



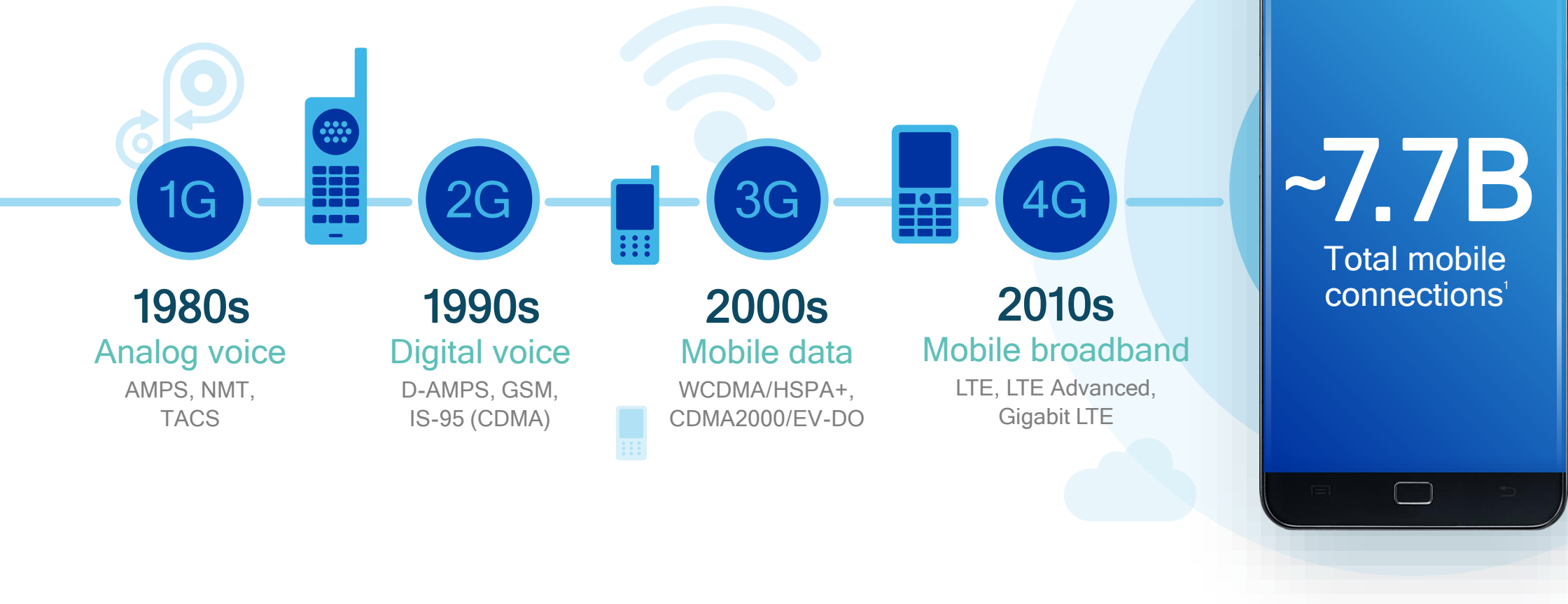
Making 5G NR a Commercial Reality

A unified, more capable 5G air interface

December 2017

@qualcomm_tech

Mobile is the largest technology platform in human history



¹ Source: GSMA Intelligence, July 2017



5G will address the insatiable demand for mobile broadband

30x growth in mobile data traffic from 2014 to 2020

>75% of traffic from multi-media streaming in 2020



~8B

Gigabytes

Daily global mobile data traffic in 2020



5G Consumer Survey

key findings

Surveyed smartphone owners from:



1,002



1,010



1,000



1,006



1,002



824



5,844
WW total

>86%

Need or would like
faster connectivity on
next smartphone

~50%

Likely to purchase a phone
that supports 5G when
available

Top 3 reasons for 5G:

10x
faster
speeds

10x
quicker
response time

More
cost-effective
data plans

Source: "Making 5G a reality: Addressing the strong mobile broadband demand in 2019 and beyond," September 2017, jointly published by Qualcomm Technologies, Inc. and Nokia.

Mobilizing media
and entertainment



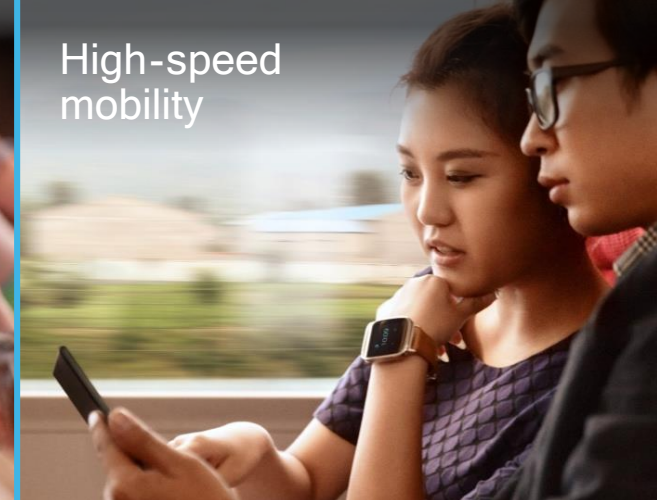
Rich user-generated
content



Congested
environments



High-speed
mobility



5G

5G is essential for
next generation
mobile experiences

- Fiber-like data speeds
- Low latency for real-time interactivity
- More consistent performance
- Massive capacity for unlimited data

Connected cloud
computing



Immersive
experiences



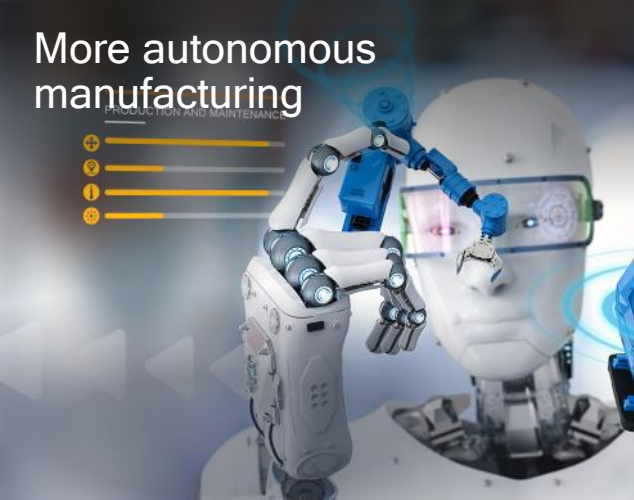
Connected
vehicle



Augmented
reality



More autonomous
manufacturing



Safety conscious, autonomous
transportation



Reliable access
to remote healthcare



Smarter
agriculture

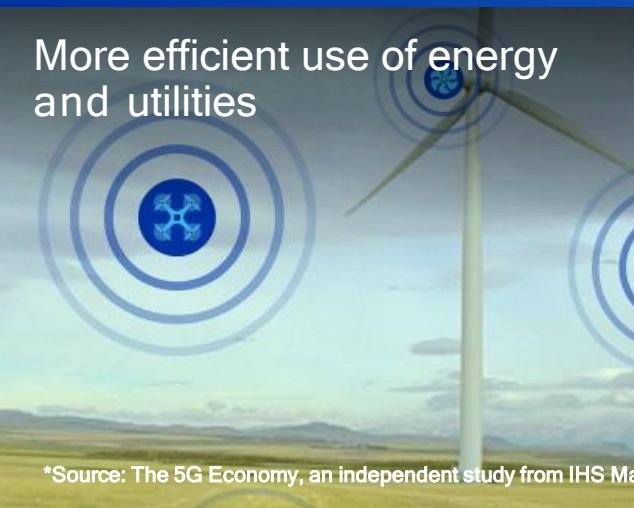


5G

5G will expand the
mobile ecosystem
to new industries

Powering the digital economy
> **\$12 Trillion**
in goods and services by 2035*

More efficient use of energy
and utilities



Improved public
safety and security



Sustainable cities
and infrastructure



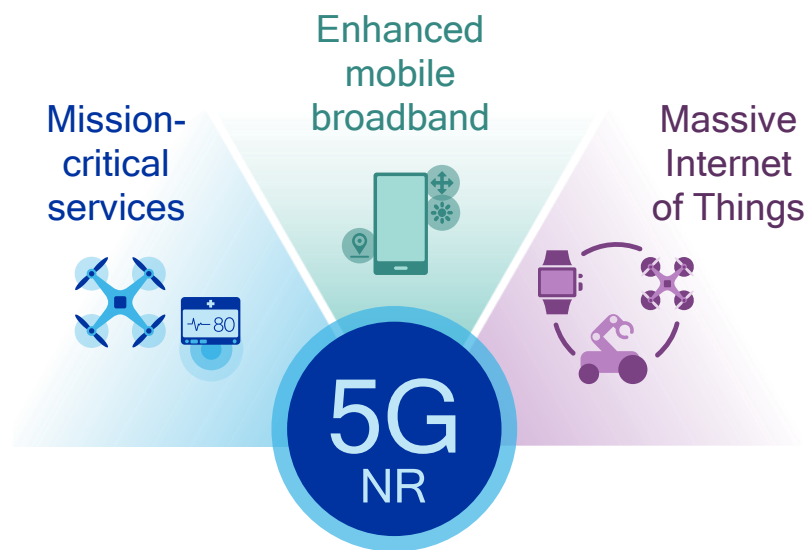
Digitized logistics
and retail



*Source: The 5G Economy, an independent study from IHS Markit, Penn Schoen Berland and Berkeley Research Group, commissioned by Qualcomm

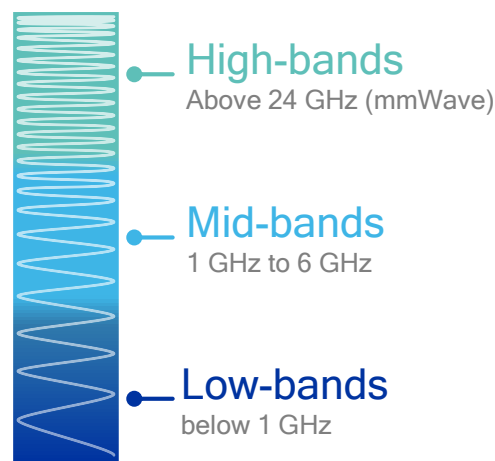


Designing a unified, more capable 5G air interface



Diverse services

Scalability to address an extreme variation of requirements



Diverse spectrum

Getting the most out of a wide array of spectrum bands/types



Diverse deployments

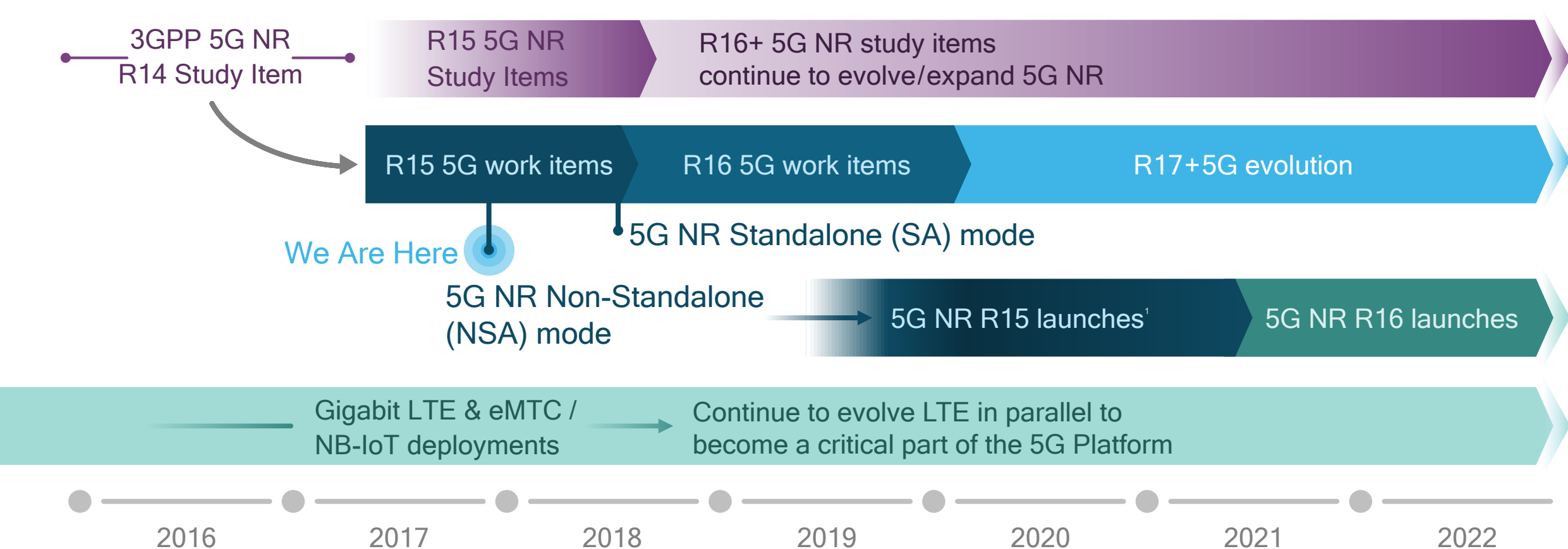
From macro to indoor hotspots, with support for diverse topologies

A unifying connectivity fabric for future innovation

A platform for existing, emerging, and unforeseen connected services



Accelerating 5G NR – the global 5G standard



5G NR NSA 3GPP Rel-15 specifications complete

Supporting eMBB deployments as early as 2019 to meet the insatiable demand



Pioneering advanced 5G NR technologies

Cellular Vehicle-to-Everything (C-V2X)

Drone communications Private Networks

Ultra-Reliable Low Latency Comms (URLLC)



Mission-critical
services

Spectrum sharing

Scalable OFDM

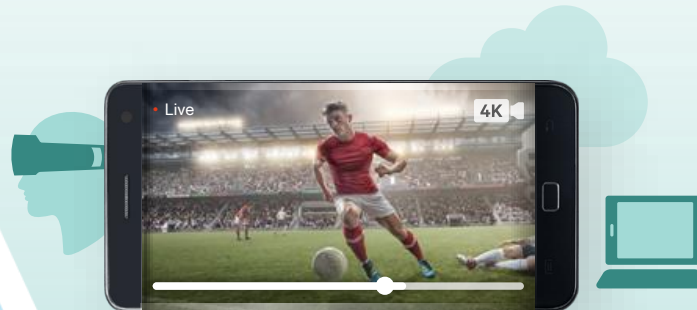
Dual Connectivity

Flexible slot-based framework

Massive MIMO

Advanced channel coding

Mobile mmWave



Enhanced mobile
broadband

Enhanced power save modes

Deeper coverage

Narrow bandwidth

Grant-free UL

Efficient signaling



Massive Internet
of Things

To meet an extreme variation of 5G NR requirements

10x

Decrease in
end-to-end latency

10x

Experienced
throughput

3x

Spectrum
efficiency

100x

Traffic
capacity

100x

Network
efficiency

10x

Connection
density

Making 5G NR a commercial reality for 2019

For standard-compliant networks and devices



Best-in-class 5G prototype systems

Designing and testing 5G technologies for many years



5G NR standards and technology leadership

Our technology inventions are driving the 5G NR standard



5G NR interoperability testing and trials

Utilizing prototype systems and our global network experience



Modem, RFFE and platform leadership

Snapdragon X50 5G modem supporting anticipated 2019 mobile device launches

LTE foundational technologies



Designing 5G New Radio (NR)

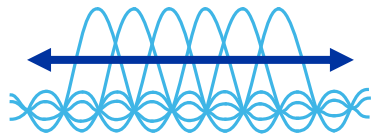
3GPP Release 15



3GPP Rel-15 establishes the foundation for 5G NR

For enhanced mobile broadband and beyond

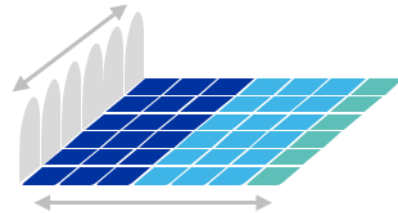
Scalable OFDM-based air interface



Scalable OFDM numerology

Efficiently address diverse spectrum, deployments and services

Flexible slot-based framework



Self-contained slot structure

Key enabler to low latency, URLLC and forward compatibility

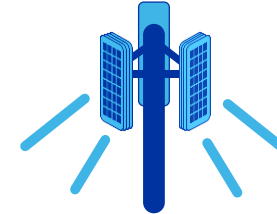
Advanced channel coding



ME-LDPC and CA-Polar¹

Efficiently support large data blocks and a reliable control channel

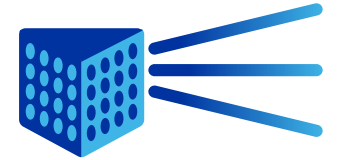
Massive MIMO



Reciprocity-based MU-MIMO

Efficiently utilize a large # of antennas to increase coverage / capacity

Mobile mmWave



Beamforming & beam-tracking

Enables wide mmWave bandwidths for extreme capacity and throughput

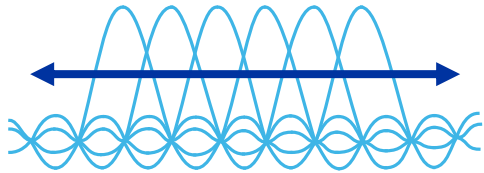
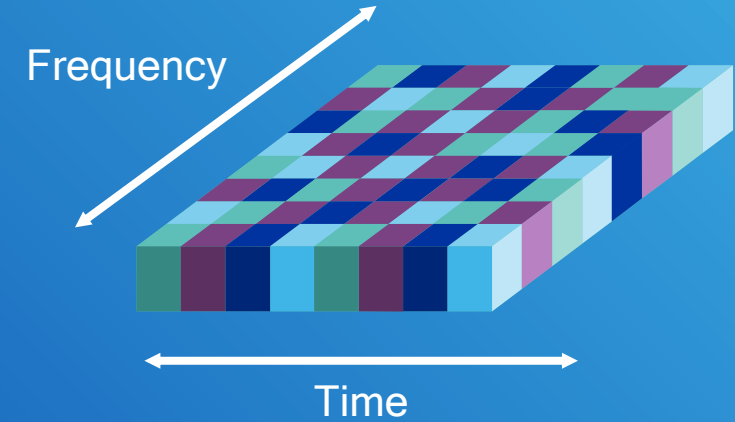


