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Technology Innovation on the Path to 6G

Lorenzo Casaccia

Vice President, Technical Standards

Qualcomm Technologies, Inc.

About the speaker

Head of Tech Standards department @ Qualcomm

Been around standardization for 20+ years

In previous lives ☺:
music critic, college degrees in philosophy,
backpacking in Asia….

Mobile has made a leap every ~10 years

Analog voice	Digital voice	Wireless internet	Mobile broadband	Connected intelligent edge	Next-gen wireless
1980s	1990s	2000s	2010s	2020s	2030s
1G	2G	3G	4G	5G	6G
Mobile voice communication	Efficient voice to reach billions	Focus shifts to mobile data	Mobile broadband and emerging expansion	Connected intelligent edge	The next innovation platform
AMPS, NMT, TACS	D-AMPS, GSM, IS-95 (CDMA)	CDMA2000/EV-DO WCDMA/HSPA+	LTE, LTE Advanced, Gigabit LTE	5G New Radio	AI-native, new spectrum, RF sensing, and many more...




Where are we in the cellular innovation cycle?

5G

Ramping volume and expanding to new use case

5G ADVANCED

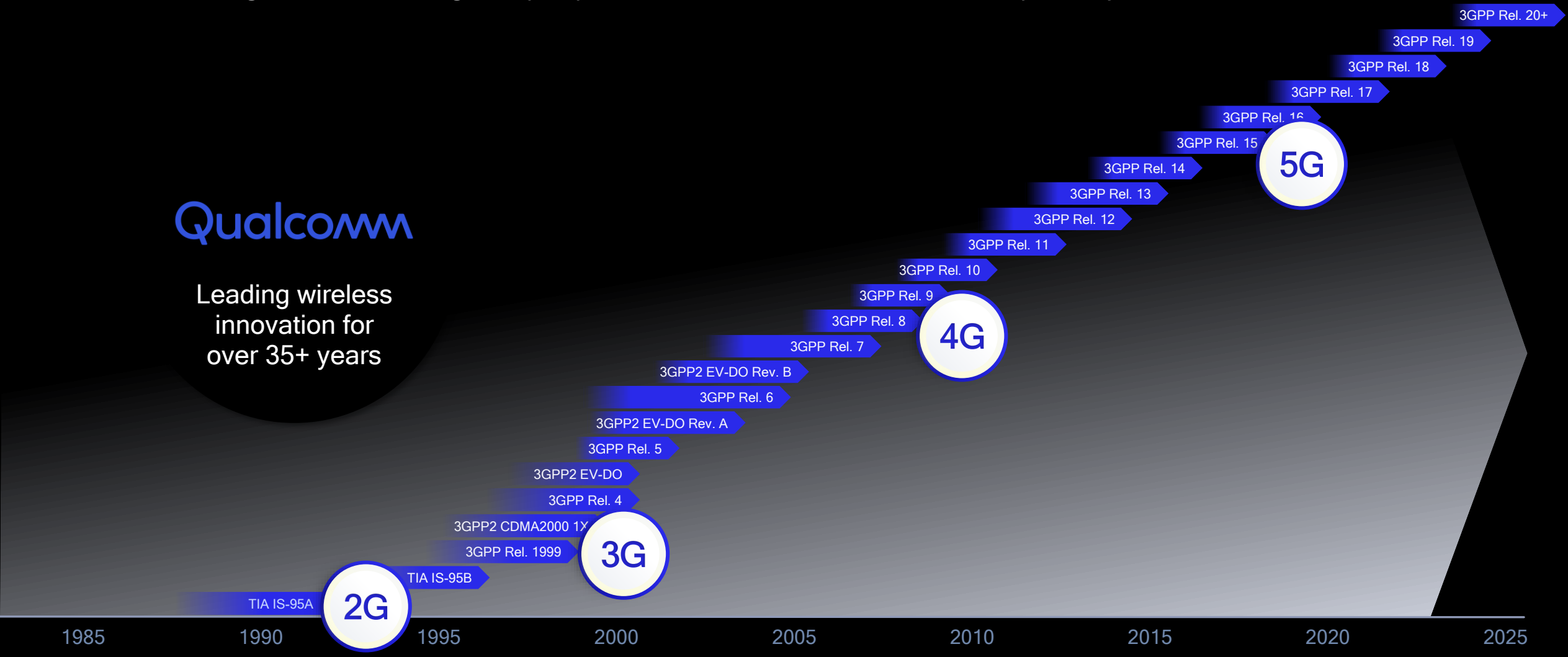
Completing 1st standard —2nd phase of 5G innovations

6G

Aligning on vision, foundational research, timeline, requirements

Cellular technology evolves gradually, building on itself

Each release or generation building on top of previous ones to enable backward compatibility



