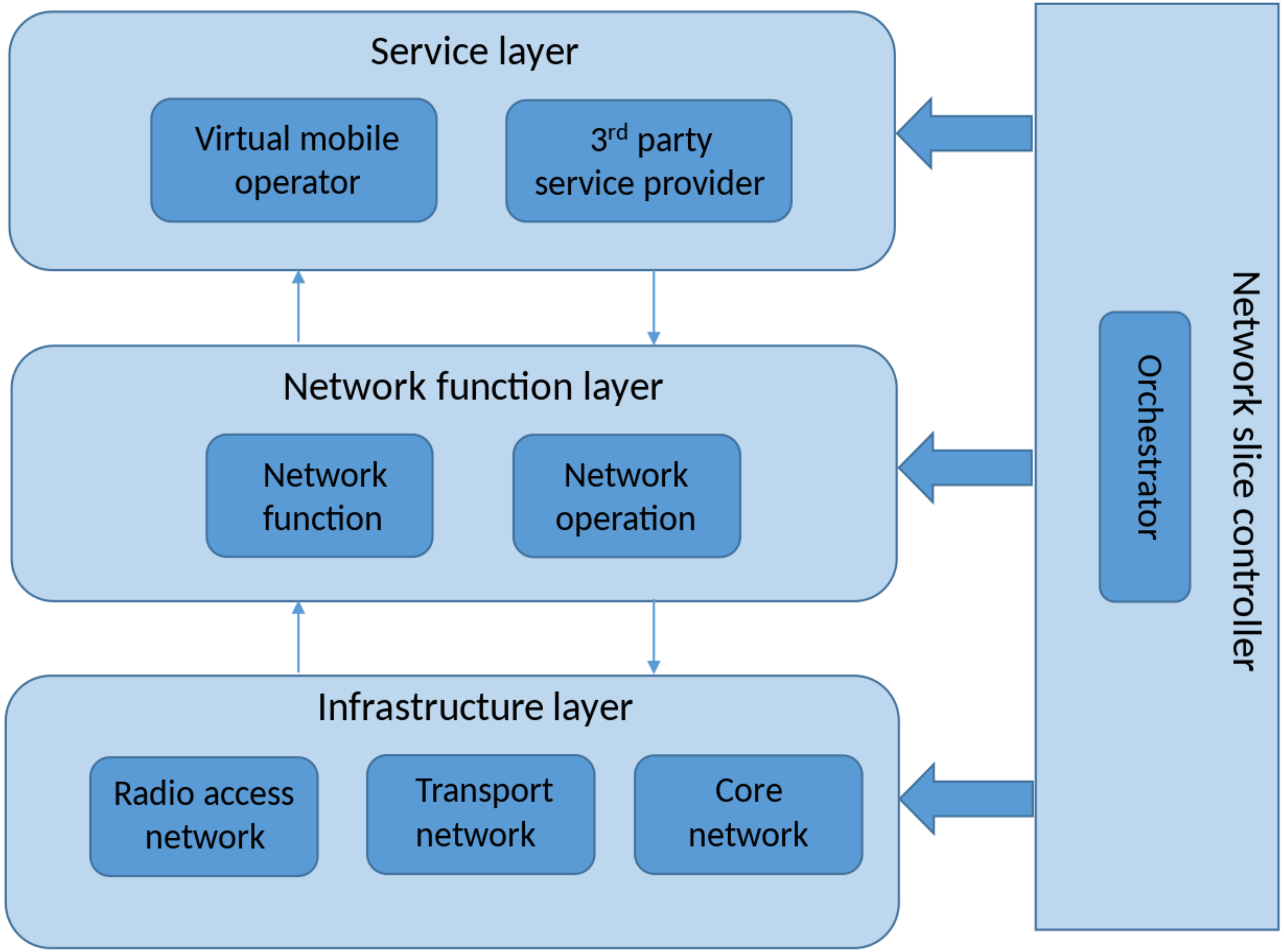
Concerns a use case of Network function virtualization!



https://www.itu.int/en/ITU-T/Workshops-and-Seminars/201707/Documents/Eric_Guttman_5G%20New%20Radio%20and%20System%20Standardization%20in%203GPP.pdf



Source: ITUNews



What is a slice?

