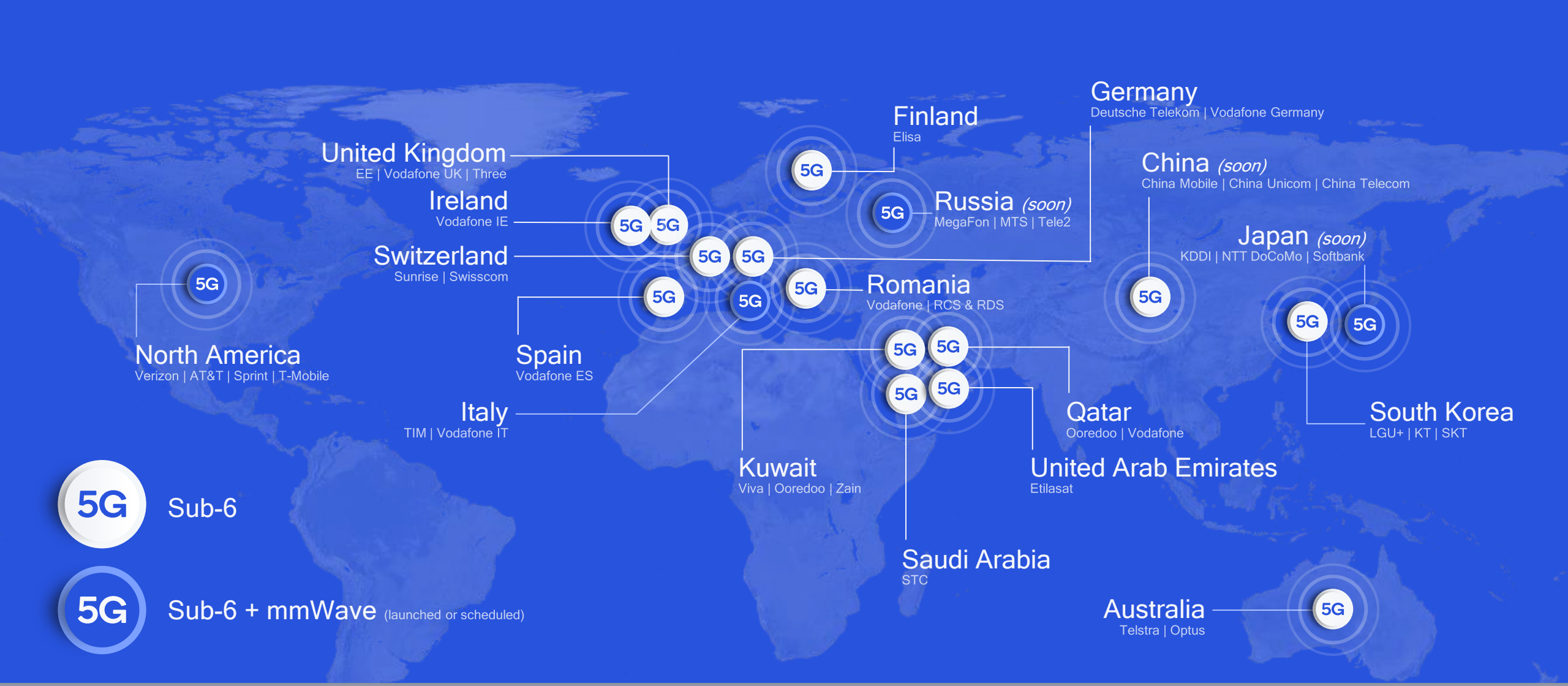
Qualcomm

October, 2019

@qualcomm_tech

What's in the future of 5G?