Our technology inventions are driving Rel-15 specifications

Early R&D investments | Best-in-class prototypes | Fundamental contributions to 3GPP

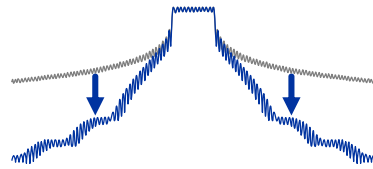
1. Multi-Edge Low-Density Parity-Check and CRC-Aided Polar

Scalable OFDM-based 5G NR air interface



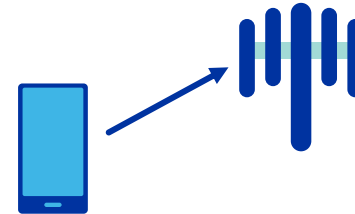
Scalable numerology

2^n scaling of subcarrier spacing to efficiently support wider bandwidths



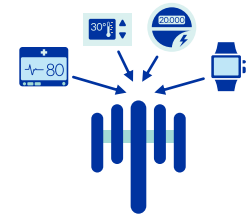
Frequency localization

Windowing¹ can effectively minimize in-band and out-of-band emissions



Lower power consumption

Single-carrier² OFDM utilized for efficient uplink transmissions



Asynchronous multiple access

Can co-exist with optimized waveforms and multiple access for IoT UL³

3GPP Rel-15 specifications aligned with Qualcomm Research whitepaper published Nov 2015 ([link](#))

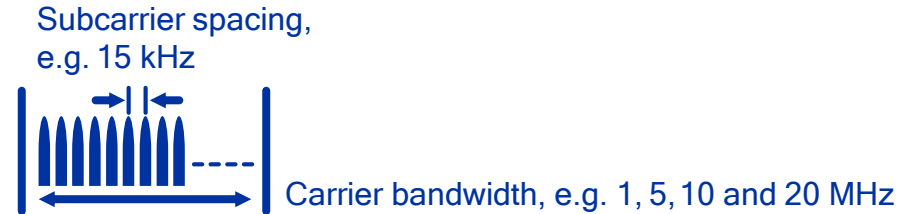
Qualcomm Research is a division of Qualcomm Technologies, Inc.

1. Such as Weighted Overlap Add (WOLA) utilized in LTE systems today. 2. DFT-Spread (DFT-S) OFDM. 3. Such as non-orthogonal Resource Spread Multiple Access (RSMA)

Scalable 5G NR OFDM numerology—examples

Outdoor macro coverage

e.g., FDD 700 MHz



2ⁿ scaling of Sub-Carrier Spacing (SCS)

Outdoor macro and small cell

e.g., TDD 3-5 GHz



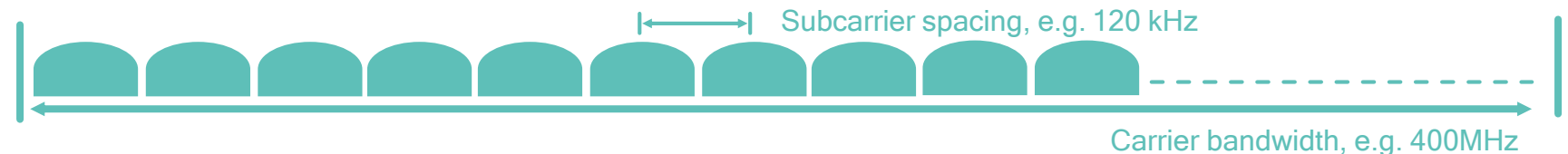
Indoor wideband

e.g., unlicensed 6 GHz



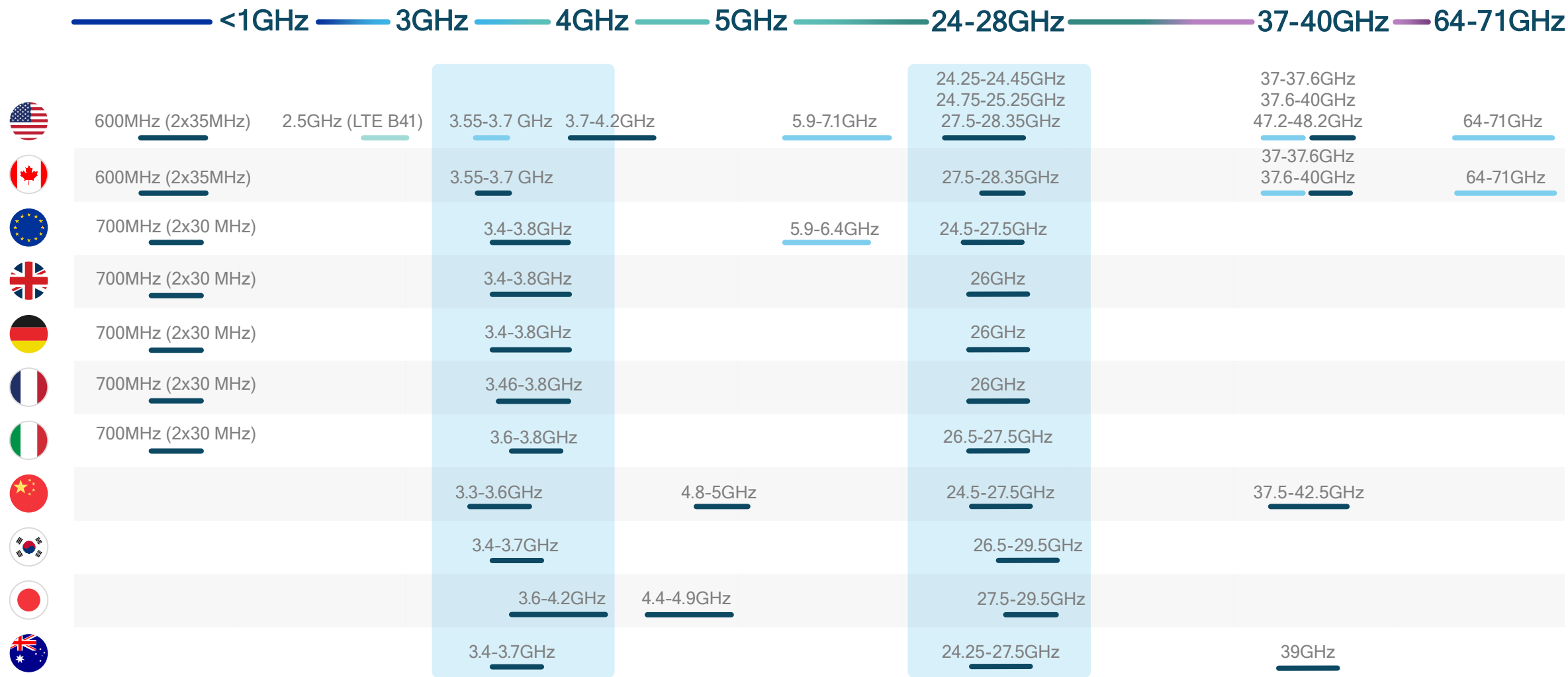
mmWave

e.g., TDD 28 GHz



Efficiently address 5G diverse spectrum, deployments and services

Scaling reduces FFT processing complexity for wider bandwidths with reusable hardware



Designed for diverse spectrum bands/types

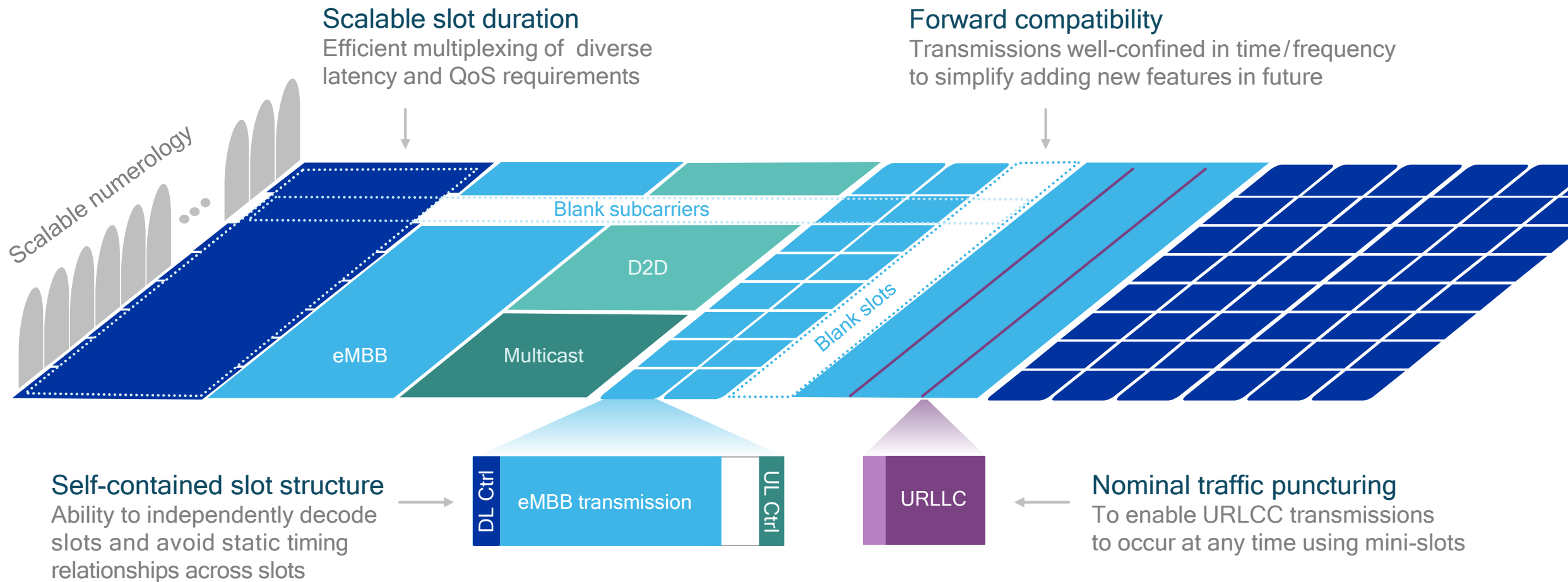
Global snapshot of 5G spectrum bands allocated or targeted

New 5G band

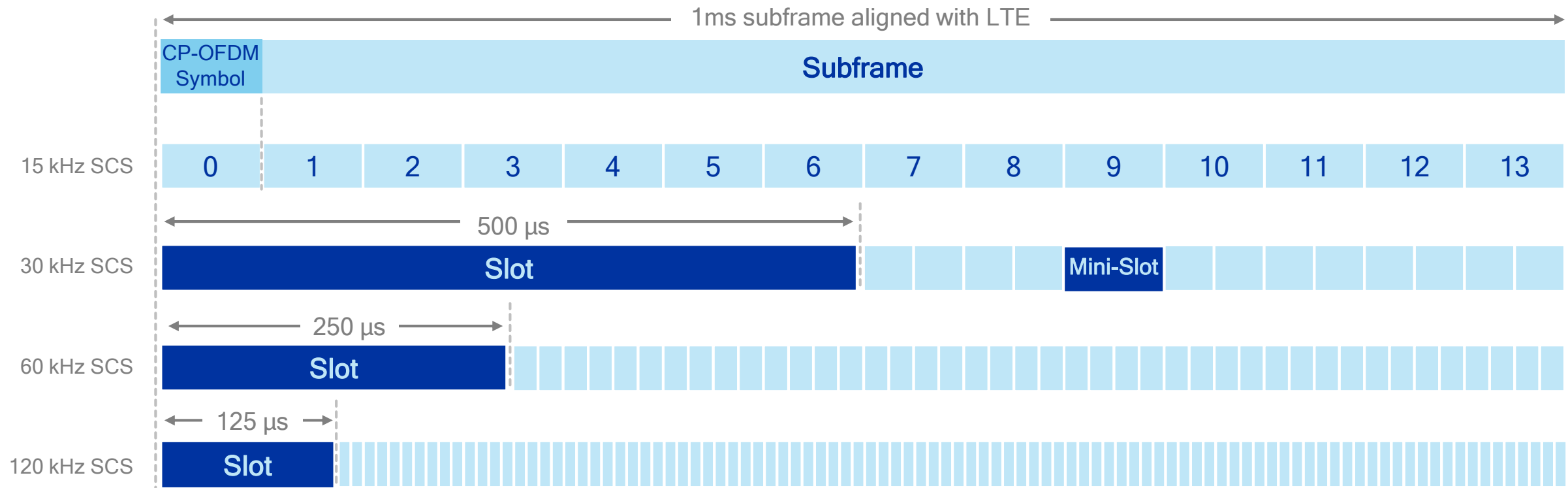
- Licensed
- Unlicensed/shared
- Existing band

Flexible slot-based 5G NR framework

Efficiently multiplex envisioned and future 5G services on the same frequency



Scalable 5G NR slot duration for diverse latency/QoS



14 OFDM symbols per slot
with mini-slot (2, 4, or 7 symbols)
for shorter transmissions¹

Supports slot
aggregation for data-
heavy transmissions

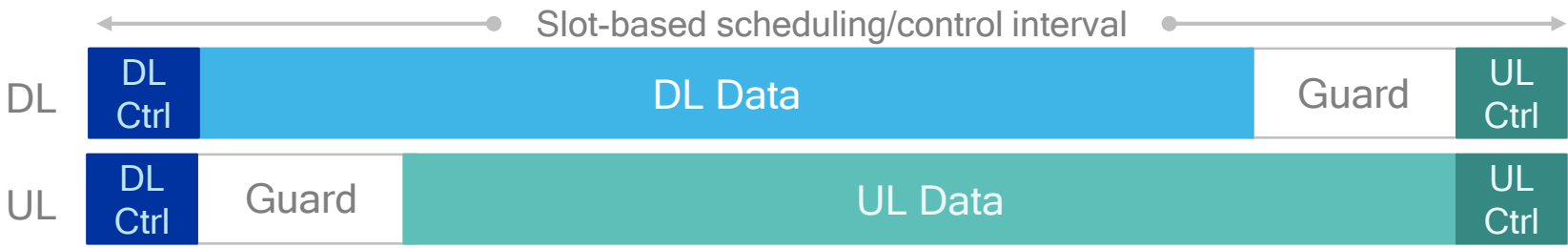
Efficient multiplexing
of long and short
transmissions²

1. As low as two symbols per mini-slot; 2. Symbols across numerologies align at symbol boundaries and transmissions span an integer # of OFDM symbols