A set of resources that is defined by 3 layers:

- **Infrastructure Layer**: The actual physical resources utilized (radio frequencies, intermediary nodes/physical topology)
- **Network Function Layer**: Defines the slice as a virtual resource as well as its lifecycle
- **Service Layer**: Operators and service providers can utilize the slices provided by the NF Layer

Network Slice Controller

- End-to-end service management
- Virtual resource definition
- Slice life-cycle management

Neutral Hosting

Network virtualisation introduces new business models!

Neutral hosting exploits network virtualization to separate network infrastructure from the service provider

- **Mobile Network Operator** (MNO): Owner of physical infrastructure (radio frequencies, antennas etc)
- **Mobile *Virtual* Network Operator** (MVNO): Rents slices from MNO in wholesale price and resells them to customers with custom branding and marketing

There is a global trend in various industries to separate infrastructure providers and service provider (e.g. in energy)

NETWORK EVOLUTION

CLOUD-RADIO ACCESS NETWORK

MULTI-ACCESS EDGE COMPUTING

Cloud Radio Access Network (C-RAN)

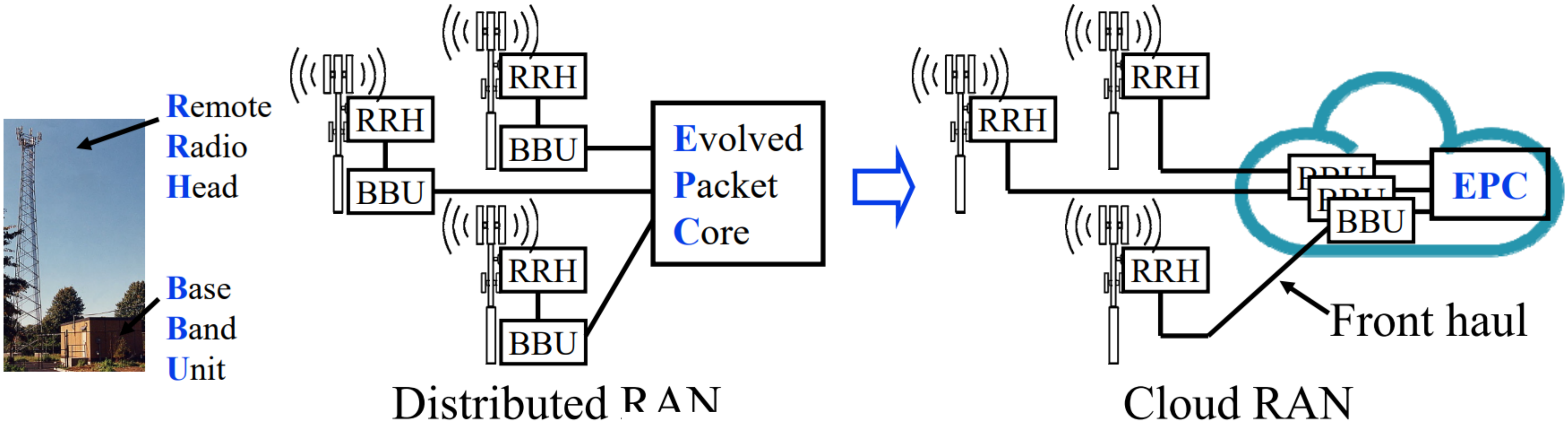
Traditionally (RAN instead of C-RAN):

- Each base station covers a small area
- A base station consists of the Remote Radio Head (RRH) and the Baseband Unit (BBU)
  - RRH → Radio transceiver, the physical air interface
  - BBU → Baseband signal processing
- Each base station processes and transmits signals from/to UEs
- Payload is forwarded to the core network via the backhaul

5G C-RAN:

- RRH and BBU are decoupled – Separated
- RRHs transmit “raw” signal to a centralized BBU which is virtualized and hosted on the cloud
- Allows scaling for low-cost dense small cells
- Optical fibre, 10+ Gbit Ethernet or microwave ~ 20km of front haul