Cellular innovation: a vibrant, decades-old tree

Not all innovations are equal

The Trunk

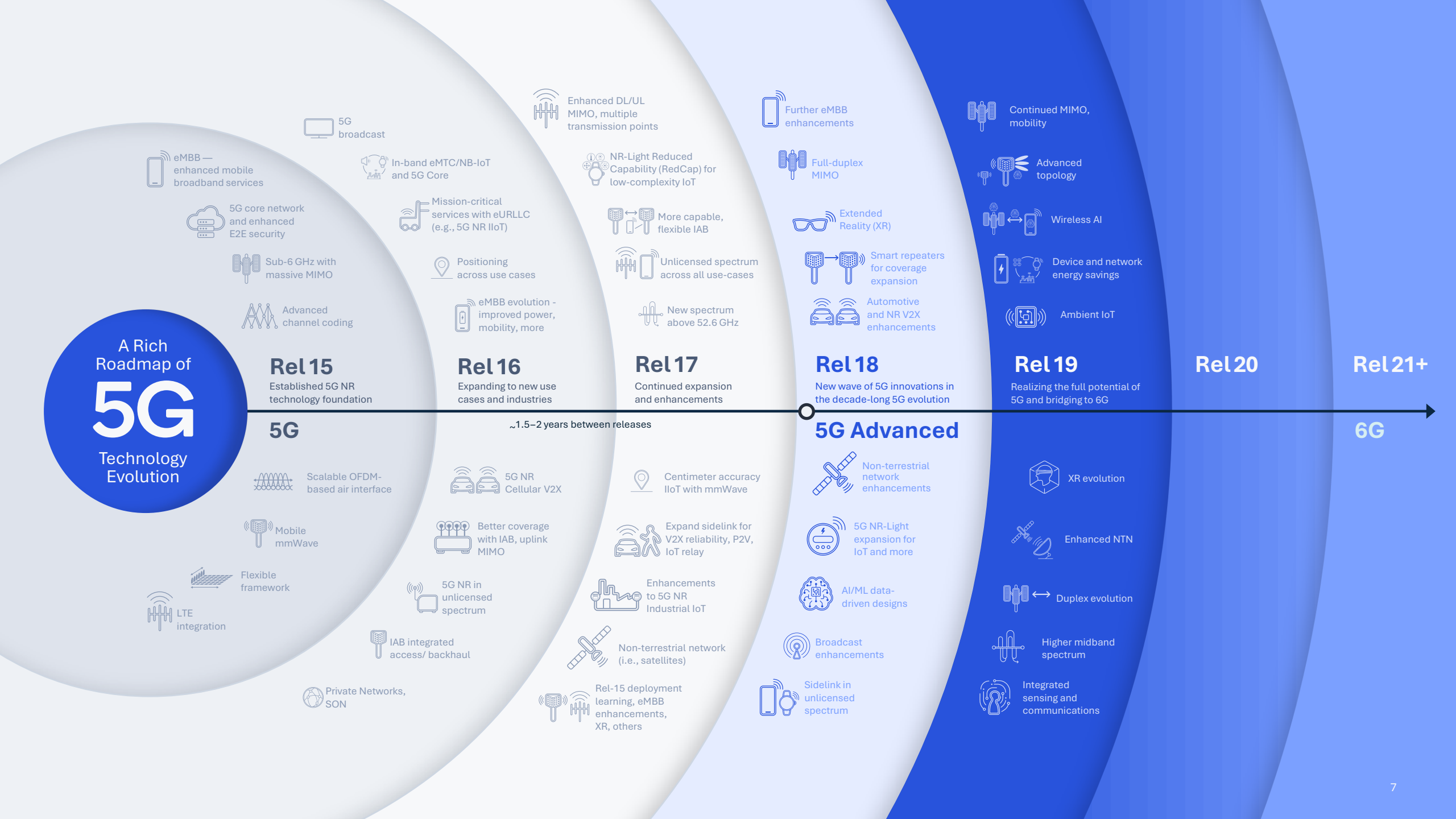
- Foundational innovations – without these 5G fundamentally wouldn't work.

The Branches

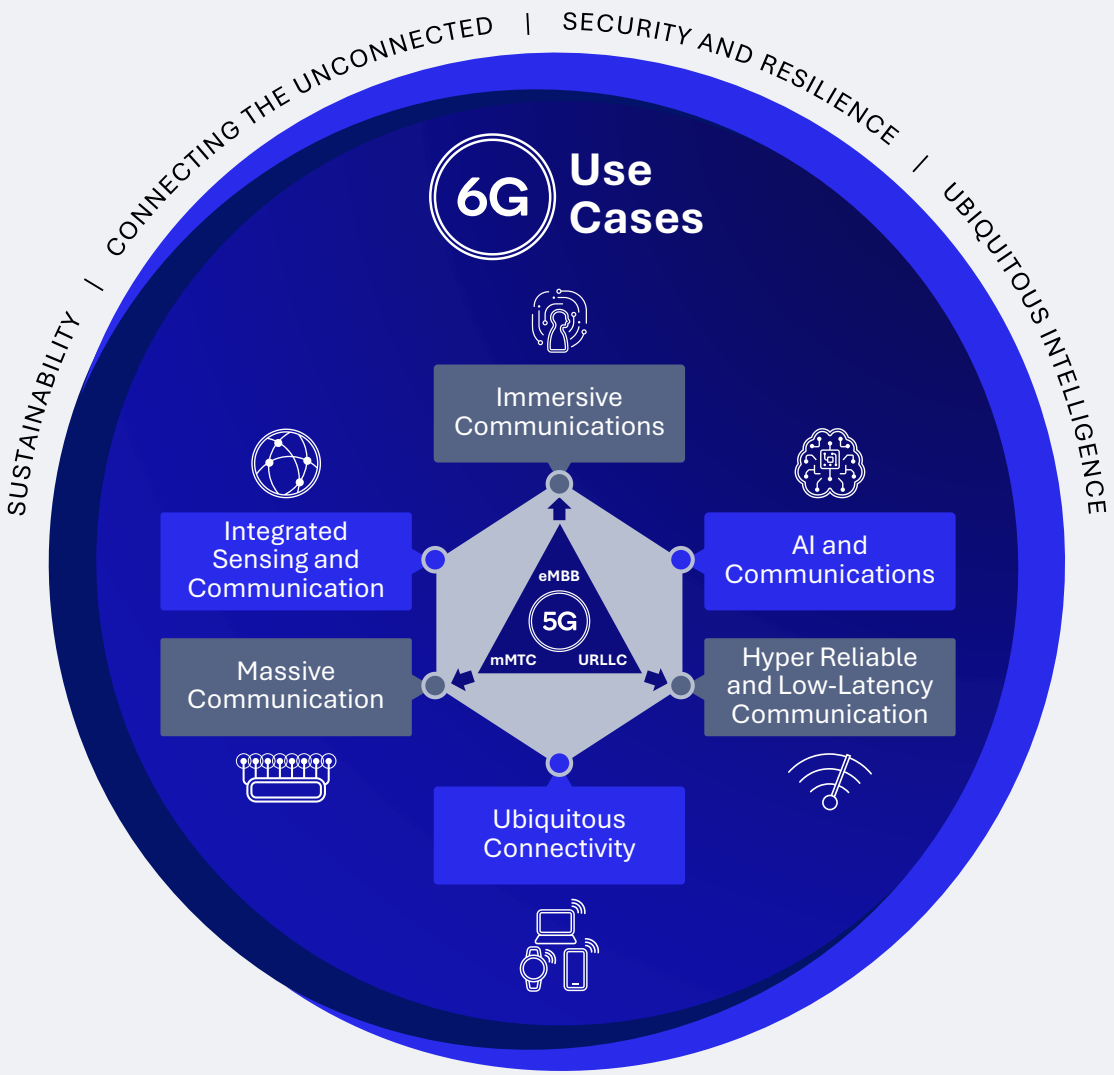
- Key innovations that allow 5G to expand and extend into new use cases.