Flexible 5G NR slot structures possible—examples

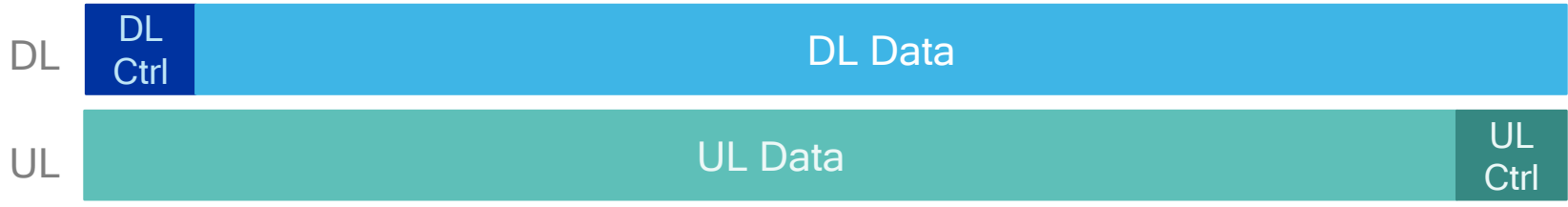
TDD Self-Contained

Opportunity for UL/DL scheduling, data and ACK/SRS in the same slot



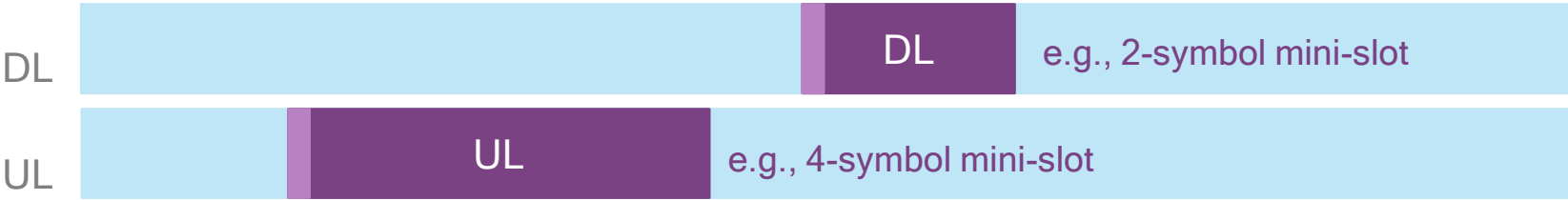
Data-centric

More relaxed TDD timing configurations + FDD operation



Mini-slot

Optimized for shorter data transmissions, e.g. URLLC



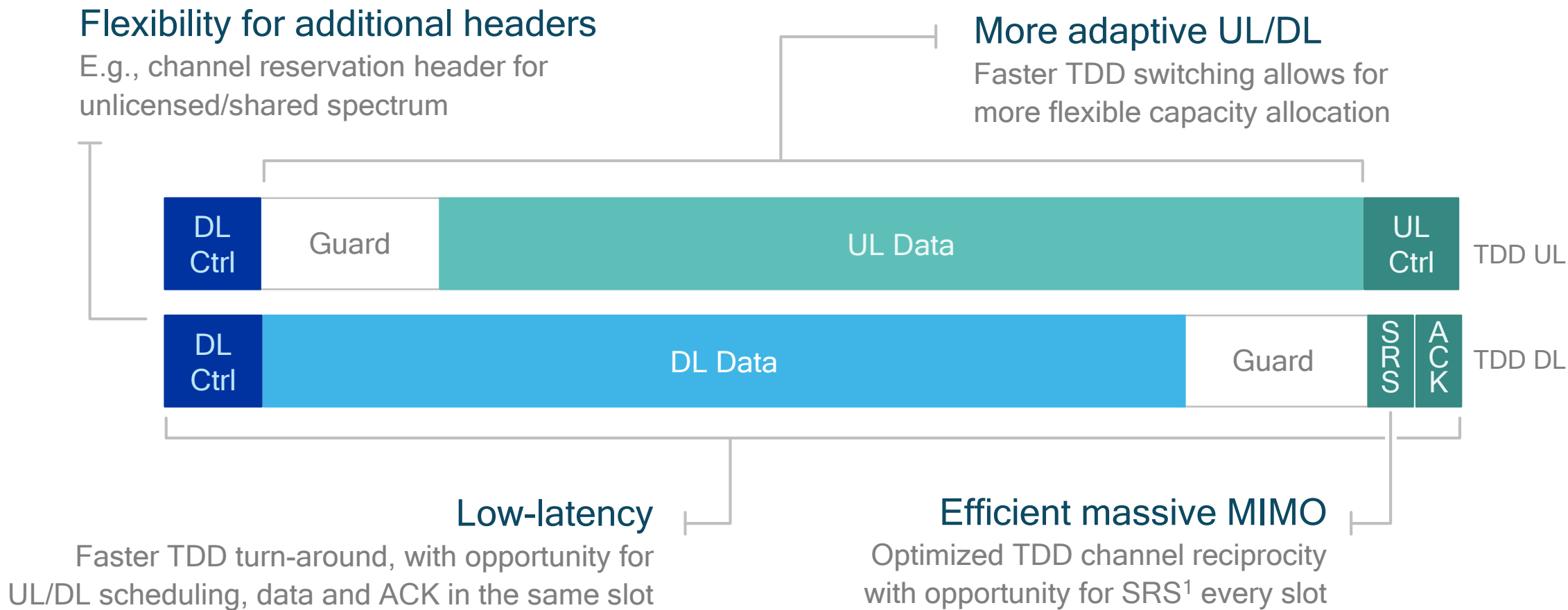
Blank slot

Designed in a way not to limit future feature introductions



Benefits of the 5G NR TDD self-contained slot

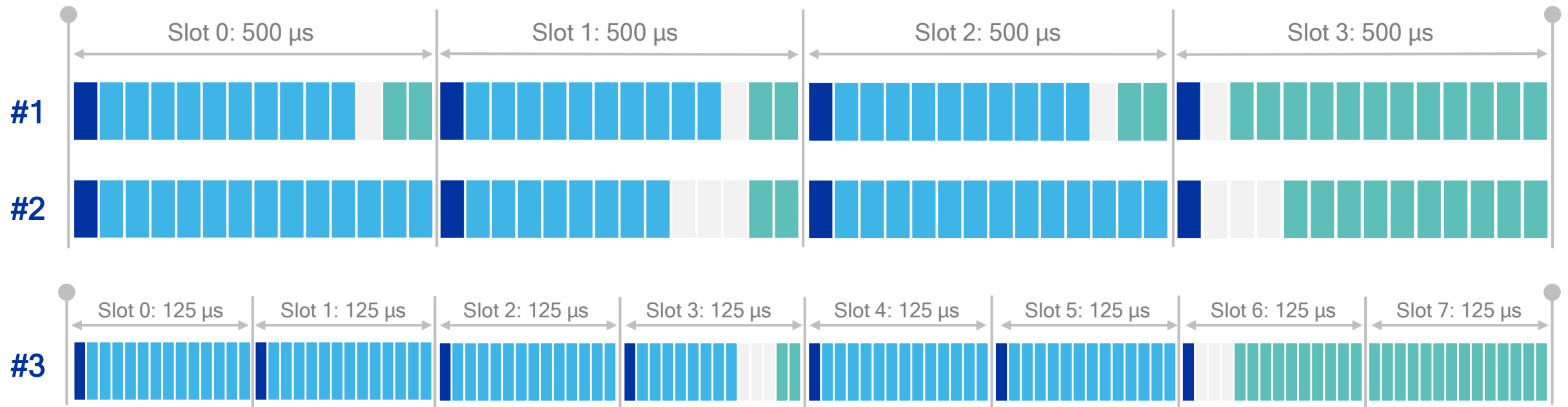
Much faster, more flexible TDD switching and turn around than 4G LTE



5G NR TDD self-contained slot structure in action

Three examples showcasing faster TDD switching for low latency

■ DL Ctrl
■ DL Data
■ UL



#1: Indoor (sub-6 or mmWave)

- Shorter guard for indoor deployment
- Fast turnaround (DL/UL switch per slot)
- Ultra-low latency possible on every slot
- Maximum flexibility for UL/DL allocation

#2: Outdoor (sub-6 or mmWave)

- Larger guard for outdoor deployment
- DL/UL switch per 1ms (5x faster than LTE)
- Slot 1 opportunity for ultra-low latency
- Bulk of UL traffic goes on Slot 3

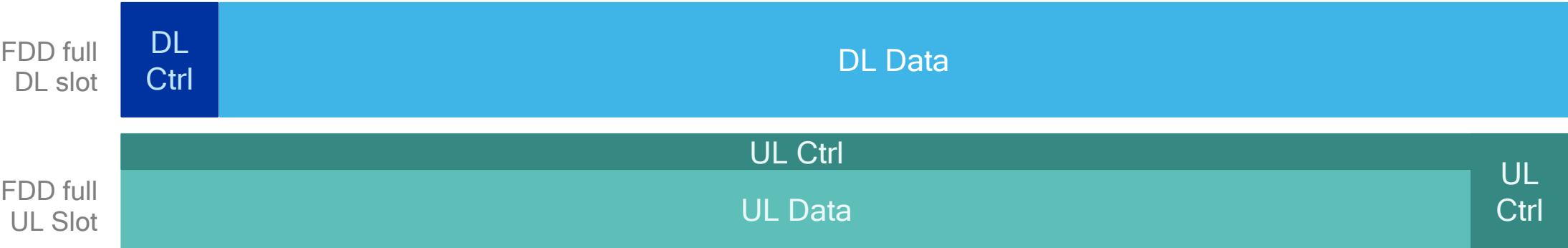
#3: Outdoor mmWave

- Larger guard for outdoor deployment
- 6:2 configuration every 1ms (120kHz SCS)
- Slot 3 opportunity for ultra-low latency
- Bulk of UL traffic goes on Slots 6 & 7

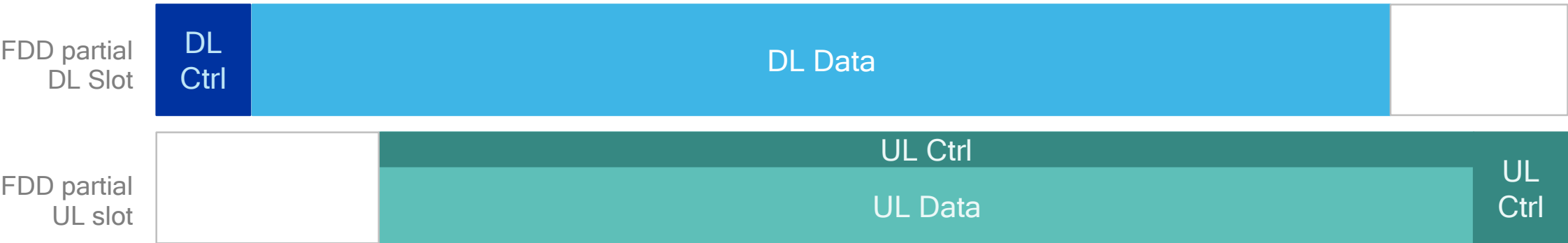
5G NR flexible FDD slot structure

Delivering low latency, extended coverage, and forward compatibility

FDD baseline for continuous transmission and extended coverage

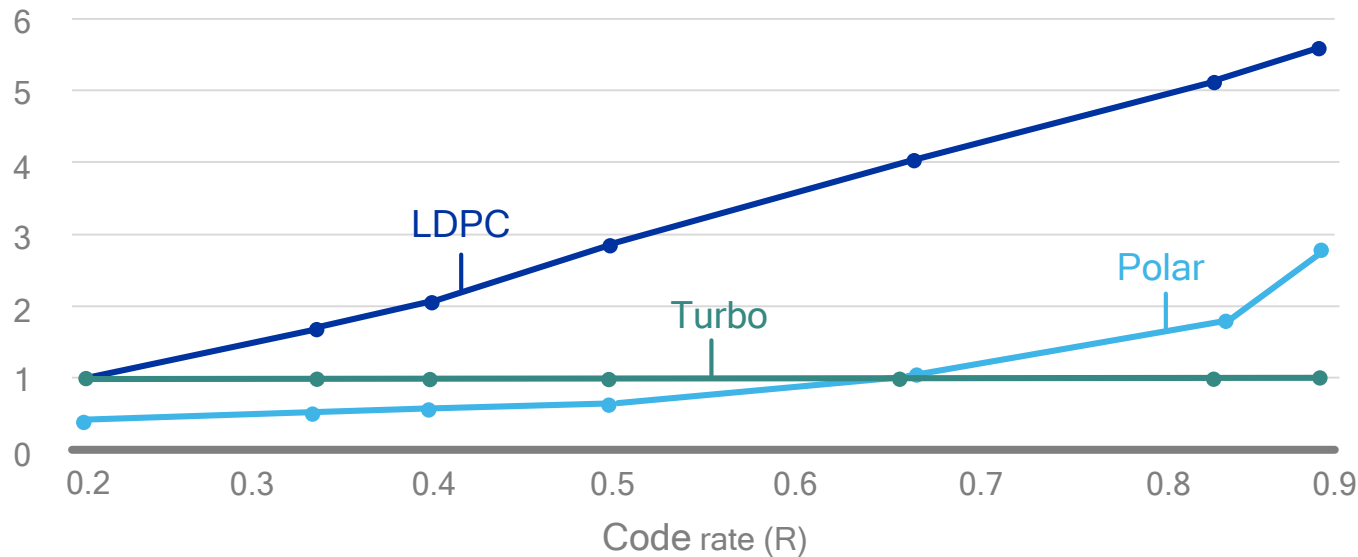


FDD partial slot for faster DL/UL turn-around and efficient half-duplex FDD implementation



Advanced ME-LDPC¹ channel coding is more efficient than LTE Turbo code at higher data rates

Normalized throughput (for given clock rate)



High efficiency

Significant gains over LTE Turbo—particularly for large block sizes suitable for MBB

Low complexity

Easily parallelizable decoder scales to achieve high throughput at low complexity

Low latency

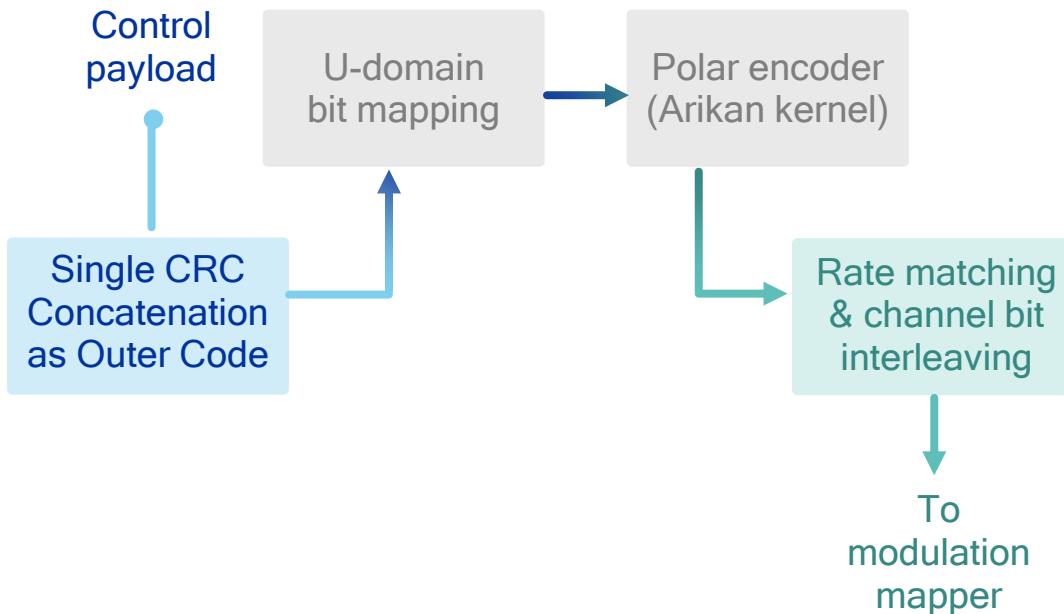
Efficient encoding/decoding enables shorter transmission time at high throughput

Selected as 5G NR eMBB data channel as part of 3GPP Release-15

Performance gains of CRC-Aided Polar channel coding led to its adoption across many 5G NR control use cases

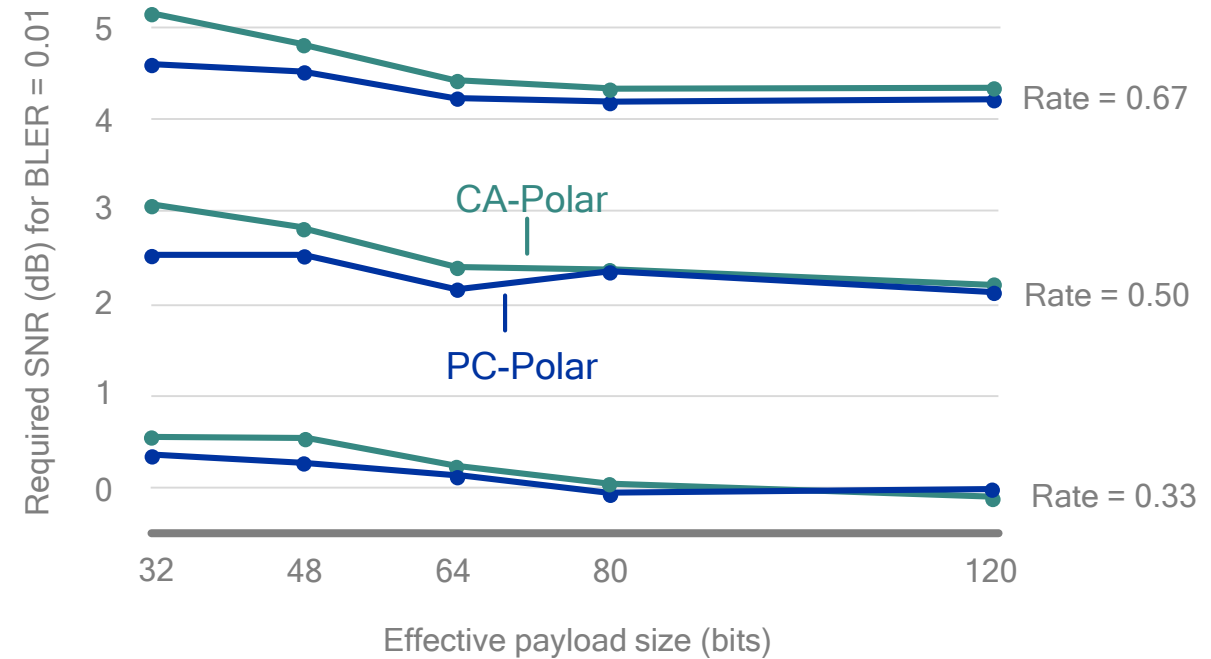
5G NR CRC-Aided (CA-Polar) design

Efficient construction based on single Cyclic Redundancy Check (CRC) for joint detection and decoding