5G global rollout

30+ launched in 6 months

Faster than 4G

Delivering on the 5G vision

Where virtually everyone and everything is intelligently connected

Driving the 5G expansion

Our technology inventions drove the 5G foundation

Rel.15
eMBB expansion

Laptops

Automotive

Fixed wireless access

New device classes like tethered XR

Smartphones

Rel.16-17

Private networks

5G massive IoT

5G broadcast

mmWave evolution, indoor, enterprises

Sub-6 GHz evolution, new use case

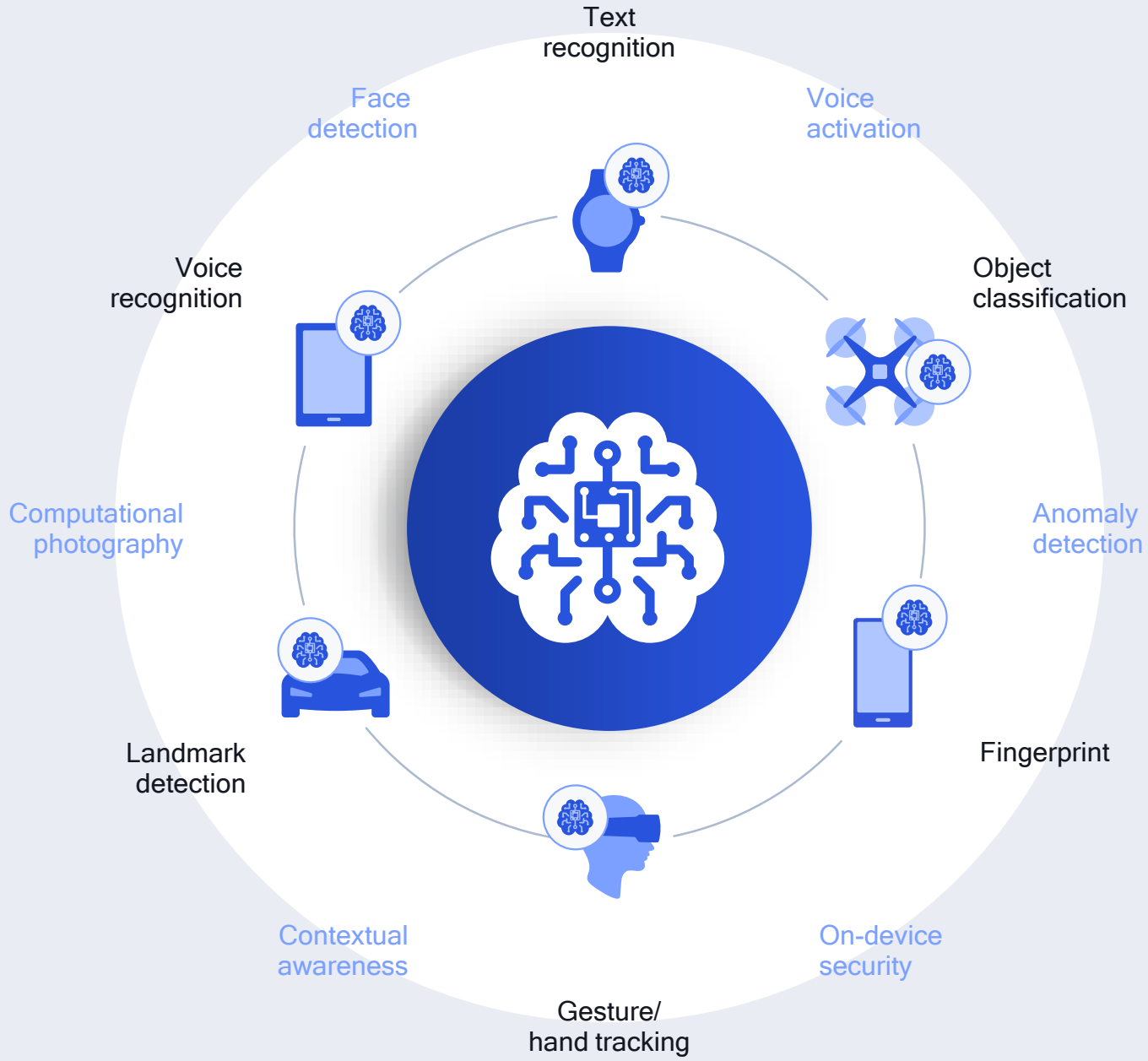
Industrial IoT with eURLLC

5G NR C-V2X, smart transportation

Future verticals, services, devices

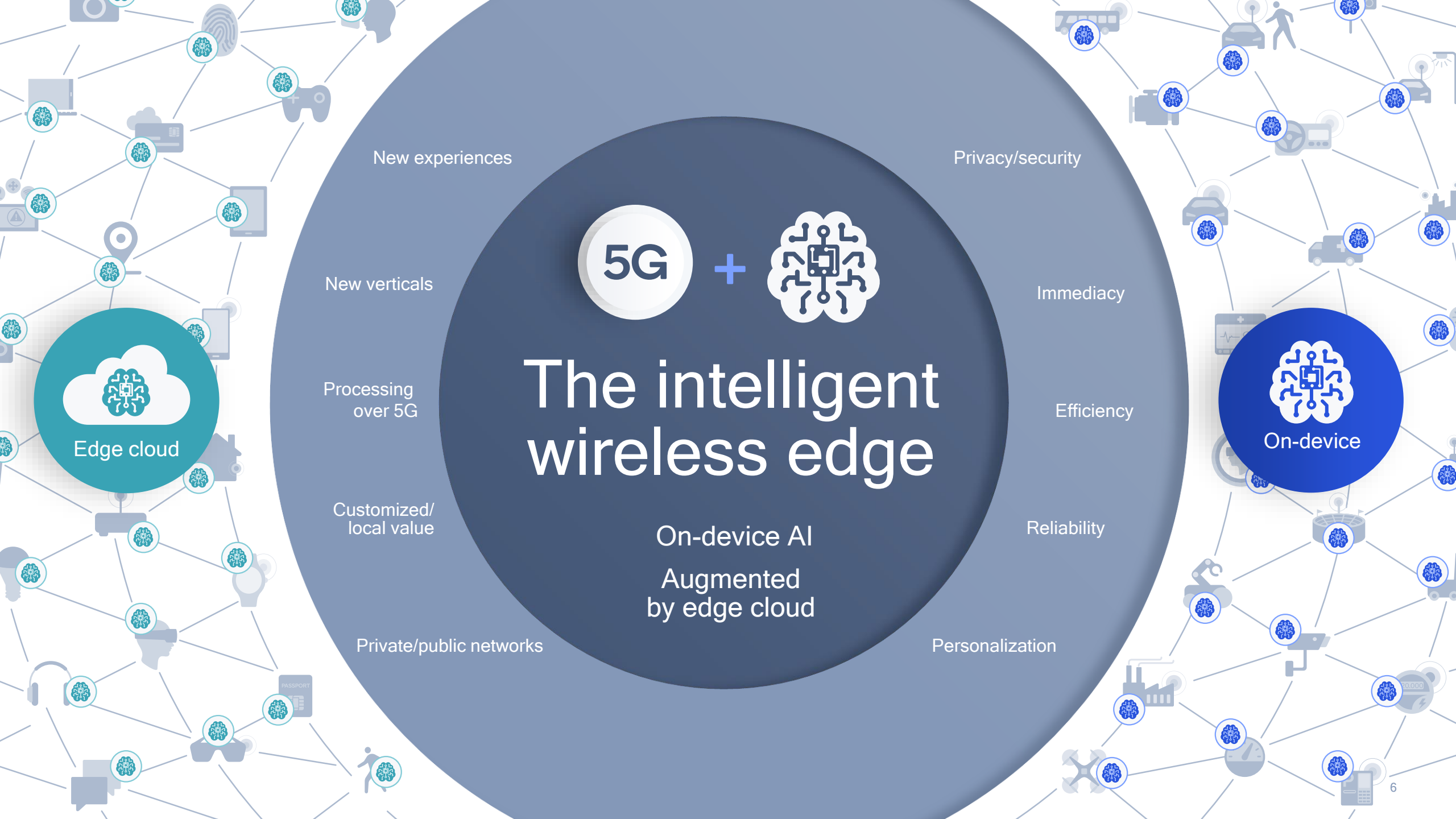
Shared / unlicensed spectrum

New device classes like boundless XR



On-device AI use-cases today

But we can do more with 5G


New experiences
Privacy/security
New verticals
Immediacy
Processing over 5G
Efficiency
Customized/ local value
Reliability
Private/public networks
Personalization
5G
+
The intelligent wireless edge
On-device AI
Augmented by edge cloud
Edge cloud
On-device