The Leaves

- Innovations that are plentiful, but less impactful compared to the system they are built on.


A Rich Roadmap of 5G Technology Evolution
eMBB — enhanced mobile broadband services
5G core network and enhanced E2E security
Sub-6 GHz with massive MIMO
Advanced channel coding
5G broadcast
In-band eMTC/NB-IoT and 5G Core
Mission-critical services with eURLLC (e.g., 5G NR IIoT)
Positioning across use cases
eMBB evolution - improved power, mobility, more
Enhanced DL/UL MIMO, multiple transmission points
NR-Light Reduced Capability (RedCap) for low-complexity IoT
More capable, flexible IAB
Unlicensed spectrum across all use-cases
New spectrum above 52.6 GHz
Further eMBB enhancements
Full-duplex MIMO
Extended Reality (XR)
Smart repeaters for coverage expansion
Automotive and NR V2X enhancements
Continued MIMO, mobility
Advanced topology
Wireless AI
Device and network energy savings
Ambient IoT
Rel 15
Established 5G NR technology foundation
Rel 16
Expanding to new use cases and industries
Rel 17
Continued expansion and enhancements
Rel 18
New wave of 5G innovations in the decade-long 5G evolution
Rel 19
Realizing the full potential of 5G and bridging to 6G
Rel 20
Rel 21+
~1.5–2 years between releases
5G
5G Advanced
6G
Scalable OFDM-based air interface
Mobile mmWave
Flexible framework
LTE integration
5G NR Cellular V2X
Better coverage with IAB, uplink MIMO
5G NR in unlicensed spectrum
IAB integrated access/ backhaul
Private Networks, SON
Centimeter accuracy IIoT with mmWave
Expand sidelink for V2X reliability, P2V, IoT relay
Enhancements to 5G NR Industrial IoT
Non-terrestrial network (i.e., satellites)
Rel-15 deployment learning, eMBB enhancements, XR, others
Non-terrestrial network enhancements
5G NR-Light expansion for IoT and more
AI/ML data-driven designs
Broadcast enhancements
Sidelink in unlicensed spectrum
XR evolution
Enhanced NTN
Duplex evolution
Higher midband spectrum
Integrated sensing and communications

6G vision from ITU-R — Usage scenarios and capabilities



Enhanced Capabilities

- Security resilience
- Reliability: 5G 1-10^{-5} | 6G ↑ 1-10^{-5} – 1-10^{-7}
- Latency: 5G 1 | 6G ↓ 0.1 – 1 ms
- Mobility: 5G 500 | 6G ↑ 500 – 1,000 km/h
- Connection density: 5G 10^{6} | 6G ↑ 10^{6} – 10^{8} devices/km^{2}
- Area traffic capacity
- Spectrum efficiency
- User experience data rate
- Peak data rate

Capabilities

New Capabilities

- Coverage
- Sensing-related capabilities
- AI-related capabilities
- Sustainability
- Interoperability
- Positioning (1-10 cm)

Source: ITU-R's IMT towards 2030 and beyond (https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx)

6G will support an unprecedented range of frequency bands

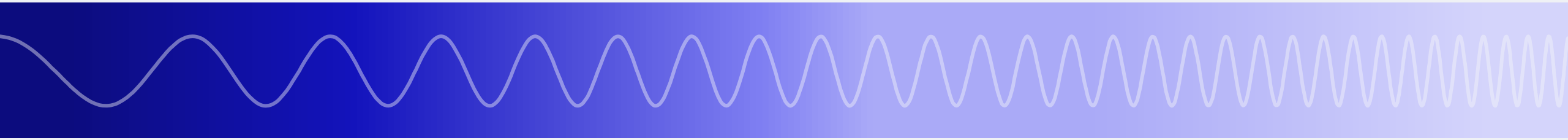
LOW BANDS
below 1 GHz (~20 MHz BW)

MID BANDS
1 — 7 GHz (~100 MHZ BW)

UPPER MID-BANDS
7 – 24 GHz (~500 MHz BW)

mmWAVE BANDS
24-71 GHz

SUB-THZ
above 100 GHz



With 6G, lower frequencies with narrower bandwidths will provide even better long-range coverage.

Bandwidths up to ~100 MHz, shorter wavelengths, massive MIMO antennas and MU-MIMO enable high capacities

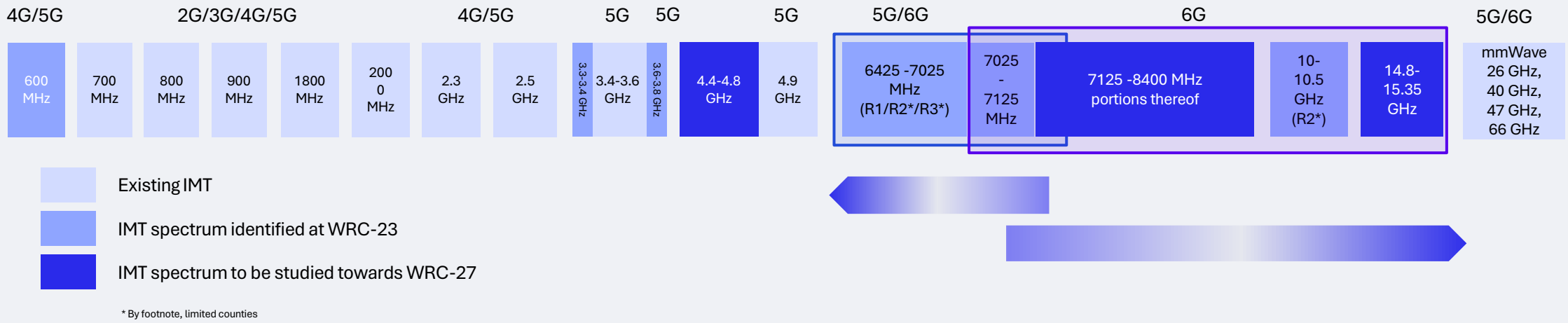
New 6G spectrum with bandwidths up to ~500 MHz bring additional wide-area capacity for communications and sensing