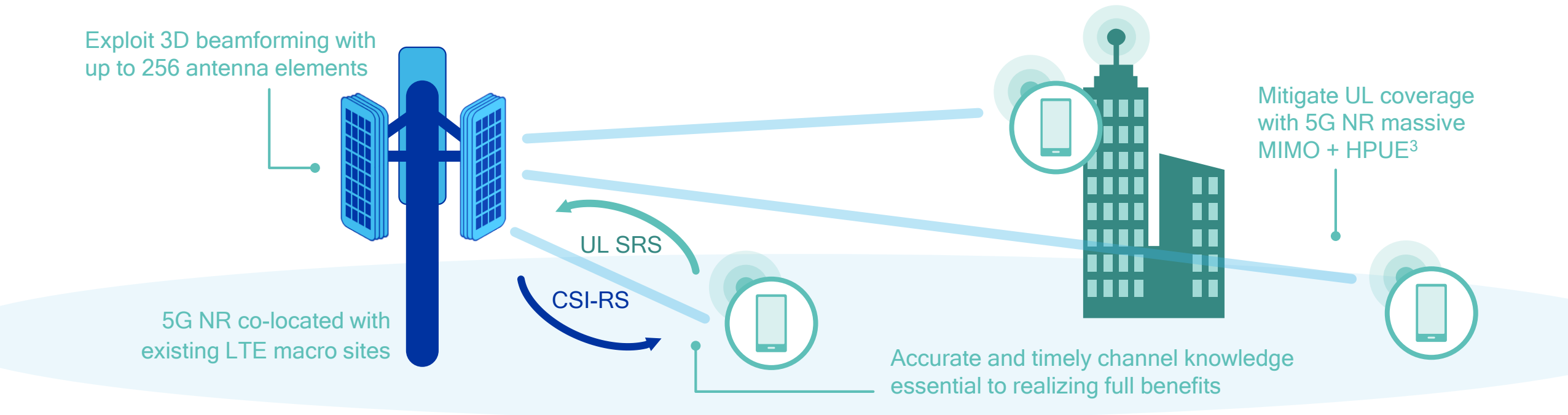
Link-level gains of 5G NR CA-Polar design

Versus PC-Polar¹ (lower is better)



5G NR optimized design for massive MIMO

Key enabler for using higher spectrum bands, e.g. 4 GHz, with existing LTE sites



— Enabled through an advanced 5G NR end-to-end Massive MIMO design (network and device) —

Optimized design for TDD reciprocity procedures utilizing UL SRS¹

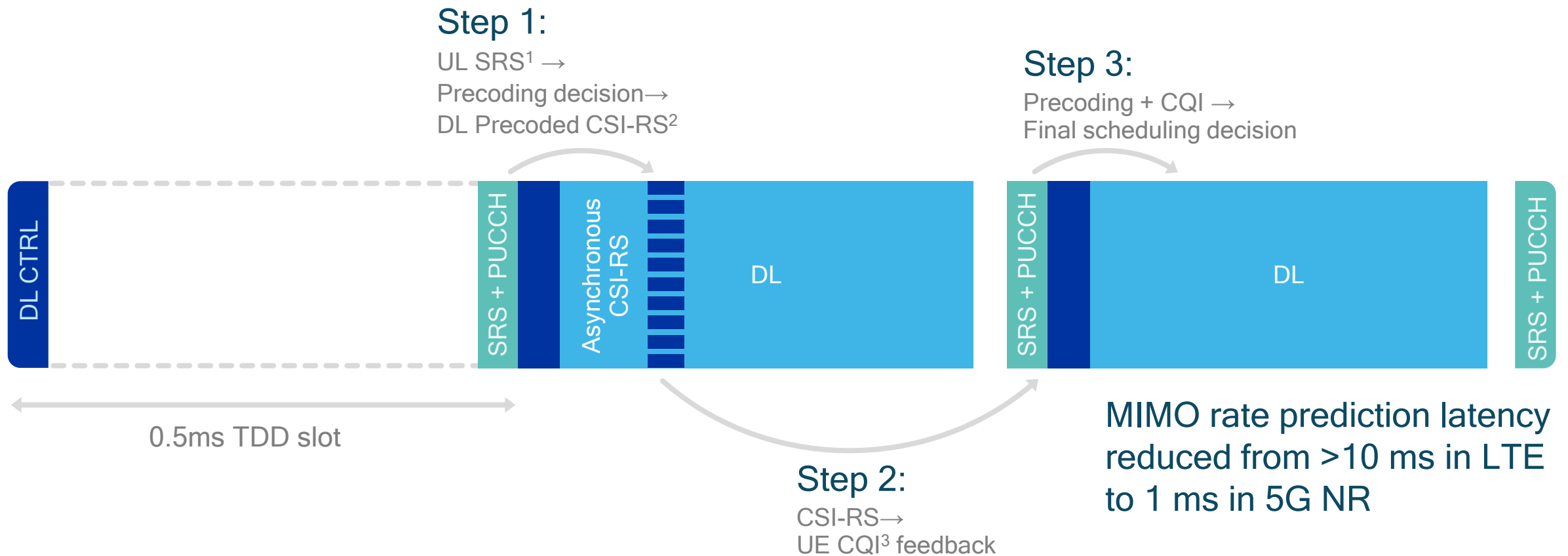
Enhanced CSI-RS² design and reporting mechanism

Advanced, high-spatial resolution codebook supporting up to 256 antennas

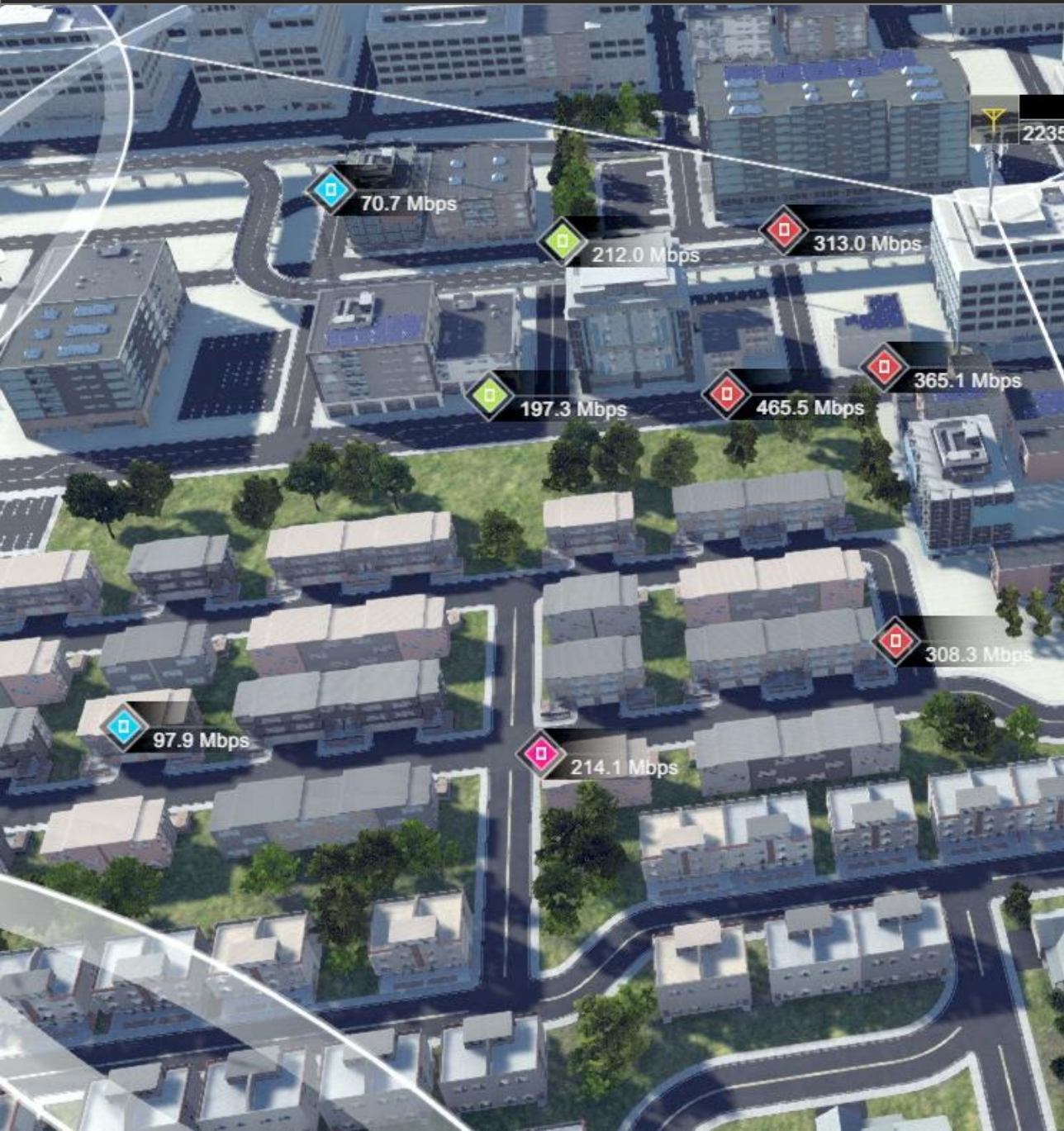
New features, such as distributed MIMO

5G NR optimized design for TDD reciprocity procedures

Self-contained slot structure & enhanced Ref Signals enable fast/accurate feedback

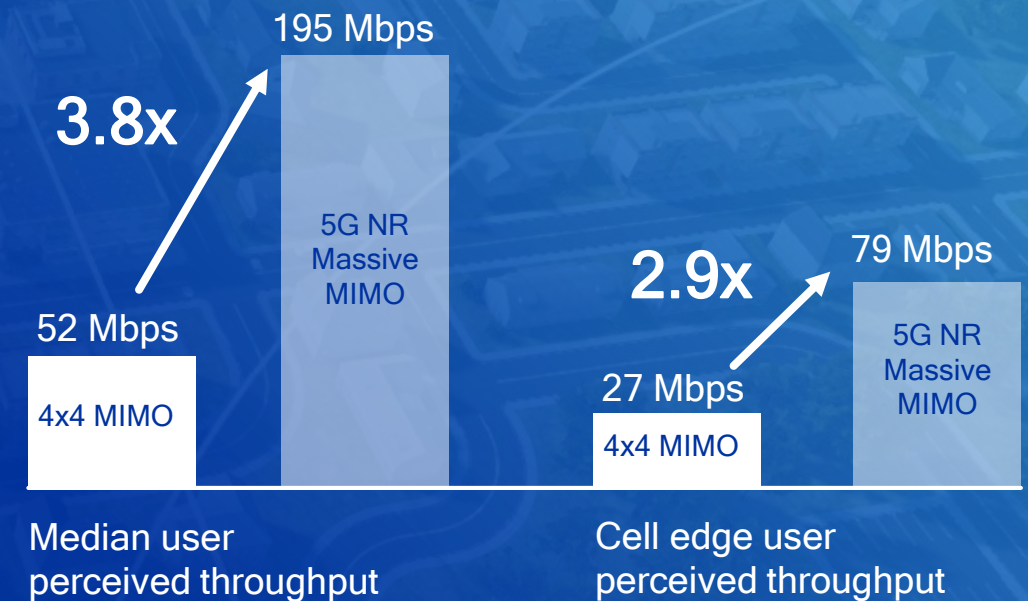


*Sub 6 GHz, macro cell numerology, 30 kHz tone spacing; Channel sounding opportunity increases from ≤ 200 Hz with LTE to 2 kHz with 5G NR. 1. Sounding Reference Signal. 2. Channel State Information Reference Signal. 3. Channel Quality Indicator



5G NR massive MIMO increases coverage & capacity

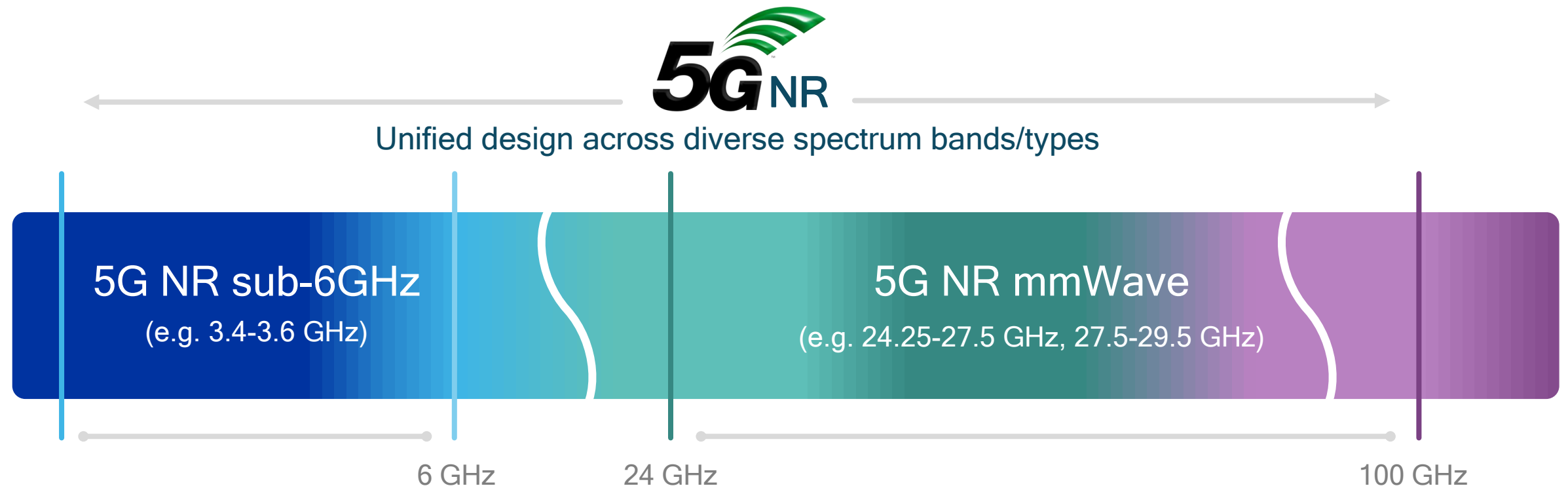
Faster, more uniform data rates throughout cell



Assumptions: carrier frequency 4GHz; 200m ISD, 200MHz total bandwidth; base station: 256 antenna elements (x-pol), 48dBm Tx power; UE: 4 Tx/Rx antenna elements, 23dBm max. Tx power; full buffer traffic model, 80% indoor and 20% outdoor UEs.

The large bandwidth opportunity for mmWave

The new frontier of mobile broadband



Multi-Gbps data rates

With large bandwidths (100s of MHz)

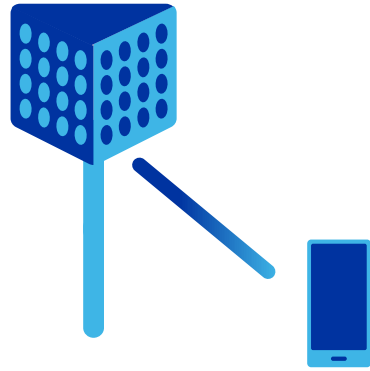
Much more capacity

With dense spatial reuse

Flexible deployments

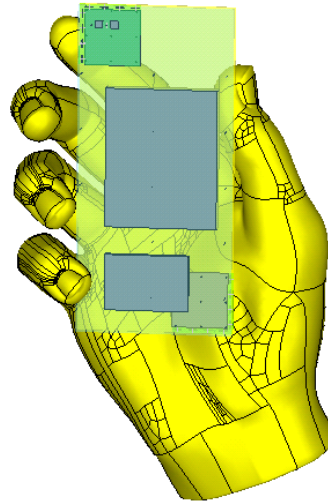
Opens up new opportunities

Overcoming numerous challenges to mobilize mmWave



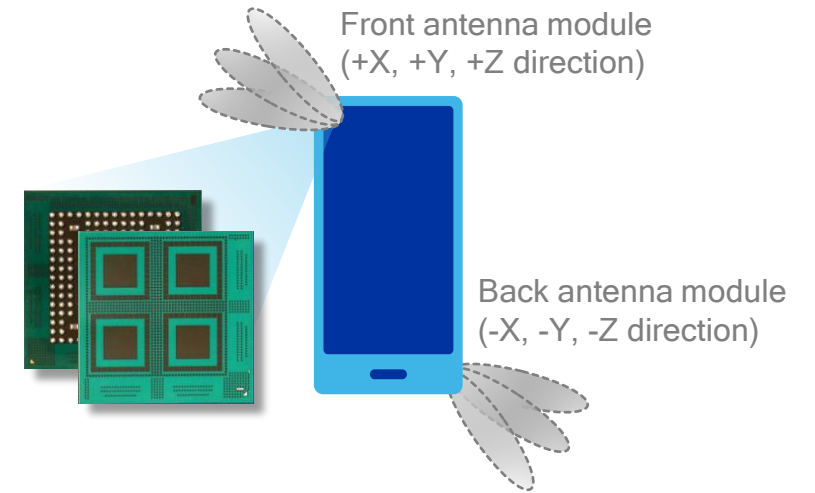
Coverage

Innovations to overcome significant path loss in bands above 24 GHz



Robustness

Innovations to overcome mmWave blockage from hand, body, walls, foliage, etc.