Distributed vs Cloud RAN



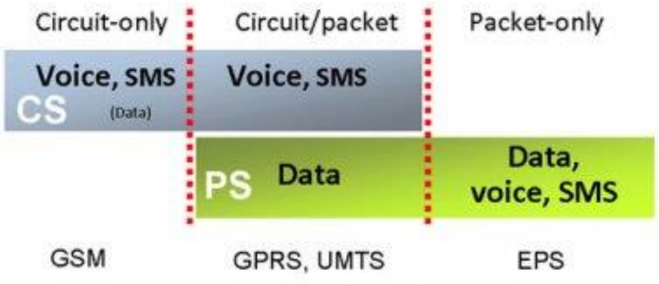
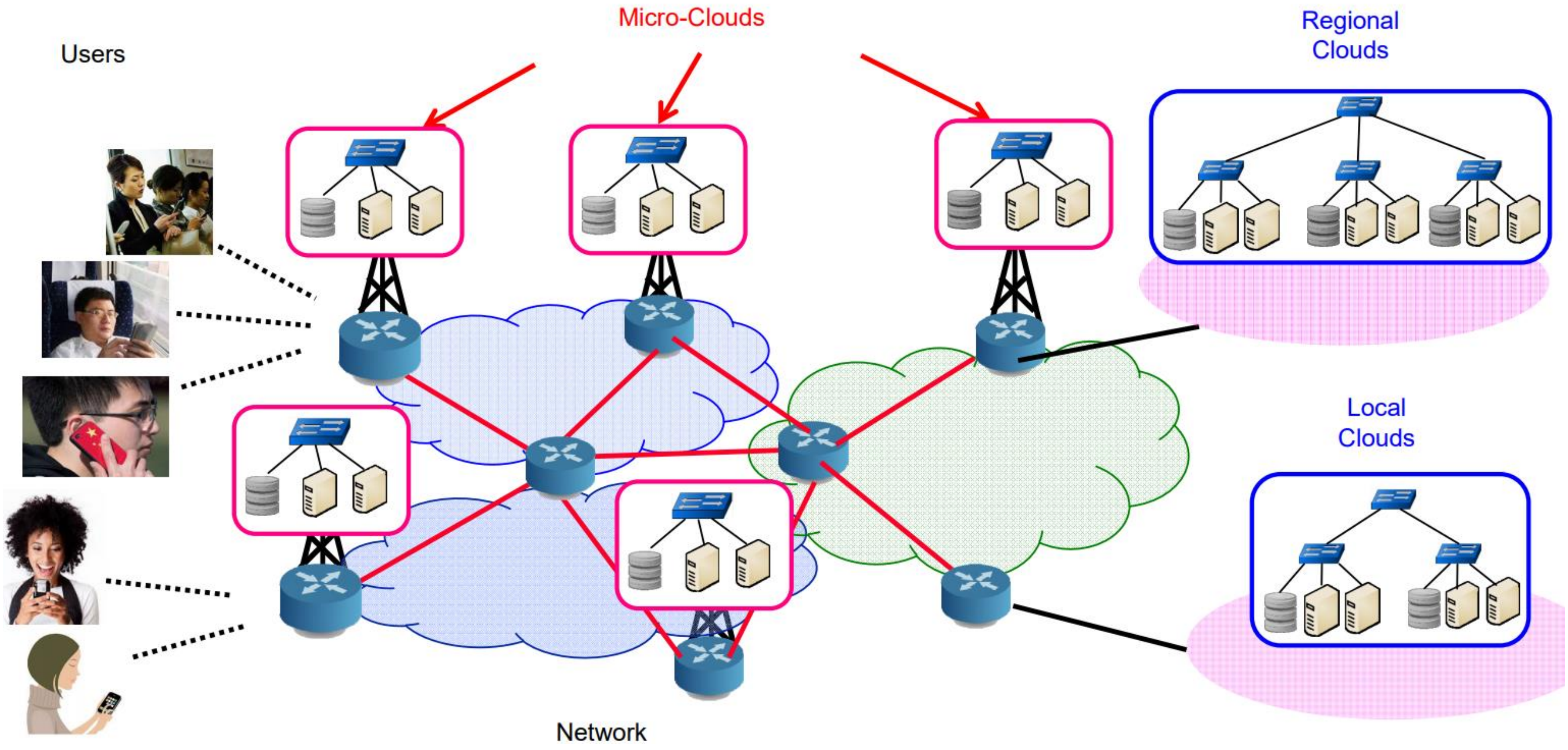