6G spectrum bringing additional local-area capacity for communications and sensing

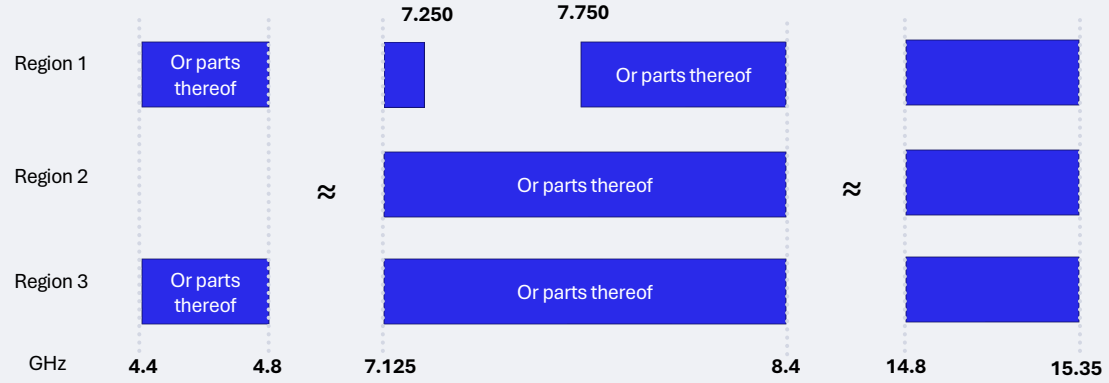
Higher frequencies with wide bandwidths provide excellent precision

Improving coverage and capacity in legacy bands and supporting new frequency bands for growth

IMT Bands and Studies for WRC-27



ITU-R will study new candidate bands for IMT-2030/6G usage with decisions to be made at WRC-27



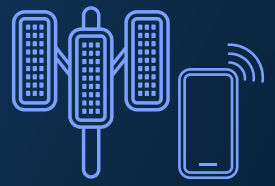
To support the usage scenarios defined in the IMT-2030 framework, i.e., ITU-R M.2160 Recommendation, there is a need to study **mid-band** spectrum with **more contiguous bandwidth**

Region 1: Europe, Middle East and Africa; Region 2: Americas; Region 3: Asia Pacific

Key drivers for the 6G air interface design

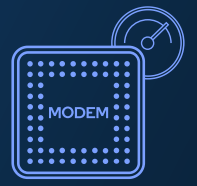
Improving spectral efficiency for all bands

- Targeting ~1.5x spectral efficiency gains from better link performance
- Targeting ~2-3x network capacity gain in dense networks from cloud RAN with joint processing with interference reduction and dimension increase
- ML-based dynamic air interface with “hyper-localized” performance optimization



Unlocking wide-area broadband access in new “FR3” upper mid-band (i.e., 6–16 GHz)

- Supporting downlink coverage with 8+ Rx antennas in smartphones, high Tx efficiency Giga-MIMO base stations
- Supporting uplink coverage with 4+ Tx antennas in smartphones, subband full duplex in base stations, Rx distortion corrections



Increasing performance for future modem chipsets

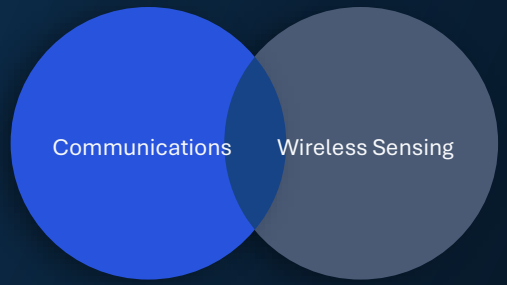
New area-efficient and power-efficient coding, modulation, and MIMO designs

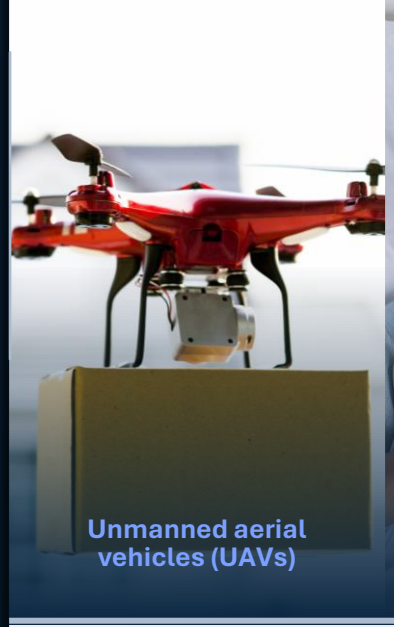
Enabling integrated services beyond data transport

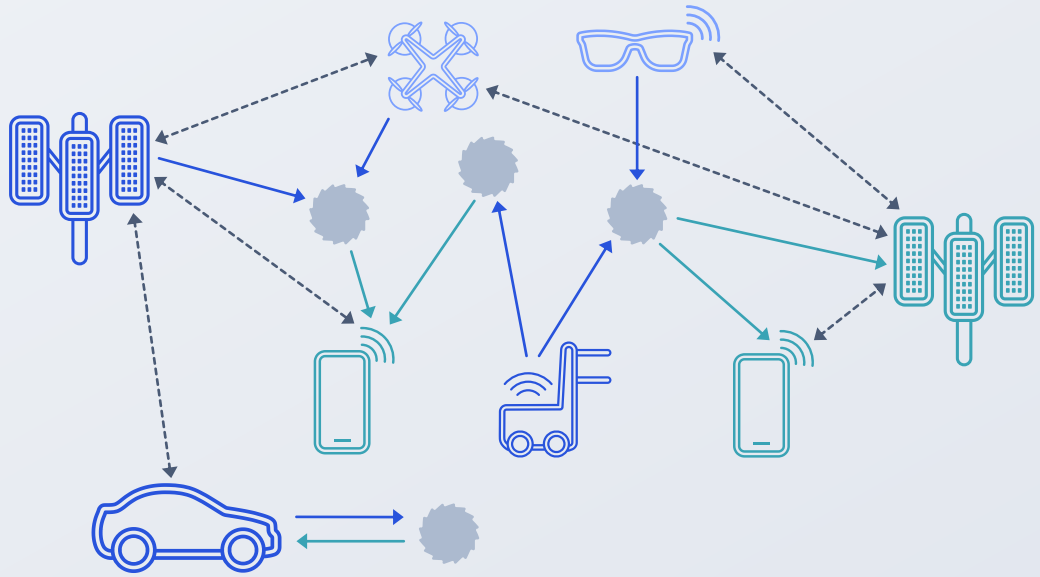
Cross-layer optimized design for outdoor AR, new device types, RF sensing, precise positioning, ambient IoT, and more