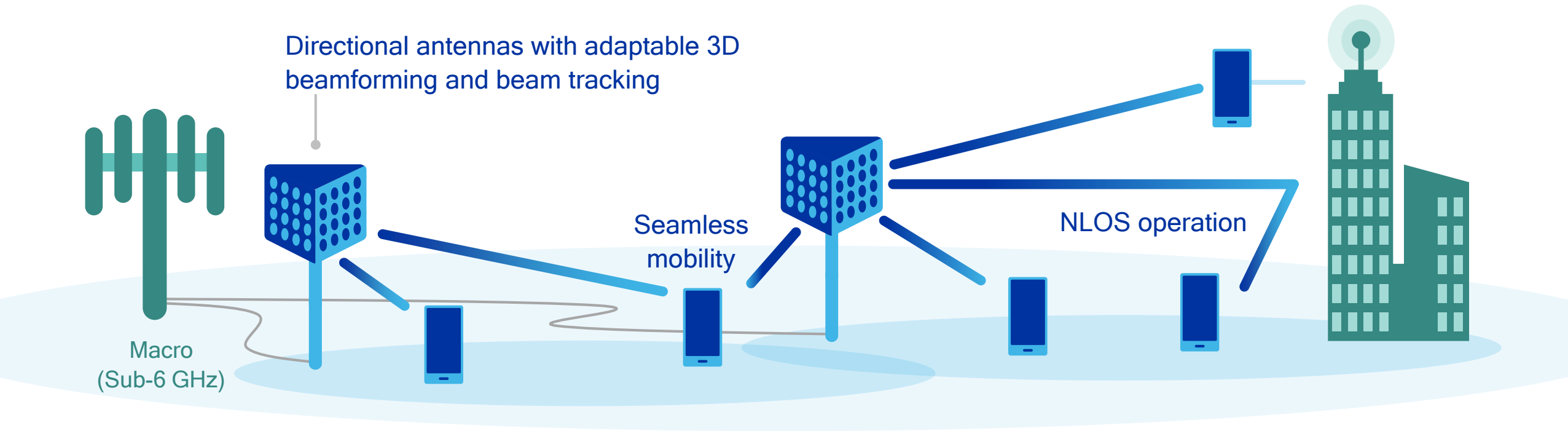


Device size/power

Innovations to fit mmWave design in smartphone form factor and thermal constraints

Mobilizing mmWave with 5G NR technologies

Key properties for robust mmWave operation in a NLOS mobile environment



Very dense network topology and spatial reuse (~150-200m ISD)

Fast beam steering & switching within/across access points

Tight integration with sub-6 GHz (LTE or NR)

Significant 5G NR mmWave coverage via co-siting

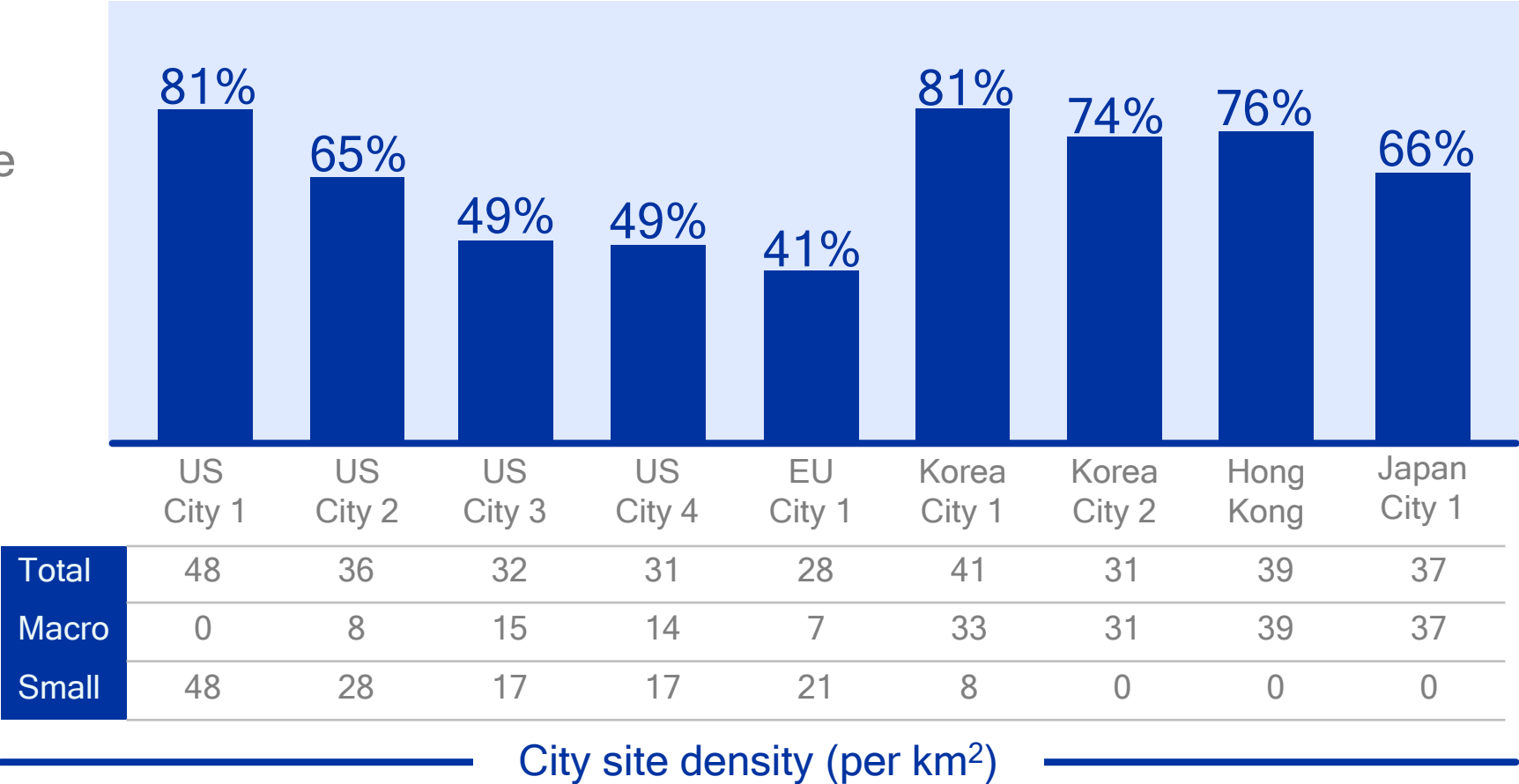
Qualcomm Research simulations based on extensive testing and measurements

28 GHz

outdoor downlink coverage
% co-siting with LTE

Frees up sub-6 GHz
resources for out-to-indoor
capacity (5G NR or LTE)

Outdoor coverage can be
complemented with targeted
indoor deployments



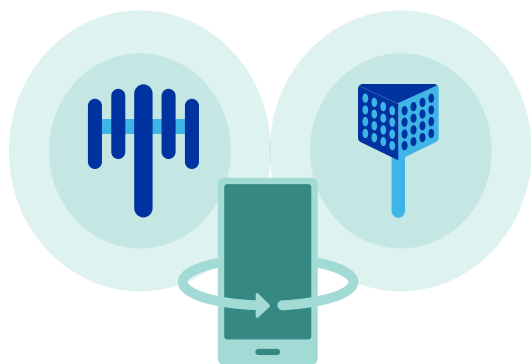
Learn more at: www.qualcomm.com/invention/technologies/5g-nr/mmwave

The essential role of spectrum aggregation and LTE in 5G NR deployments

3GPP Release 15



Spectrum aggregation essential to 5G NR deployments



Carrier Aggregation (CA) and Dual Connectivity enable deployments with tightly and loosely coordinated cells

Dual Connectivity across LTE and NR

Fully leveraging LTE investments and coverage, including NSA operation for early 5G NR deployments

CA across spectrum bands

E.g., tight CA between 5G NR mmWave and sub-6 GHz to address mmWave coverage gaps

CA across FDD and TDD bands

Sub-1 GHz and mid/high band aggregation; supplemental uplink for better coverage, supplemental downlink for capacity

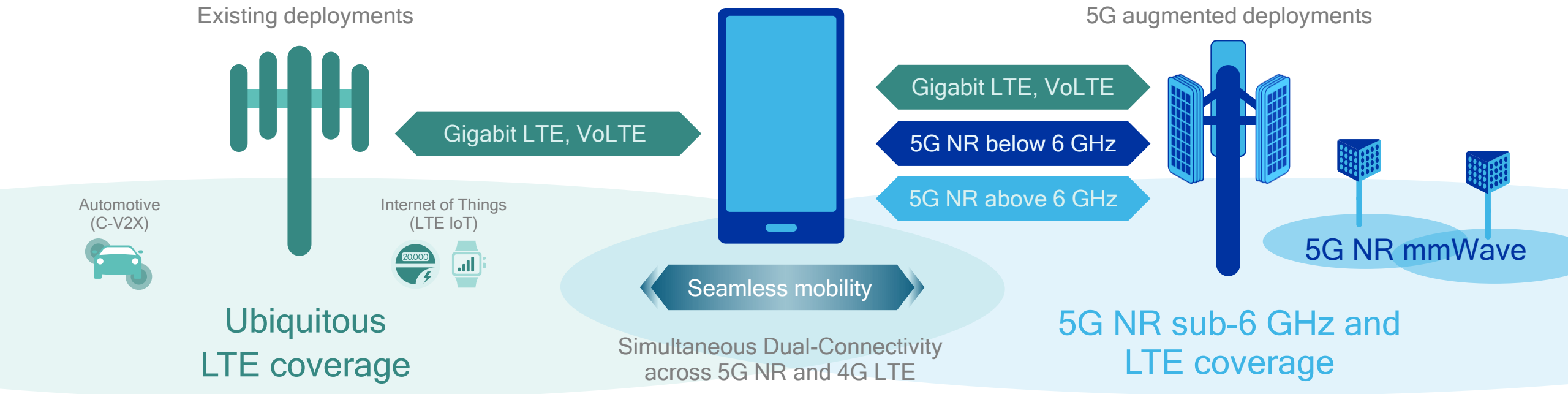
CA across spectrum types

E.g., Licensed and unlicensed with 5G NR Licensed Assisted Access (LAA) – approved Rel-15 Study Item

Building on solid LTE CA and Dual Connectivity foundation



Dual Connectivity to fully leverage LTE investments



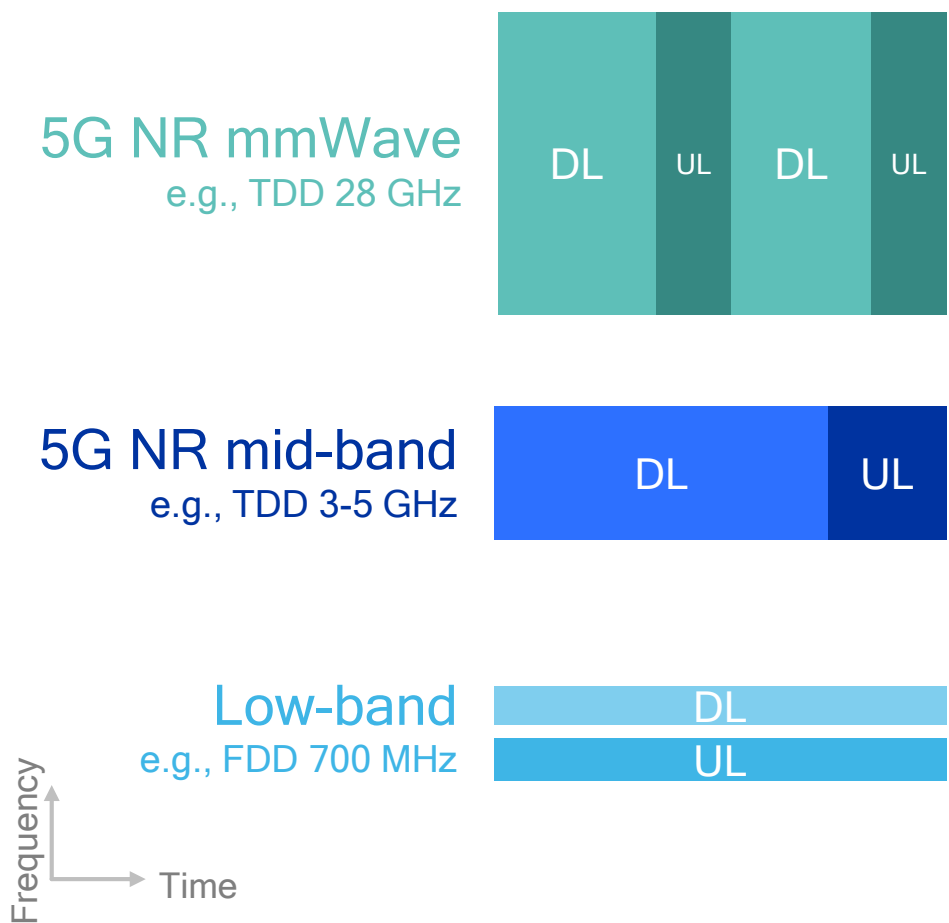
Ensures a seamless 5G eMBB experience – Gigabit LTE the anchor

Provides VoLTE services using LTE's ubiquitous coverage (500+ commercial networks)

Delivers foundation for new 5G verticals with LTE IoT, C-V2X, etc.

