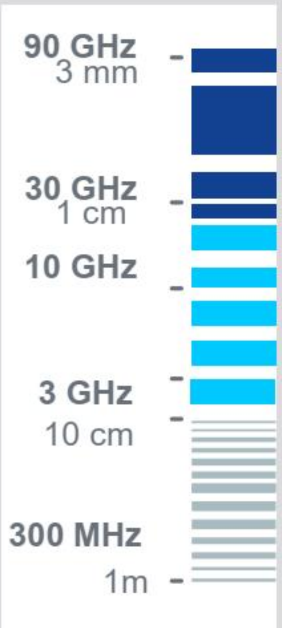
# Rel 15: The Era of 5G Begins!

| Release | Rel.13 | Rel.14 | Rel.15 | Rel.16 | Rel.17 |
|---|---|---|---|---|---|
| Freeze date | 3/2016 | 3/2017 | 9/2018 (early drop) 4/2019 (late drop) | 3/2020 | TBC |
| Comment | LTE-A Pro | | 5G NR | | |

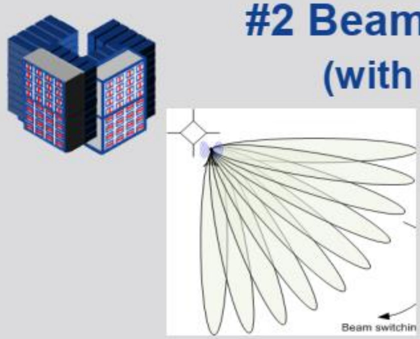
- Rel.13 and 14 = LTE-A Pro ("pre-5G")
- Rel.15: Specs for 5G New Radio (NR) start to appear
  - 5G NR Non-Standalone (NSA) operation→ "early drop" due to demand from operators
  - 5G NR Standalone (SA) operation
- Rel. 15 also includes work items continuing LTE enhancements (e.g. 1024 QAM)! (*not covered in this course*)
- Rel.16 continues enhancements to 5G NR → freeze dates are tentative

# 5G Key Technology Components

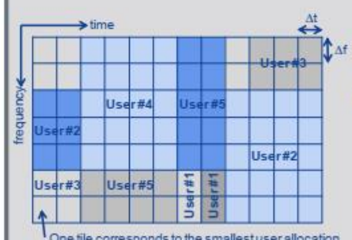
## #1 New spectrum




## #2 Beamforming (with mMIMO)



## #3 Slicing and flexibility




- Lean carrier
- Flexible size, control, TDD, bandwidth etc

## #4 Multi-connectivity


## #5 Edge computing

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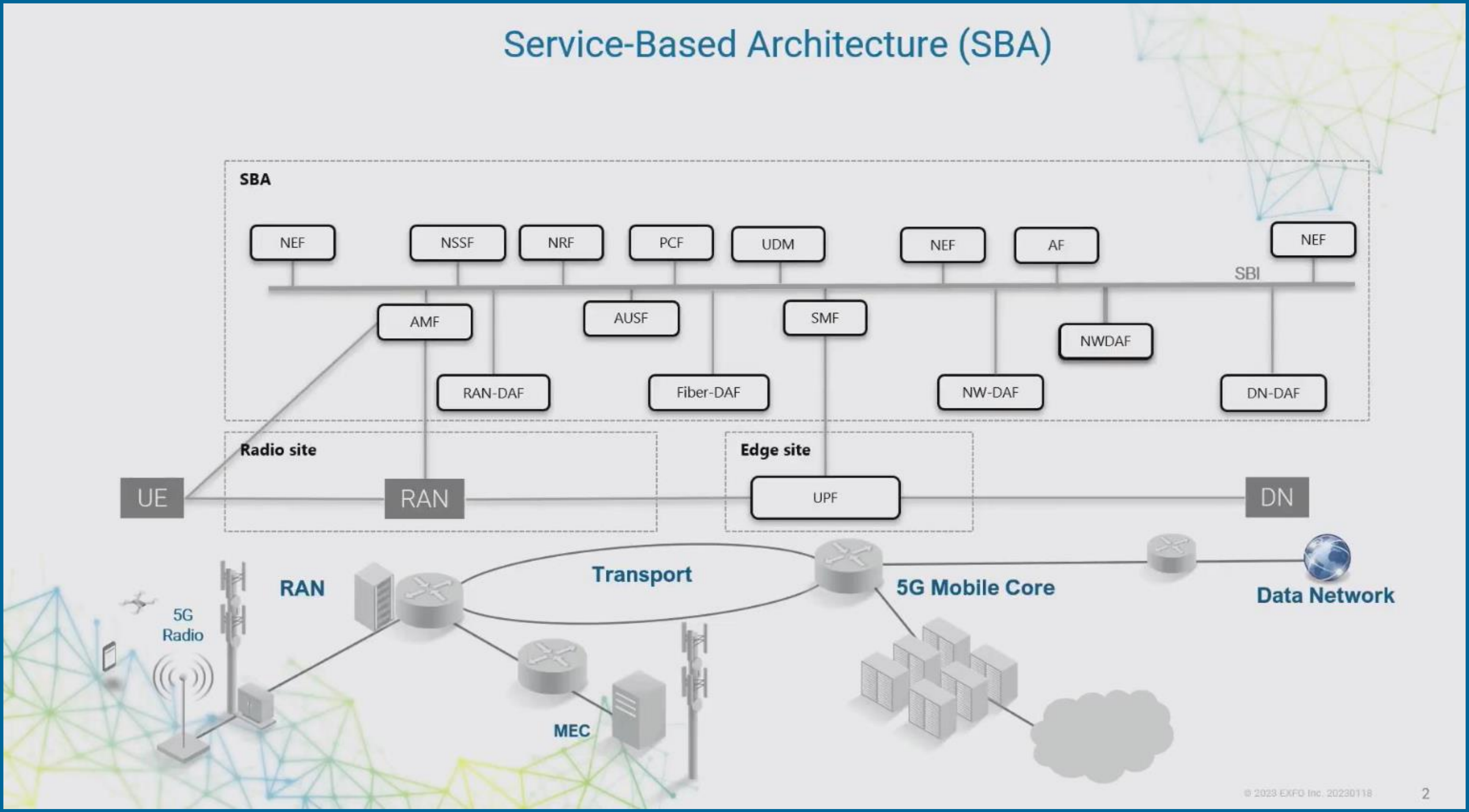
# 5G Architecture



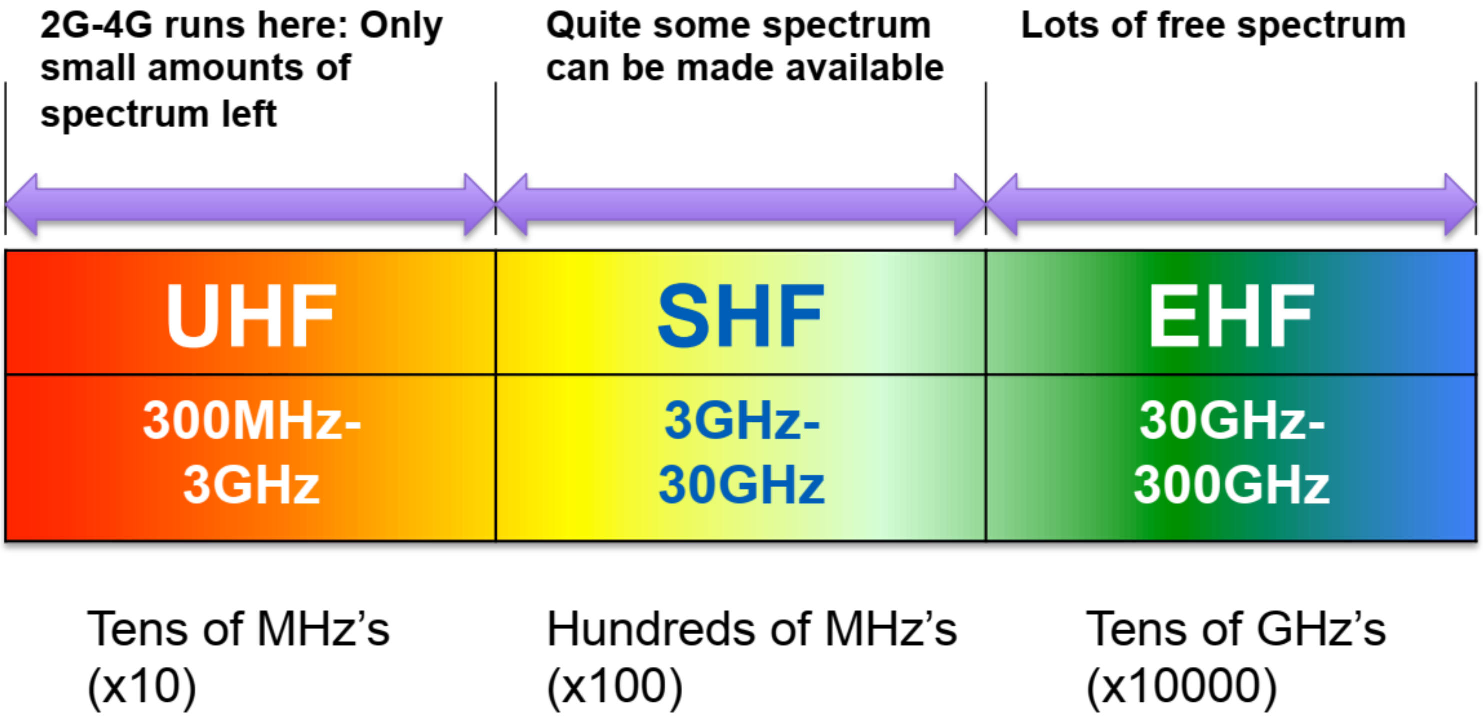
# 5G Requirements

- Use case driven targets
  - Peak rate: 20 Gbps (1 Gbps in LTE-A)
  - Cell edge user experienced throughput (5th percentile): DL 100 Mbps, UL 50 Mbps
  - Latency: Maximum 1 ms RTT delay for URLLC (10 ms in LTE Rel.8)
  - Connection density: 1 million connected devices per $km^2$
  - Service availability: 99.999%

| | | LTE Rel.8 | LTE-A target | 5G (IMT-2020) |
|---|---|---|---|---|
| Peak data rate | DL | 150/300 Mbps | 1 Gbps | 20 Gbps |
| | UL | 75 Mbps | 500 Mbps | 10 Gbps |
| Peak spectral efficiency | DL | 15 bps/Hz | 30 bps/Hz | 30 bps/Hz |
| | UL | 3.75 bps/Hz | 15 bps/Hz | 15 bps/Hz |

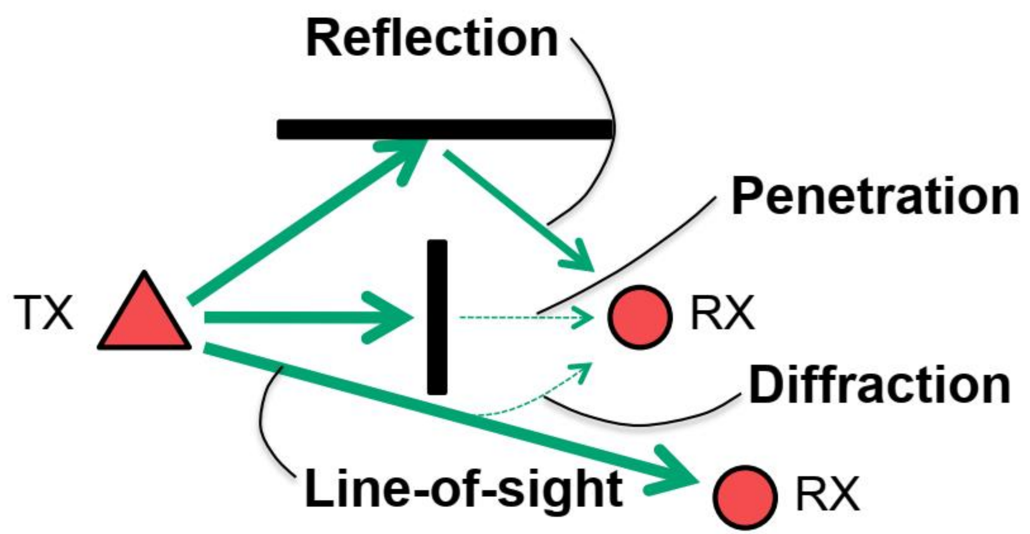
# Easiest Option: More frequency!

## More natural resources for mobile communication = more spectrum




**OK, there is more bandwidth – but can we use it?**

# What is wrong with high frequencies?

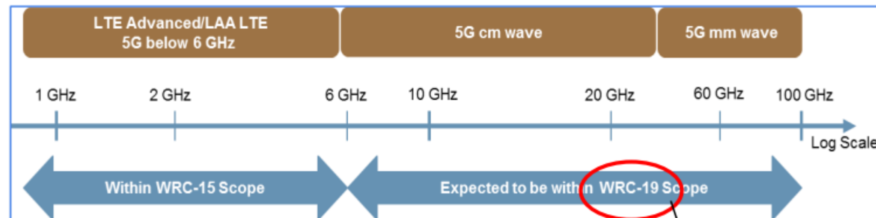


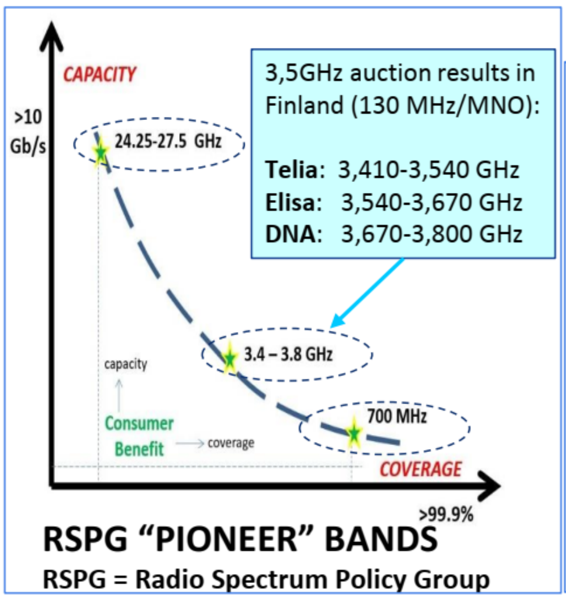

**When carrier frequency increases … 10GHz, 30GHz, 60GHz**

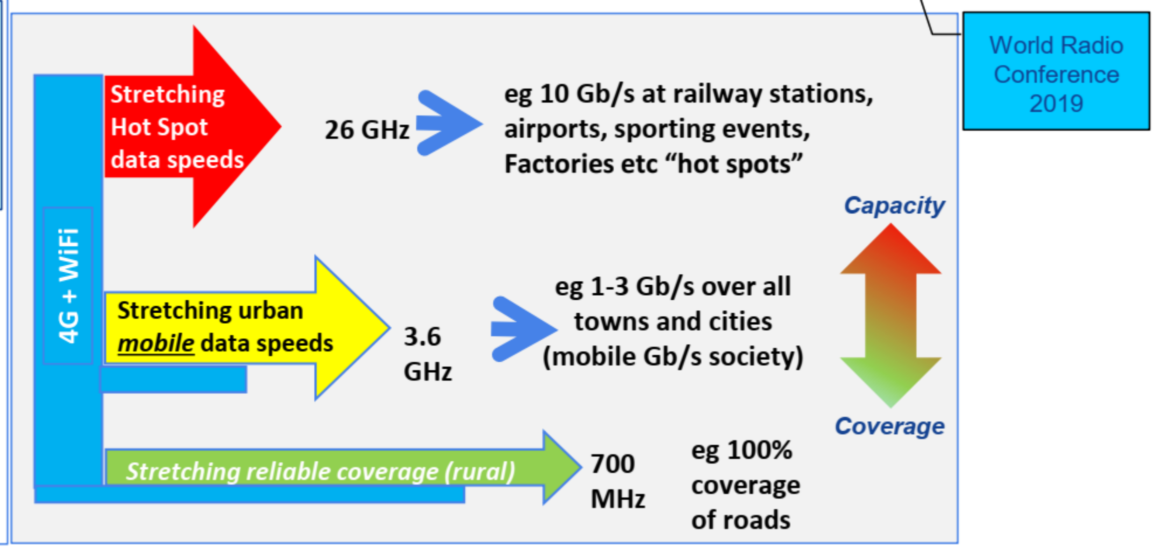
- *Signal penetration loss increases*
- *Diffracted signal component becomes weaker and weaker*
- *Importance of LOS signal and reflected signal component increases*

# 5G Spectrum & Bands

High data rates up to 20 Gbps require bandwidth up to 1 GHz which is available at higher frequency bands.
5G is the first radio technology that is designed to operate on any frequency bands between 450 MHz and 90 GHz.



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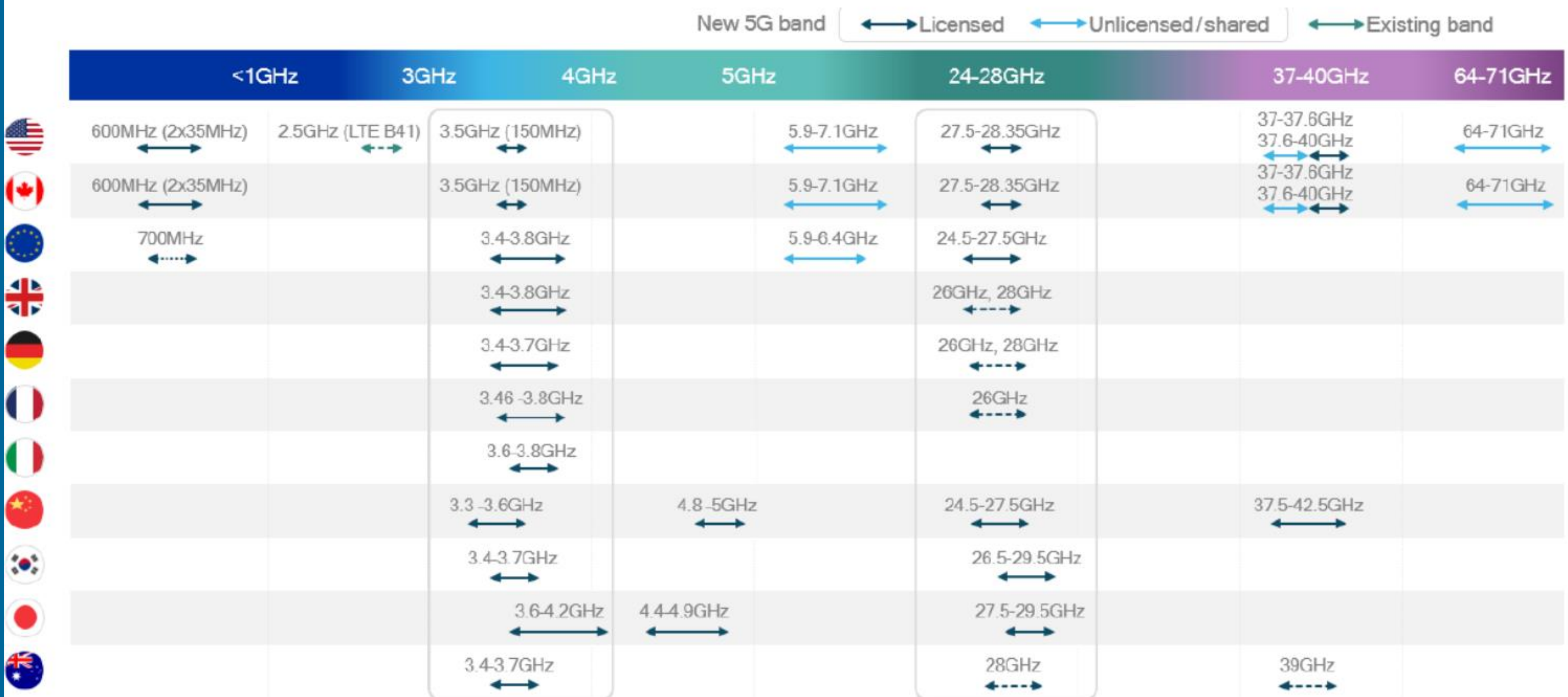
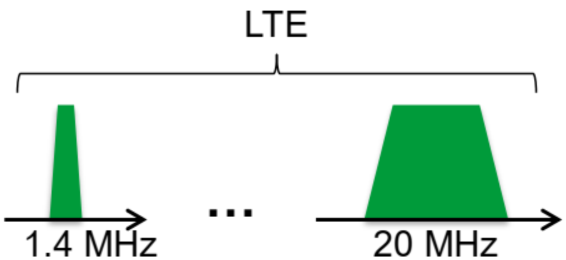
# 5G NR Frequency Bands