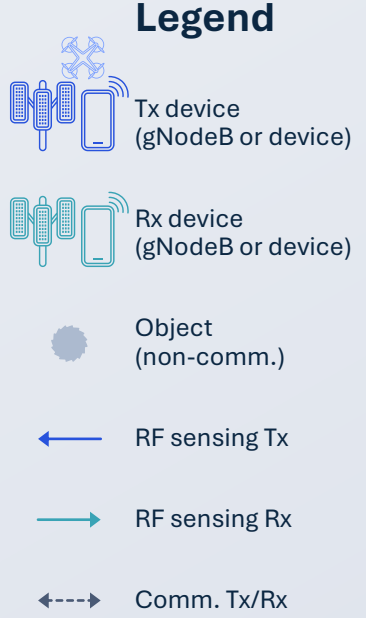
6G can deliver communication and sensing services with a unified network

5G Advanced Release 19 starts the preparation for 6G ISAC





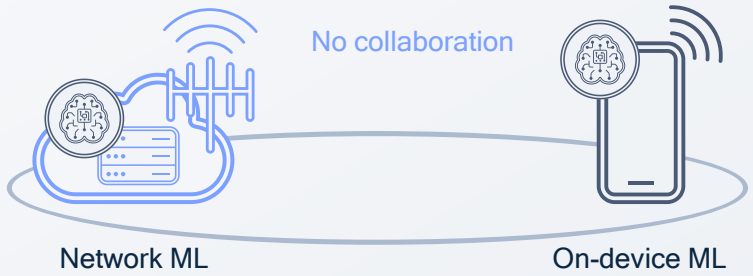




Multiple sensing modes to be evaluated in this study project, including TRP-TRP bistatic, TRP monostatic, TRP-UE bistatic, UE-TRP bistatic, UE-UE bistatic, UE monostatic

Overlay AI/ML

Independently at the device or network



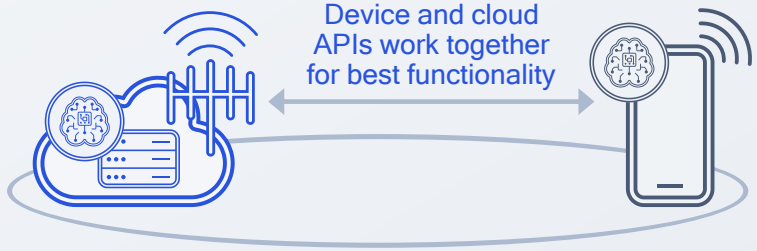
ML operates independently at the device and network as an optimization of existing functions

Proprietary ML procedures including model development and management

Proprietary and standardized data collection used as input to training

Cross-node AI/ML

Coordinated between device and network



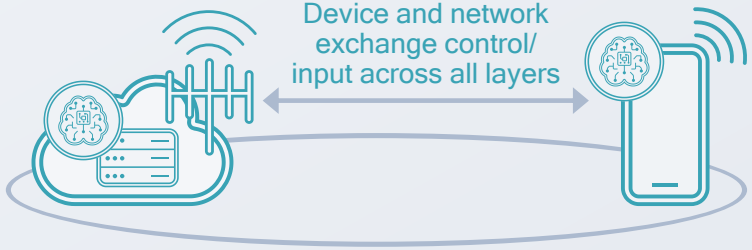
ML operates in a coordinated manner between the device and network

Proprietary and standardized ML procedures including model development and management

Further data collection used as input to training as well as monitoring

Native AI/ML

At all device and network layers



ML operates autonomously between the device and network across all protocols and layers

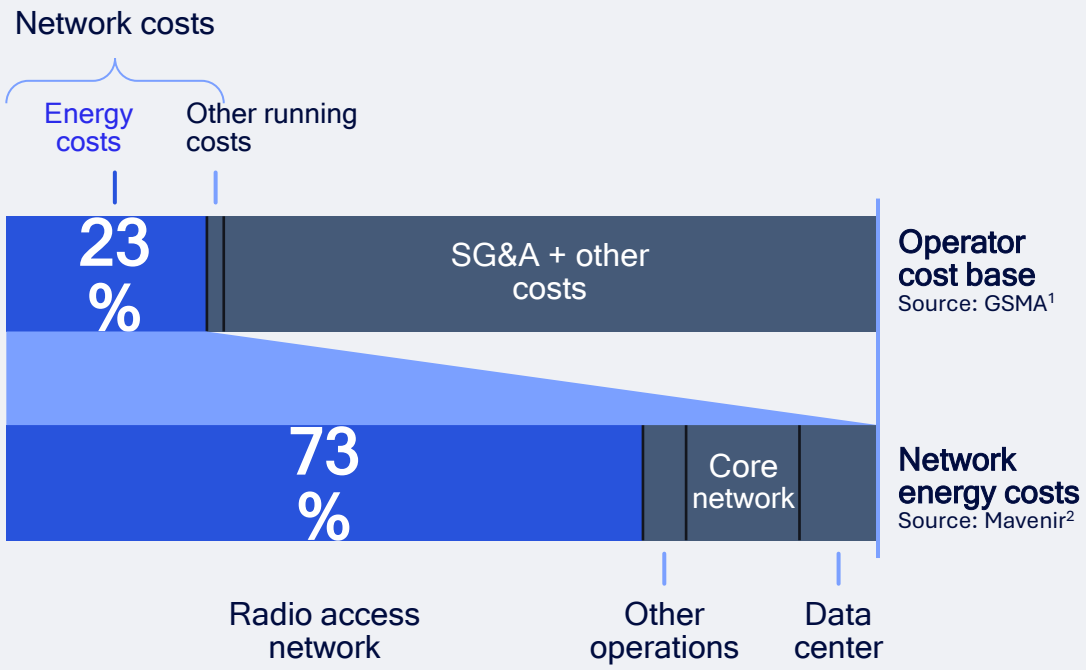
Integrated ML procedures across to train performance and adapt to different environments