Process data at the source to scale and make sense of a digitized world

Past

Cloud-centric AI

AI training and AI inference
in the central cloud

Today

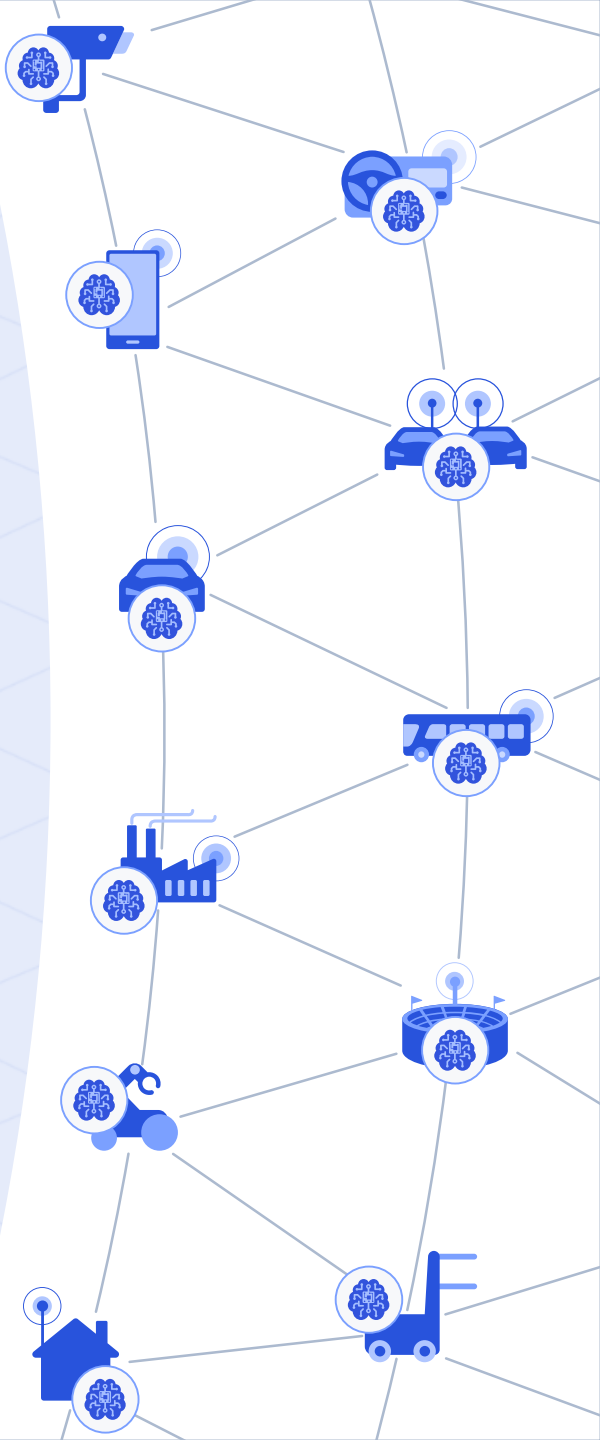
Partially-distributed AI

Power efficient
on-device AI inference

Future

Fully-distributed AI

With lifelong on-device learning

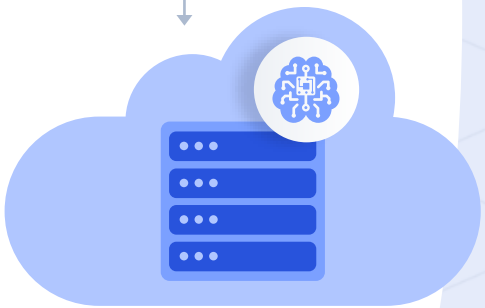


Enriched user experiences, new use case, new verticals

Distributed functionality

5G

Longer latency
Big data/aggregated value
Content/storage/AI/processing



5G low latency
Customized/local value
Content/storage/AI/processing

Compute, vision, sensing
AI powered use cases
Internal AI optimizations

On-premise control for ultra-low latency

On-device intelligence assisted by cloud

Distributed processing, like boundless XR

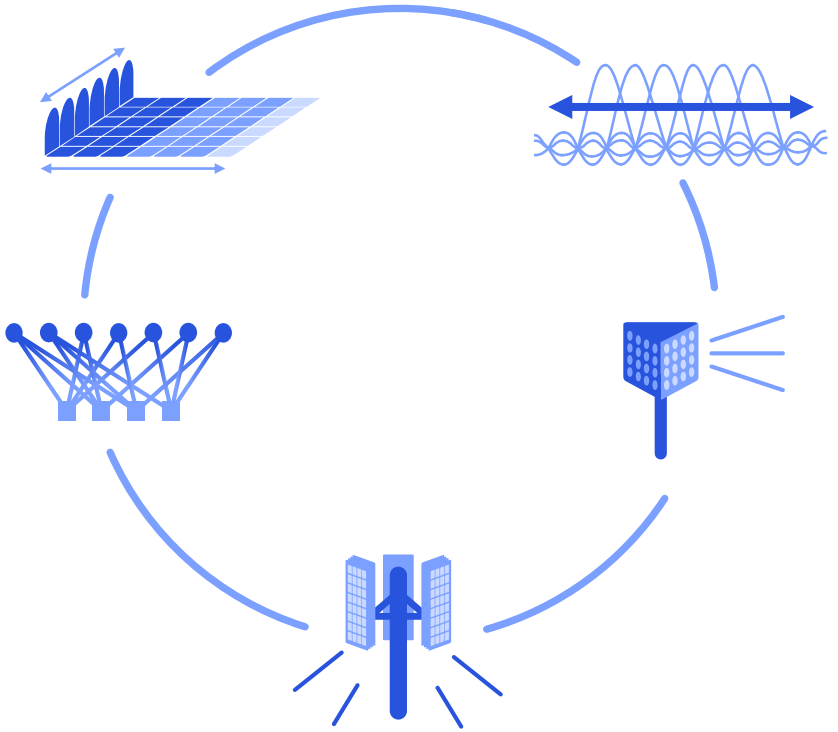
New services

Cloud computing, storage, instant access

Low-latency gaming

Real time assisted services like voice UI

Why is the 5G foundation key for the future?



Mobile has made a leap every ~10 years

Mobile voice communication

1G

1980s

Analog voice

AMPS, NMT, TACS

Efficient voice to reach billions

2G

1990s

Digital voice

D-AMPS, GSM, IS-95 (CDMA)

Focus shifts to mobile data

3G

2000s

Wireless Internet

CDMA2000/EV-DO WCDMA/HSPA+,

Mobile broadband and emerging expansion

4G

2010s

Mobile broadband

LTE, LTE Advanced, Gigabit LTE

A unified future-proof platform

2020s

Wireless Edge

5G New Radio (NR)

The 5G foundation started long ago

1985: Qualcomm founded to solve system-level problems

1993: Wireless Internet first OTA demo over CDMA

1998: EV-DO as we realized a new design was needed

2002: Integration of low-power compute

2007: Device to device proximity services

Foundation to 3G and 4G mobile broadband

2012: Cellular in unlicensed spectrum

2014: Flexible framework, scalable OFDM, spatial design, mobile mmWave

Foundational to 5G

EV-DO is the foundation to mobile broadband

1993 vision: Wireless Internet

Megabit/s

10's megabit/s

100's megabit/s

Gigabit/s

Multi gigabit/s

All-IP EV-DO

Demo

Launch

Data optimized channel with Turbo Codes[1]
Adaptive modulation/coding[2]
Opportunistic scheduling[3]

Foundation to HSPA

OFDM in EV-DO (broadcast)
Multiple antennas for RX diversity
Carrier aggregation (rev B/HSPA+)
Mobile VoIP with QoS

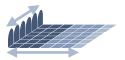
Foundation to LTE

Unlicensed spectrum
OFDM/A for wider spectrum
More antennas-MIMO
FDD/TDD/DC/SDL aggregation

Foundation to 5G NR eMBB

Our inventions drove the 5G foundation

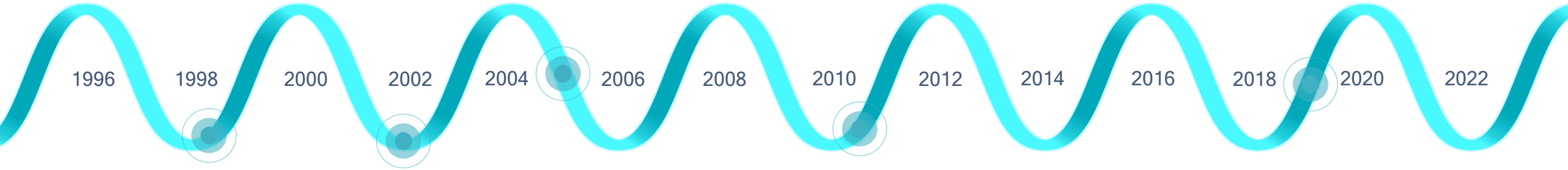
Mobile mmWave


Unified, flexible framework

Scalable OFDM numerology

Reciprocity-based massive MIMO

Multi-Edge LDPC & CRC-Aided Polar codes

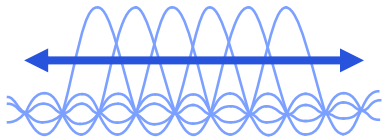


Continuous research and innovations, early prototyping, industry-first demos and trials

1. Assign all resources to a user, fast hybrid ARQ and power control 2 Higher order modulation for users with good signal quality 3 Multi-user diversity to prioritize users with better radio signal–with fairness