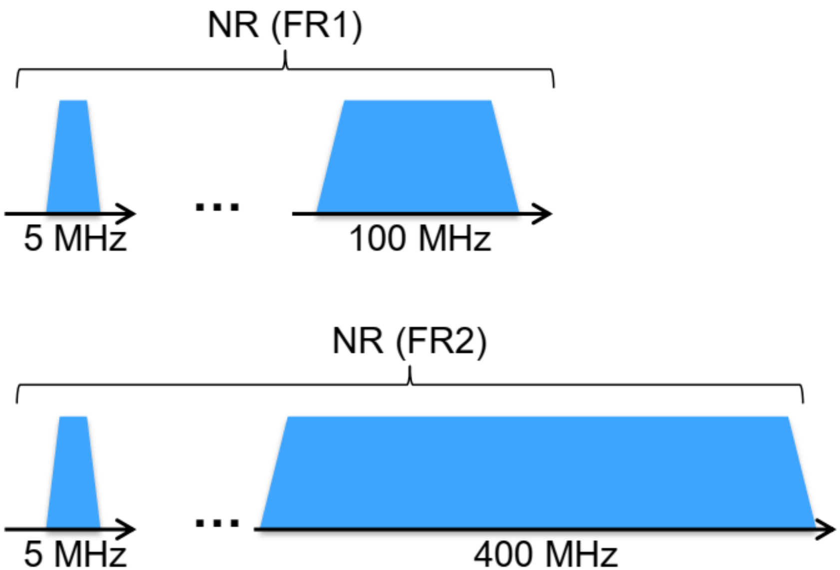
- Both licensed and unlicensed bands considered in various regions
  - Regional variations noted



# 5G NR Carrier Bandwidths

- LTE
  - Minimum carrier bandwidth 1.4 MHz to facilitate migration of 2G bands to LTE
- NR
  - Minimum carrier bandwidth 5 MHz to enable future migration of LTE to 5G NR
  - Wider bandwidths (up to 400 MHz in high bands) for very high rate services



# Details of 5GNR

## What is 5G in Release 15? Radio Design (NR)

A new set of technologies for a generation leap in capabilities

| | 3G | 4G | 5G |
|---|---|---|---|
| Downlink waveform | CDMA | OFDM | OFDM, SCFDMA |
| Uplink waveform | CDMA | SCFDMA | OFDMA, SCFDMA |
| Channel coding | Turbo | Turbo | LDPC (data) / Polar (L1 contr.) |
| Beamforming | No | Only data | Full support |
| Spectrum | 0.8 – 2.1 GHz | 0.4 – 6 GHz | 0.4 – **52.6** GHz* |
| Bandwidth | 5 MHz | 1.4 – 20 MHz | Up to 100 MHz (200 or 400MHz for >6GHz) |
| Network slicing | No | No | Yes |
| QoS | Bearer based | Bearer based | Flow based |
| Small packet support | No | No | Connectionless |
| In-built cloud support | No | No | Yes |

June 2018

June 2018



*** More after Release 16**

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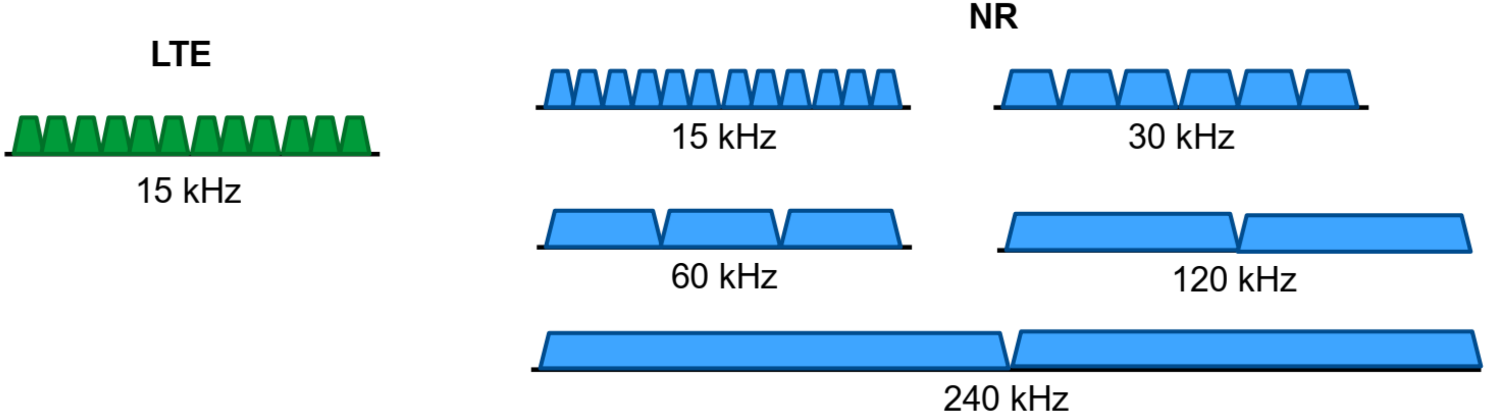
# 5G NR Numerology

- LTE
  - Single numerology → 15 kHz subcarrier spacing (which in turn fixes durations of OFDM symbols, slots etc.)
- 5G NR
  - Flexible numerology with different subcarrier spacing possible ($2^{\mu} \times 15$ kHz) → 15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz
  - Symbol lengths is also scaled accordingly → wider spacing results in shorter symbol durations



# 5G NR Numerology

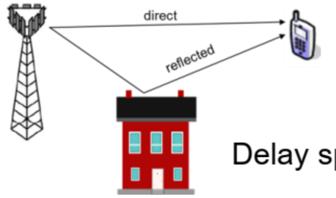
- Higher numerology preferred in high bands (FR2)
  - Needed in high bands because Doppler spread (spectral broadening) is higher and frequency/phase errors more severe → interference between subcarriers
  - Shorter symbol durations desirable for low latency applications
- Lower numerology preferred in low and mid bands (FR1)
  - To support larger cell areas (more delay spread tolerated)

| 3GPP freq. range | Corresponding frequency range | Numerology (subcarrier spacing) |
|---|---|---|
| FR1 | 450-6000 MHz | 15 kHz, 30 kHz, 60 kHz |
| FR2 | 24250-52600 MHz | 60 kHz, 120 kHz, 240 kHz |

$$f_m = \frac{v f_c}{c}$$

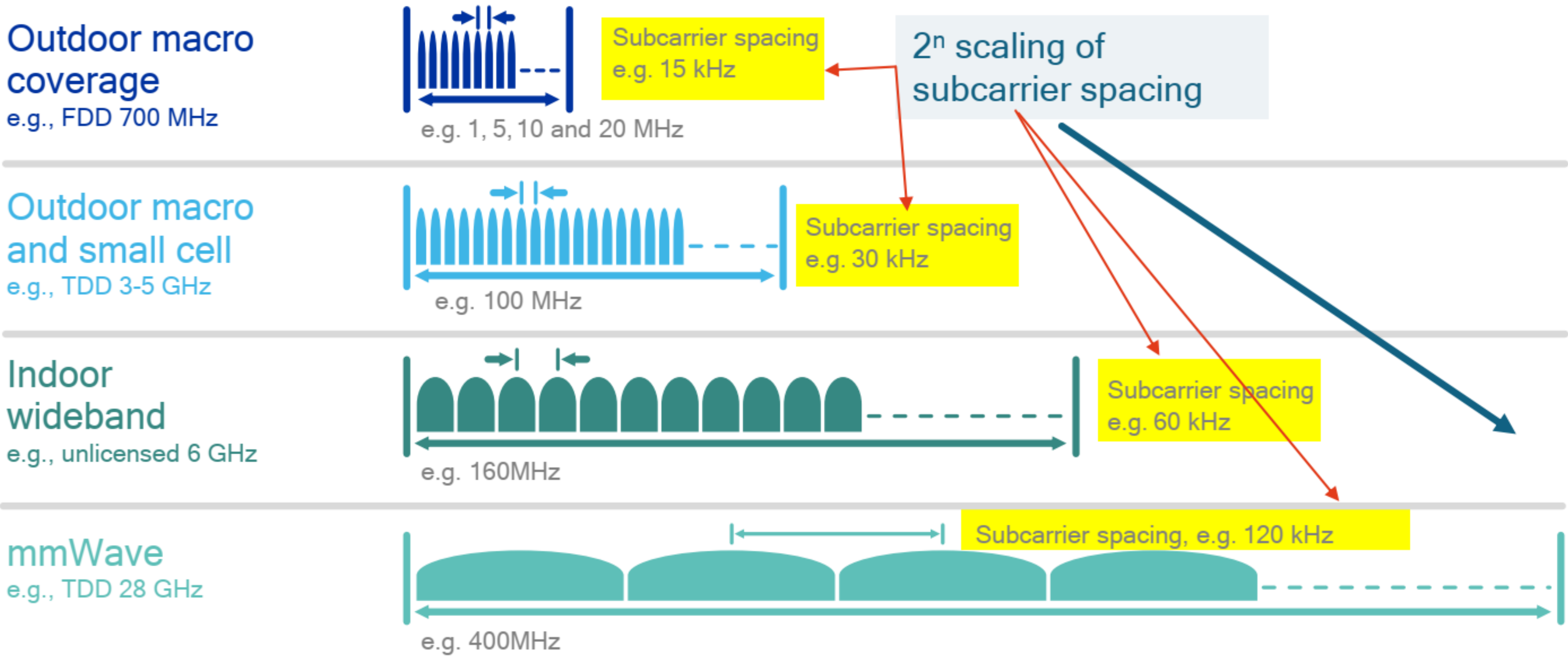
$f_m$ = Doppler spread
$f_c$ = Carrier frequency
$c$ = Speed of light
$v$ = Moving speed

Doppler spread




Delay spread

# Scalable OFDM numerology to efficiently address diverse spectrum, deployments, and services




Example usage models and channel bandwidths

# 5G NR Radio Frame Structure

| Attributes | LTE radio frame | NR radio frame |
|---|---|---|
| **Frame length** | 10 ms | 10 ms |
| **Subframe length** | 1 ms | 1 ms |
| **Slots per subframe** | Fixed number of slots:<br>2 slots each 0.5 ms | Slot number of varies with numerology:<br>If $\Delta f$ = 15 kHz, 1 slot of 1 ms<br>If $\Delta f$ = 30 kHz, 2 slots each 0.5 ms<br>If $\Delta f$ = 60 kHz, 4 slots each 0.25 ms<br>If $\Delta f$ = 120 kHz, 8 slots each 0.125 ms<br>If $\Delta f$ = 240 kHz, 16 slots each 0.0625 ms |
| **OFDM symbols per slot** | 7 symbols per slot (normal CP)<br>6 symbols per slot (extended CP) | *Standard slot*: 14 symbols per slot (normal CP), 12 symbols per slot (extended CP)<br><br>*Mini slots*: 7, 4 or 2 symbols per slot |
| **OFDM symbol duration** | Fixed at 66.67 μs (= 1/15 kHz) | Duration varies with numerology:<br>= $1/\Delta f$ |
| **CP duration** | 4.7 μs 5.2 μs (normal CP)<br>16.7 μs (extended CP) | Duration varies with numerology:<br>= 4.7 μs / $m$ whereby $\Delta f = 2^m \times 15$ kHz |

## Frame structure: Multiple OFDM numerologies (2/3)

- Numerology options based on **sub-carrier spacing of $15*2^N$ kHz**

**Available OFDM numerologies for 5G New Radio, Normal CP length (NR Phase I)**

| Subcarrier spacing [kHz] | 15 | 30 | 60 | 120 | 240* |
|---|---|---|---|---|---|
| Symbol duration [us] | 66.7 | 33.3 | 16.7 | 8.33 | 4.17 |
| Nominal Normal CP [us] | 4.7 | 2.3 | 1.2 | 0.59 | 0.29 |
| Min scheduling interval (symbols) | 14 | 14 | 14 | 14 | - |
| Min scheduling interval (slots) | 1 | 1 | 1 | 1 | - |
| Min scheduling interval (ms) | 1 | 0,5 | 0.25 | 0.125 | - |

*Only used for synch-block

- 15 kHz similar to LTE, good **for wide area** on traditional cellular bands
- 30/60 kHz **for dense-urban**, lower latency and wider carrier BW
- 60 kHz or higher needed **for >10 GHz** bands to combat phase noise

**LTE (15 kHz SCS, Normal CP length) is a subset of numerologies supported by NR**

# Frame structure: Multiple OFDM numerologies (3/3)

- **RAN4 agreements for subcarrier spacing** (Rel-15)
  - below 6 GHz: [15, 30, 60] kHz
  - 6…52.6 GHz: [60, 120] kHz, 240 kHz can be considered if clear benefits are shown
- **RAN4 agreements for minimum/maximum channel bandwith** (Rel-15)
  - below 6 GHz: 5 MHz / 100 MHz
  - 6…52.6 GHz: 50 MHz / 400 MHz

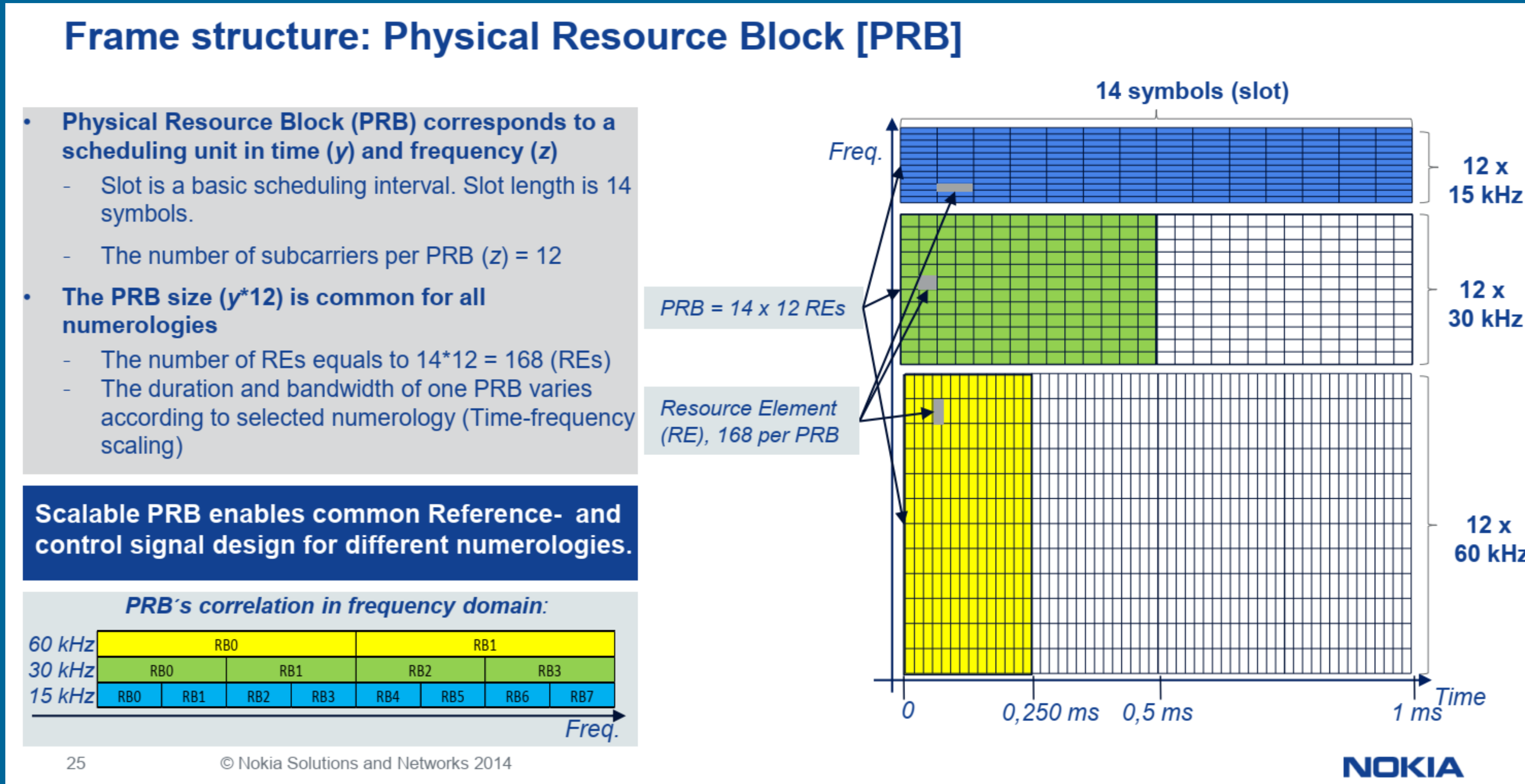
**Maximum channel bandwidth with different numerologies & FFT size (Rel-15):**

| Subcarrier spacing [kHz] | 15 | 30 | 60 | 120 | 240 | |
|---|---|---|---|---|---|---|
| Maximum bandwidth, 2k FFT (MHz) | 25 LTE | 50 | 100 | 200 | 400 | FFT size used already in LTE |
| Maximum bandwidth, 4k FFT (MHz) | 50 | 100 | 200 | 400 | 800 | RAN4: Feasible FFT size |
| Maximum bandwidth, 8k FFT (MHz) | 100 | 200 | 400 | 800 | 1600 | RAN4: Feasibility of 8k FFT is FFS |

- FFT size as such is an implementation issue
- 4k FFT needed to support a maximum channel BW on particular band

Combinations with red colour are (most likely) outside of Rel-15

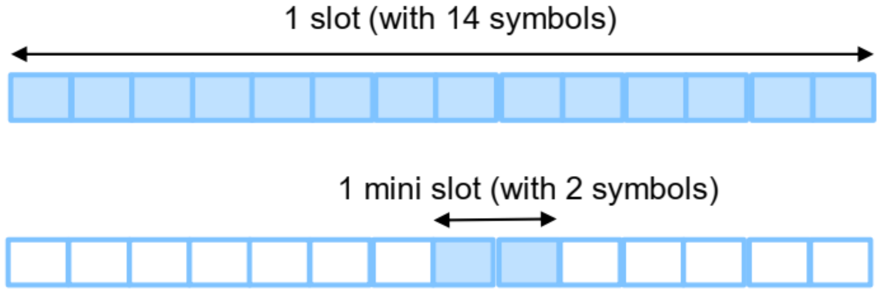
**Increased subcarrier spacing as well as larger FFT size increase the maximum channel bandwidth from LTE's 20 MHz to NR's 400 MHz (20x)**




- In LTE
  - RB = 1 Slot (0.5 msec) * 12 subcarrier = 7 symbol * 180KHz
  - RE  = 1 Symbol * 1 subcarrier
  - 1RB = 7 * 12 RE = 84 RE

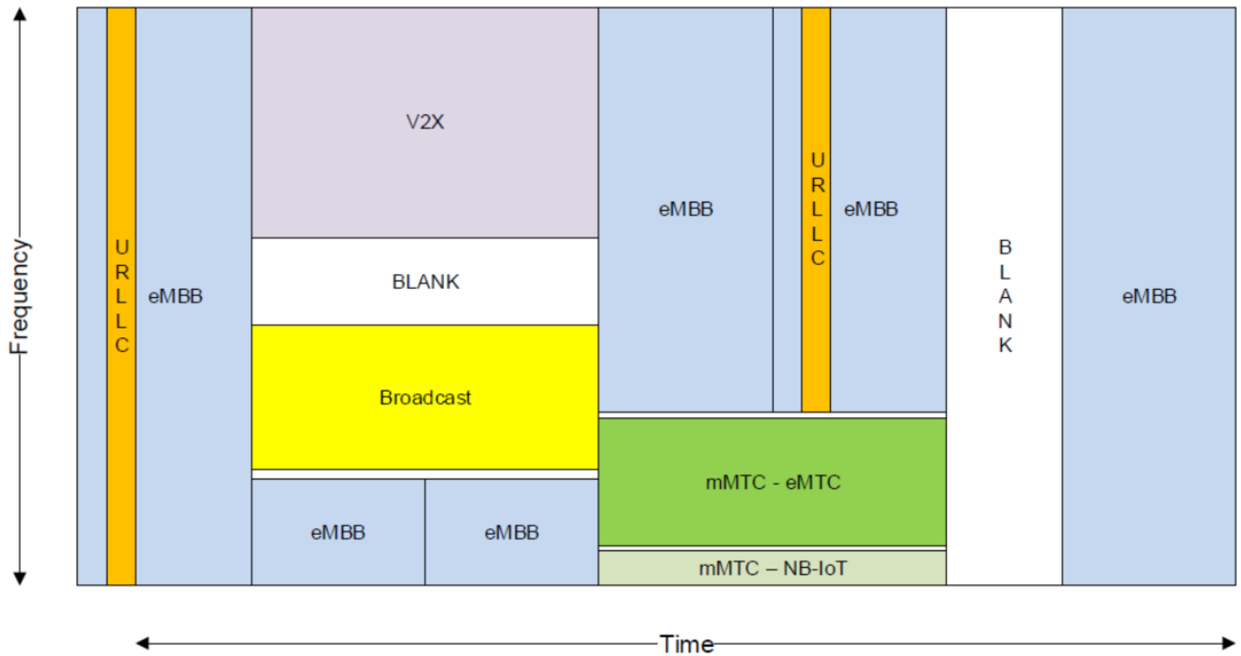
# Low Latency in 5G

- Mini slot transmissions may begin any time (immediately) within a standard slot → no need to wait for the beginning of the standard slot
  - Contributes to reduced latency for URLLC
  - Enables fast retransmission in case of errors → enhances reliability