Data fusion for integrated dynamic ML lifecycle management

5G — 5G ADVANCED — 6G

Evolving towards native wireless AI/ML

Multiple wireless AI/ML training and inference scenarios



Breakdown of the operator cost base

5G standard

Release 16 (2020)

- Wakeup signal (WUS)
- Other power saving techniques
- Low-power carrier aggregation control

Release 17 (2022)

- PDCCH skipping
- Search Space Set Group (SSSG) Switching
- Low-complexity RedCap devices
- Paging optimizations

5G-Advanced standard

Release 18 (2024)

- Adaptation of DTX/DRX
- Mobility and Paging Enhancement
- PDSCH transmission power adaptation
- Adaptation of antenna elements
- Inter-band carrier aggregation with SSB-less carriers
- Enhanced eDRX in inactive mode for RedCap devices

5G-Advanced standard

Release 19 (2025)

- Low-power wakeup signal and receiver (WUS/WUR)
- On-Demand SSB
- Ambient IoT
- Energy efficiency as a service

Release 20 (2027)

Potential additional improvements

6G standard

Release 21 (2029+)

The next generation of technology for new capabilities and efficiencies

Building on the 3GPP's long standing efforts to improve energy efficiency

1. https://data.gsmaintelligence.com/research/research/research-2020/5g-energy-efficiencies-green-is-the-new-black ,
2. https://www.mavenir.com/resources/a-holistic-study-of-power-consumption-and-energy-savings-strategies-for-open-vran-systems/

Trending toward an open system

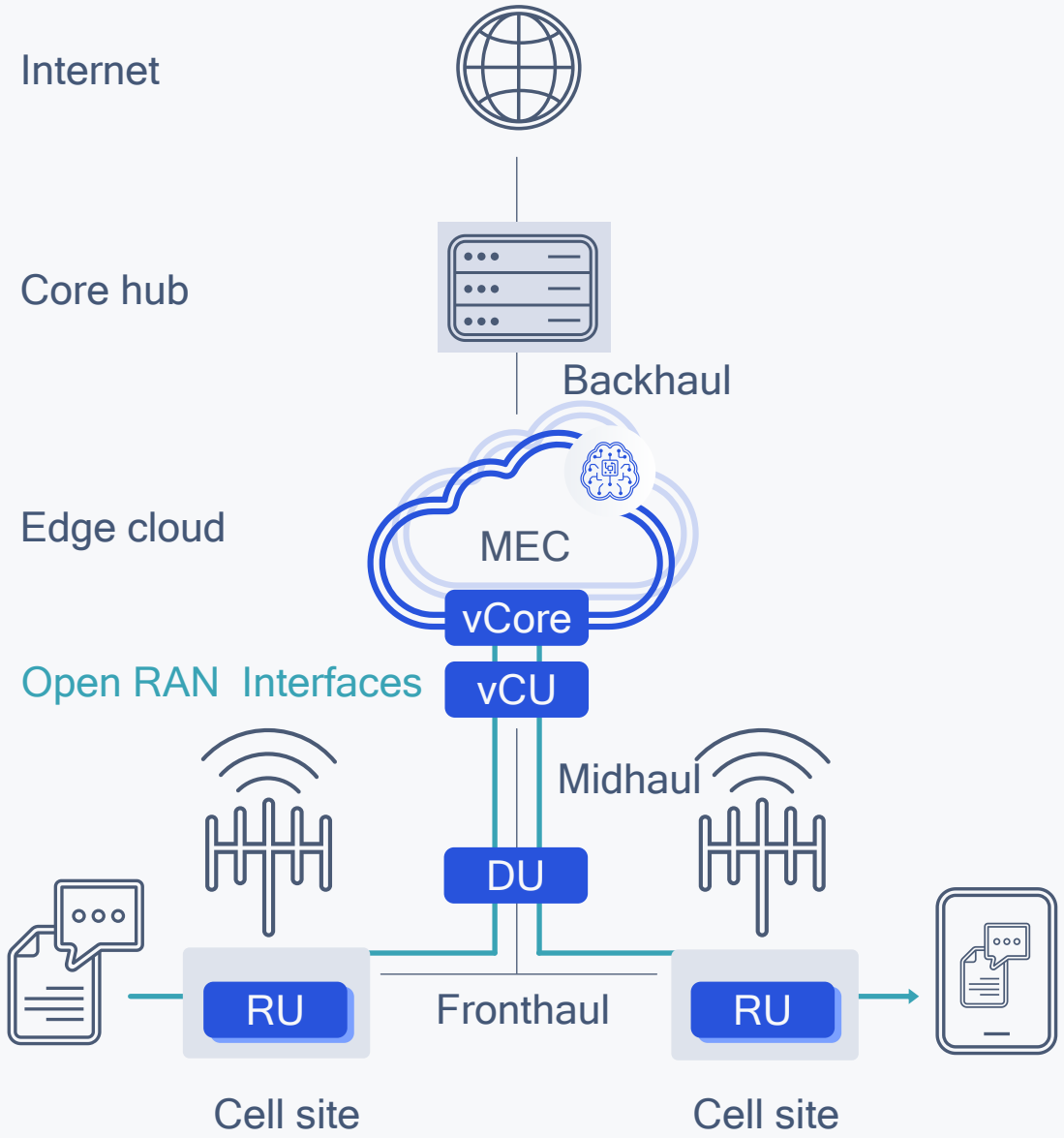
Virtualization of network functions

Common hardware where possible

O-RAN/open fronthaul

IP based connectivity (services over user plane)