Our technology inventions drove Release 15 specifications

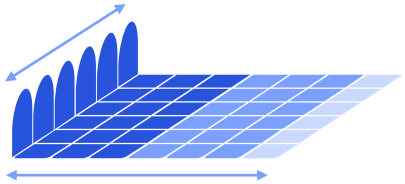
Scalable OFDM-based air interface



Scalable OFDM numerology

Address diverse services, spectrum, deployments

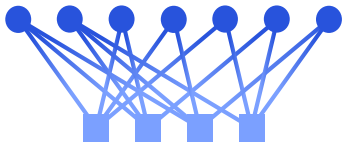
Flexible slot-based framework



Self-contained slot structure

Low latency, URLLC, forward compatibility

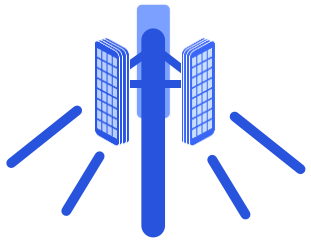
Advanced channel coding



Multi-Edge LDPC and CRC-Aided Polar

Support large data blocks, reliable control channel

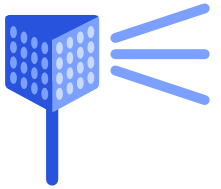
Massive MIMO



Reciprocity-based MU-MIMO

Large # of antennas to increase coverage/capacity

Mobile mmWave

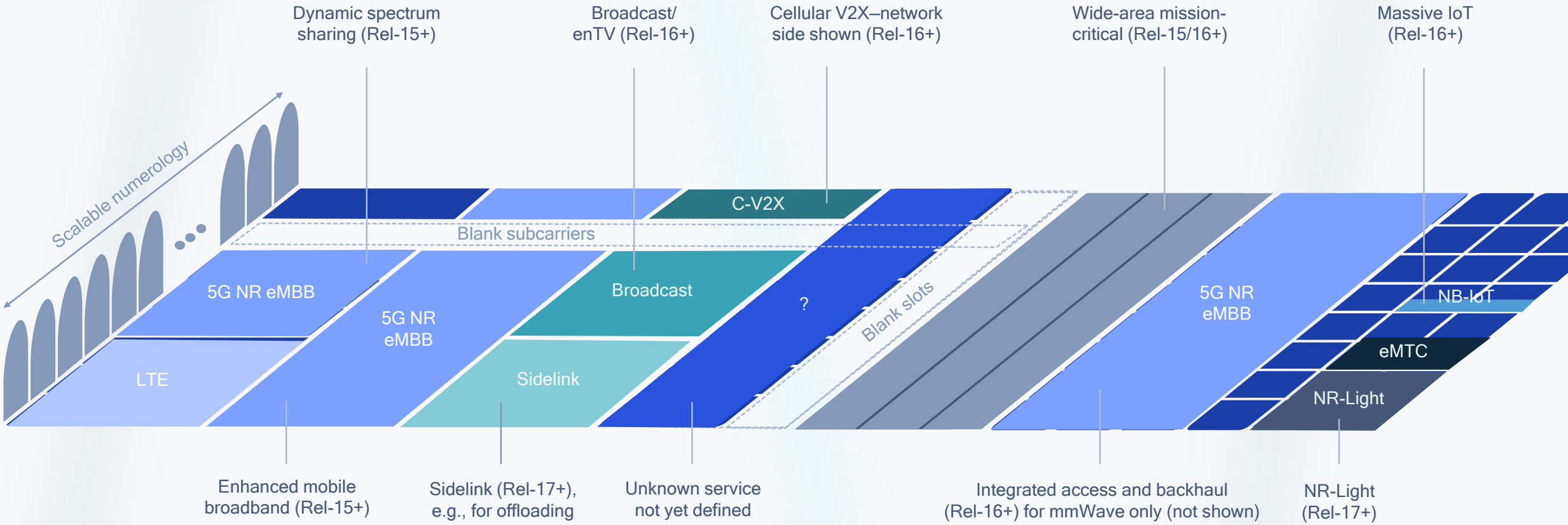


Beamforming and beam-tracking

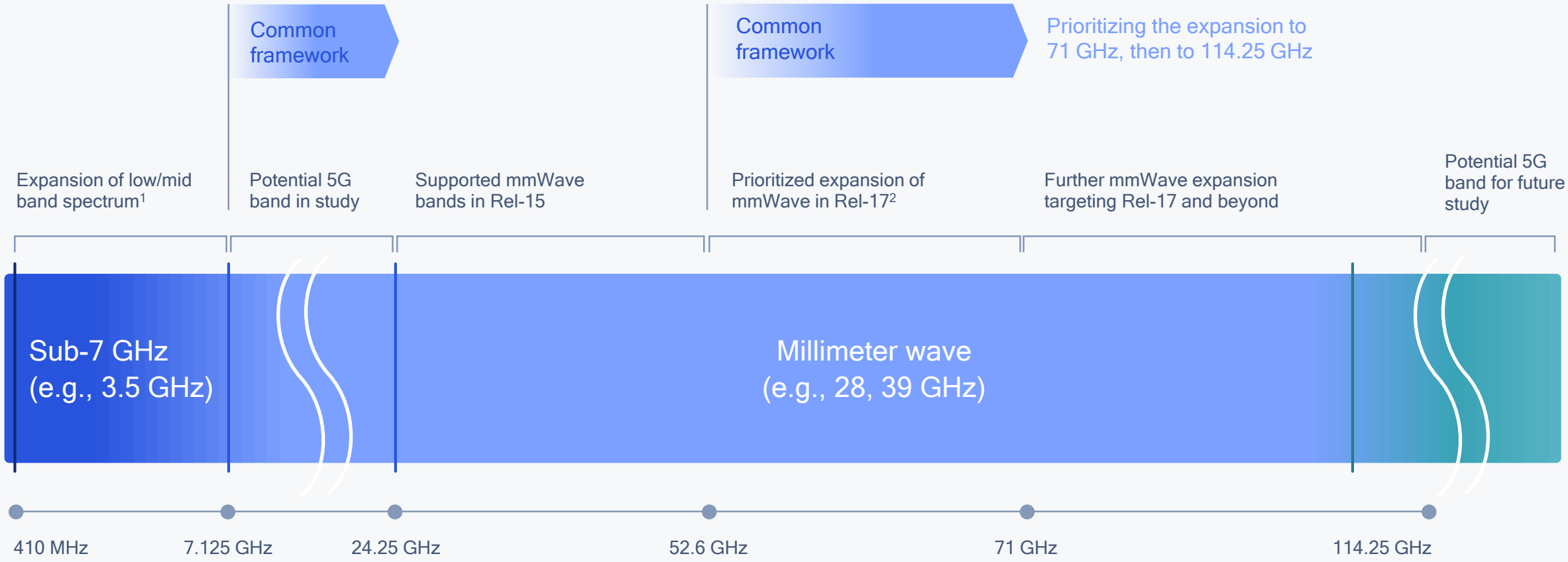
For extreme capacity and throughput

Early R&D investments | Cutting-edge prototypes | Fundamental contributions to 3GPP

Expanding 5G with the flexible slot-based framework



Expanding mmWave spectrum with the common framework

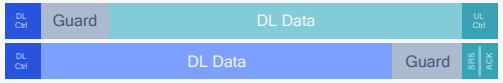


1. Rel-15 supported 450 MHz to 6 GHz; 2 To support global unlicensed 60 GHz bands, SCS scaling from 24.25-52.6 GHz band with same characteristics (e.g., waveforms)

5G enabled capabilities not possible when 4G was defined

Efficient TDD spatial design

Flexibility, lower latency, reciprocity-based massive MIMO, new feedback/pilot/measurements



Scalable numerology

Low, to mid, to high mmWave bands, deployment types

Hardware enablers

Such as faster baseband processing

Mobile mmWave

Overcoming an “impossible challenge”

LTE

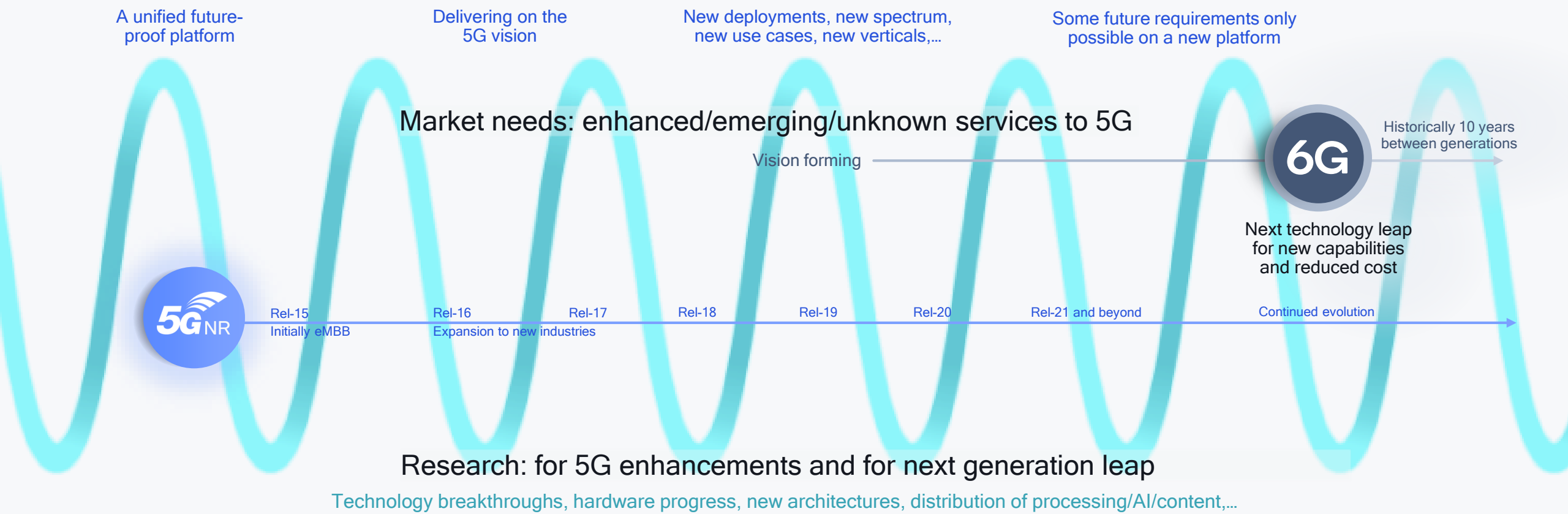
5G NR

Continuous research, technology breakthroughs, new architectures, distribution of processing/AI/content,...