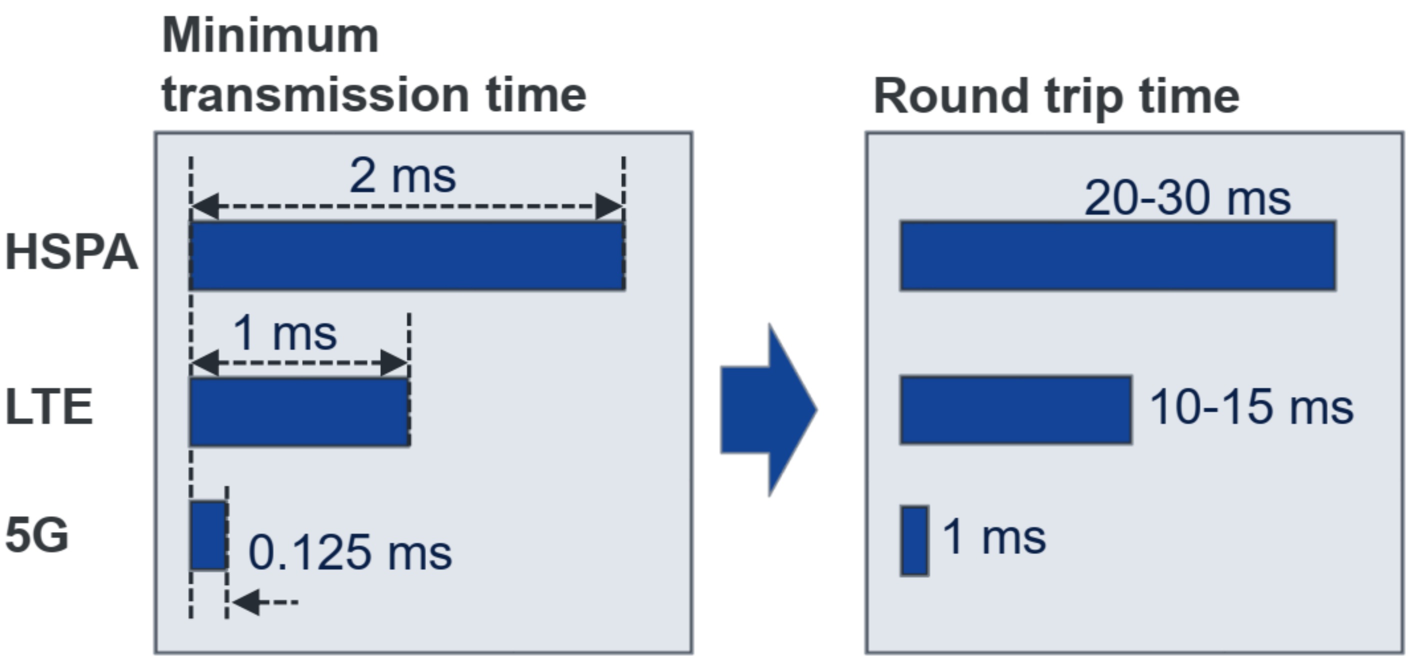


# 5G NR Physical Resources

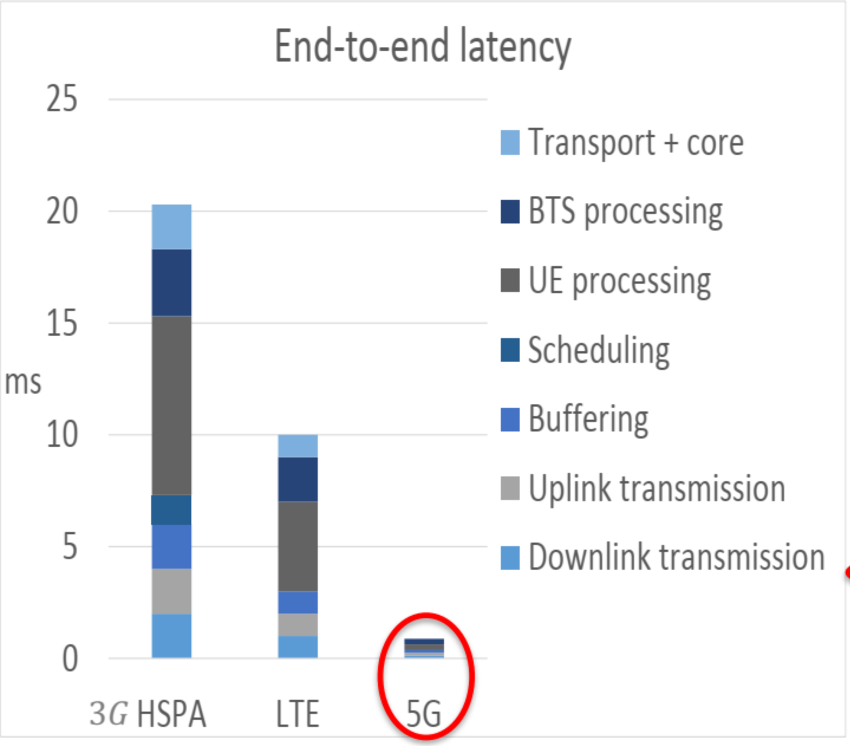
- Flexible numerology in NR provides framework for more effective support of different services and QoS requirements
  - Flexible radio resource allocation in time-frequency grid

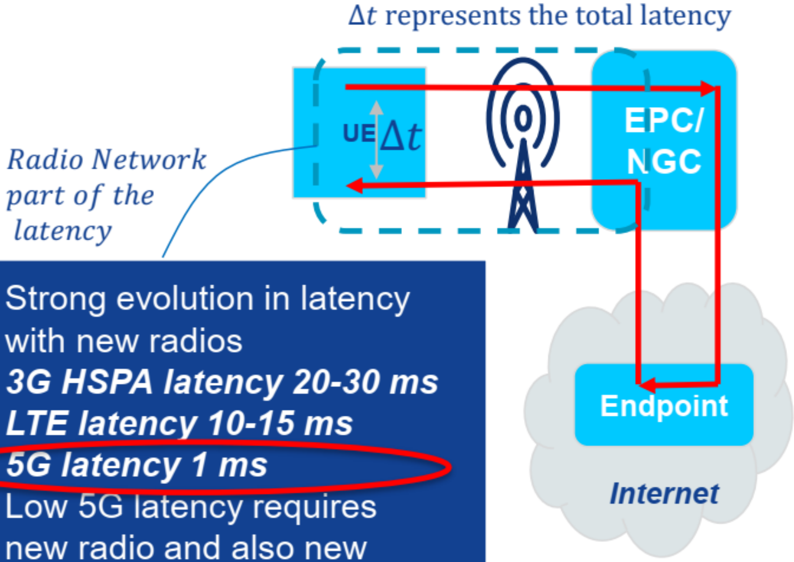


# Innovations for Low Latency Radio Transmission – 1 millisecond in 5G



# Latency in Mobile Networks




- Strong evolution in latency with new radios
- ***3G HSPA latency 20-30 ms***
- ***LTE latency 10-15 ms***
- ***5G latency 1 ms***
- Low 5G latency requires new radio and also new architecture with local content



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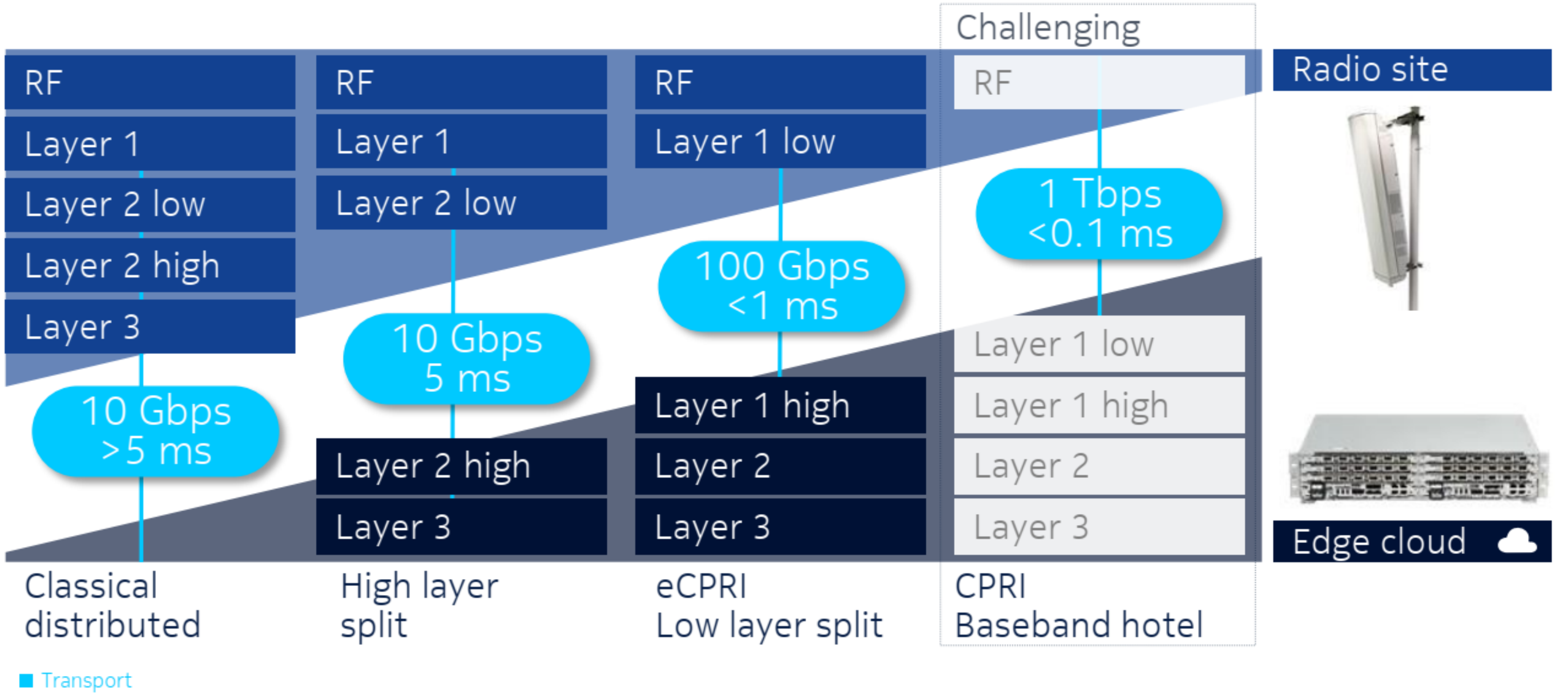
# Trade off between latency reduction and growing transport requirements

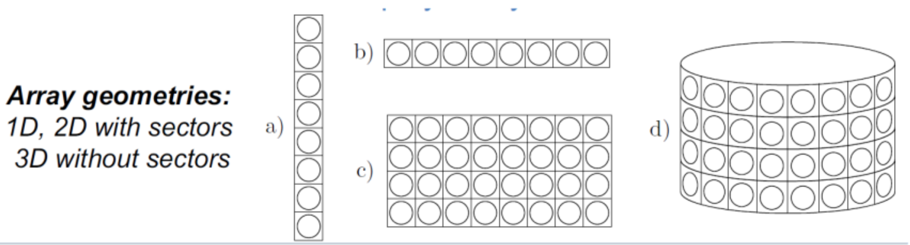
## 5G radio architecture options for cloud RAN gNB

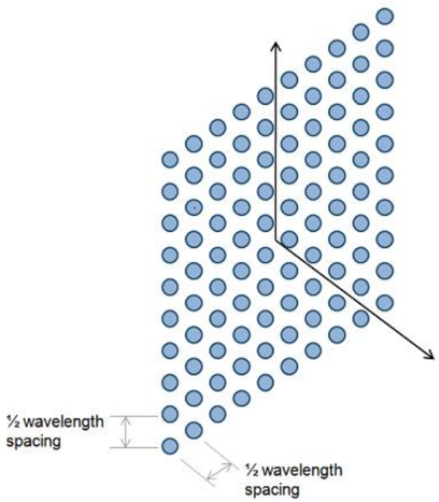


# Other PHY layer tools..

## Massive MIMO for 5G NR

- Active antenna array technology becoming more technically and commercially feasible
  - Antenna array size decreases with increased carrier frequency e.g. antenna arrays in FR2 frequencies could be a hundredth of corresponding FR1 array
  - More antennas enables increased directivity (*see example in next slide*)

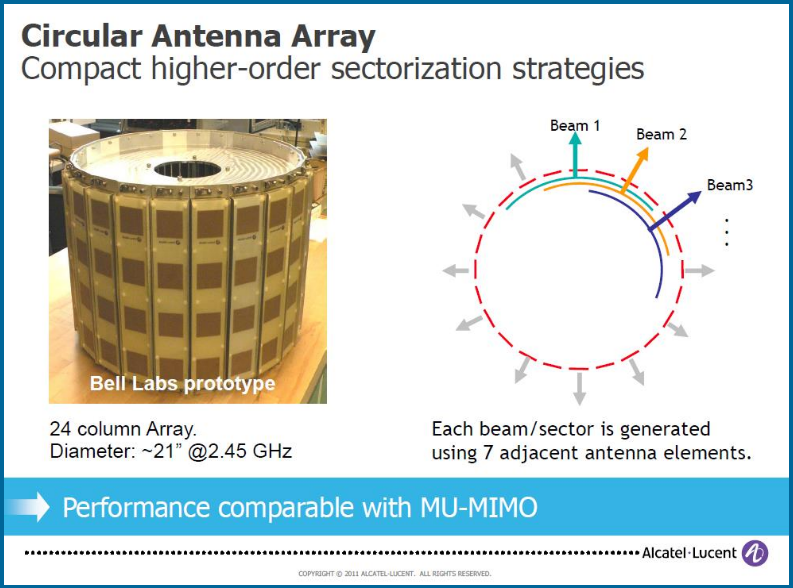


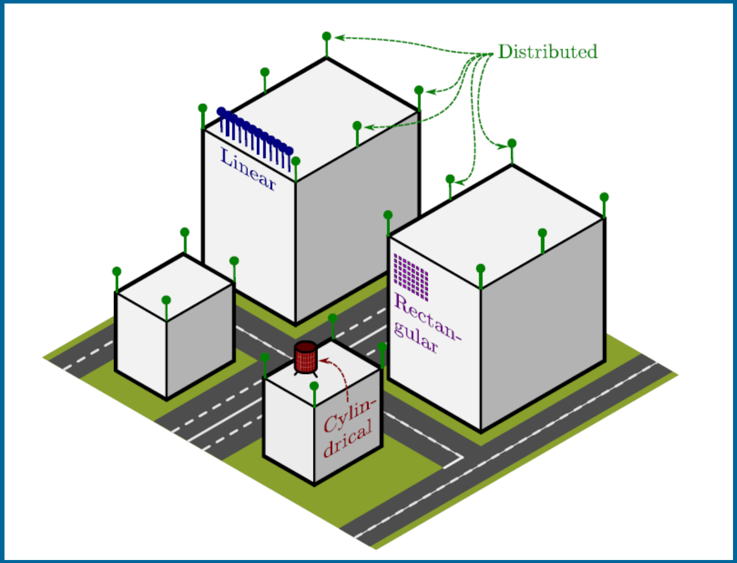




Source: E. Björnson, Massive MIMO for 5G: How Big Can it Get?

# Massive MIMO

- MIMO a key enabler in recent years
- Next step: Use large number of antennas instead of a few
- Makes life simpler in algorithm and circuit design
- But many new challenges..



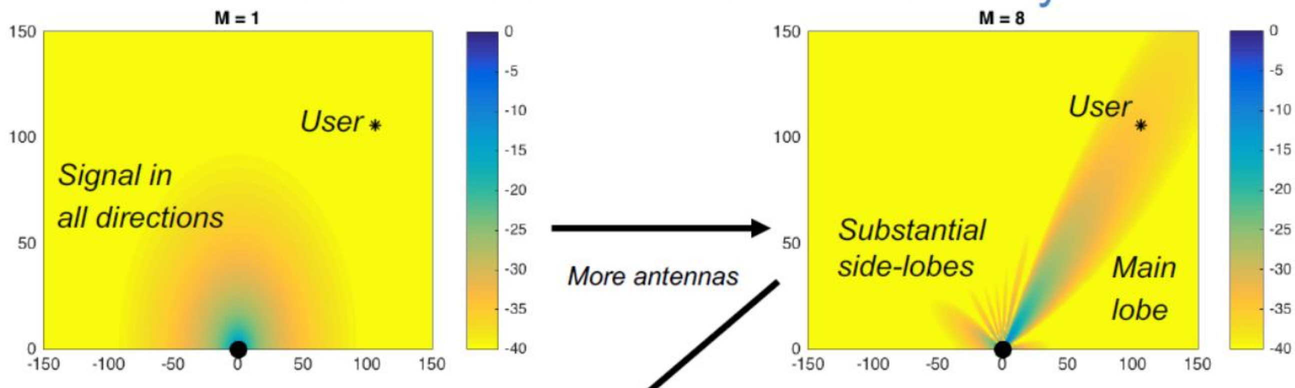
# Massive MIMO for 5G NR

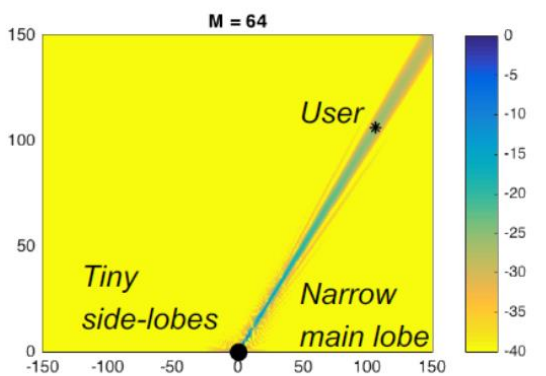
- Extension of the MIMO configurations to antenna arrays with with a large number of controllable antennas (32 or more antennas in NR)

| 3GPP freq. range | Corresponding frequency range | Need and benefit for Massive MIMO |
|---|---|---|
| FR1 | 450-6000 MHz | - Interference-limited (SINR limit)<br>- Spectrum scarcity (capacity limitation)<br>- Benefit: Improved spectral efficiency |
| FR2 | 24250-52600 MHz | - High path loss (coverage-limited)<br>- Stringent line-of-sight requirements<br>- Benefit: Beamforming increases signal strength by focusing to individual UEs |

# Massive MIMO for 5G NR

## More Antennas → More Directivity




**Same transmit power**

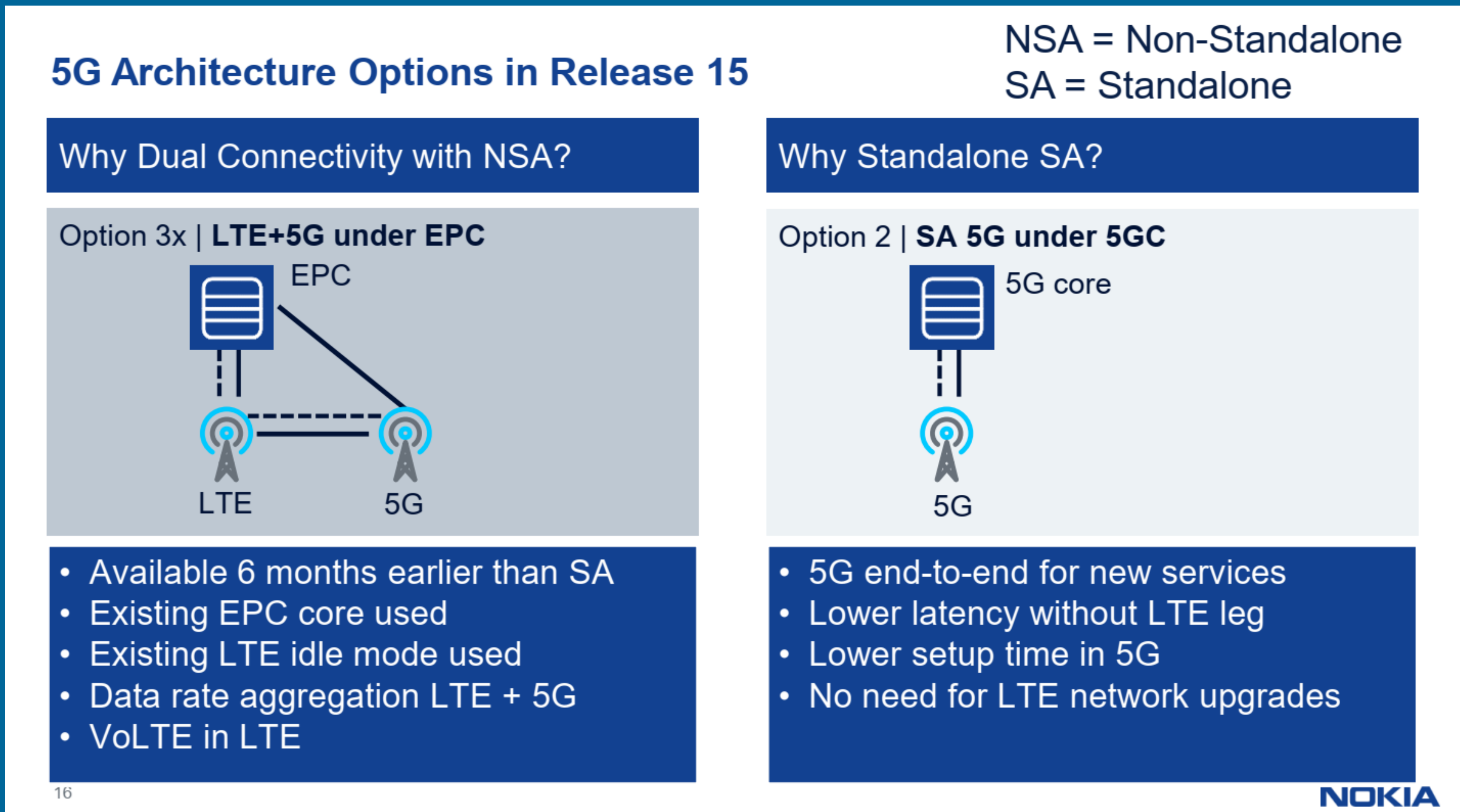
- *M* base station antennas
- Color indicates pathloss in dB
- Main lobe focused at user

**More antennas**

- Array gain: $10 \log_{10}(M)$ larger at user
- Less leakage in other directions

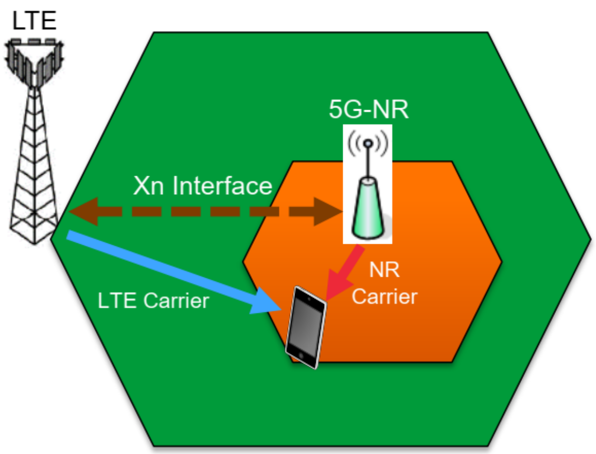
Source: E. Björnson, Massive MIMO for 5G: How Big Can it Get?