5G NR FDD/TDD CA to support mid-band deployments

Low-band FDD can help increase 5G NR TDD UL data rate/range¹



Non-Standalone (NSA)

Low band LTE or NR UL can help increase UL data rate/range



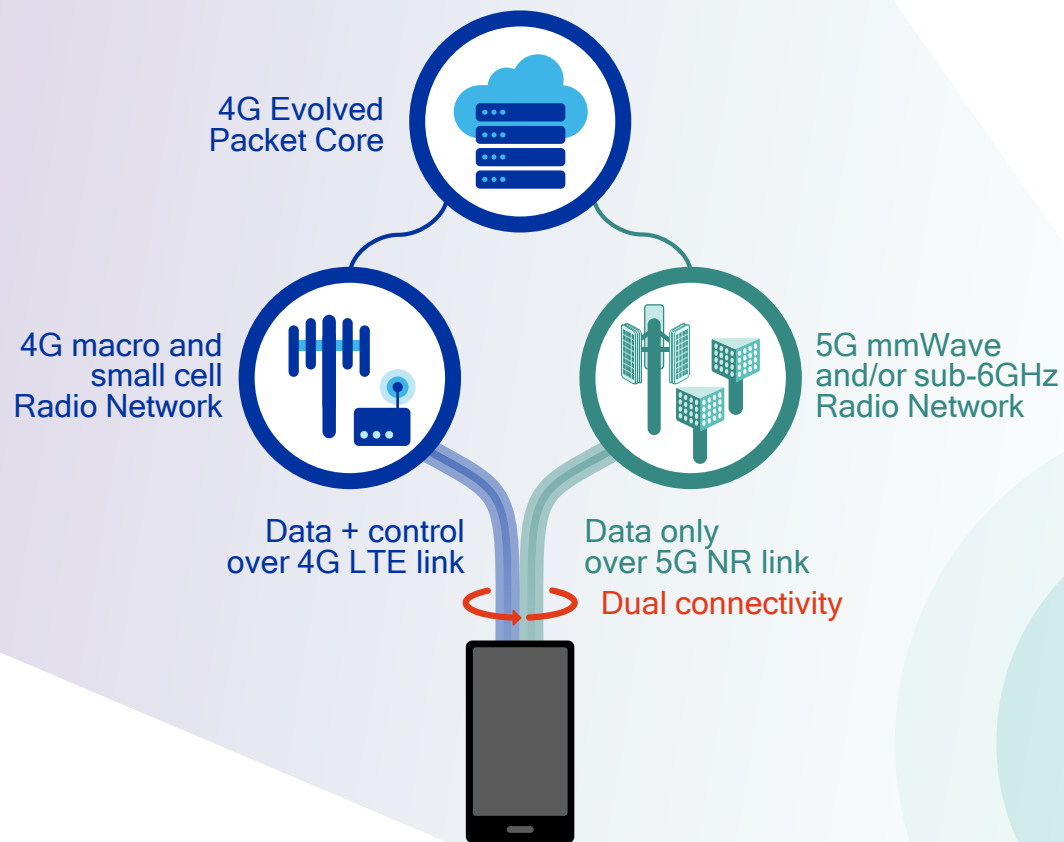
Standalone (SA)

NR low band can carry NR uplink control and data for edge cell users



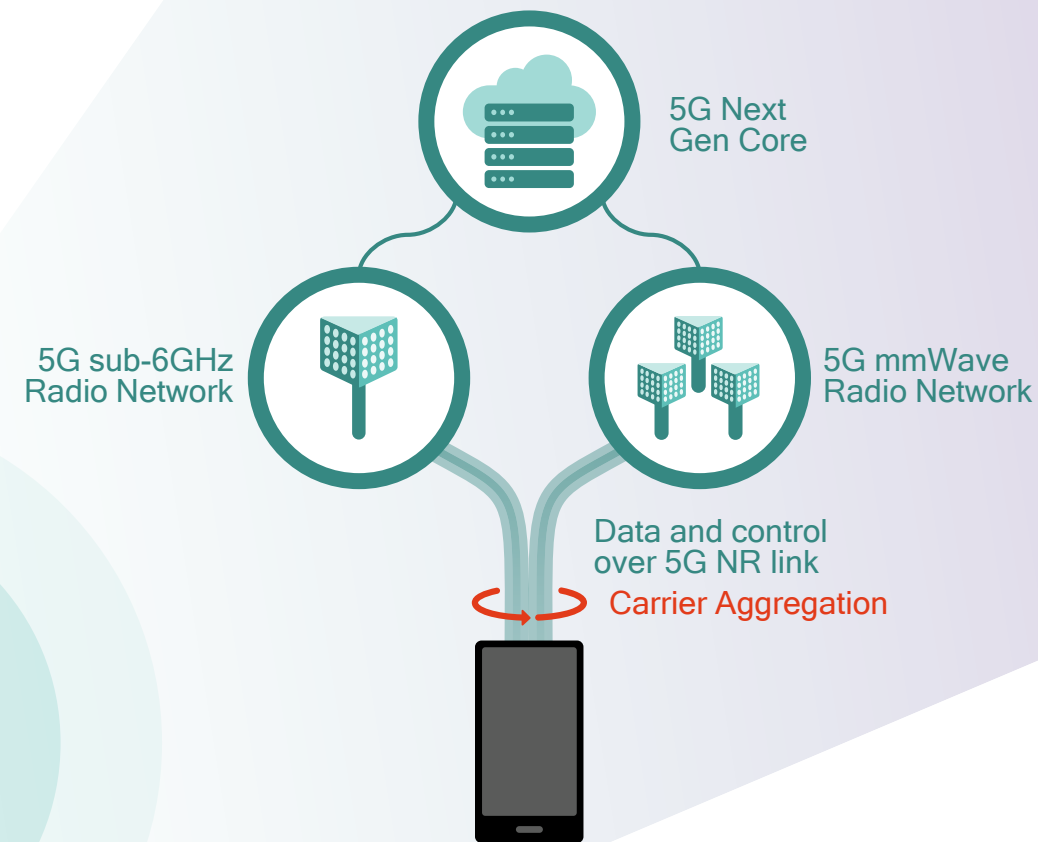
¹ Thanks to less path loss and no DL:UL split - depends on massive MIMO, site density, TDD configuration

Network architecture options for 5G NR



Non-Standalone (NSA) option

Fast-to-launch | Higher BW & UX* | VoLTE & CS voice

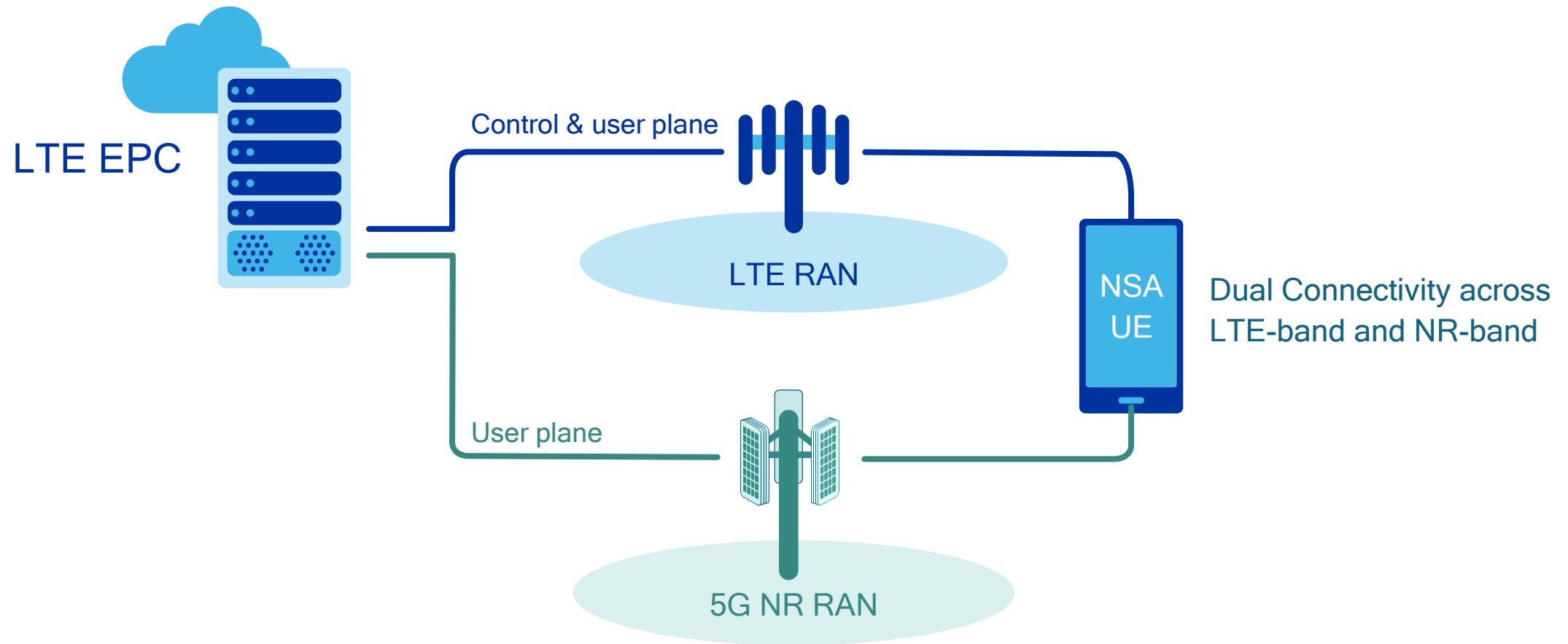


Standalone (SA) option

Network slicing | New services | VoNR & 4G fallback

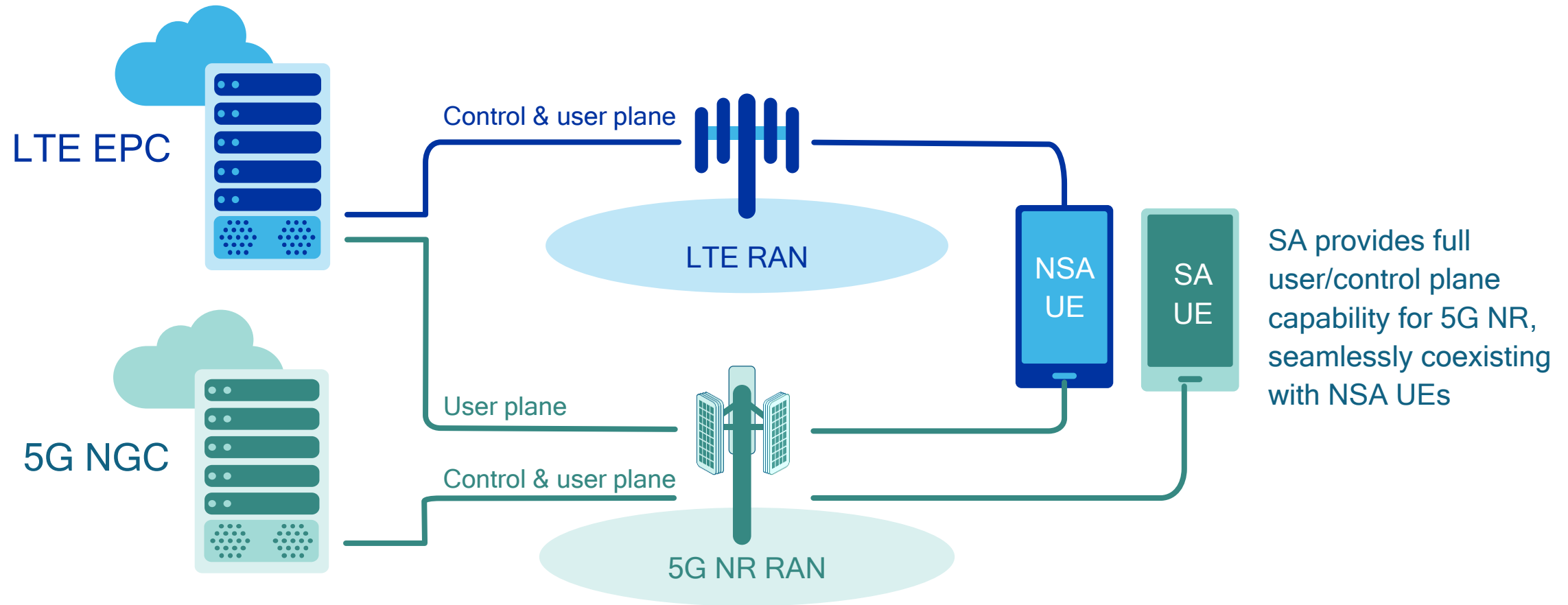


NSA 5G NR is accelerating 5G NR deployments for 2019



Non-Standalone (NSA) leverages LTE RAN and EPC for coverage and mobility
While introducing 5G NR to enhance the user plane performance and efficiency

NSA stepping stone to SA 5G NR for full 5G capability

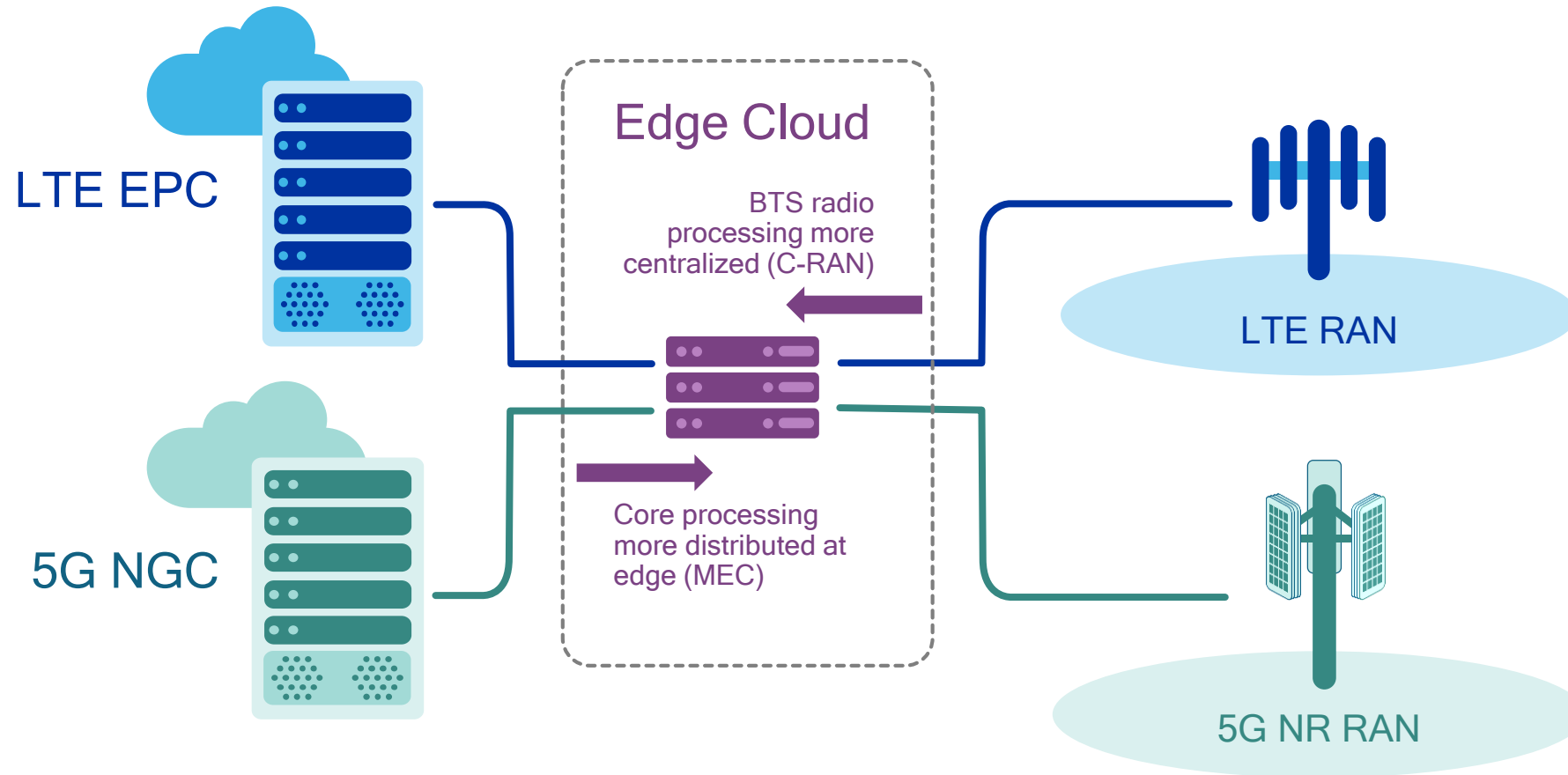


Standalone (NSA) utilizes 5G NextGen Core Network (NGC)

Leveraging SDN/NFV technologies to create optimized network slices and deliver on 5G's full potential

Ongoing network evolutions simplify NSA to SA evolution

Mitigate impact to legacy services and in-market devices while network evolves



More cloud-based RAN

Trend starting today to help minimize changes to RAN for 5G NR evolution

More edge-based computing

Key enabler to low latency services such as VR and industrial automation

Making 5G NR a commercial reality

Qualcomm, leading the world to 5G

5G

QUALCOMM®



Our system-level inventions fuel the mobile industry

Taking significant risks to start early with an end-to-end design

>46 Billion^{*}

In research and development

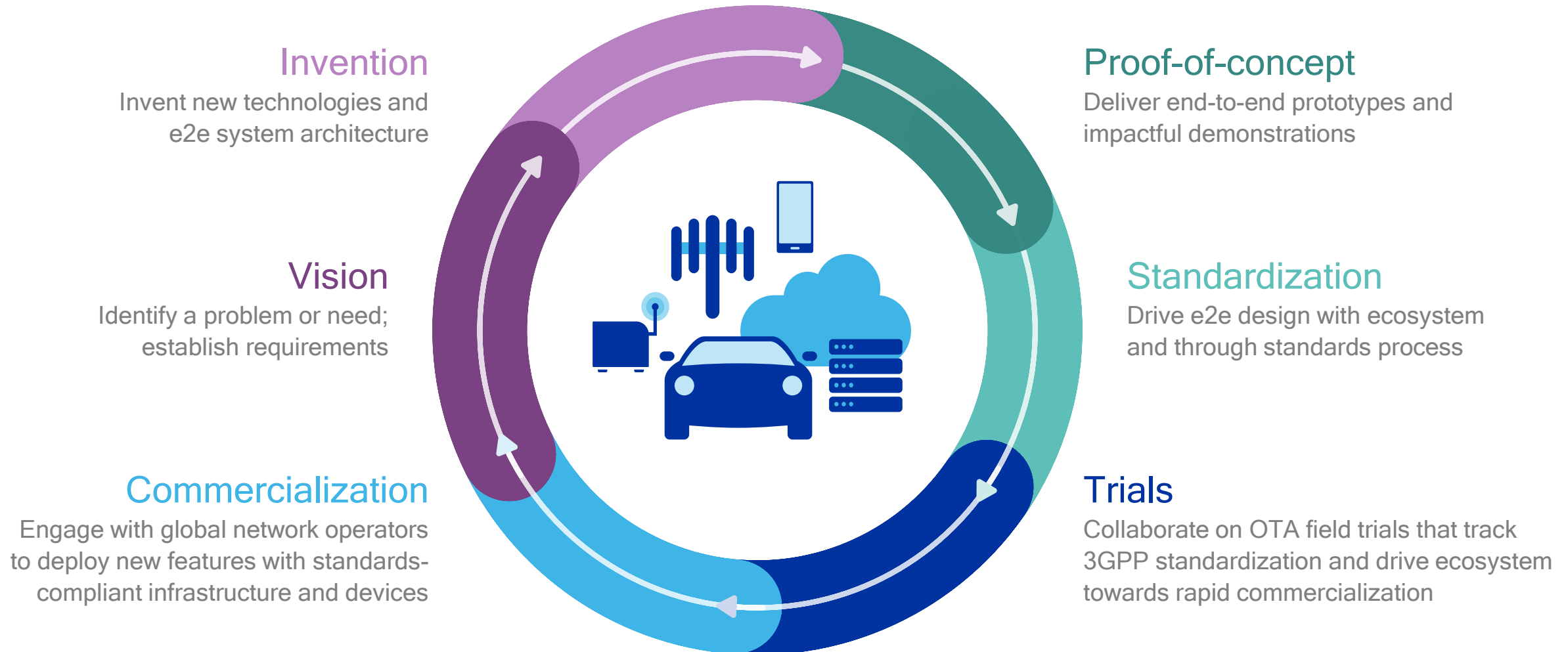
QUALCOMM[®]