Technology leap for new capabilities and reduced cost

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

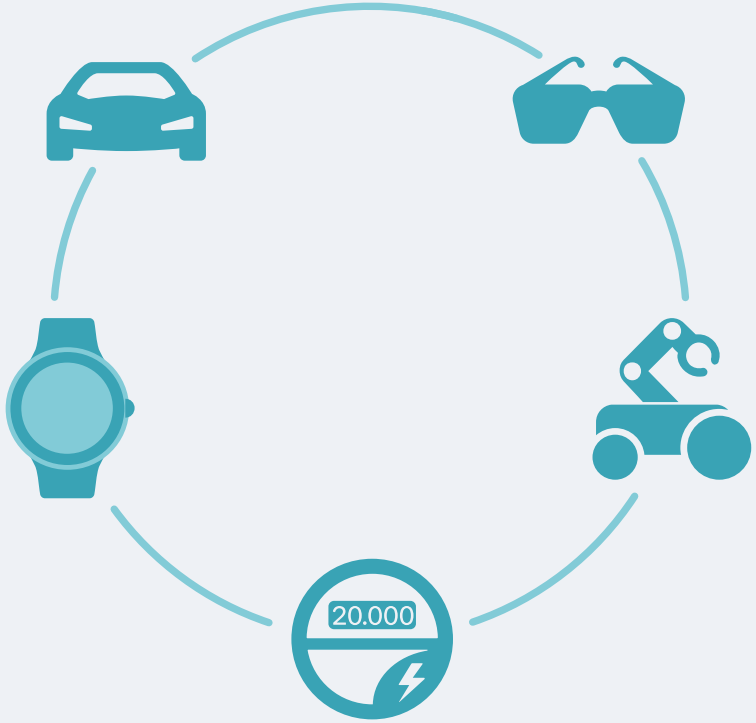
5G is the innovation platform for the next decade



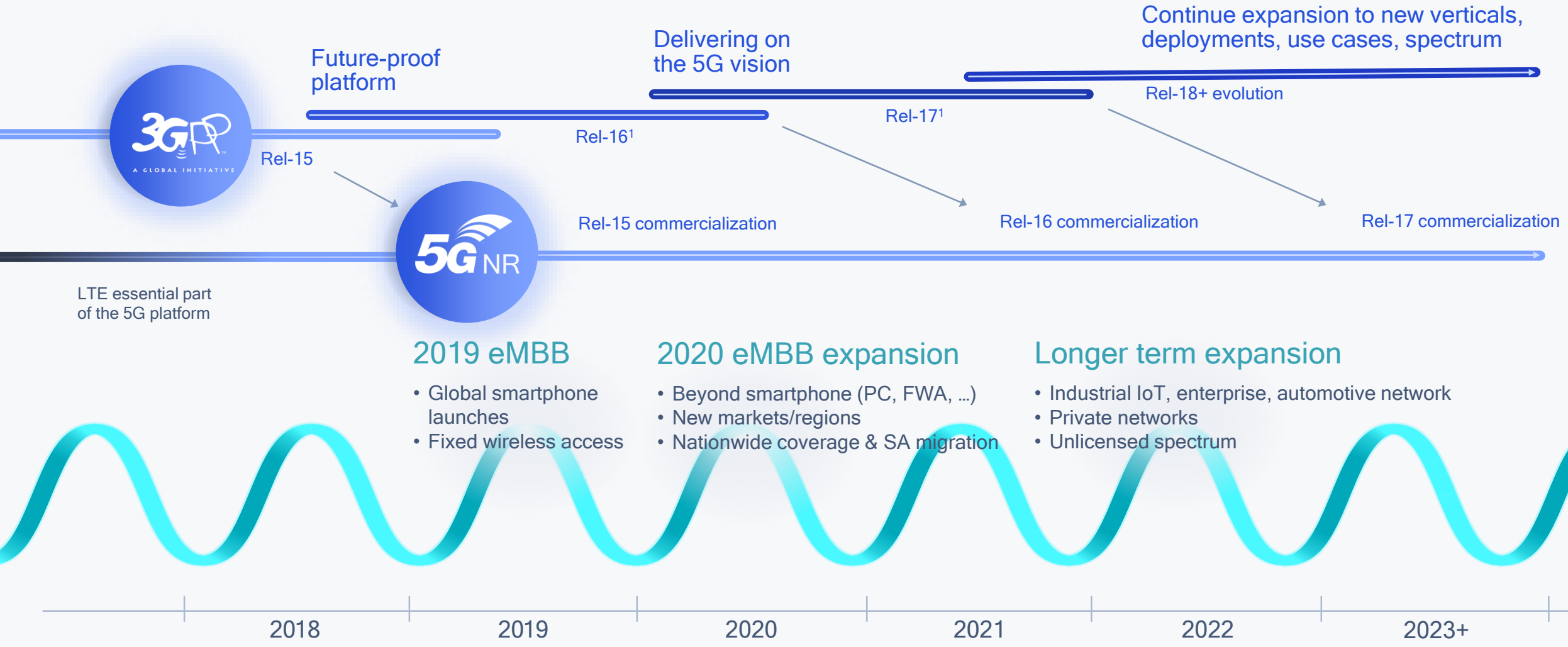
Research: for 5G enhancements and for next generation leap

Technology breakthroughs, hardware progress, new architectures, distribution of processing/AI/content,...