# Evolution from 4G to 5GNR

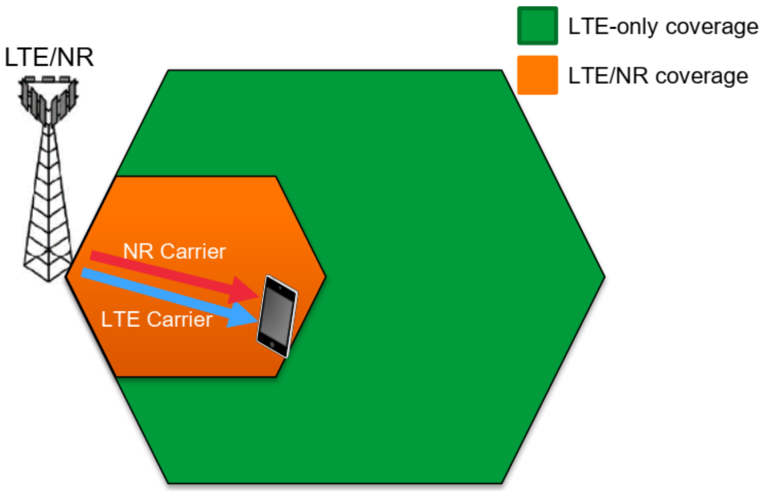


# 5G NR Architectures

- Possible deployment scenarios with non-standalone architecture → LTE/NR dual connectivity




Heterogeneous deployment
- LTE macro cell and NR small cell
- LTE connection provides redundancy when UE out of NR coverage




LTE-NR co-sited deployment
- Migrational approach allowing continue service to LTE only UEs
- If high band NR, dual connectivity not available in cell edge

# Rel 16: Freeze date March 2020

## Some Example 5G NR Release 16 Work Items

- Operation in unlicensed bands (e.g. 60 GHz)
  - Complementing licensed bands
  - Similar to what is done in LTE-A Pro
- Enhancement of Ultra-Reliable (UR) Low Latency Communications (URLLC)
- Cellular IoT support and evolution
- Advanced V2X support
- 5G Location and Positioning Services
- Satellite Access in 5G

# Rel 17: Started in January 2020 Completed June 2022

## Release 17

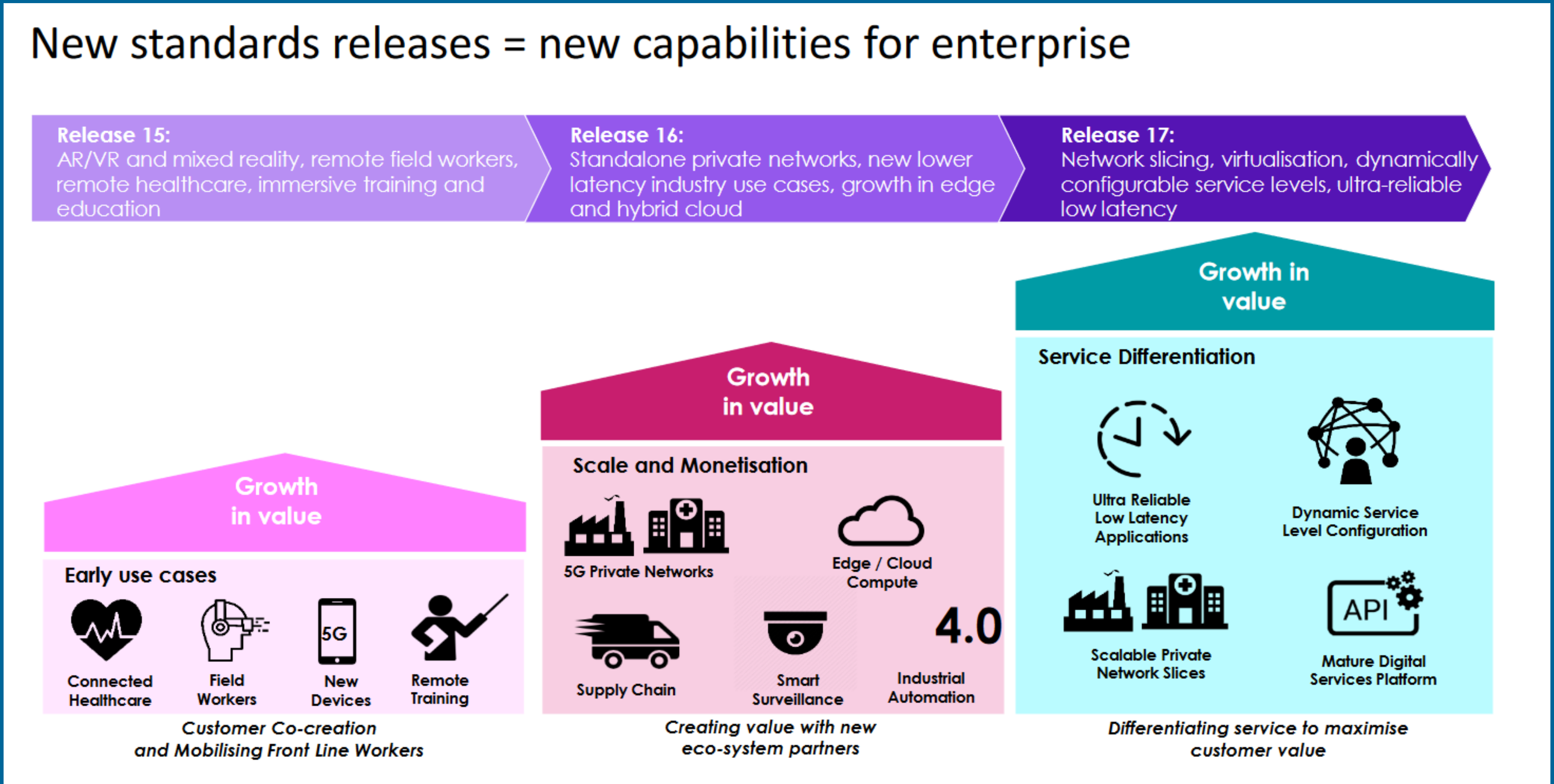
- NR MIMO
- NR Sidelink enh.
- 52.6 - 71 GHz with existing waveform
- Dynamic Spectrum Sharing (DSS) enh.
- Industrial IoT / URLLC enh.
- Study - IoT over Non Terrestrial Networks (NTN)
- NR over Non Terrestrial Networks (NTN)
- NR Positioning enh.
- Low complexity NR devices
- Power saving
- NR Coverage enh.
- Study - NR eXtended Reality (XR)
- NB-IoT and LTE-MTC enh.
- 5G Multicast broadcast
- Multi-Radio DCCA enh.
- Multi SIM
- Integrated Access and Backhaul (IAB) enh.

- NR Sidelink relay
- RAN Slicing
- Enh. for small data
- SON / Minimization of drive tests (MDT) enh.
- NR Quality of Experience
- eNB architecture evolution, LTE C-plane / U-plane split
- Satellite components in the 5G architecture
- Non-Public Networks enh.
- Network Automation for 5G - phase 2
- Edge Computing in 5GC
- Proximity based Services in 5GS
- Network Slicing Phase 2
- Enh. V2x Services
- Advanced Interactive Services
- Access Traffic Steering, Switch and Splitting support in the 5G system architecture

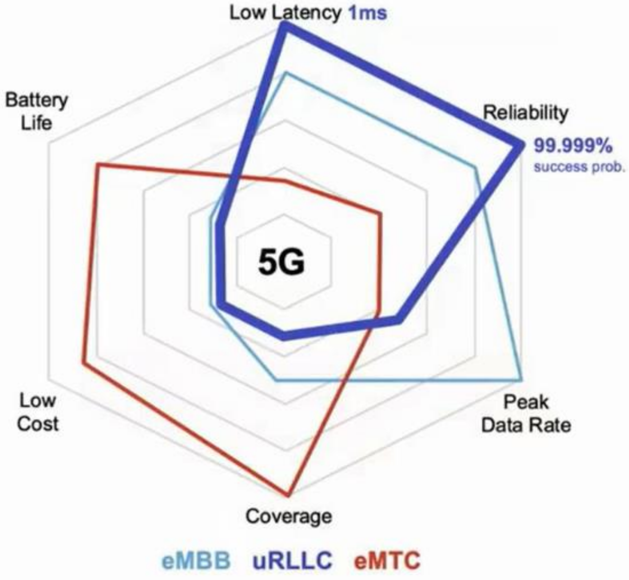
- Unmanned Aerial Systems
- 5GC LoCation Services
- Multimedia Priority Service (MPS)
- 5G Wireless and Wireline Convergence
- 5G LAN-type services
- User Plane Function (UPF) enh. for control and 5G Service Based Architecture (SBA)

These are some of the Rel-17 headline features, prioritized during the December 2019 Plenaries (TSG#86)

Start of work: January 2020


New standards releases = new capabilities for enterprise
Release 15:
AR/VR and mixed reality, remote field workers, remote healthcare, immersive training and education
Release 16:
Standalone private networks, new lower latency industry use cases, growth in edge and hybrid cloud
Release 17:
Network slicing, virtualisation, dynamically configurable service levels, ultra-reliable low latency
Growth in value
Early use cases
Connected Healthcare
Field Workers
5G
New Devices
Remote Training
Customer Co-creation and Mobilising Front Line Workers
Growth in value
Scale and Monetisation
5G Private Networks
Edge / Cloud Compute
Supply Chain
Smart Surveillance
4.0
Industrial Automation
Creating value with new eco-system partners
Growth in value
Service Differentiation
Ultra Reliable Low Latency Applications
Dynamic Service Level Configuration
Scalable Private Network Slices
API
Mature Digital Services Platform
Differentiating service to maximise customer value

# 3GPP sets a **pathway**




| Rel. 15 | Rel. 16 | Rel. 17 | Rel. 18 |
|---|---|---|---|
| • Reduced UE and gNB processing time.<br>• New numerology with short Transmission Time Interval.<br>• Frequency diversity.<br>• Enhanced hybrid ARQ (Blind repetitions).<br>• Multi-connectivity for data duplication transmissions. | • Enhancements in the 5G Core to support URLLC.<br>• Uplink grant-free transmissions.<br>• Pre-empting uplink eMBB transmissions (URLLC prioritization).<br>• Improved DL transmission efficiency to help optimize latency.<br>• V2X enhancements for short latency and high reliability. | • Enhanced M-MIMO operations to reduce signaling latency.<br>• Higher compression efficiency to reduce uplink transmission latency.<br>• Enhanced physical layer feedback.<br>• Enhanced time synchronization.<br>• Network QoS enhancements. | • Traffic management for low-latency radio resource allocation<br>• Resource allocation and scheduling enhancements for bounded latency for XR & Cloud gaming.<br>• Co-existence of downlink and uplink at the same time within a TDD band.<br>• Layer 1 & 2 inter-cell mobility procedures to reduce latency, overhead. |

Key 5G latency features & enhancements

# One example

## Powering 5G deployments on multiple platforms

Radisys

**Integrated on Multiple SoCs, Hardware and Cloud Platforms**

- **Network in a box**
- **Femtocell**
- 16/32 UEs, >1 Gbps

- **Enterprise small cell**
- **Indoor DU**
- 64/128 UEs. 2Gbps

- **Outdoor Micro CU+DU**
- 256 UEs, 2 Gbps

- **CU+DU at Cell Site**
- 3 cells per DU
- Per cell: 512 UEs, 2Gbps

- **vCU an vDU (CNF)**
- Multi cell
- Multi Gbps
- Scale in/out

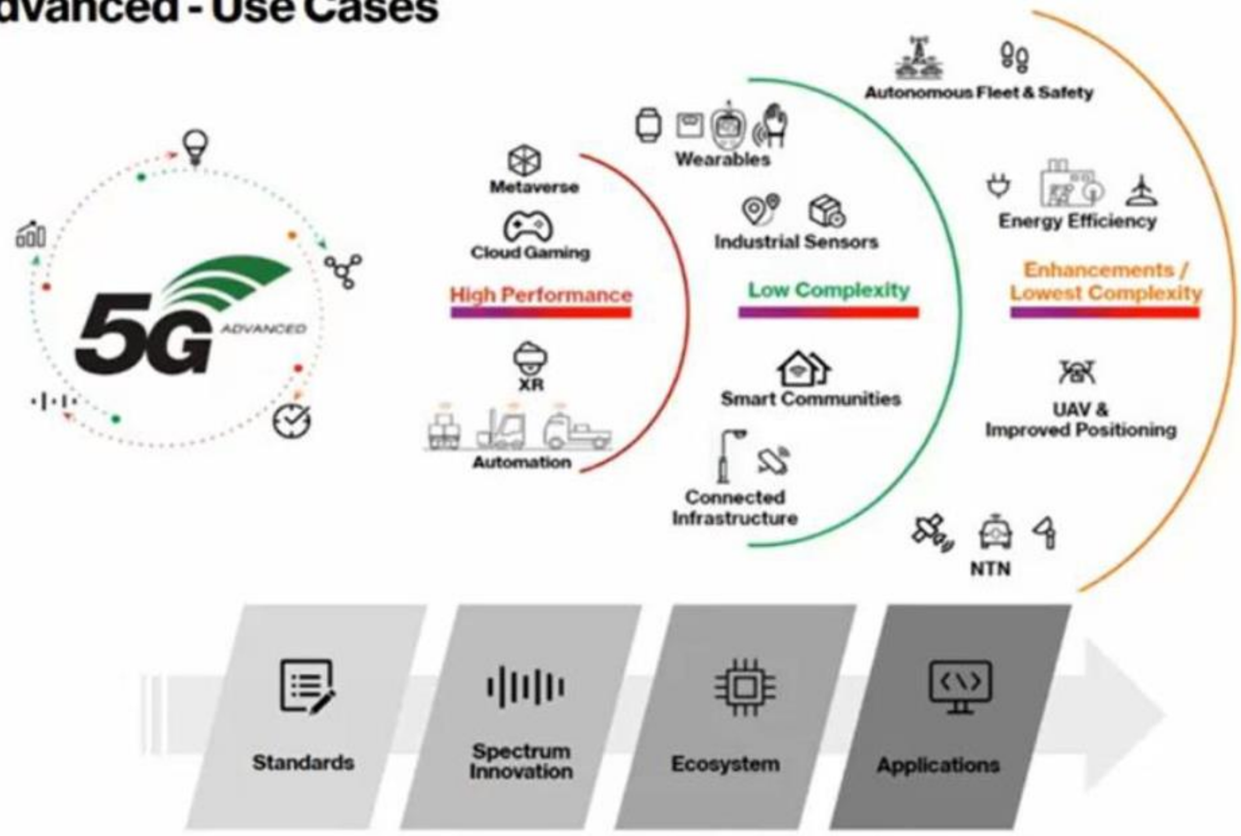
### Flexible Architecture

- All-in-one gNB
- Option 2 CU/DU/RU split
- Option 2 CU, DU+RU
- LLS option 6 split
- LLS option 7.2a/b split

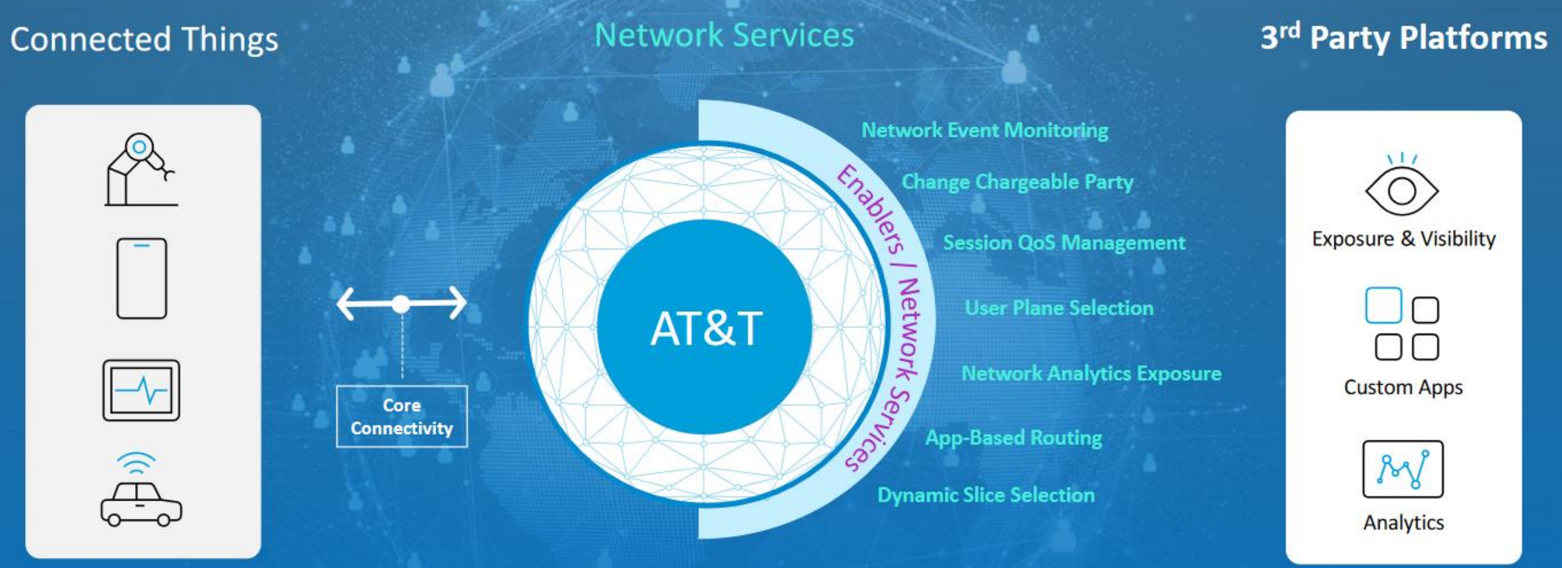
### vRAN (vDU and vCU)

- Containerization ( Kubernetes)
- Red Hat Openshift Cloud Platform (OCP), Windriver Cloud Platform (WRCP)
- CUPS (CU-CP and CU-UP) architecture
- PNF equivalent performance
- Optimized scale-in and scale-out as per #cells, layers and throughput