*Cumulative expenditures to date since 1985

Foundation to 5G leadership is technology leadership

Early R&D and technology inventions essential to leading ecosystem forward



Qualcomm has led the evolution and expansion of LTE

Delivering fundamental systems-level inventions that are essential to 5G

Leading in 5G requires
4G LTE leadership



Carrier aggregation



Hybrid ARQ



Fast link adaptation



OFDMA, SC-FDMA waveforms



CoMP



CSFB



LTE-U/LAA/eLAA



MulteFire



Lower power consumption technologies, e.g. DTX/DRX



LTE Broadcast (eMBMS)



Small cells interference management



LWA



Handover procedure



Small cell self-configuration techniques



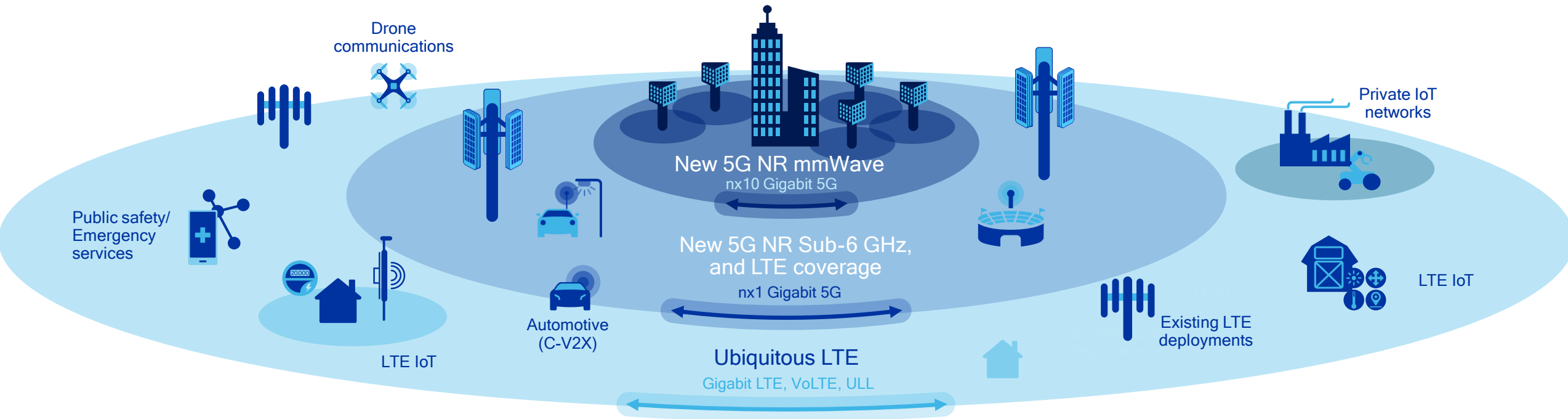
Advanced MIMO technologies, e.g. UL MIMO



LTE Direct and C-V2X

Our LTE advancements will be essential to 5G NR

Learn more at: www.qualcomm.com/lte-advanced-pro



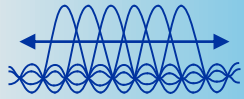
Gigabit LTE essential to a seamless 5G mobile broadband experience

LTE IoT, C-V2X, etc. are expanding the mobile ecosystem today

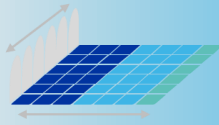
LTE will be submitted with 5G NR to meet IMT-2020 requirements¹

5G NR will fully leverage LTE investments for a phased roll-out

Our technology inventions are driving the 5G NR standard



Scalable OFDM-based air interface



Flexible slot-based framework



Advanced channel coding



Massive MIMO



Mobile mmWave



Early R&D investments and
best-in-class prototypes

First successful 5G NR
interoperable connection



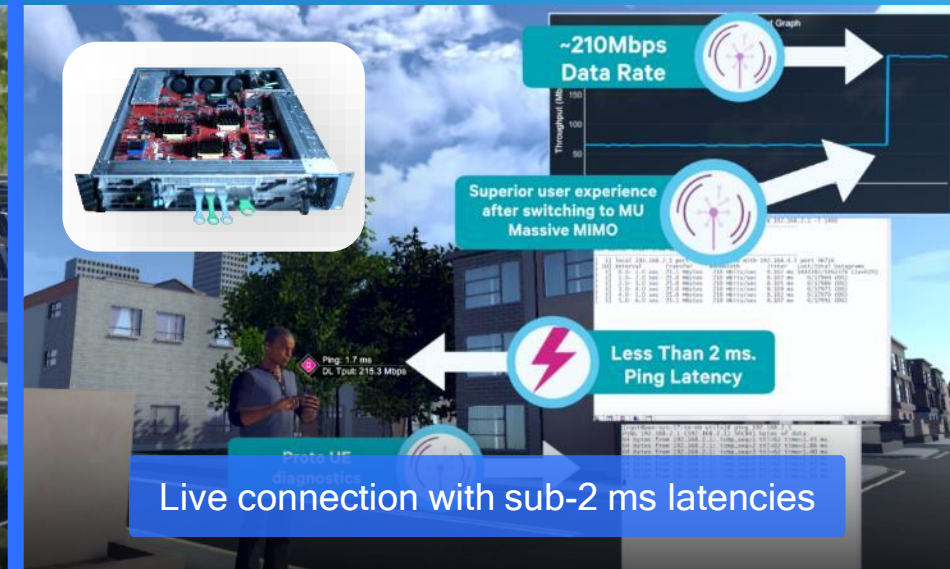
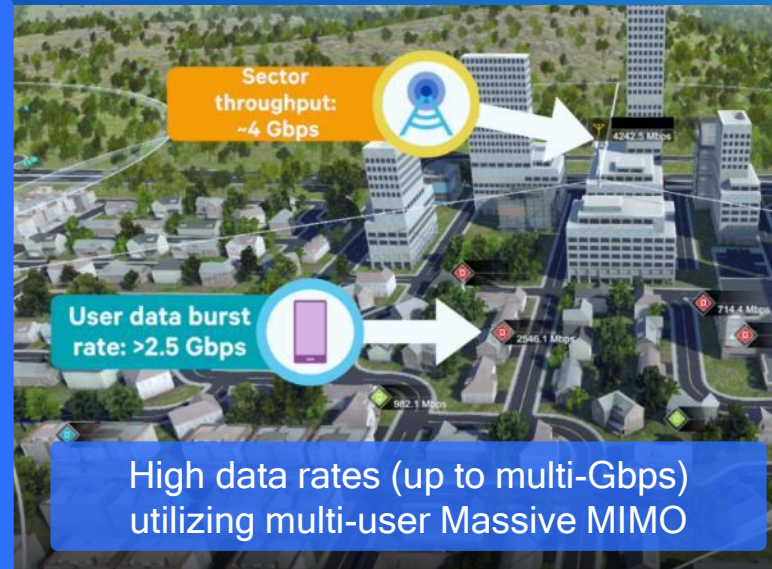
A GLOBAL INITIATIVE

Fundamental contributions
to 3GPP standardization

Technologies part of
5G NR Release-15

Qualcomm Research 5G NR Sub-6 GHz Prototype

Showcasing 5G NR technologies to achieve multi-Gbps at ultra-low latency

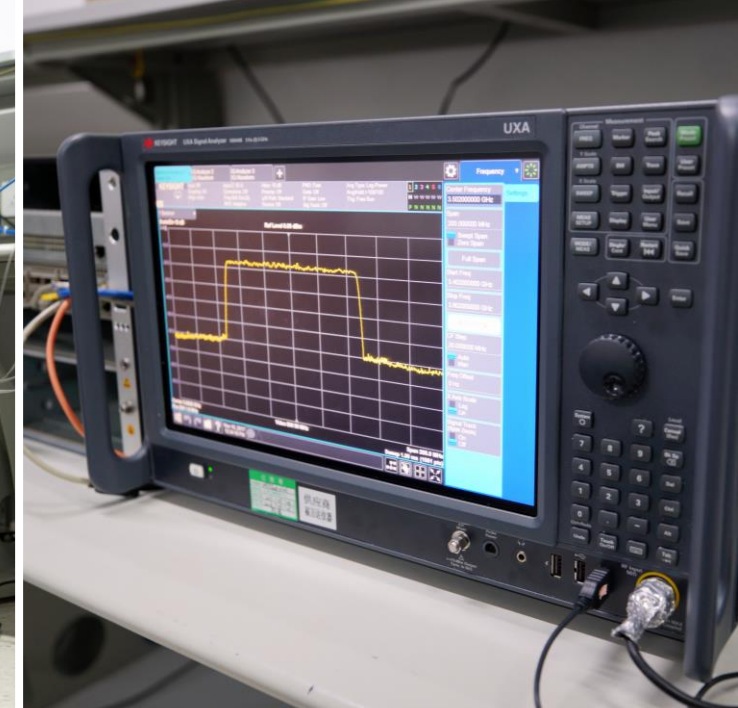
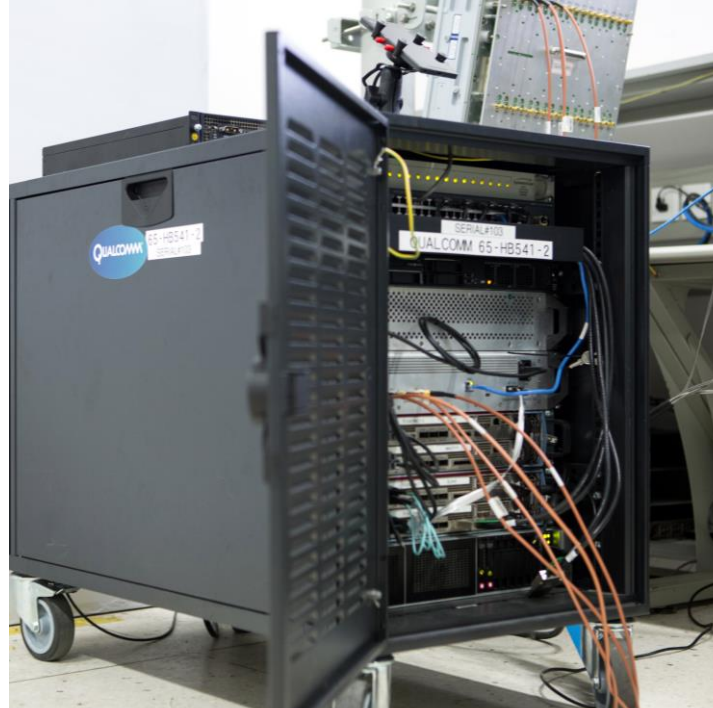


The world's first end-to-end 5G NR sub-6 GHz interoperable connection based on 3GPP standard



Compliant with the 5G NR layer 1 standard
currently being finalized by 3GPP

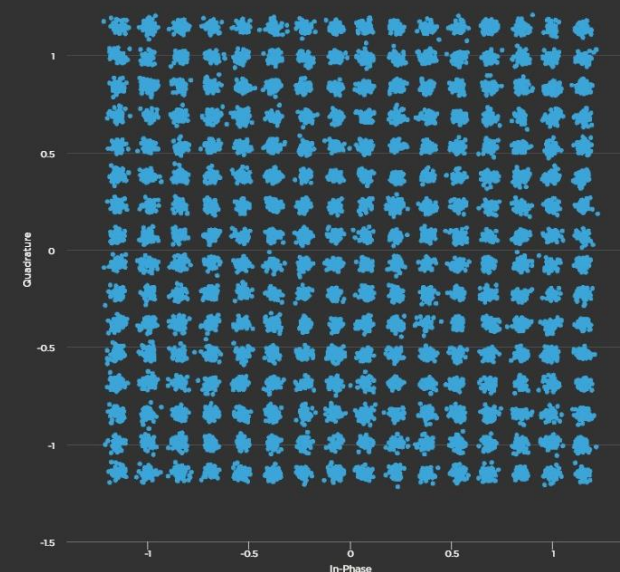
- ✓ 5G NR scalable OFDM air interface
- ✓ 5G NR low-latency slot-based framework
- ✓ 5G NR advanced channel coding
- ✓ 100 MHz bandwidth, operating at 3.5 GHz



Total Data Throughput
3GPP compliant 5G NR advanced LDPC channel coding



5G NR Data Channel
256-QAM constellation

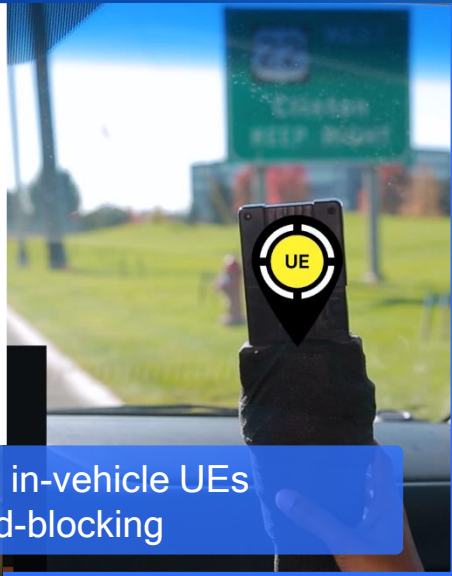


Qualcomm Research 5G mmWave prototype

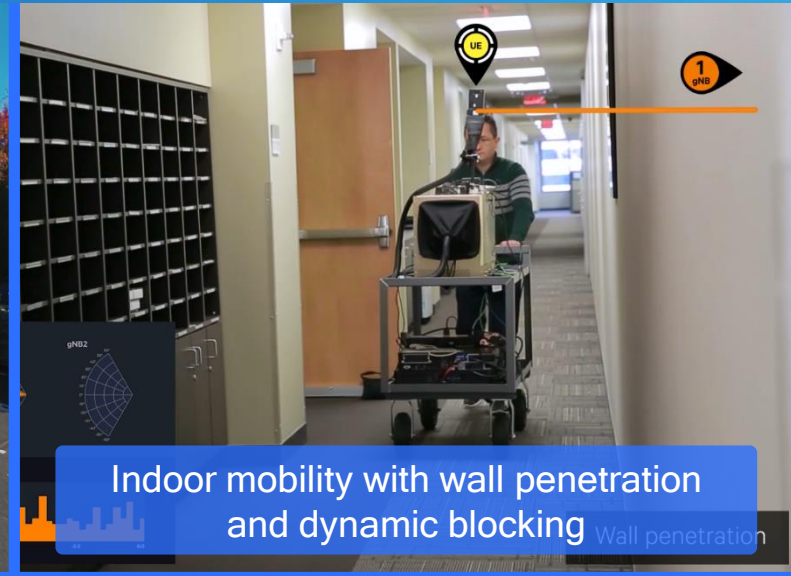
Showcasing robust mobile communications in real-world OTA testing