Figure 1: Circuit and packet domains

Multi-Access Edge Computing (MEC)

MEC brings computation and cloud closer to the edge



Multi-Access Edge Computing (MEC)

Aims to bring cloud computing capabilities closer to the end-user premises
- Cloud suffers from unavoidable latency

5G + edge = mobile edge computing → Leverages 5G connectivity for wireless URLLC in the customer premises

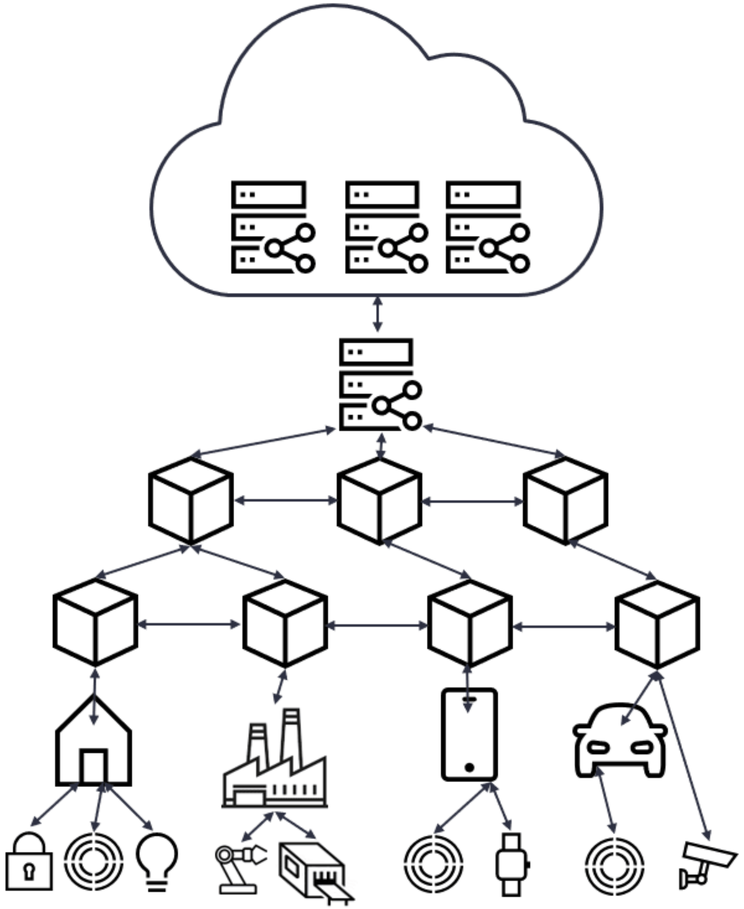
The end user has direct access and control over the local Radio Access Network (RAN)

Core network is relieved from additional traffic and real-time information can be served more efficiently

The result of converging IT and telecommunications networking

New vertical use cases that have strict latency requirements, including:
- VR glasses that are in sync with the movement
- Remote surgery
- Remotely operating manufacturing equipment
- Federated Learning / Local AI training and detection

IoT Edge Computing – What it is and how it is becoming intelligent



1. Open architectures
2. Data pre-processing and filtering
3. Edge analytics
4. Distributed applications
5. Consolidated workloads
6. Scalable deployment / management
7. Secure connectivity