# 5G Advanced - Use Cases



# Bringing to market a new set of innovative Network Services




## VERTICAL USE CASES

**Healthcare**

Remote Monitoring, Accelerated Training

**Manufacturing**

Predictive maintenance, Worker Safety

**Automotive**

Over-The-Air Updates, Enabling Advanced Driver Features





AT&T Business

# TELCO AND CLOUD COMMUNITIES COLLABORATE TO OVERCOME THESE CHALLENGES

CAMARA — THE TELCO GLOBAL API ALLIANCE
Open Source **Telco Service APIs**
Facilitates NaaS usage by developers

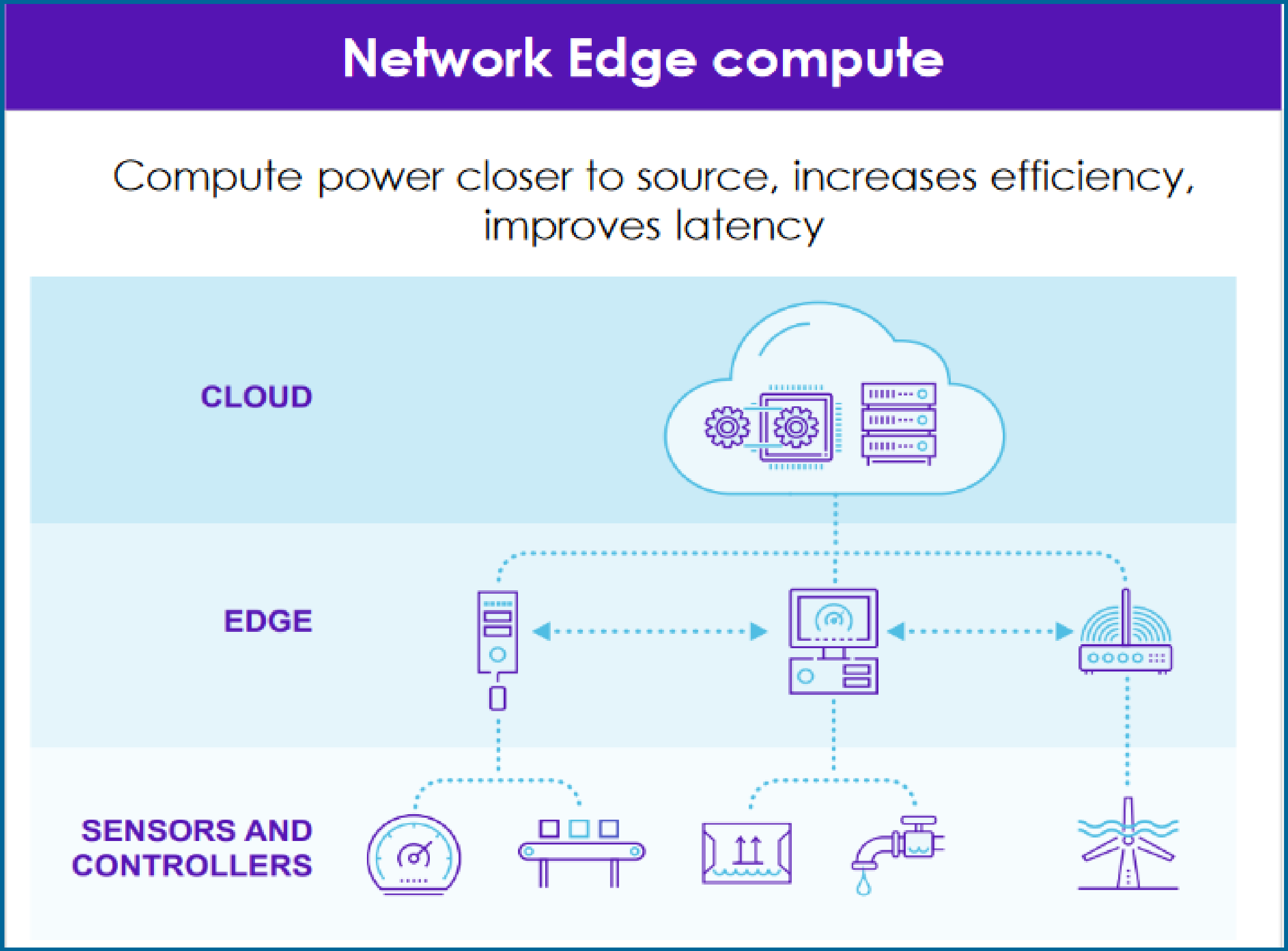
GSMA Operator Platform
**Telco Capability Exposure** Platform
Facilitates NaaS implementation by telcos

Sylva
**Cloud Software Framework** for Network and Edge applications
Manages Telco Cloud diversity

Anuket
Standardized **Reference Infrastructure framework** for Network Functions
Reduces Infrastructure heterogeneity

NEPHIO
**Kubernetes-based cloud native intent automation**
Facilitates Telco Edge and Cloud operation and management

# Next key step: Moving to the edge

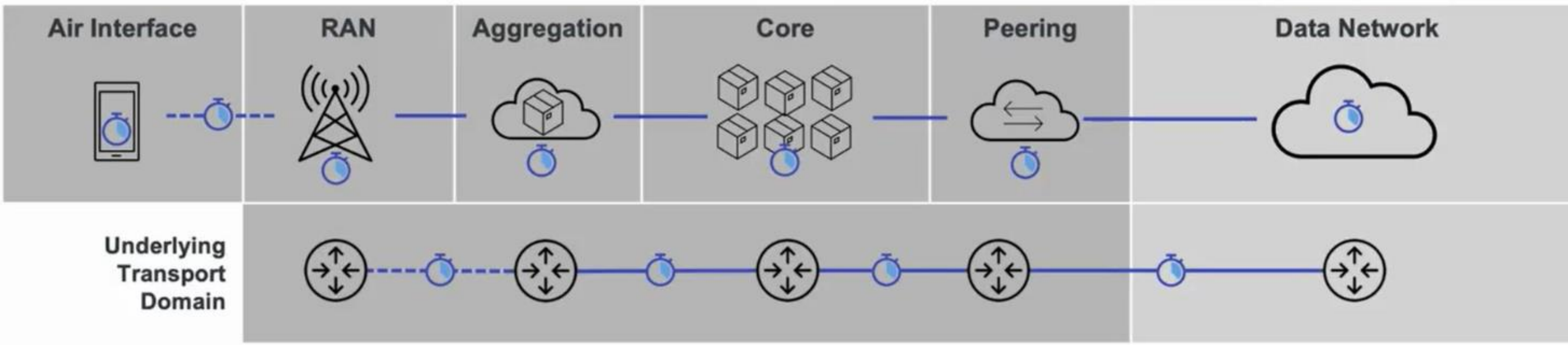


A CLOSER LOOK AT END-TO-END TESTING TO DELIVER ON SLAS

# How important will **latency** be?

| Use Case | Latency |
|---|---|
| AR/VR motion-to-photon (picture) | 7-15ms |
| Collaborative gaming | <20ms |
| Time critical sensing | <30ms |
| Remote drone operation | 10-30ms |
| Real-time control for discrete automation | ≤1ms |
| HD Digital map update | 100ms |
| Remote operation | 10-30ms |
| Sensor sharing | <20ms |
| Time critical sensing | <30ms |
| Mobile robots (machine control) | ≤10ms |
| Mobile robots (video-operated remote control) | 10-100ms |
| Process automation | 50ms |
| Mobile control panels (assembly robots, milling) | 4-8ms |
| AR monitoring | <10ms |

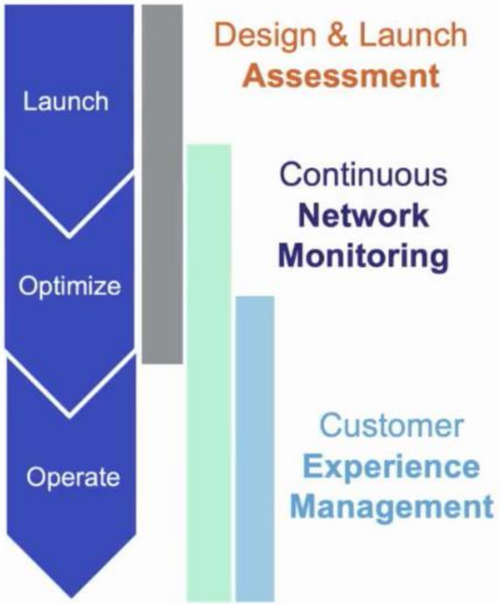
# What **impacts** latency?

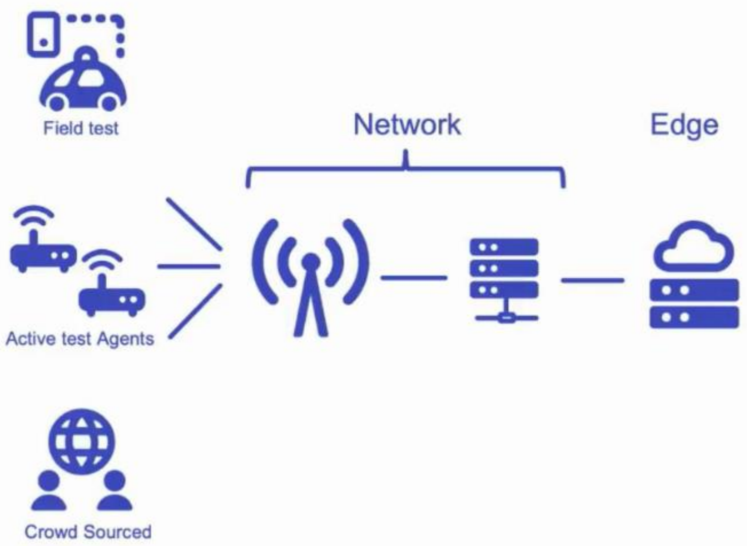



example **Causes of Latency**

| DEVICE / RADIO | NETWORK | TRANSPORT | DATA NETWORK / APPS |
|---|---|---|---|
| • Radio scheduling<br>• Mobility (handovers)<br>• Link adaption<br>• OTA (distance, noise, congestion)<br>• Admission control | • Core locations (distance)<br>• Edge distributions<br>• Security functions<br>• Congestion<br>• Network slices resource contention | • Routing paths & protocols<br>• QoS settings<br>• Transport capacity<br>• Storage delays (at bridges & switches) | • App design (processing)<br>• Cloud location & processing |

# When to test. What to test.



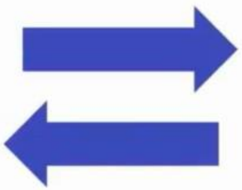



spirent

# Latency Measurement **Methods**

## Ping RTT

- ☑ Widely available
- ☒ ICMP-based so will miss routing priority; Not representative of real world MEC applications
- ☒ Does not separate down- and uplink



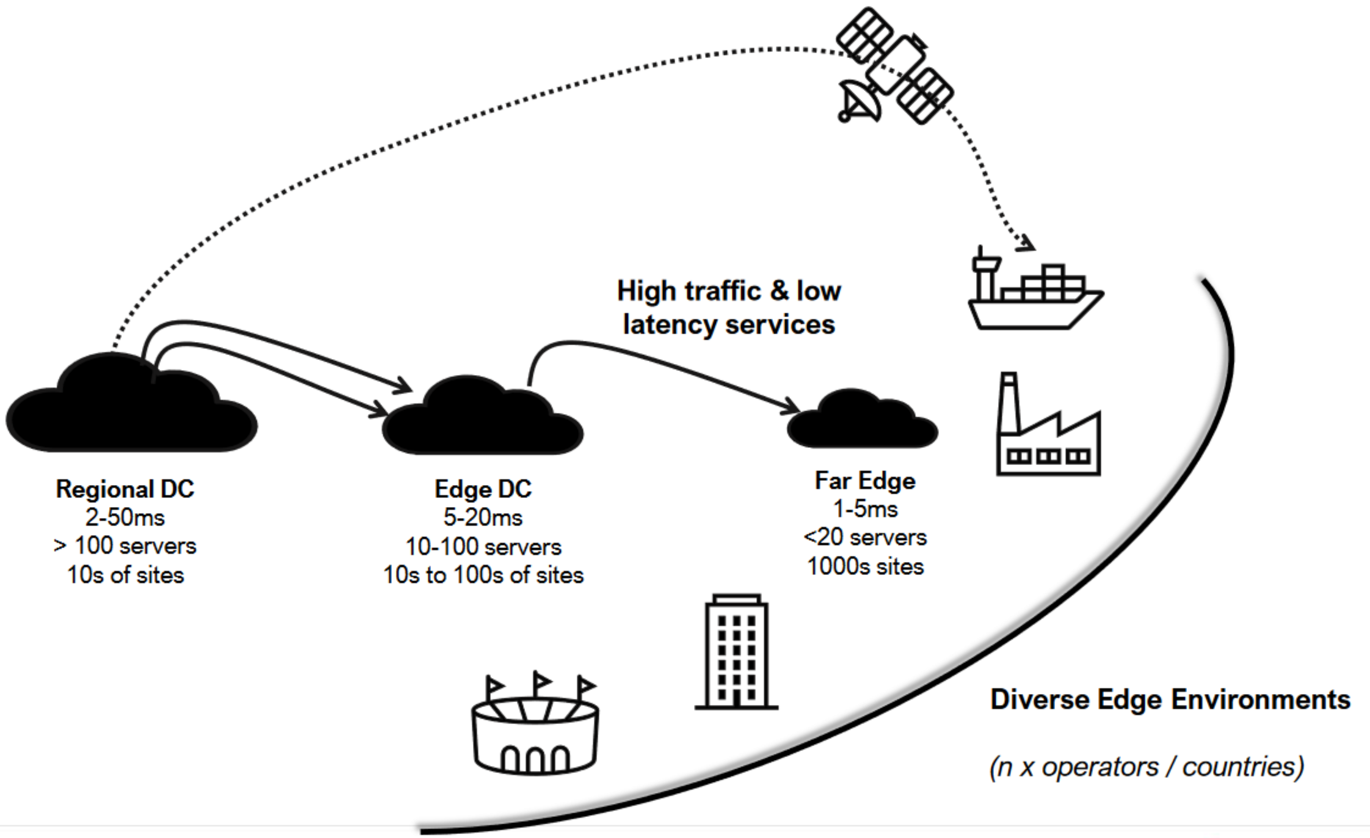
## UDP One-Way

- ☑ Spirent-supported
- ☑ UDP-based so will be properly prioritized
- ☑ Separates down- and uplink
- ☑ Latency trending by packet size and data rate


## QED / DeltaQ

- ☑ Spirent-supported
- ☑ UDP-based so will be properly prioritized
- ☑ Separates down- and uplink
- ☑ Delineates between delays to geography (G), serialization (S) and loading (V)
- ☑ Latency trending by packet size

# 5G Edge: Wherever the customer wants it



## THE DEPLOYMENT OF THE 5G EDGE POSES SOME CRITICAL REQUIREMENTS

### FOR NETWORK FUNCTIONS

Carrier-grade secure and efficient Cloud environment → Open source, standard (K8s-based), light weight, performing stack

Hybrid multicloud solution, combining Edge and Cloud, private and public → Automated orchestration of the complex Edge-Cloud continuum
Dynamic workload deployment

Real-time processing, signalling and synchro requirements → Virtualization of hardware acceleration and I/O, for certain NFs

## THE DEPLOYMENT OF THE 5G EDGE POSES SOME CRITICAL REQUIREMENTS

## FOR BUSINESS APPLICATIONS

| | |
|---|---|
| Low Latency | Optimized transport topology, distributed User Plane, QoS control |
| Residency, privacy | Highly distributed (localized) edge |
| Efficiency | Dynamic resource allocation (EdgeaaS)<br>Collocation with Network Functions |
| Security | Embedded in the trusted Network environment and using its mechanisms |

# 5G EDGE OPENS SERVICE OPPORTUNITIES

5G RAN and Core, IP Network (FW, SDN-C…), Fixed Access (BNG) and CDN Network Functions will be hosted in the future in a set of **tens/hundreds of Edge Cloud nodes** that can serve as a basis for other advanced Business Applications that may enjoy:

- **Low latency and jitter:** Provided by 5G radio access, a distributed user plane (UPF) and QoS control of the connectivity over the edge-cloud continuum
- **Privacy and residency:** coming from its location in a very distributed compute environment (close to the end-user) embedded in the Network.
- **Controlled QoS** for the user-to-edge and edge-to-cloud connectivity

**Real-time data analytics/AI:**

- Video analysis for security cameras
- Massive sensor data collection and processing

**Real-time media and entertainment:**

- AR/VR Gaming
- Immersive video streaming
- Remote video production

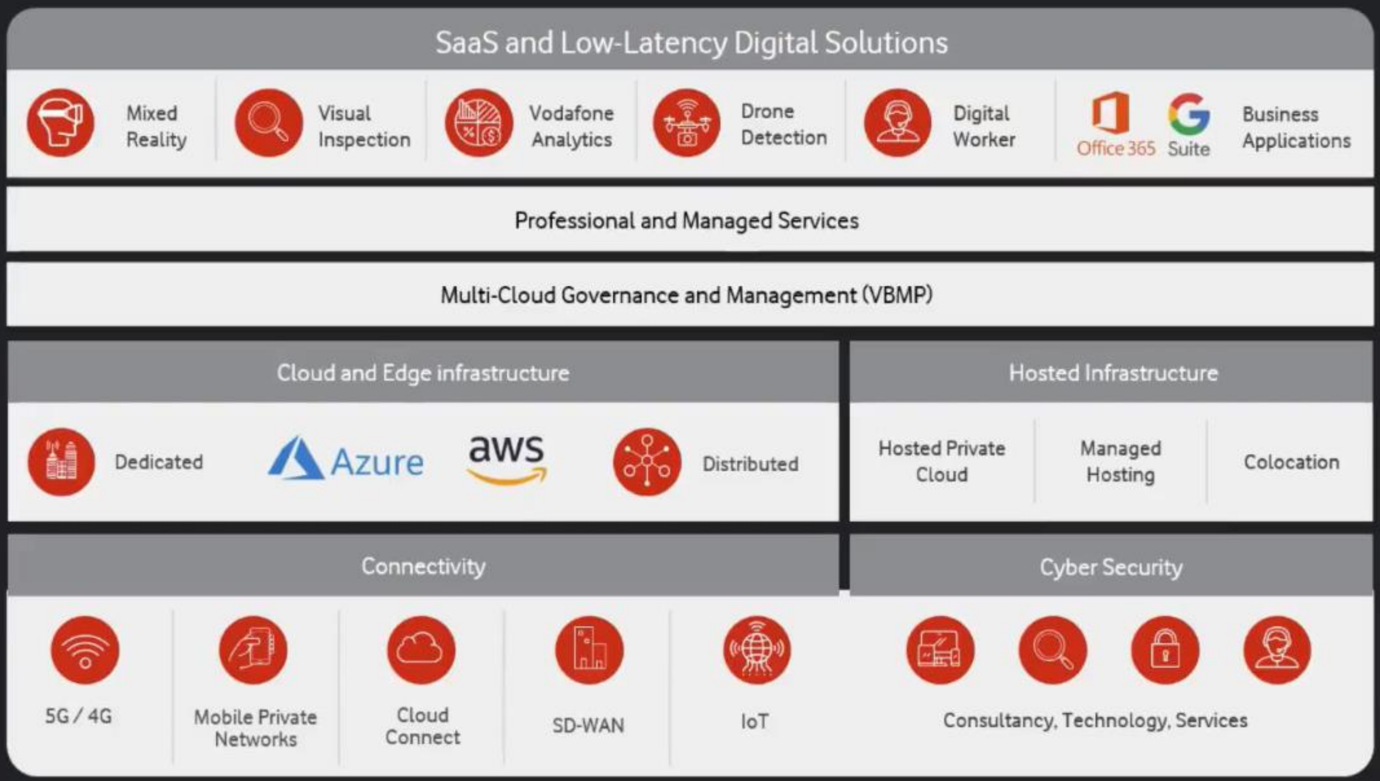
**Remote control of machines and vehicles:**

- Robotized production plants
- Autonomous or assisted driving
- Drones, autonomous guided vehicles (AGV)