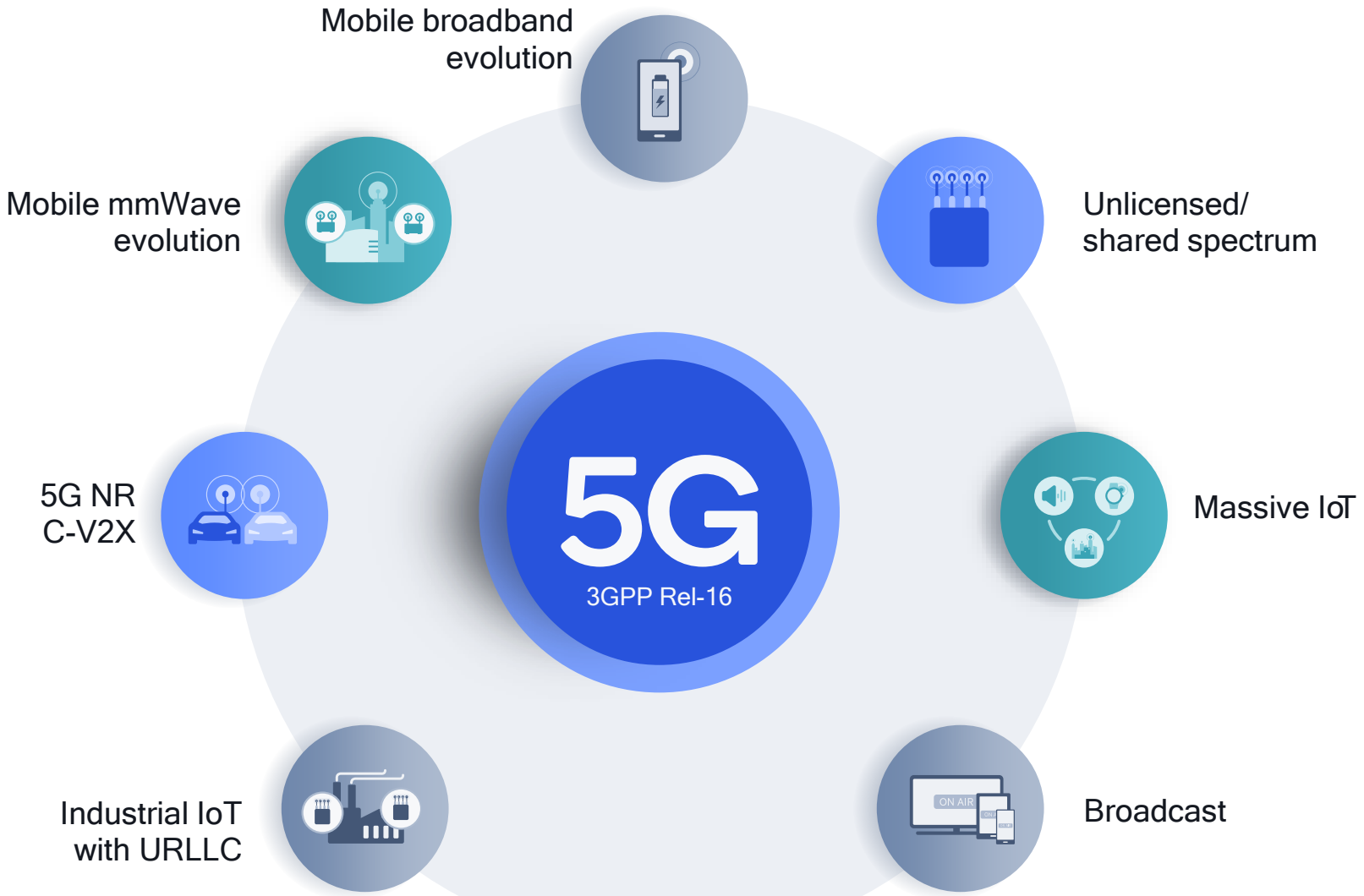
How will 5G NR evolve in Rel-16 and beyond?



Driving the 5G expansion



1. 3GPP start date indicates approval of study package (study item->work item->specifications), previous release continues beyond start of next release with functional freezes and ASN.1

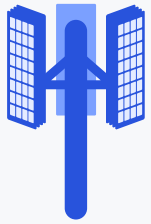


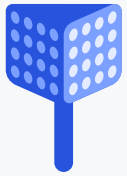
5G NR is expanding to new use cases and verticals

Continue to enhance the eMBB foundation

Rel-15 lessons learned

Optimizations to Rel-16 and
New features to Rel-17





Foundational

Coverage, capacity, latency, power saving, mobility

Enhanced DL/UL MIMO and multiple transmission points

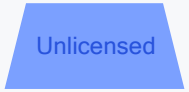
Device power saving with C-DRX and 2-step RACH

More robust mobility with minimal interruption during handover

Deployment

New spectrum, topologies, integrated backhaul, ….

Integrated access/backhaul for easier mmWave deployments



Unlicensed spectrum including standalone and license assisted

Enhanced low/mid-band and mmWave CA and async DC

New services

Latency, reliability, positioning, use cases like XR

Further improved MIMO for e.g., higher mobility

Further power saving for idle and small data

Further enhanced mobility for mixed topologies

Enhanced IAB with full duplex and spatial multiplexing

Supporting even higher bands, up to 114.25 GHz

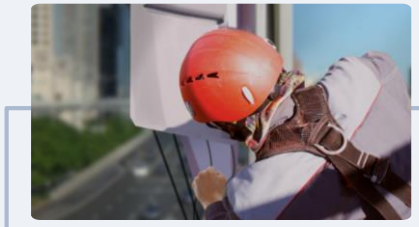
Others such as, >4 Rx, 1024-QAM, multi-SIM

Rel-15

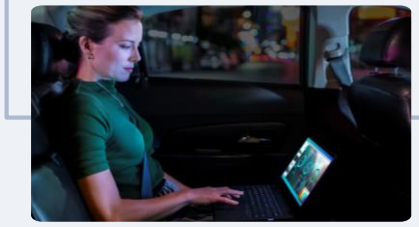
Rel-16

Rel-17:
Likely candidates

Expand 5G coverage and performance



Expand fixed wireless access, integrated with Wi-Fi



Expand device classes to always connected PC/Laptop

Expand mobile gaming including cloud gaming

Expand experiences, like XR tethered to smartphones

Expand eMBB to vehicles – initially with R14 C-V2X

Expand reach with our small cell solutions

Expand 5G eMBB modules to more verticals

Expanding our eMBB solution beyond the smartphone

Indoor enterprises

Offices, meeting rooms, auditoriums

Indoor/outdoor venues

Conventions, concerts, stadiums

Transportation hubs

Airports, train terminals, subway stations

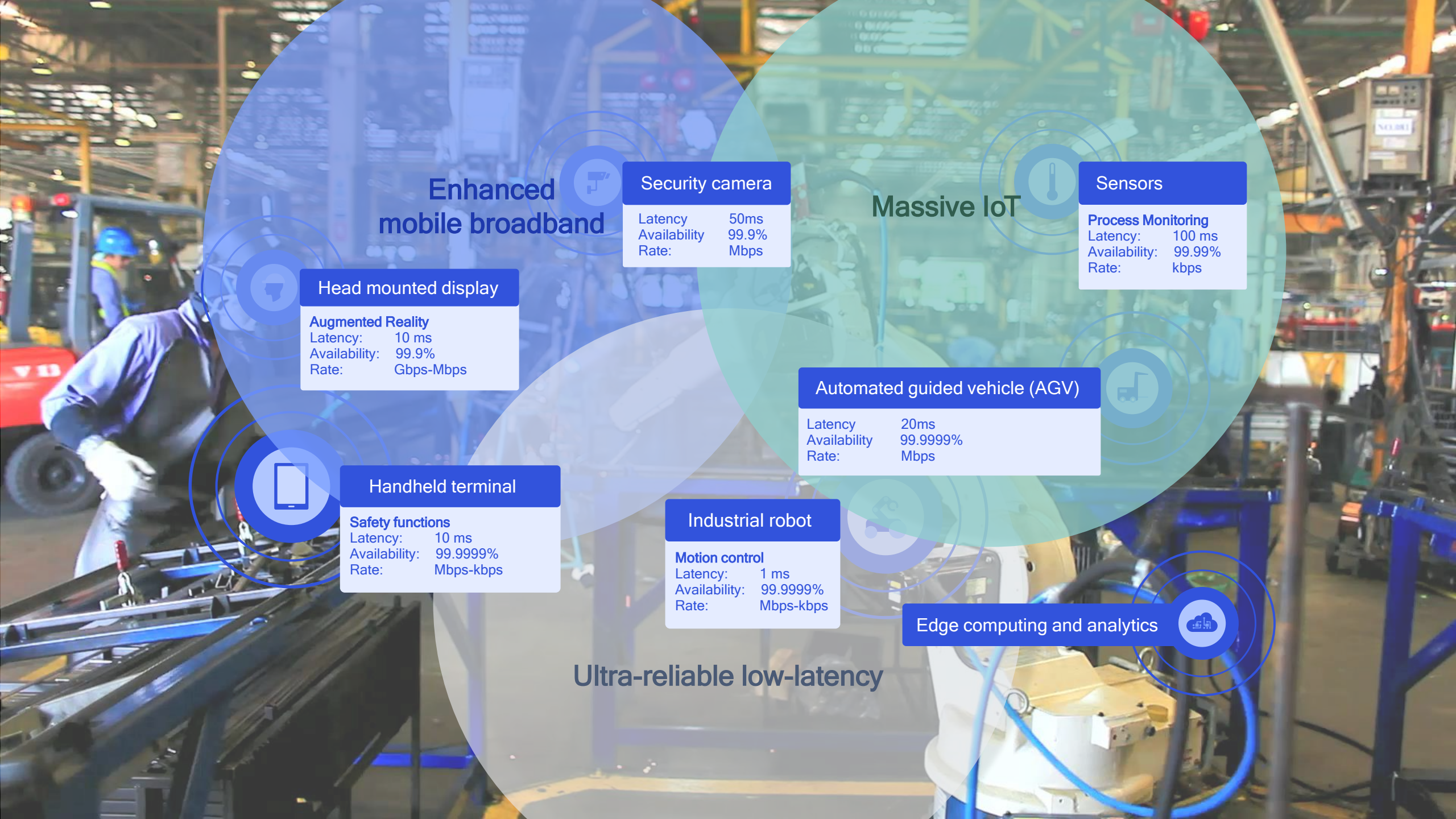
Expanding mmWave indoors, public/private networks