Open source



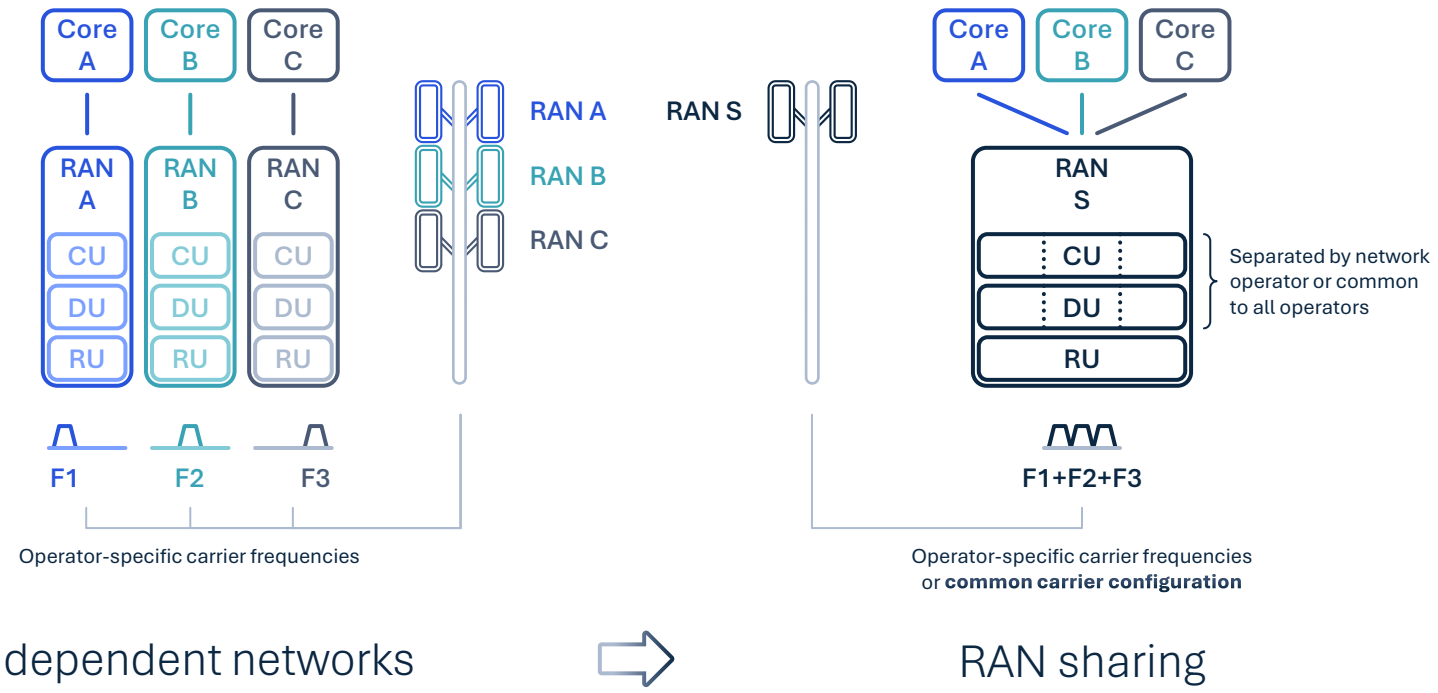
Reduce TCO and accelerate rollouts with advanced RAN sharing

Share some or all RAN components to reduce CAPEX and OPEX

Differentiate network services and user experiences with separate core networks

Continue with operator-specific spectrum or combine spectrum resources for joint scheduling over a common wide carrier (~ 500 MHz BW)

Reduce antenna tower loading and tower lease costs with fewer antennas by using the common carrier configuration



Other TCO reduction technologies:

AI-based network automation for continuous operational optimization

Non-terrestrial networks for energy- and cost- efficient rural coverage

Green networks with energy-saving operational modes for lower OPEX

Examples of commercial RAN sharing:

4G/5G regional RAN sharing in Europe, Japan and Latin America

5G national RAN sharing in China

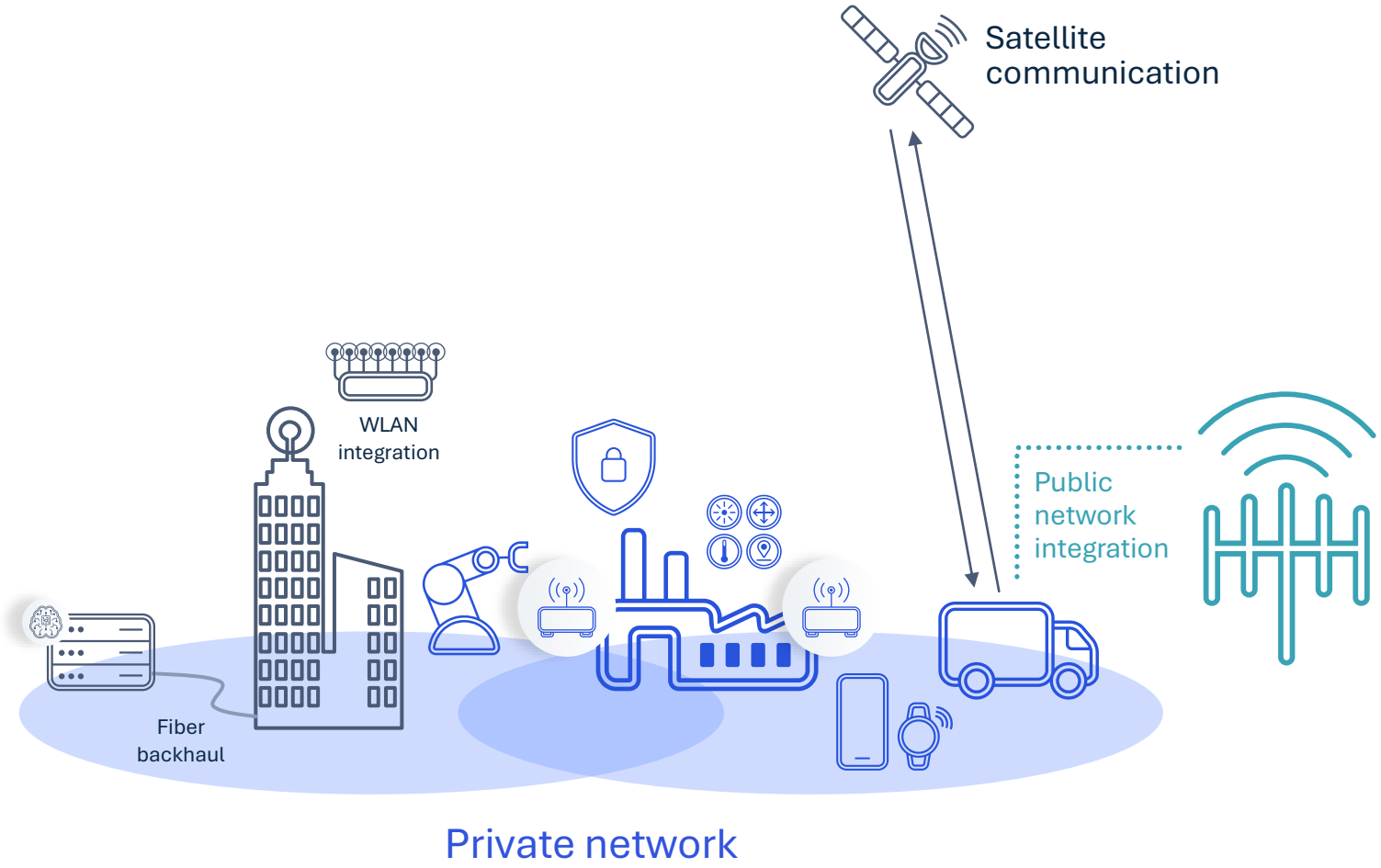
Integration with other communications systems