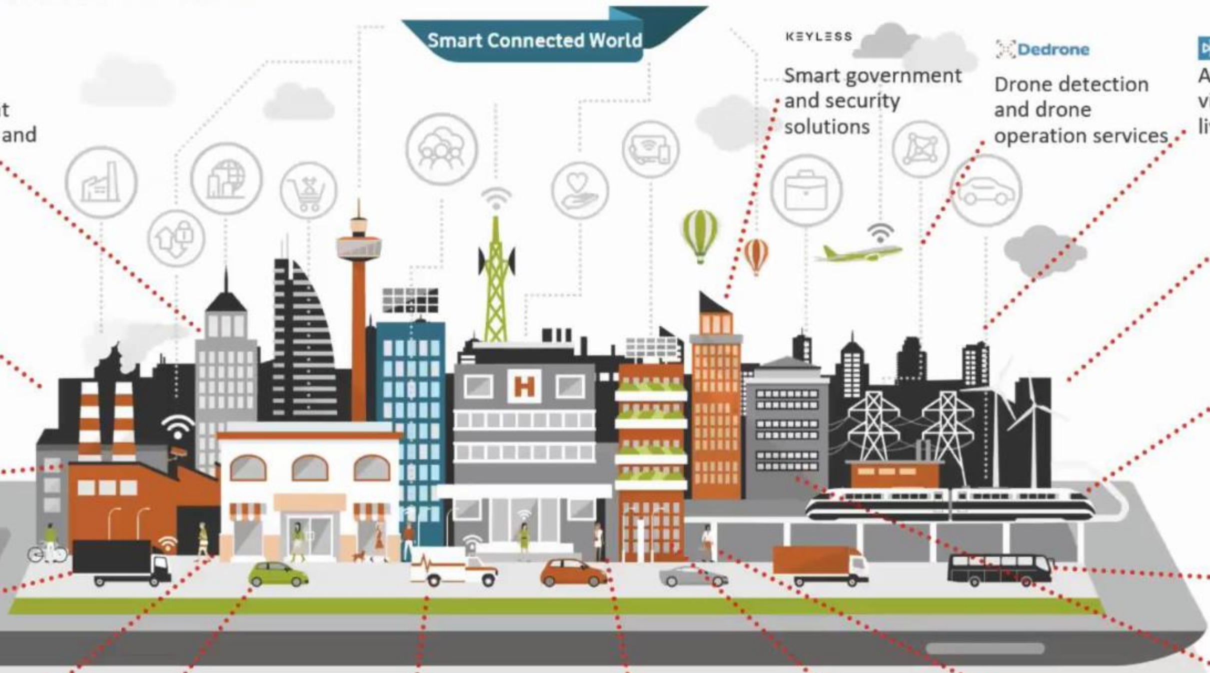
**Digitalization of industrial processes**

- Process/asset/operator monitoring, safety
- Digital Twins for engineering and operation

# The journey to the edge requires the orchestration of many players



# Bringing MEC to life




ELK
Live video and event production, editing and broadcasting

sportable
In-stadium IoT and AR/VR experiences

FESTO interdigital
AR/VR training, advanced robotics and computer vision

TACTILE
Field force engineer remote support and training

Enhanced AR/VR in-store visitor experiences and footfall/customer analytics

PORSCHE
In-car entertainment with enhanced Cloud Gaming

Digital Barriers
Remote medical support with connected ambulances and first responders

PROXIMIE
Remotely assisted hospital operations and medical training

Real-time venue management and Health & Safety measures

AR/VR tourism apps and immersive experiences

AR/VR education and remote learning

here
V2X solutions for connected / autonomous vehicles

UNLEASH
Public transport accident prevention and advanced video surveillance

Autonomous vehicles

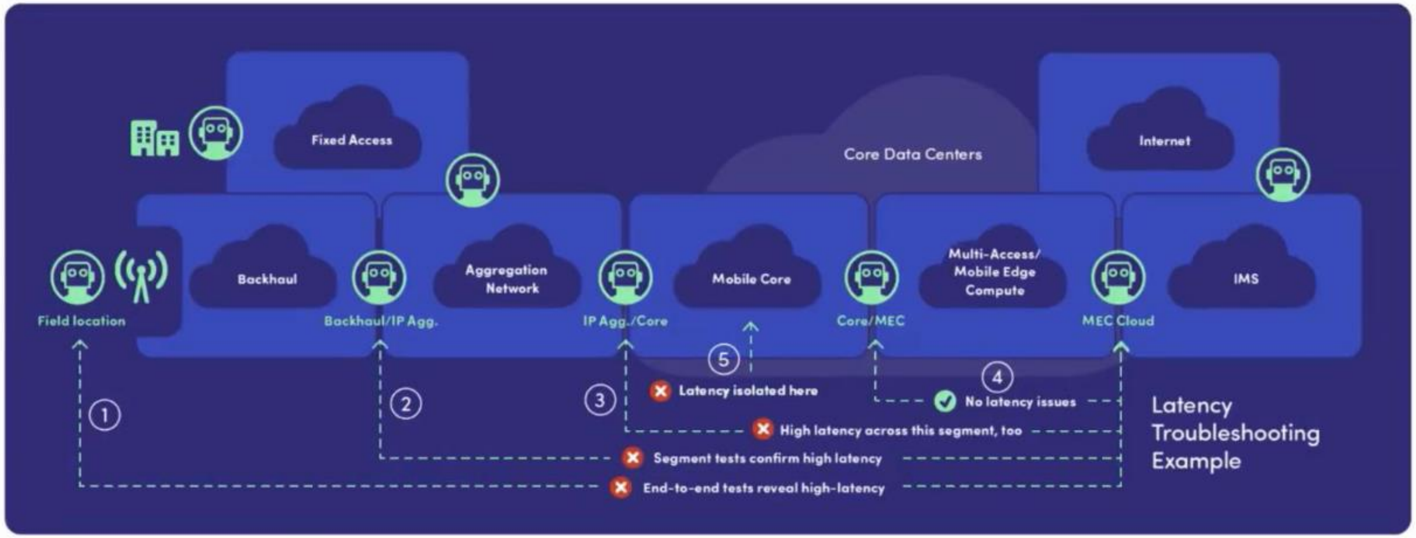
Advanced gaming, video sharing and smart living solutions

Dedrone
Drone detection and drone operation services

KEYLESS
Smart government and security solutions

C2 General

# Continuous MEC Latency Testing




## Active Test Agents

**Emulates** end users & traffic (L2-7) from demarcation points inside & outside the network.

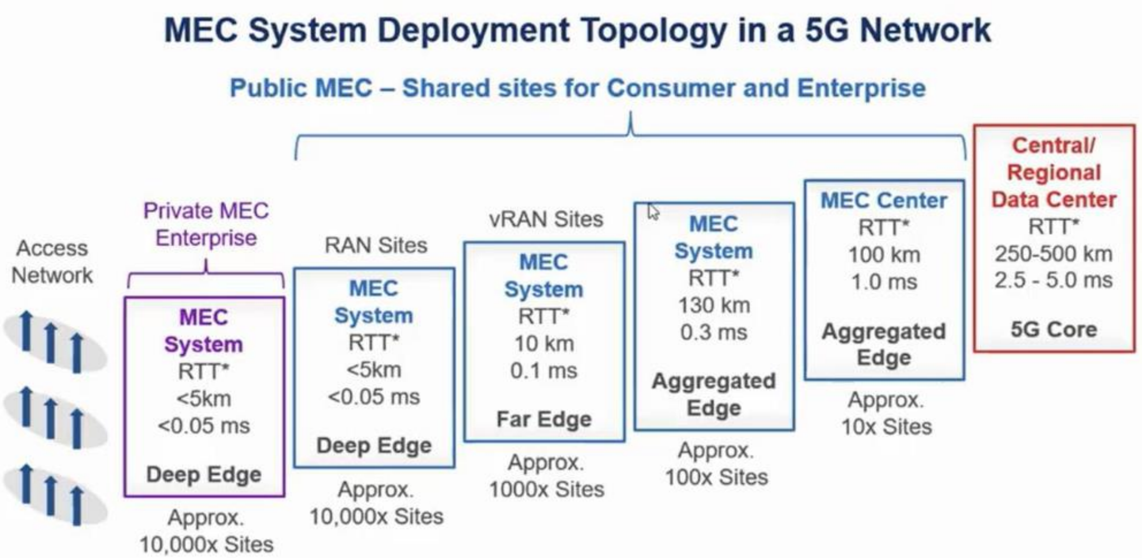
**Actively** injects realistic user traffic across the network.

Deployed on open compute (VNFs, CNFs, COTs HW).

**Used to proactively**:

1. Validate service(s) & network functions for live turn-up.
2. Test & measure live network performance & quality.
3. Identify & isolate faults.
4. Re-validate efficacy after network changes.

# **Public** MEC vs. **Private** MEC




Source: Dell'Oro Group
*RTT – Round Trip Time Propagation Delay – one-hop fiber link

- > **Private MEC** (on-premises) is for enterprises that need the lowest latency possible and want to retain their data on-premises for data sovereignty reasons.
- > **Public MEC** (off-premises) offers low latency services to enterprises & consumers for broad geographic coverage requirements. The lowest latency possible would be to have a MEC node at every base station in the RAN. Over time, this is the expected density.

# **RAN and Edge Computing** – A Marriage under Open RAN

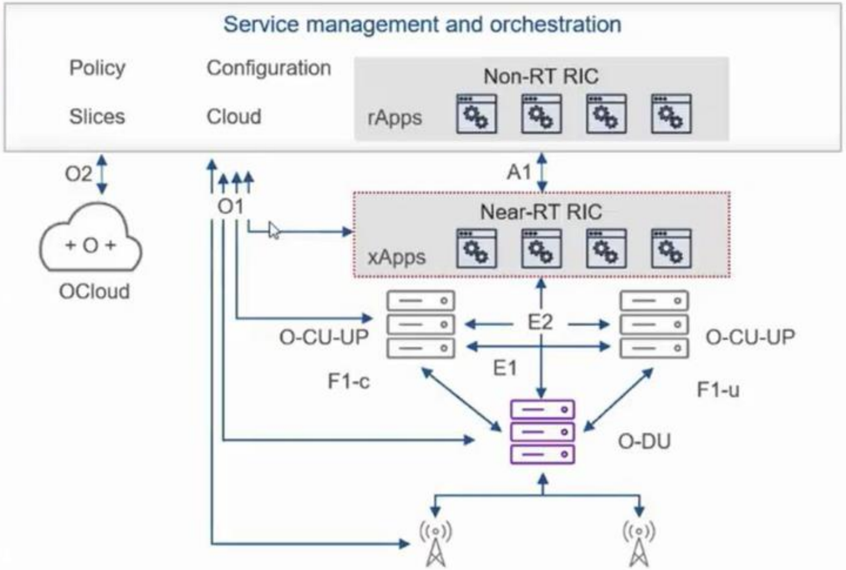
## Open RAN

RAN Disaggregation

Open specification

Distributed Arch

COTS hardware




Near-real-time RIC: Enabling AI/ML-driven extreme automation and granular control of Open RAN: Analysys Mason, June 2021

**ORAN Logic Architecture**

## Computing at the Edge

**RAN Intelligent Controller (RIC)**

RAN Control and management

Fine-grain programmatic control

RAN orchestration of CU/DU across far, near and aggregated sites

RAN automation

**xApps**

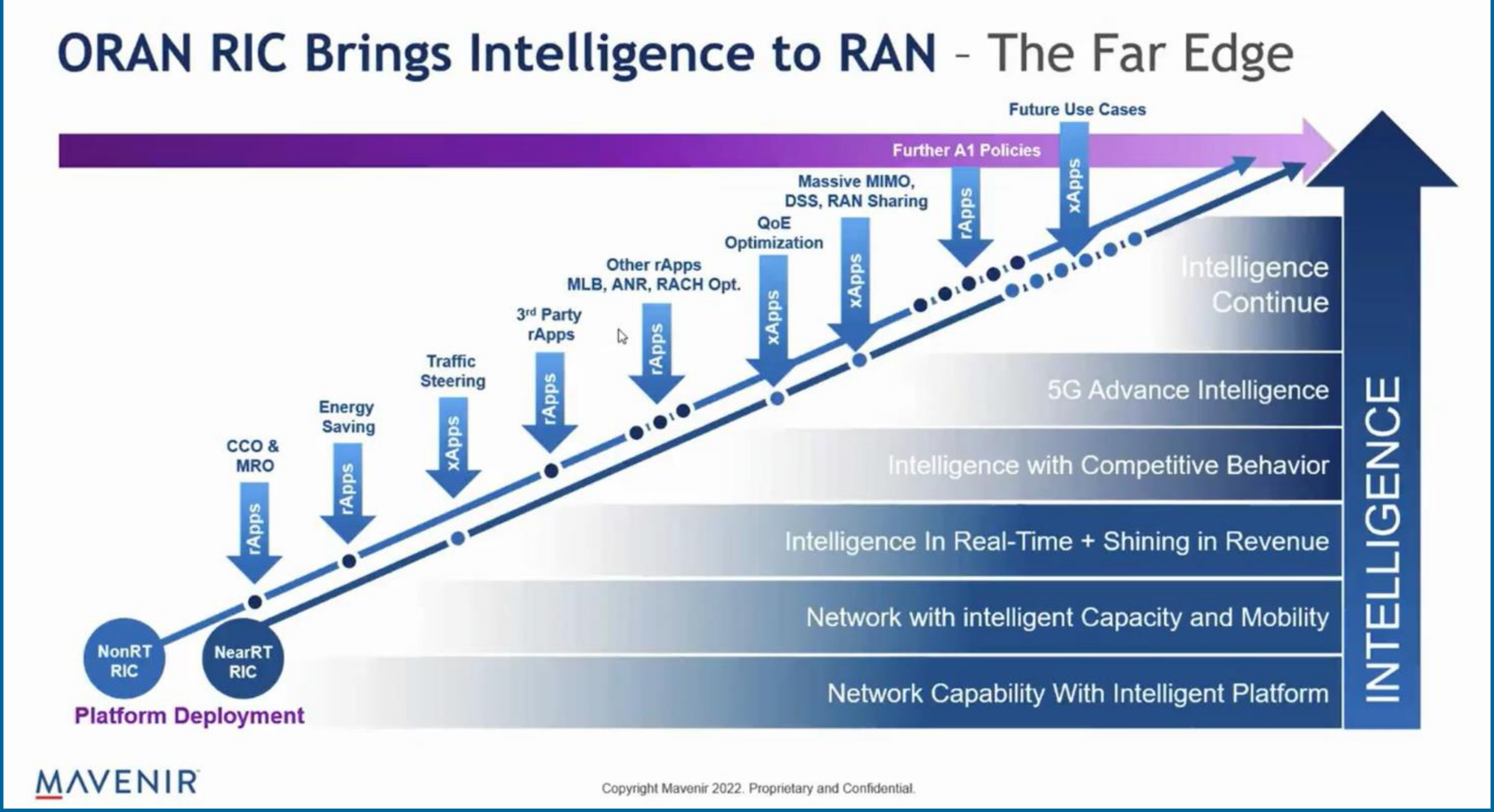
Near-Real Time apps

**rApps**

Non-Real Time apps

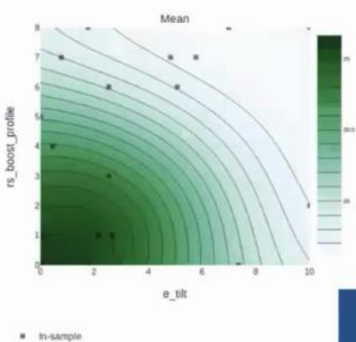
MAVENIR

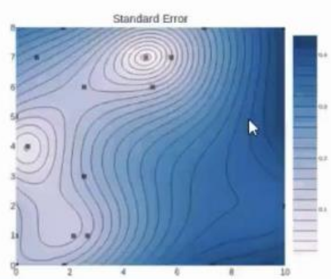
# RAN Intelligent Controller (RIC)

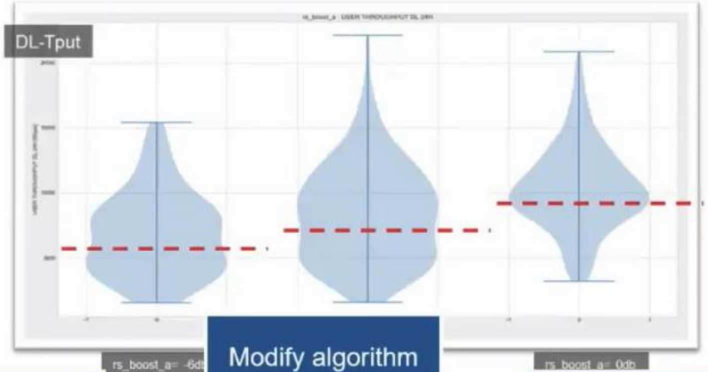


# Building Network Intelligence at the Far Edge

Requires deep telco domain knowledge + expertise in RAN data analysis + expertise in ML algorithm
*…and some serious math skills*



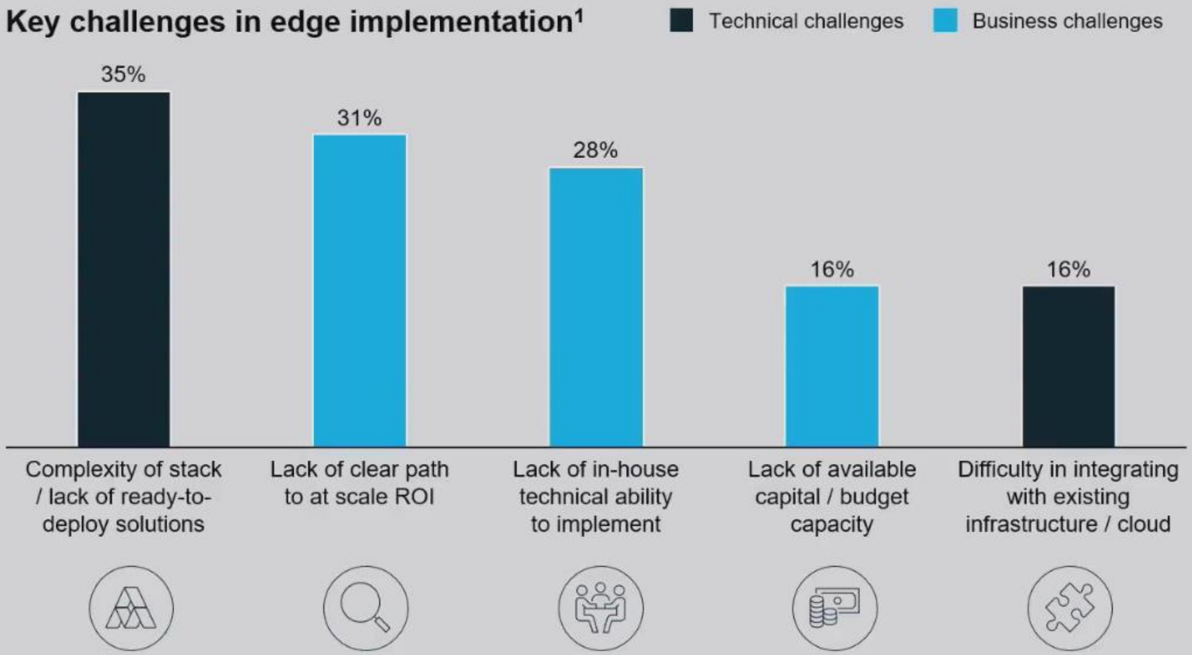

Use case designed based on network data pattern analysis → Complex mathematical modeling → Algorithm selection based on modeling → Modify algorithm based on modeling → Train algorithm using proper network data

**Building library of NW Intelligence Services that can be leveraged by r/x Apps**

# However, the edge journey is not smooth as companies encounter challenges while scaling POCs

Survey results further validated with enterprise customer interviews

**Key challenges in edge implementation**[1]




1. Challenges ranking reflects percentage of 93 survey respondents who ranked criteria as either 1st or 2nd most critical for their edge implementation