Multi-Gigabit speeds with virtually unlimited capacity

Beyond smartphones, laptops, tablets, extended reality, …

Leveraging existing Wi-Fi or cellular by co-siting

Emerging dedicated private networks for targeted needs


Enhanced mobile broadband
Security camera
Latency 50ms
Availability 99.9%
Rate: Mbps
Head mounted display
Augmented Reality
Latency: 10 ms
Availability: 99.9%
Rate: Gbps-Mbps
Massive IoT
Sensors
Process Monitoring
Latency: 100 ms
Availability: 99.99%
Rate: kbps
Automated guided vehicle (AGV)
Latency 20ms
Availability 99.9999%
Rate: Mbps
Handheld terminal
Safety functions
Latency: 10 ms
Availability: 99.9999%
Rate: Mbps-kbps
Industrial robot
Motion control
Latency: 1 ms
Availability: 99.9999%
Rate: Mbps-kbps
Edge computing and analytics
Ultra-reliable low-latency

Dedicated and reliable networks optimized for local services

Scalable wireless connectivity on a future proof platform

Capabilities for new use cases e.g. wireless Industrial Ethernet

5G

Private 5G network

Licensed, shared and unlicensed spectrum

Ultra-reliable low-latency communication (URLLC)

Time Sensitive Networking (TSN)

Positioning

Designing 5G to meet industrial IoT requirements

5G

Private 5G network

- Unique network ID
- Integrated and independent architectures
- Virtually seamless fallback to public networks

Licensed, shared and unlicensed spectrum

With NR-U, 5G NR will support:

- Licensed spectrum
- Shared spectrum
- Unlicensed spectrum

Ultra-reliable low-latency communication (URLLC)

- Low latency
- Ultra-reliability
- CoMP multi-TRP
- Service multiplexing
- Enhanced mobility

Time Sensitive Networking (TSN)

- Ethernet over 5G
- Deterministic networking
- Device time synch.

Positioning

- Network & device based
- Industrial IoT requirements

5G NR supports many industrial IoT use cases today

3GPP Rel-16 brings additional capabilities

Multiple spectrum options

For private 5G networks

Licensed spectrum by mobile operators

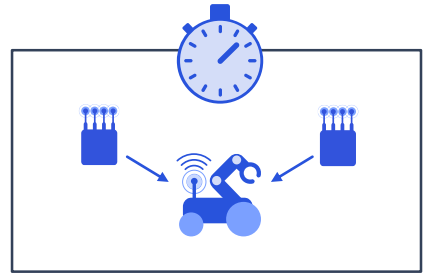
Operators can allocate spectrum in a specific area