Satellite (NTN)

Wi-Fi

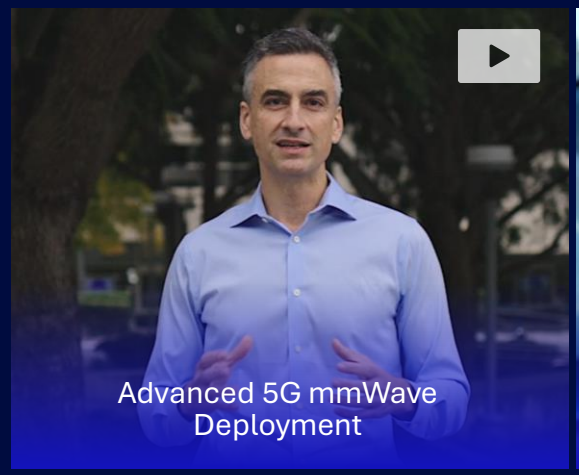
Private networks

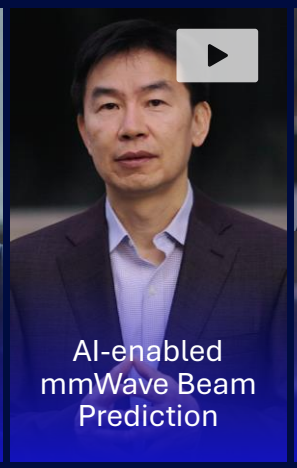
Optical networks

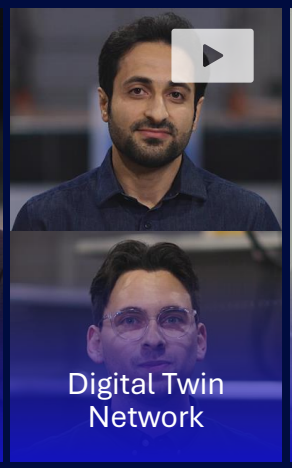


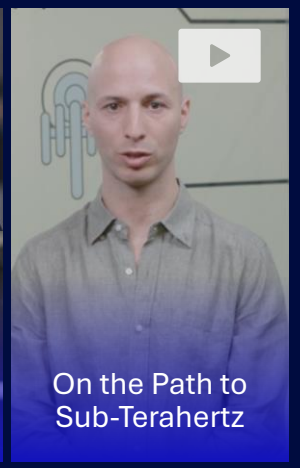
Qualcomm Showcasing the latest technology innovations on the path to 6G

FOUNDATIONAL WIRELESS INNOVATIONS

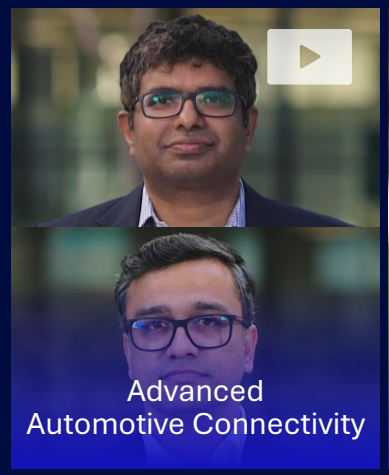


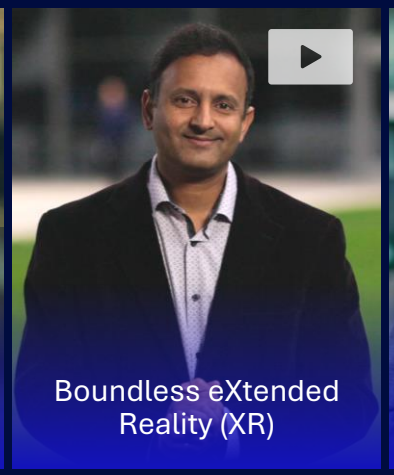


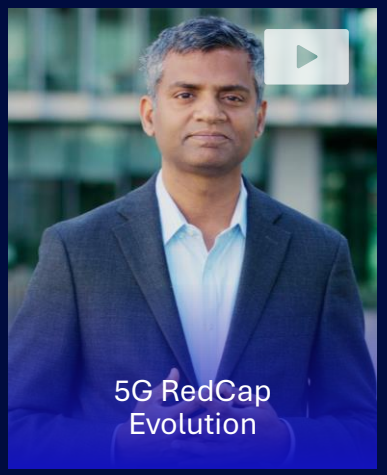


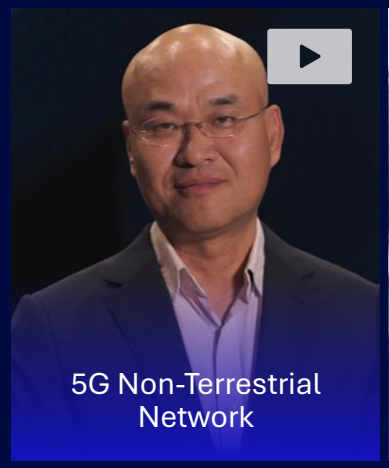


5G BEYOND MOBILE BROADBAND









Watch all demos on YouTube

Other demonstrations: Super-QAM | Enhanced Link Adaptation | Enabling Subband Full Duplex | ...

Thank you

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