# Moving to 6G..

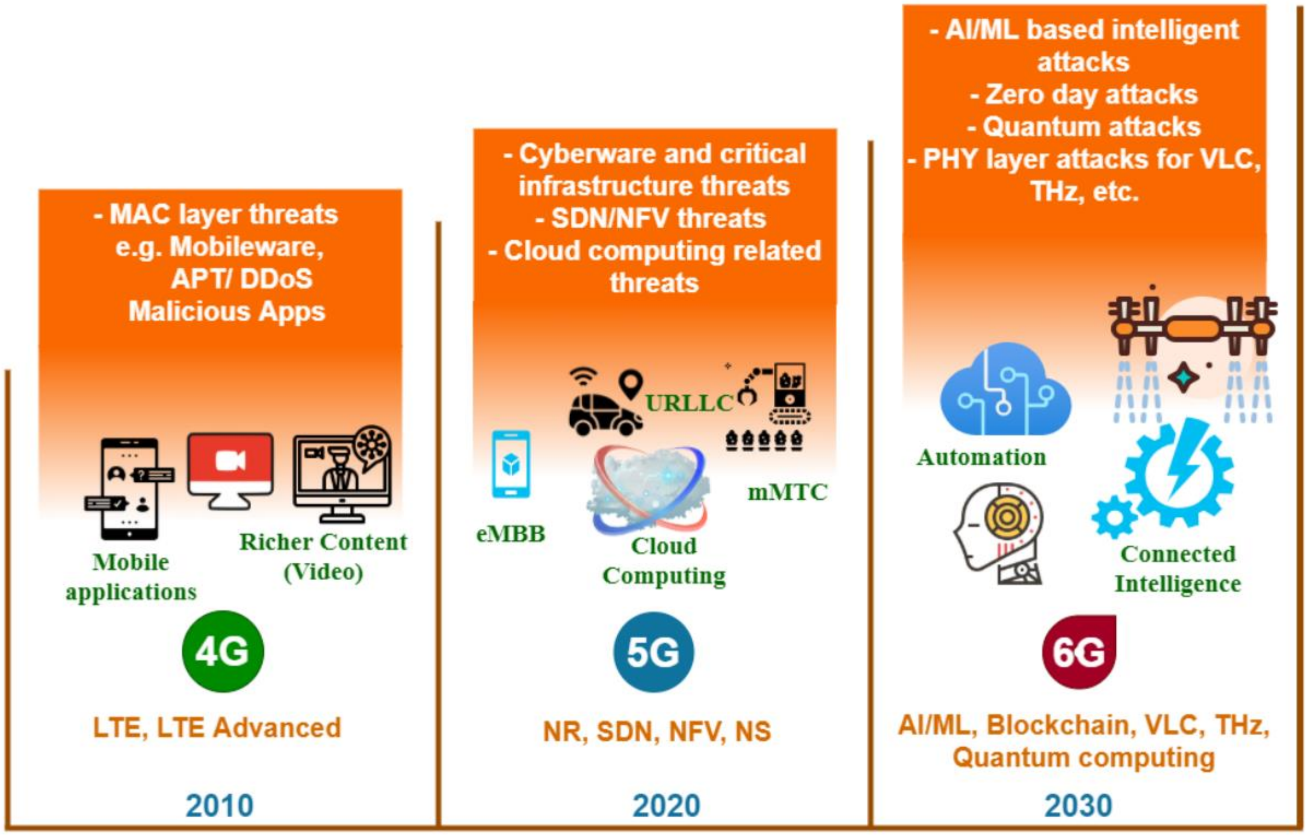
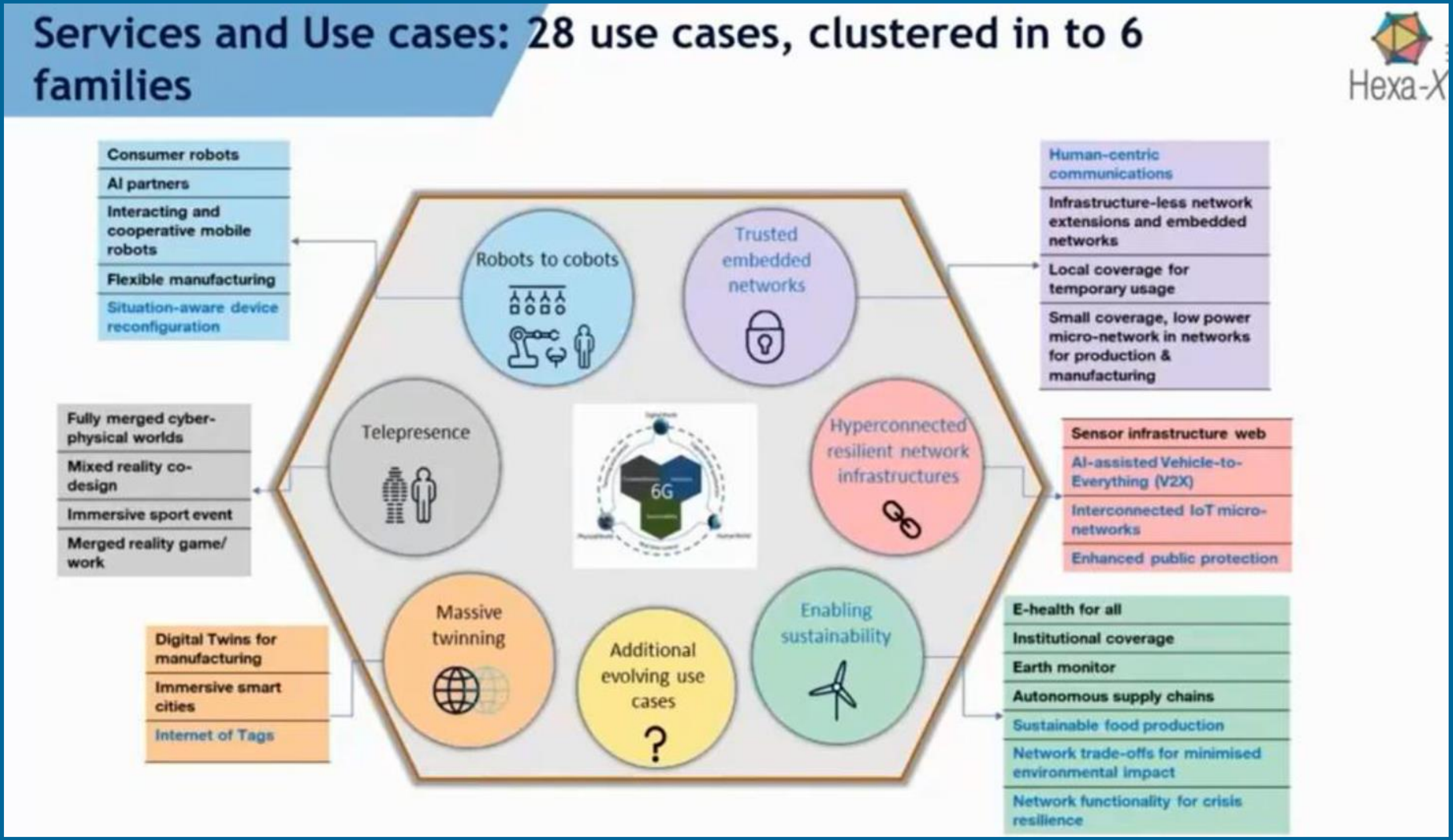
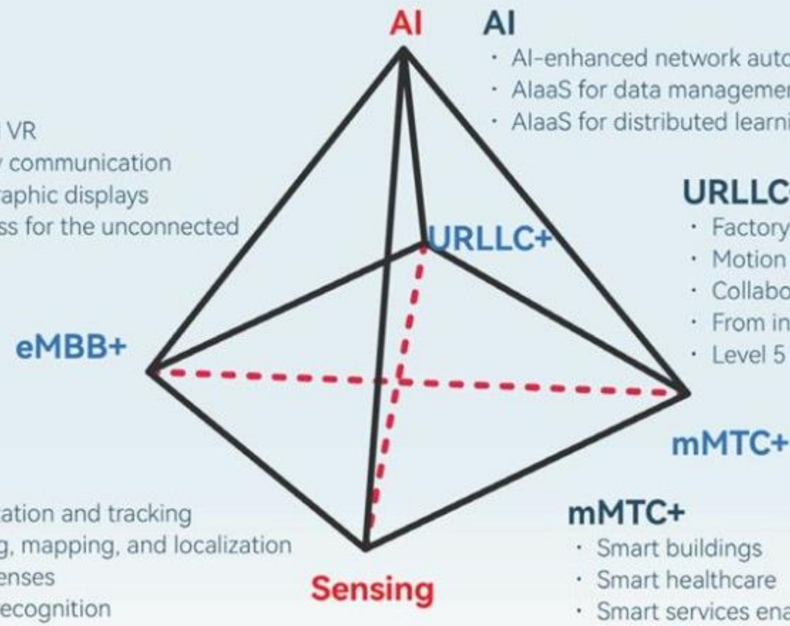



Fig. 1: Evolution of Mobile Security Landscape from 4G towards 6G

# 6G Use cases


Services and Use cases: 28 use cases, clustered in to 6 families
Hexa-X
Consumer robots
AI partners
Interacting and cooperative mobile robots
Flexible manufacturing
Situation-aware device reconfiguration
Robots to cobots
Trusted embedded networks
Human-centric communications
Infrastructure-less network extensions and embedded networks
Local coverage for temporary usage
Small coverage, low power micro-network in networks for production & manufacturing
Telepresence
Fully merged cyber-physical worlds
Mixed reality co-design
Immersive sport event
Merged reality game/ work
6G
Hyperconnected resilient network infrastructures
Sensor infrastructure web
AI-assisted Vehicle-to-Everything (V2X)
Interconnected IoT micro-networks
Enhanced public protection
Massive twinning
Digital Twins for manufacturing
Immersive smart cities
Internet of Tags
Additional evolving use cases
?
Enabling sustainability
E-health for all
Institutional coverage
Earth monitor
Autonomous supply chains
Sustainable food production
Network trade-offs for minimised environmental impact
Network functionality for crisis resilience

# Overview of typical 6G Use cases




**AI**
- AI-enhanced network automation
- AIaaS for data management
- AIaaS for distributed learning and inferencing

**eMBB+**
- Ultimate immersive cloud VR
- Haptic and multi-sensory communication
- Glass-free 3D and holographic displays
- Broadband wireless access for the unconnected

**URLLC+**
- Factory of the future
- Motion control
- Collaborative robots in groups
- From intelligent cobots to cyborgs
- Level 5 autonomous vehicles

**Sensing**
- High-accuracy localization and tracking
- Simultaneous imaging, mapping, and localization
- Augmented human senses
- Gesture and activity recognition

**mMTC+**
- Smart buildings
- Smart healthcare
- Smart services enabled by UAVs
- Wide-range IoT services

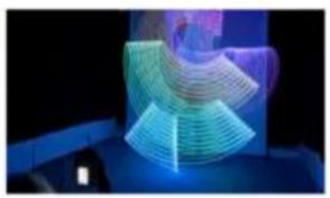
# The Evolution Towards 6G

Achronix Data Acceleration

**Technological Advances Driven by Metaverse Use Cases**

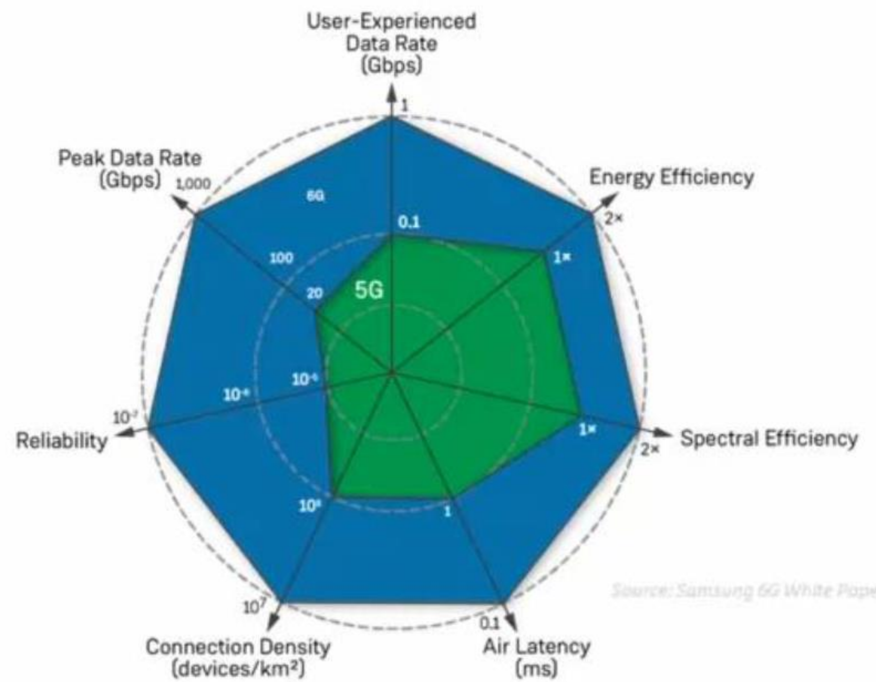
Digital Twin

Holographic Communications



Tactile Internet & Haptic Feedback

Connection Density & Ubiquitous Coverage




**6G Network Performance Targets**

# Specification Towards 6G

Achronix
Data Acceleration

## Air Interface & Management

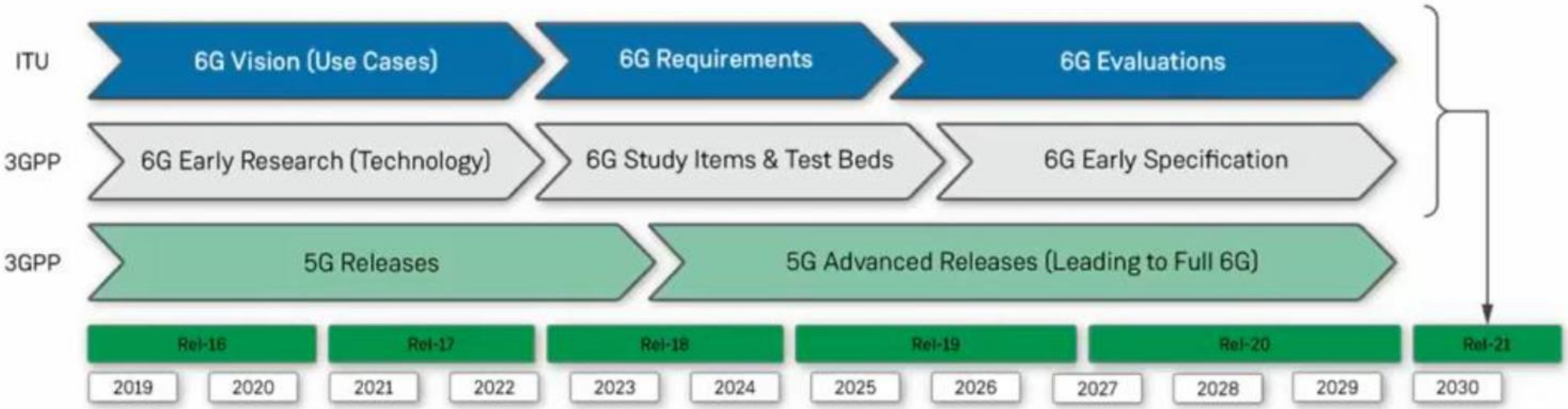
- ✓ Advanced RF
  - ✓ Management of high bands
  - ✓ Sub-THz bands offer available spectrum and performance
- ✓ Silicon and material technology
  - ✓ Faster and more efficient baseband and radio processing

## Network Hieracrchy & Management

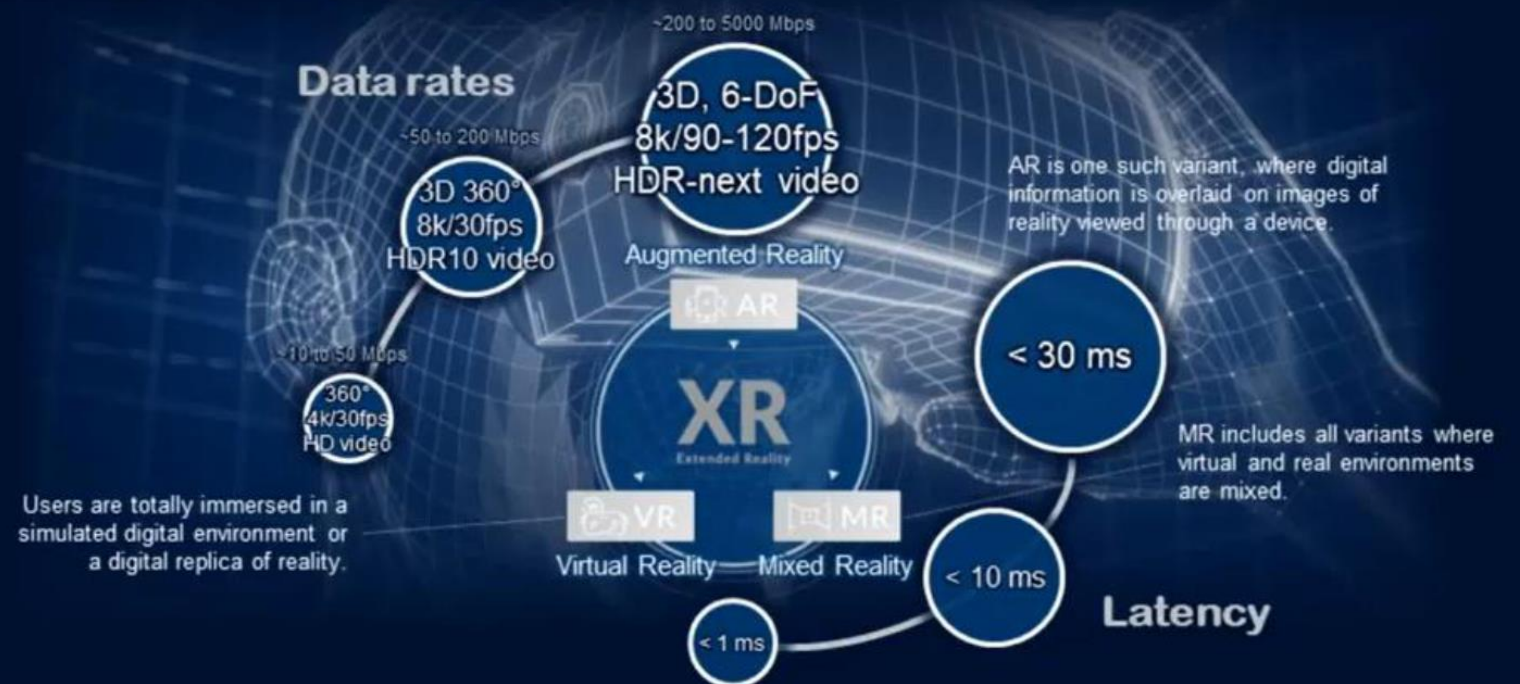
- ✓ Extreme RAN disaggregation
  - ✓ Facilitating decision making throughput the network
- ✓ Network slicing and dynamic resource allocation
- ✓ Virtualized and containerized workloads driving a software-defined network.