Unlicensed spectrum with async sharing

NR-U with asynchronous sharing work for many applications

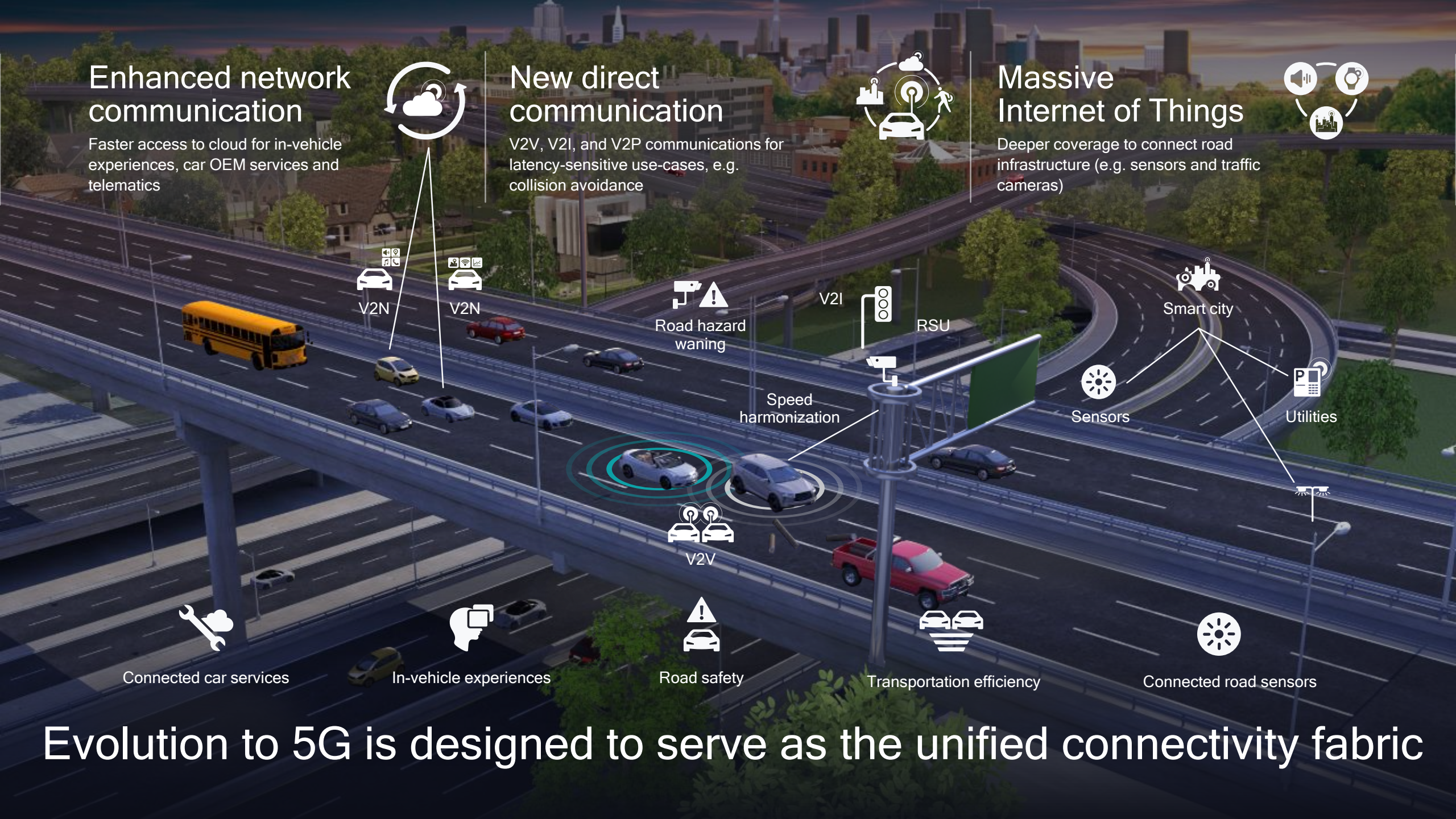
Dedicated regional spectrum

Regional spectrum such as 3.7GHz in Germany for IIoT



Unlicensed spectrum with synch sharing

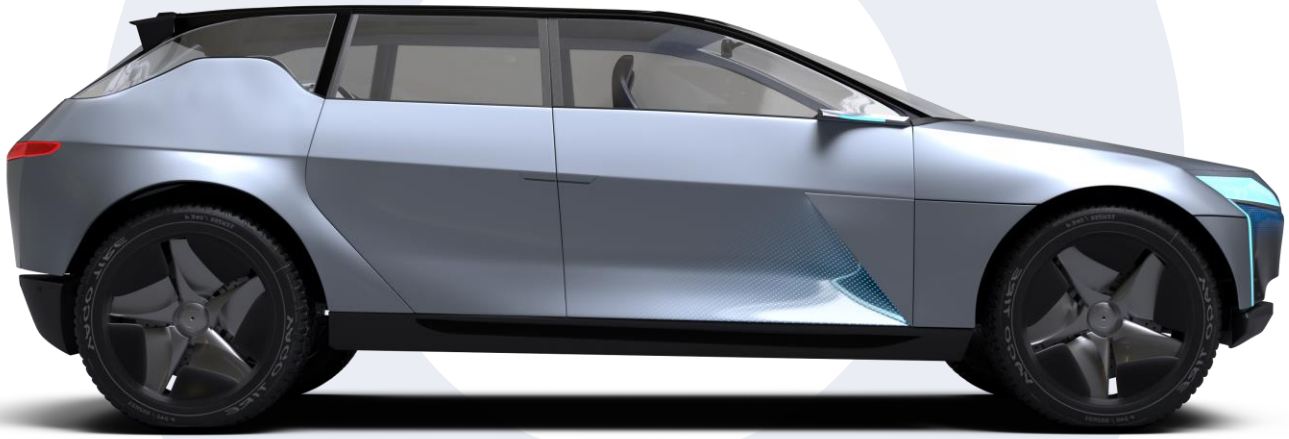
Synchronized sharing can provide reliability and eURLLC for IIoT


Enhanced network communication
Faster access to cloud for in-vehicle experiences, car OEM services and telematics
New direct communication
V2V, V2I, and V2P communications for latency-sensitive use-cases, e.g. collision avoidance
Massive Internet of Things
Deeper coverage to connect road infrastructure (e.g. sensors and traffic cameras)
V2N
V2N
Road hazard waning
V2I
RSU
Smart city
Sensors
Utilities
Speed harmonization
V2V
Connected car services
In-vehicle experiences
Road safety
Transportation efficiency
Connected road sensors
Evolution to 5G is designed to serve as the unified connectivity fabric

RSU with AI-based camera
Traffic hazard warning
AI-based camera detects hazards and alerts
Road safety
V2V/V2I: Intersection assist, non-line of sight warning
RSU with AI-based camera
Pedestrian alert
Traffic light detects crossing and alert cars via I2V
V2V
C-V2X direct communication
I2V
V2P
Burger spot
.5 miles
On-device intelligence
Key for cars to act with immediacy
Evolving 5G for smart transportation

5G NR C-V2X

Brings new benefits



Increased situational awareness

Sensor sharing

Coordinated driving / intention sharing

Real-time infrastructure updates

Advanced safety

Real-time situation awareness and sharing of new kinds of sensor data take safety to the next level

Faster travel / energy efficiency

More coordinated driving for faster travel and lower energy usage

Accelerated network effect

Sensor sharing and infrastructure deployment bring benefits, even during initial deployment rollouts

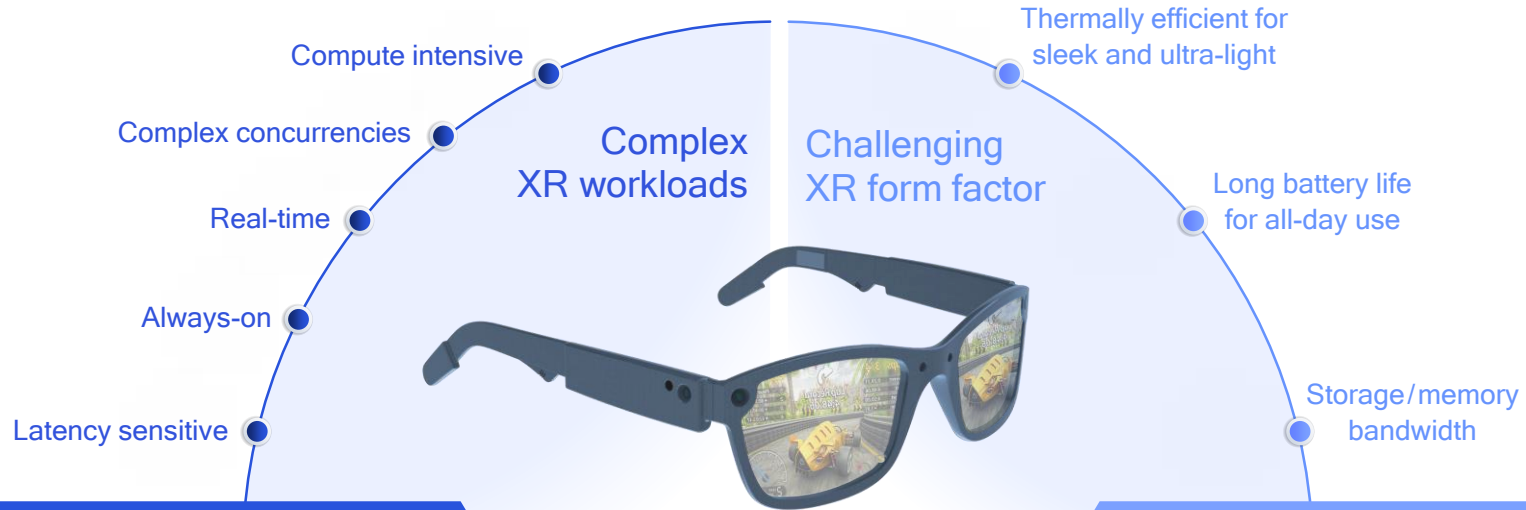
Virtual telepresence collaboration

5G

Edge cloud–but not necessarily on-premise

Augmenting on-device processing over 5G

A new era in distributed processing



Essential on-device processing

Optimized under strict power, thermal, size constraints

Premium experiences today that continuously improve

Split rendering

5G

Low latency
High capacity
Reliable link

Augment by edge cloud processing

Significant higher power envelope–beyond PC class

Augment on-device rendering with edge cloud rendering

Continued evolution to deliver on the 5G vision

Initial focus: eMBB – enhanced mobile broadband services

5G core network

5G NR IIoT with eURLLC

5G NR Cellular V2X

5G NR in unlicensed spectrum

Enhancements to 5G NR IIoT

Expand sidelink e.g., V2X reliability, P2V, IoT relay

Unlicensed spectrum across all uses cases

Advanced channel coding

Sub-6 GHz with massive MIMO

LTE integration

5G broadcast[1]

5G massive IoT[2]

Positioning across use cases

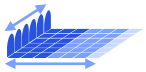
New spectrum above 52.6 GHz

NR-Light e.g., wearables, industrial sensors

Centimeter accuracy e.g., IIoT with mmWave

Mobile mmWave

Scalable OFDM-based air interface



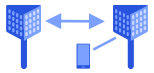
Flexible framework

eMBB evolution[3]

IAB – integrated access/backhaul

Continuation of Rel-15 projects, others[4]

Continued eMBB enhancements[5]



More capable, flexible IAB

Rel-15 deployment learning, XR, drones, others[6]

Rel-15

Established 5G NR technology foundation

Rel-16

Expanding to new use cases and industries

Rel-17: Likely candidates

Continued expansion and enhancements

1. Enhancing Rel-14 LTE enTV to meet 5G requirements; 2. eMTC/NB-IOT in-band 5G NR and connected to 5G core; 3. MIMO, power consumption, mobility, MR DC/CA, interference management and more; 4. Non-terrestrial networks, non-public networks (private networks), NR SON/MDT and more; 5. further improvements to capacity, coverage, mobility, power consumption, spectral efficiency; 6. mixed-mode multicast, small data transmission, multi-SIM, satellite, multimedia

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