Source: IoT Analytics Research 2020

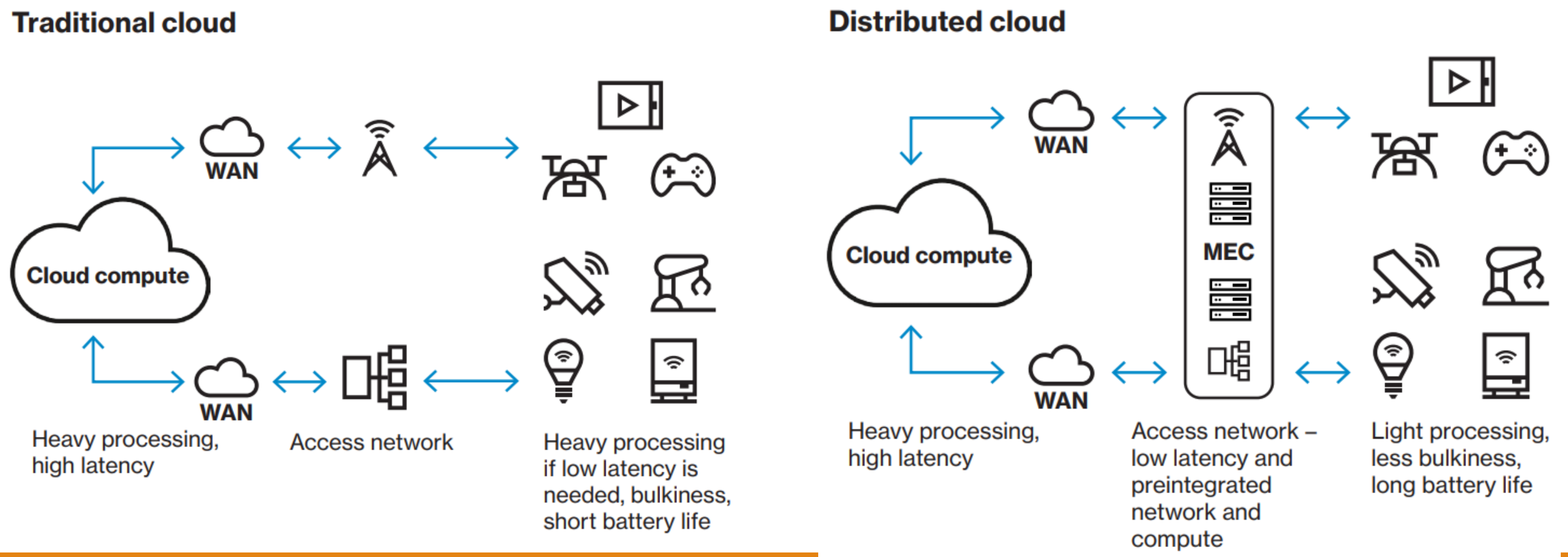
Multi-Access Edge Computing (MEC)

MEC merges edge computing with cloud computing

- Brings every latency-strict or data-heavy application closer to the data source

MEC addresses data privacy requirements / Compliance with GDPR

- Sensitive data should remain and be processed on the edge



https://enterprise.verizon.com/content/dam/resources/whitepapers/5g-and-edge-computing.pdf

MEC and 5G use cases

Autonomous and assisted-driving vehicles → A single autonomous vehicle can produce 30 TB per day (Twitter's daily data)

AR/VR/MR/XR (Augmented, Virtual, Mixed, Extended) Reality → Hyperrealistic training, medical imaging, remote repair, augmented retail, safety and security

Media delivery → Reliable 4k/8k video streaming

Smart safety → Enhanced training, improve responsiveness to safety incidents

Massive IoT → Drive analytics and artificial intelligence with huge amounts of sensors.

Predictive maintenance and proactive actions → Predict upcoming faults and enable proactive actions in order to prevent cascading effects (e.g. fault in electrical system)

Towards 3GPP Release 16

NR V2X (Vehicle to Anything)

- Vehicle Platooning (group of vehicles that travelling together in an optimal way)
- Remote driving and extended sensors for data/video sharing

Non-terrestrial Networks

- 5G through satellites
- Unmanned aircrafts as cell towers

Above 52.6 GHz

IoT-centric

- MEC / Private 5G network for Industrial IoT
- Usage of unlicensed spectrum

How to implement?

Grafana

Prometheus

openslice

open5Gcore

openstack

Open Source MANO

kubernetes

Software-Defined Radio (ETTUS)

ZXRAN R8894E

ZXRAN R8998E

5G Demonstration by NOKIA

Nokia 5G Demonstration Video – 5G: driving the automation of everything - YouTube