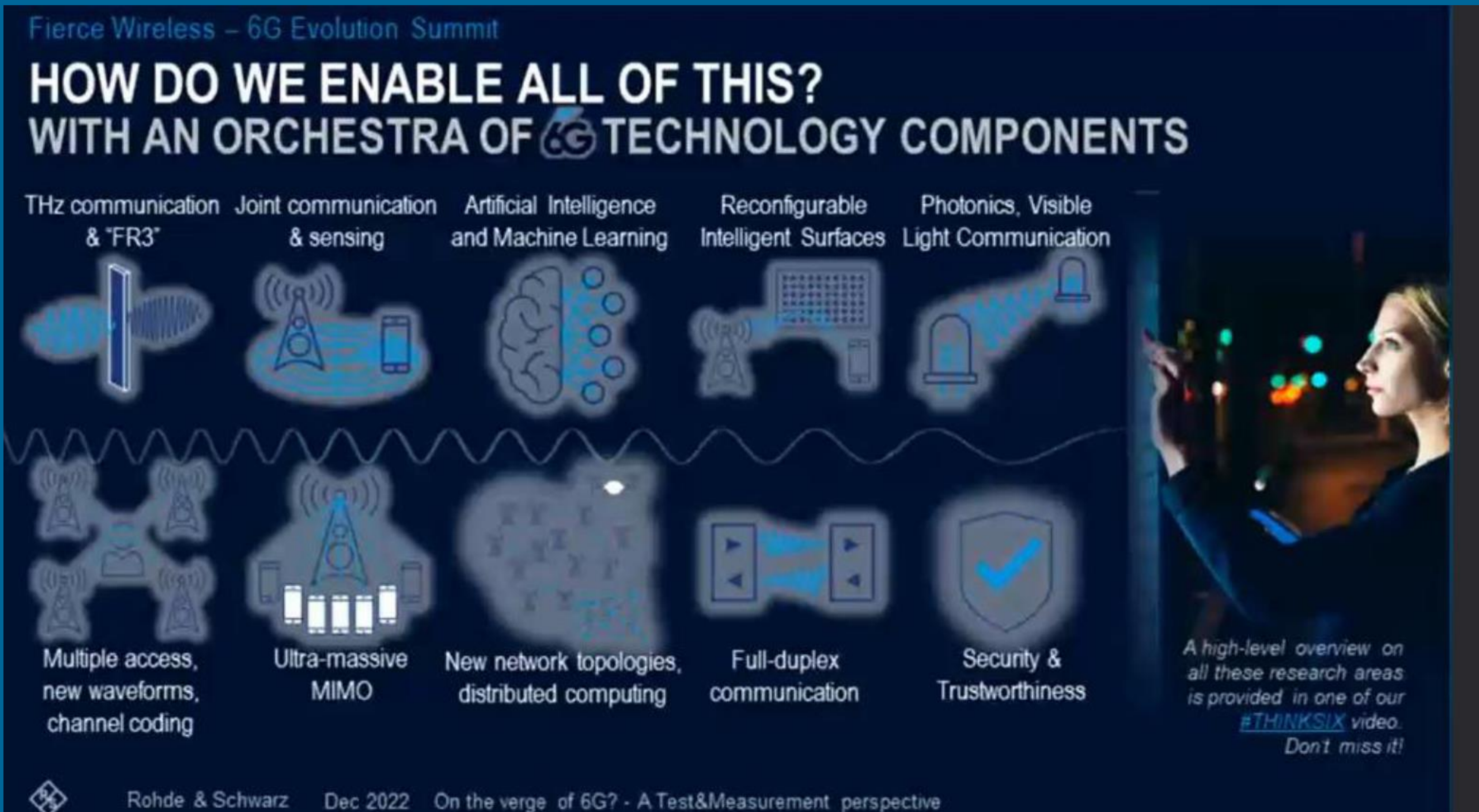
## Network Compute Fabric

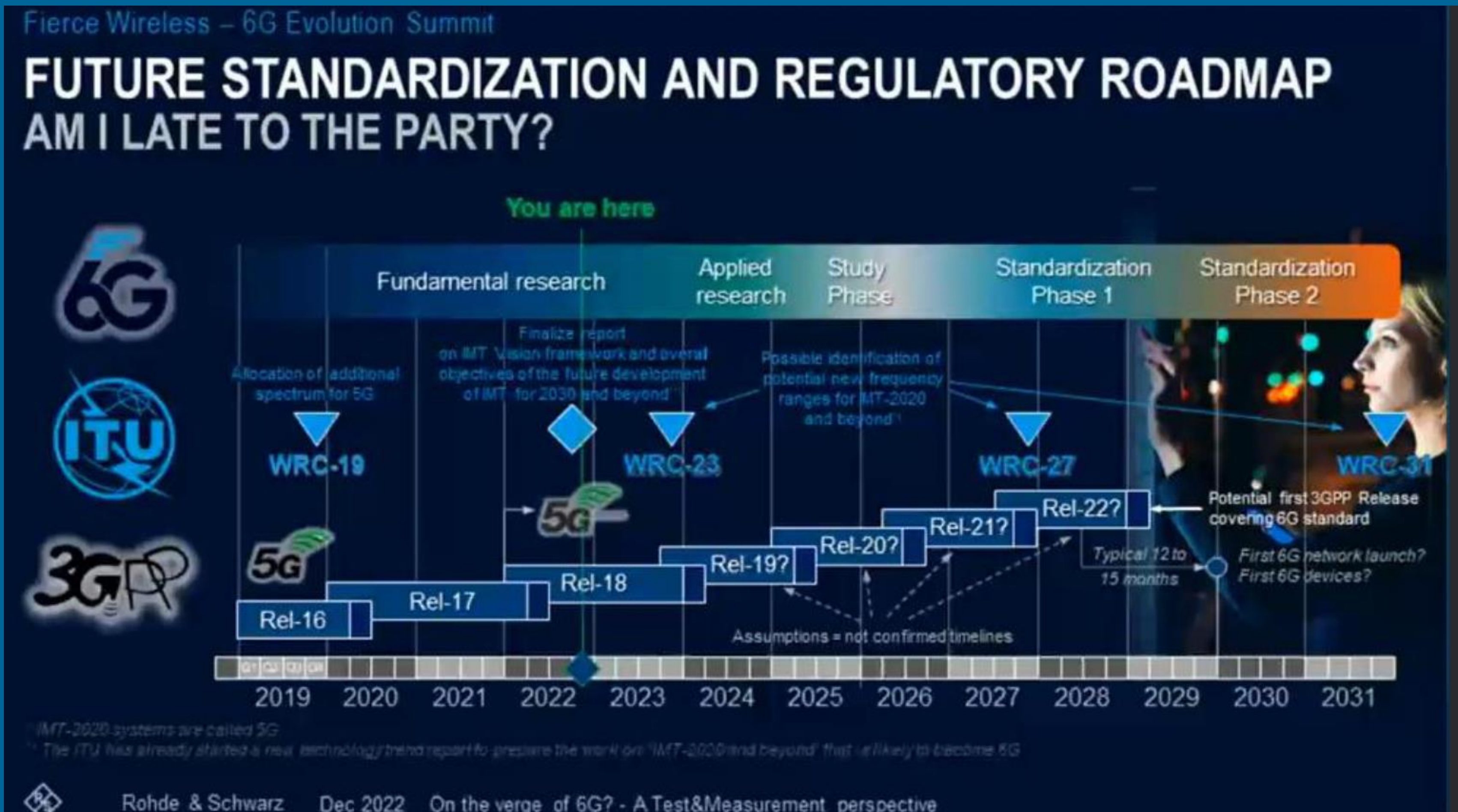
- ✓ Processing and acceleration
- ✓ C & U plane management: application of ML/AI plane
- ✓ Network data analytics and security
- ✓ ML radio and application-based processing



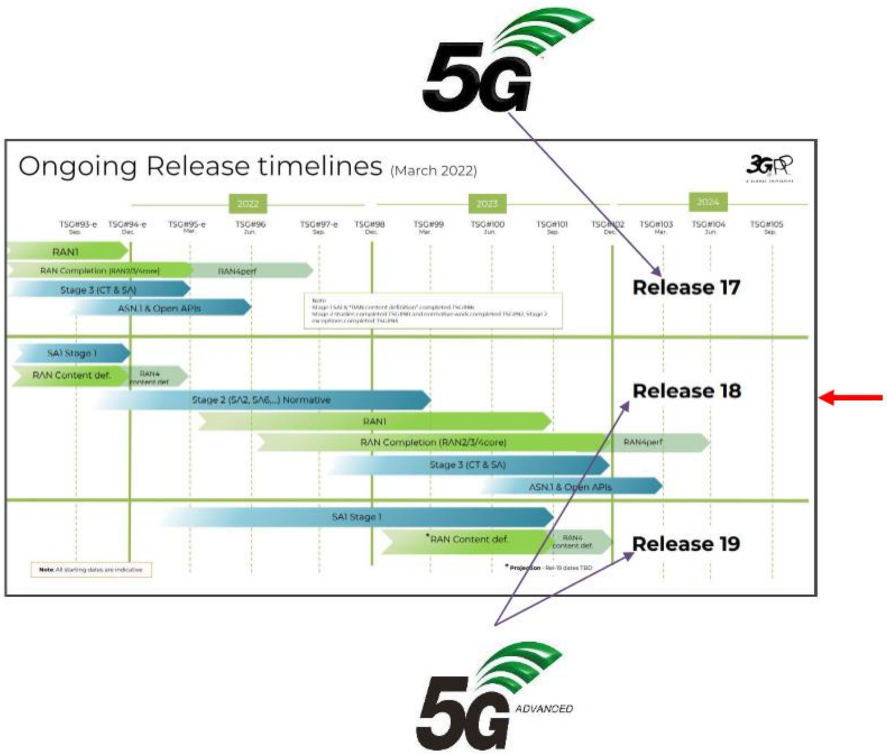
# IF 6G IS FOR THE CONSUMER, WHAT DO WE NEED?
## ENABLING THE METAVERSE!?




Fierce Wireless – 6G Evolution Summit
HOW DO WE ENABLE ALL OF THIS?
WITH AN ORCHESTRA OF 6G TECHNOLOGY COMPONENTS
THz communication & "FR3"
Joint communication & sensing
Artificial Intelligence and Machine Learning
Reconfigurable Intelligent Surfaces
Photonics, Visible Light Communication
Multiple access, new waveforms, channel coding
Ultra-massive MIMO
New network topologies, distributed computing
Full-duplex communication
Security & Trustworthiness
A high-level overview on all these research areas is provided in one of our #THINKSIX video. Don't miss it!
Rohde & Schwarz
Dec 2022
On the verge of 6G? - A Test&Measurement perspective


Fierce Wireless – 6G Evolution Summit
FUTURE STANDARDIZATION AND REGULATORY ROADMAP
AM I LATE TO THE PARTY?
You are here
Fundamental research
Applied research
Study Phase
Standardization Phase 1
Standardization Phase 2
6G
ITU
3GPP
Allocation of additional spectrum for 5G
Finalize report on IMT Vision framework and overall objectives of the future development of IMT for 2030 and beyond
Possible identification of potential new frequency ranges for IMT-2020 and beyond
WRC-19
WRC-23
WRC-27
WRC-31
5G
Rel-16
Rel-17
Rel-18
Rel-19?
Rel-20?
Rel-21?
Rel-22?
Potential first 3GPP Release covering 6G standard
Typical 12 to 15 months
First 6G network launch?
First 6G devices?
Assumptions = not confirmed timelines
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
Rohde & Schwarz
Dec 2022
On the verge of 6G? - A Test&Measurement perspective

# 3GPP 5G to 6G Path




- Release 18 Study Items
  - **eMBB:** Dynamic spectrum sharing, network energy savings, duplex operation evolution, NR sidelink evolution, UL coverage enhancements, smart repeater, CA enhancements, NTN evolution
  - **eMBB and URLLC:** Positioning evolution, enhancements for XR, mobility enhancements
  - **Public safety:** UAS/UAV/UAM, NR sidelink evolution, multicast/broadcast
  - **Cross domain:** AI/ML RAN enhancements, resiliency of gNB-CU-CP
  - **Mobile IAB**
  - **MIMO Evolution for Downlink and Uplink**
  - **Network Slicing Phase 3**
  - **Non-Terrestrial Networks**
  - **System Support for AI/ML-based Services**

Institute for the Wireless Internet of Things at Northeastern

# 6G Use Cases

| 6G Use Case | Description | 6G Network KPI Perspective (Preliminary) |
|---|---|---|
| Holographic/Immersive communications | Dynamic interaction among people, things, and environments through lifelike 3D rendering<br>-Personalized education, training | -Throughput per stream: multi-Gbps<br>-Number of streams: 100’s<br>-Latency and jitter: <20 ms |
| Multi-sensory communications | Experiencing touch (including the feelings of temperature, pressure, texture) as well as smell and taste in a more distant future<br>-Remote work, Virtual meetings | -Throughput per stream: multi-Gbps<br>-Number of streams: 100’s to 1000’s<br>-Latency and jitter: <20 ms<br>-Synchronization across streams: <10ms |
| Mapping, positioning, sensing, twinning | Sense, detect, locate, identify, and image targets during remote operation, thus improving situational awareness, and enabling better allocation of for physical resources including preventive maintenance<br>-Manufacturing<br>-Smart cities | -Throughput per stream (Bidirectional): Multi-Gbps<br>-Number of streams: 1000’s<br>-Latency and jitter: < 10 ms |
| Robots and Cobots | Humans working collaboratively with robots to achieve outcomes that are challenging to be done by robots alone<br>-Industry 5.0 applications | -Throughput: Multi-Gbps<br>-Latency: <10 ms<br>-Number of streams: 100’s<br>-Reliability: 7 9’s<br>-Positioning accuracy: < 1 cm<br>-Sensing accuracy: >99% |

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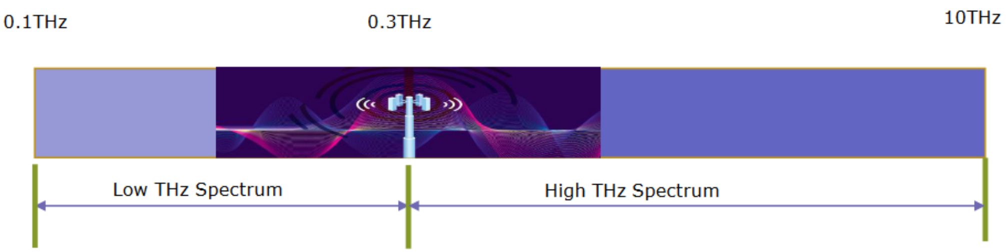
# 6G: Spectrum, Specs & Major Timelines

- As we all know that industry has already started working on the use cases and recommendations on 6G technology and adoption.
- At present its going to be a Tera Hertz Play for short range Communication.
- Here is the summary of Spectrum projection:
  - As per IEEE THz communication starts at 300 GHz , whereas by statements from Brown and Rice Universities it starts from 100 GHz.
  - Industry also calls THz communication a sub mmWave communication.




| Specs | Value |
|---|---|
| Jitter | 1 µ Seconds |
| Latency | 0.1 mSec |
| Energy/bit | 1 pj/bit |
| Traffic Capacity | 10 Gbps/$m^3$ |
| Localization | 1 cm |
| User Experience | 10 Gbps |
| Peak Rate | 1 Tbps |
| Reliability | FER $10^{-9}$ |
| Spectral Efficiency | 100 bps/hz |
| Mobility Support | 1000 km/hr |
| AI /ML | E2E support |
| Device Density | 10 Million/$km^2$ |

1. Major Timelines for the Industry Adoption:
   1. T0 : 2019, when the Base line Talks Started.
   2. Expected Deployment: 2028.
   3. Initial Trials (South Korea Govt): 2026.
   4. As per the United Nations’ Sustainable Development Goals (UN SDGs) 6G is targeted for 2030.
   5. 3GPP R20 may start getting 6G Specs included, R21 for sure

# 6G: Revenue Potential, Use Cases, Major Tech Enablers

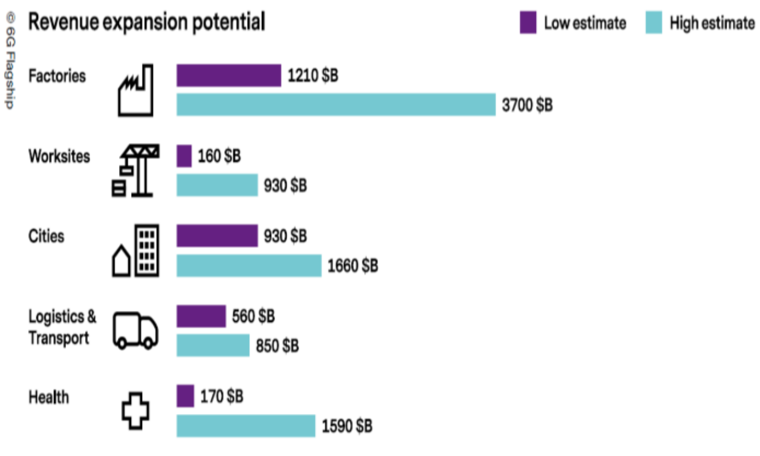


Figure 1. Market potential verticals according to McKinsey Global Institute [2]

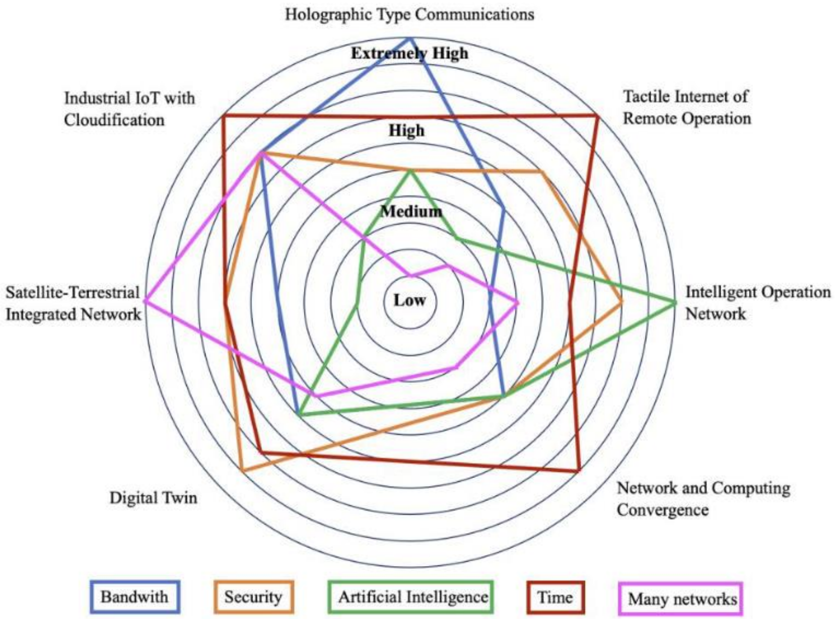
## Use Cases

- Cognitive Network
- Limitless Connection
- Connected Sustainable World.
- Connected Intelligent Machines
- Network Compute fabric
- The internet of Senses
- Programable Physical World.
- Digitalized and Trustworthy System

## Enablers

- ❑ New Freq Band, Large Bandwidth
- ❑ Dense Arrays
- ❑ Smart Meta Surfaces
- ❑ Quantum Compute
- ❑ High Speed, Ultra Low Latency Connectivity
- ❑ Control, User and Management Stack w/ AI & ML
- ❑ Advance Beamforming
- ❑ Localization and sensing.
- ❑ Evolved Edge infra with Next Gen Accelerator Platform.
- ❑ Joint Communication and Sensing
- ❑ Integrated NTN Networks
- ❑ Reconfigurable Intelligent Surface.

# 6G: Use Cases and Usage Scenario




Ref: IEEE-Networks

- 6G applications can be classified in ubiquitous Mobile Ultra-Broadband (uMUB), ultra-High Data Density (uHDD), and ultra-High Speed and Low-Latency Communications (uHSLLC)
- Base Line Requirements for 6G NTN: Data Rate>=1 Gbps, Peak 1 Tbps, Data Density 1 Gbps/ m2, Speed 1000km/hr, Low Latency 0.01 – 0.1 ms.

# Metaverse: Major Enabler of 6G NW

**Metaverse is the Digital platform with flexible interoperable connection among various types of Devices and interfaces on the top of reality, where Virtual/Real world is stitched together as per the 3D Next Gen Service. 5G Advance and 6G Connectivity ecosystem with all major enablers provides a versatile Metaverse environment**

## Metaverse Platform

**Experience**: Gaming, theater, shopping, eSports
**Discovery:** Stores, Agents, Ratings, Ad NW

**Economic Enablers**: Commerce, Workflow, Design and Asset Management Tools

**Special Computing**: XR platforms, 3D Engine, Geospatial Mapping, Multicasting UI Skin.

**Human Interface and Devices**: Smart Glasses, Wearable, Mobile, Neural, Haptic, Voice

**Decentralized and Distributed Infrastructure-**
**Connectivity-**5G/6G/WiFi6/7
**Edge**: AI loaded, Microservice and Blockchain Enabled w/ NFT and IPFS

**As per fortunes business insights the global metaverse market size was valued at USD 100.27 billion in 2022 and is projected to grow USD 1.5 Trillion by 2029, at a CAGR of 47.6%**

## Metaverse Facts

- Major Platforms: uHive, SandBox, Hypernation, Decentraland
- Major Use Cases:
  - Immersive Gaming
  - Non-Stop Entertainment
  - Infinite Shopping
  - Meta Space meeting
  - Metaverse Billboard
  - Service Provider's

Metaverse World

- One of the key objectives of the 6G connectivity is to support 1-microsecond latency. Somewhere crucial use cases like immersive gaming, industry 5.0 robotics and precision manufacturing need this kind of QoS.

# 5G Non-Terrestrial Network

## Trends Developing

- Satellite Network Operators like Starlink, Kuiper and OneWeb are trying to align their satellite Base station as per 5G Specs max up to 3GPP Rel 16 first. A big portion of these satellite base stations are not fully compliant to 5G.
- Major focus for these business cases are around Broad Band services to the rural areas with FWA modal.
- 6G NTN efforts are mainly focused on ubiquitous high-capacity global connectivity and communication.
- A feeder link Connects Satellites to the Core NW via Earth station Gateway.
- 6G encompasses a three-dimensional HetNet architectural framework in which terrestrial infrastructures are complemented by non-terrestrial stations including.
- 6G NTN base station can come into 3 different flavors- Satellites, High Altitude Platforms and Unmanned Arial Vehicle fully utilizing mmWave and Optical Bands for high-capacity connectivity.
- 3GPP Rel 17 and Rel 18 covers NTN specs in coordination with the terrestrial NW.
- 3GPP Rel 17 will support FR1-NR based Satellite Radio for Handheld Devices with Global Service Continuity.
- NB-IoT and mMTC will also be supported for NTN in Rel 17.
- GaN – Gallium Nitrate will be the component platform.
- Antenna- Reconfigurable Phased Array, Meta surface Antenna, Coherent Antennas and Inflatable Antennas

## Spectrum evolution of the Gs

| Generation | Frequency bands, low, mid and high MHz | Bandwidths | TDD/FDD |
|---|---|---|---|
| ≤ 2G | 800, 850, 1900 | < 1.25 MHz | FDD |
| 3G | 800, 850, 1900, 2100 | 1.25 MHz – 5 MHz | FDD |
| 4G | 600, 700, 850, 1700, 1900, 2100 2300, 2500, unlicensed 5 GHz, | 5 MHz – 20 MHz | TDD/FDD |
| 5G | 600, 3500, unlicensed 5 and 6 GHz, 24000, 26000, 28000, 29000 | 5 MHz – 100 MHz | TDD/FDD with mid and high-band being TDD |
| 6G? | All of the above + 7 – 24 GHz? | 100- 500 MHz? | TDD? |

- Key takeaway: every G **has required new spectrum, because the G's are not backward compatible.**
  - This requires new infrastructure roll-out approximately every decade
  - Starting with 4G, unlicensed spectrum has been added in to the mix.

# END