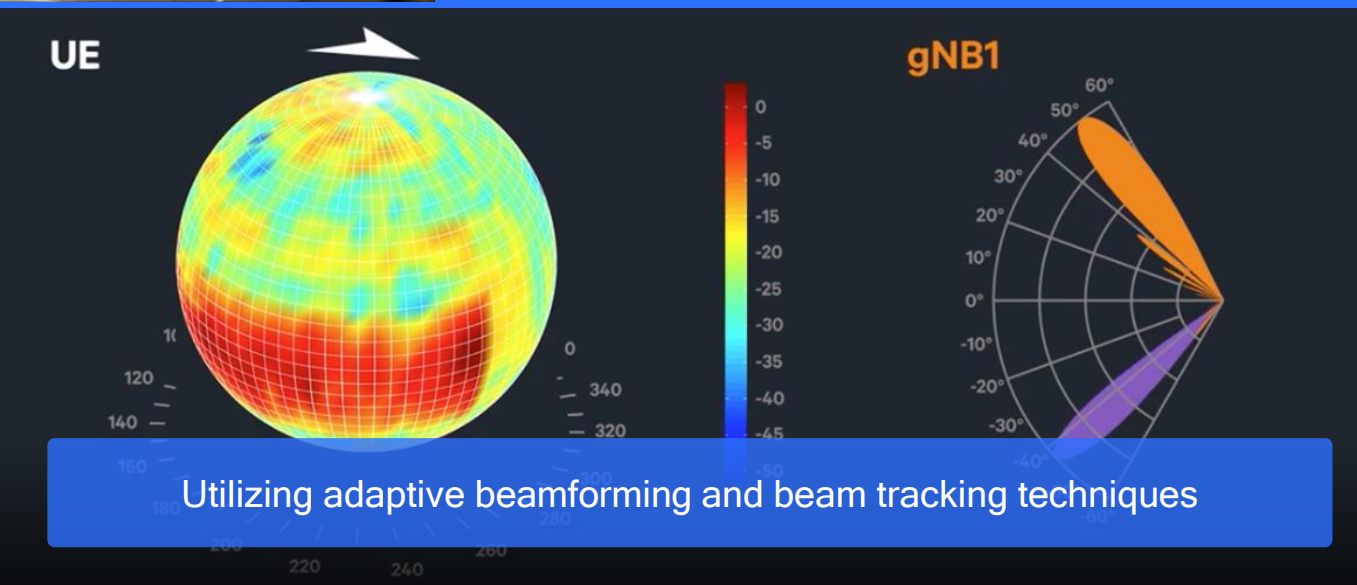
Handheld and in-vehicle UEs with hand-blocking



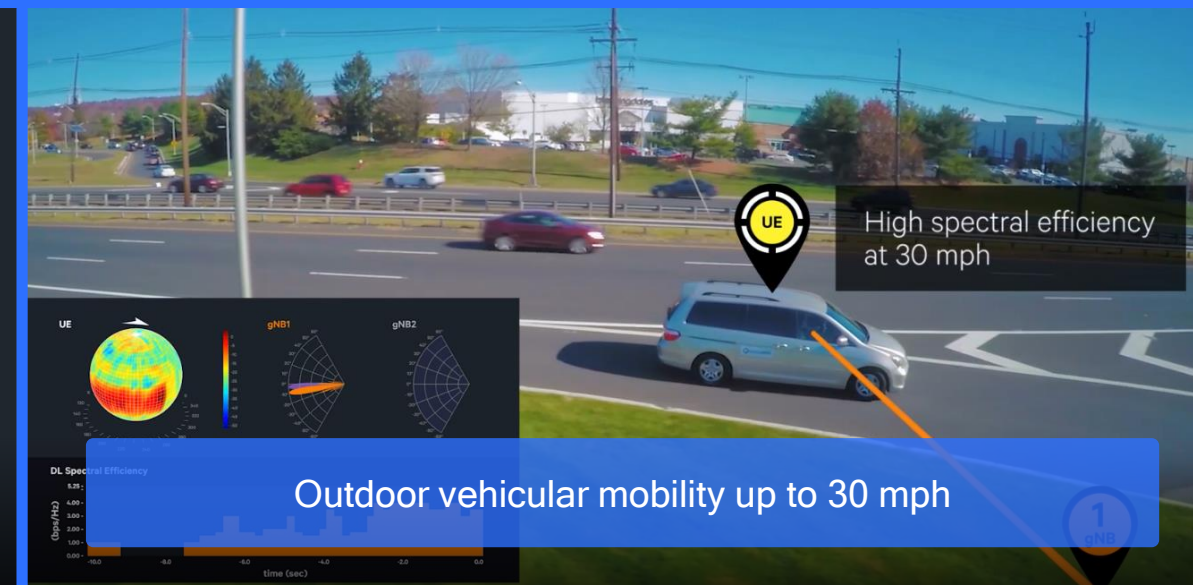
Multiple gNodeBs with seamless handovers



Indoor mobility with wall penetration and dynamic blocking



Utilizing adaptive beamforming and beam tracking techniques



Outdoor vehicular mobility up to 30 mph

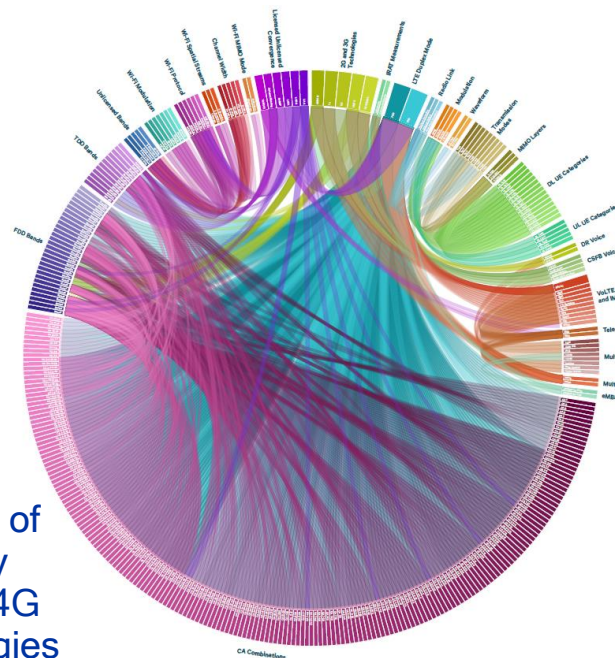
High spectral efficiency at 30 mph

Complexity of mobile systems is accelerating

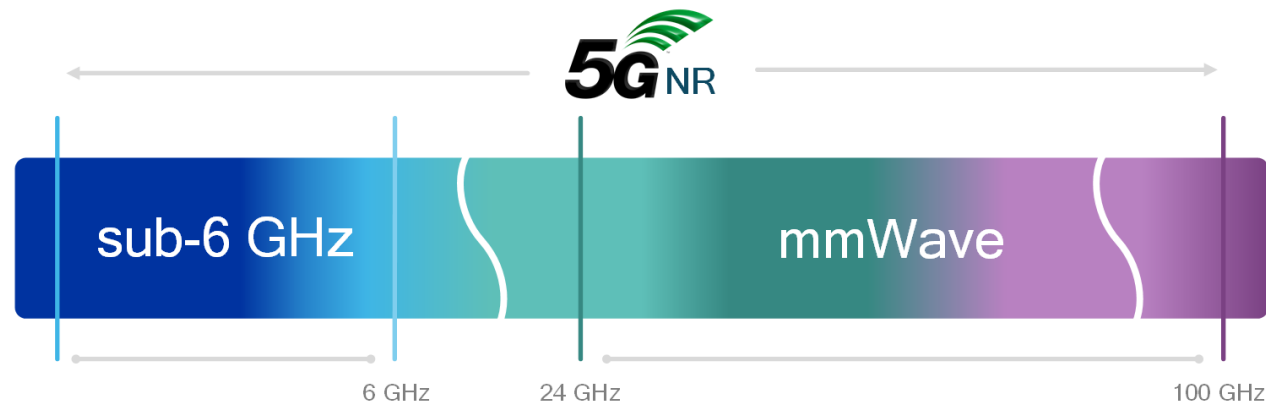
5G NR massively impacts RF front end design



Support of legacy 2G/3G/4G technologies

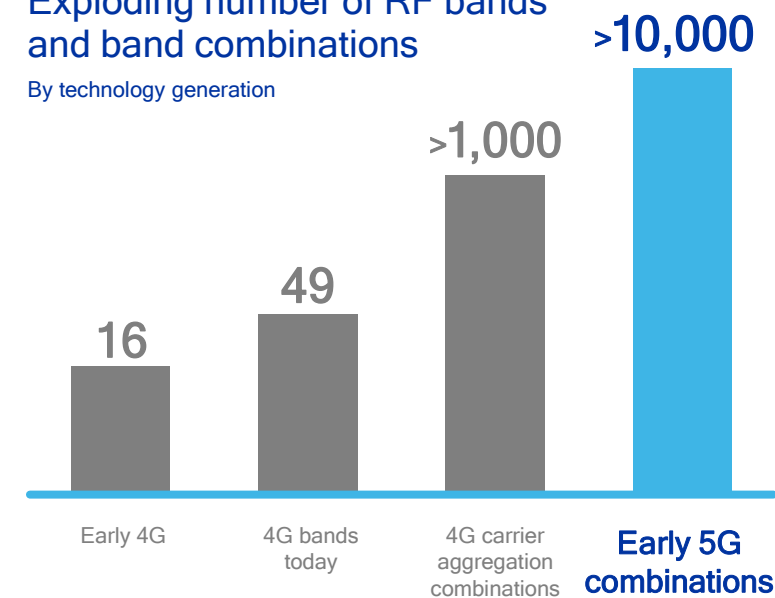


Extremely wide spectrum range

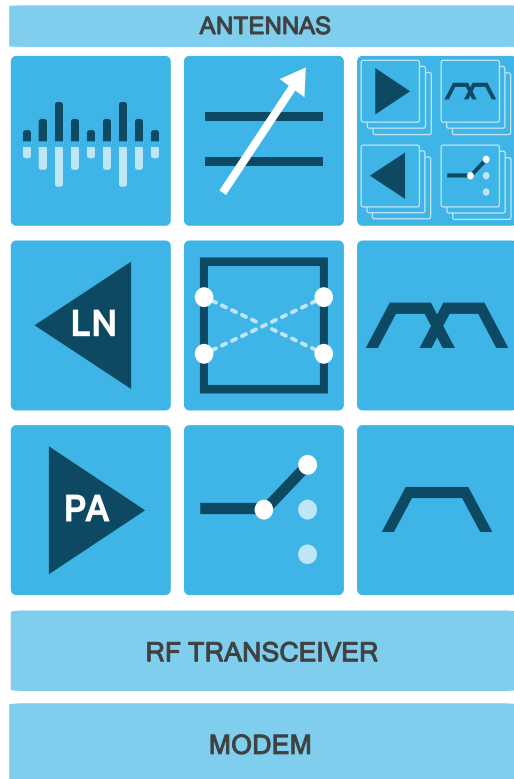
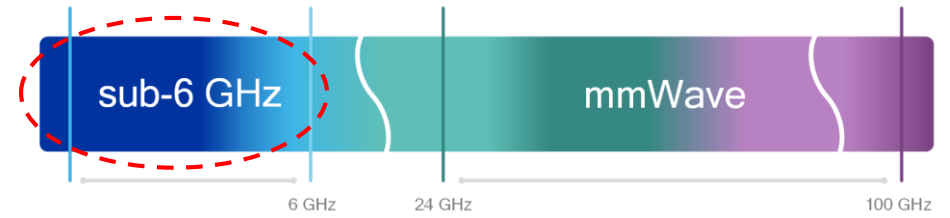


Exploding number of RF bands and band combinations

By technology generation



Qualcomm® RF Front End evolution



Frequency Bands

More aggregated carriers*
Adding cellular >3.5 GHz
and below 700 MHz
Up to 100 MHz BW

Antennas

Wider bandwidths*
Wider frequency range*
Antenna sharing with
Wi-Fi, GPS
Antenna tuning
optimization

Power efficiency

High Tx power
High peak-to-avg
power ratio
Wider-band ET*

Antenna tuning and power tracking key to achieving NR requirements

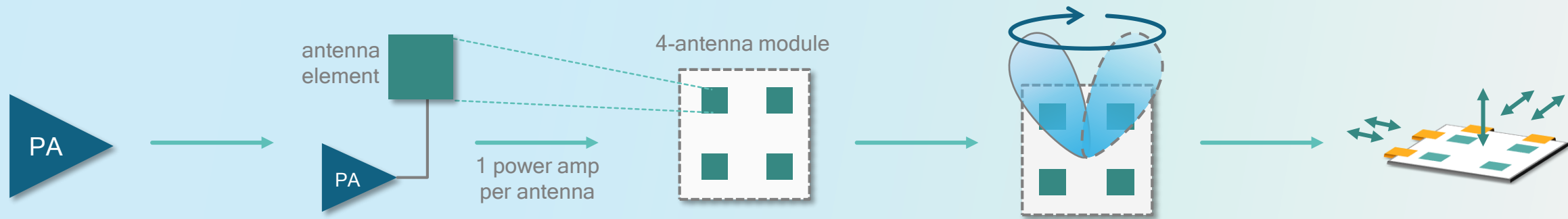
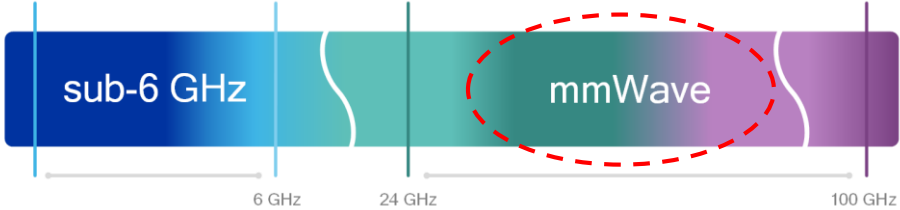
RFFE
capabilities

RFFE
enhancements

*As compared to current commercially available solution

Realizing 5G mmWave in mobile devices

Achieving coverage, power efficiency and size



Power amp output + Antenna element gain + Power summation gain + Beamforming gain + Single polarization

Physics dictates antenna size and spacing

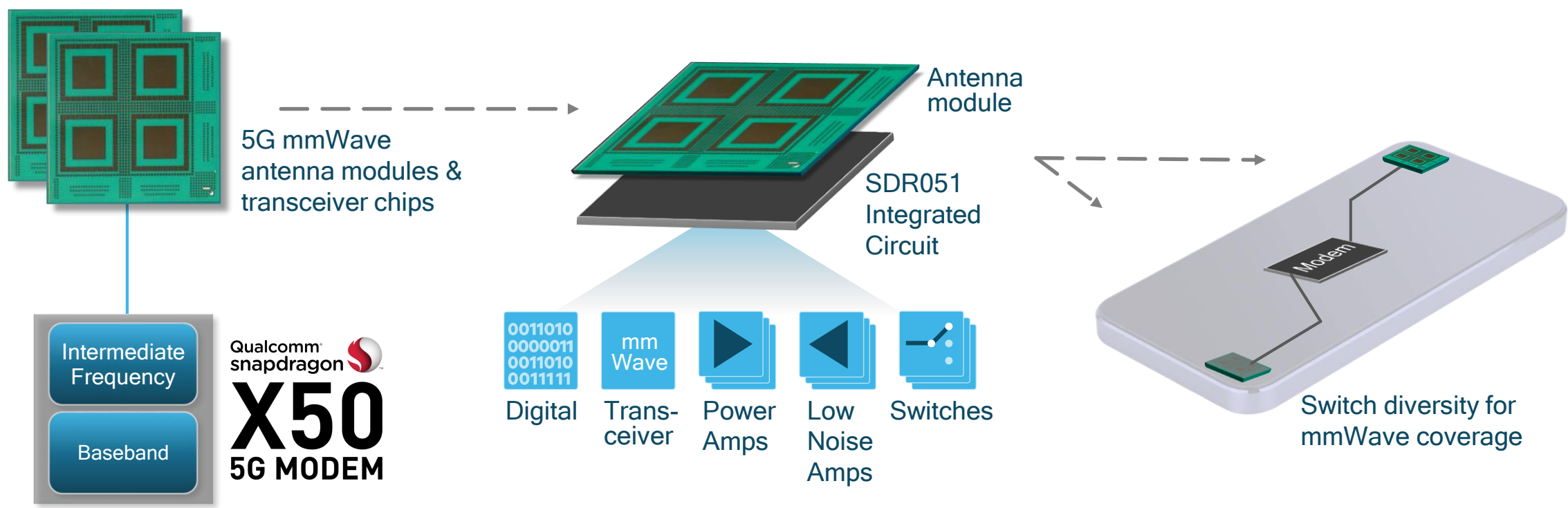
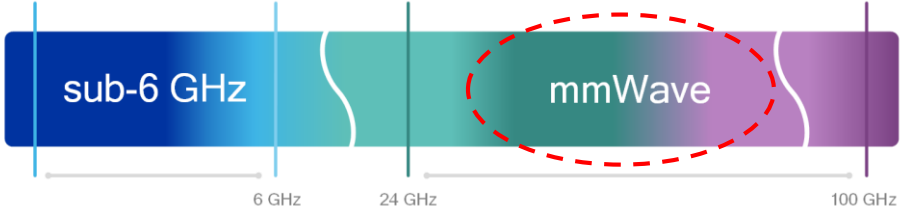
of PAs and antennas determines max EIRP¹

Beamforming and directional architectures allow more gain

Effective directional transmit power (aka EIRP¹)

¹ EIRP = Effective Isotropic Radiated Power. Represents peak directional power transmitted from the antenna array relative to an isotropic transmission

Snapdragon X50 mmWave solution



Snapdragon X50 5G mmWave architecture

Integrated antenna array and RFFE for performance and ease-of-use

Architecture allows flexible placements and multiple modules

Commercializing mmWave in a smartphone form factor

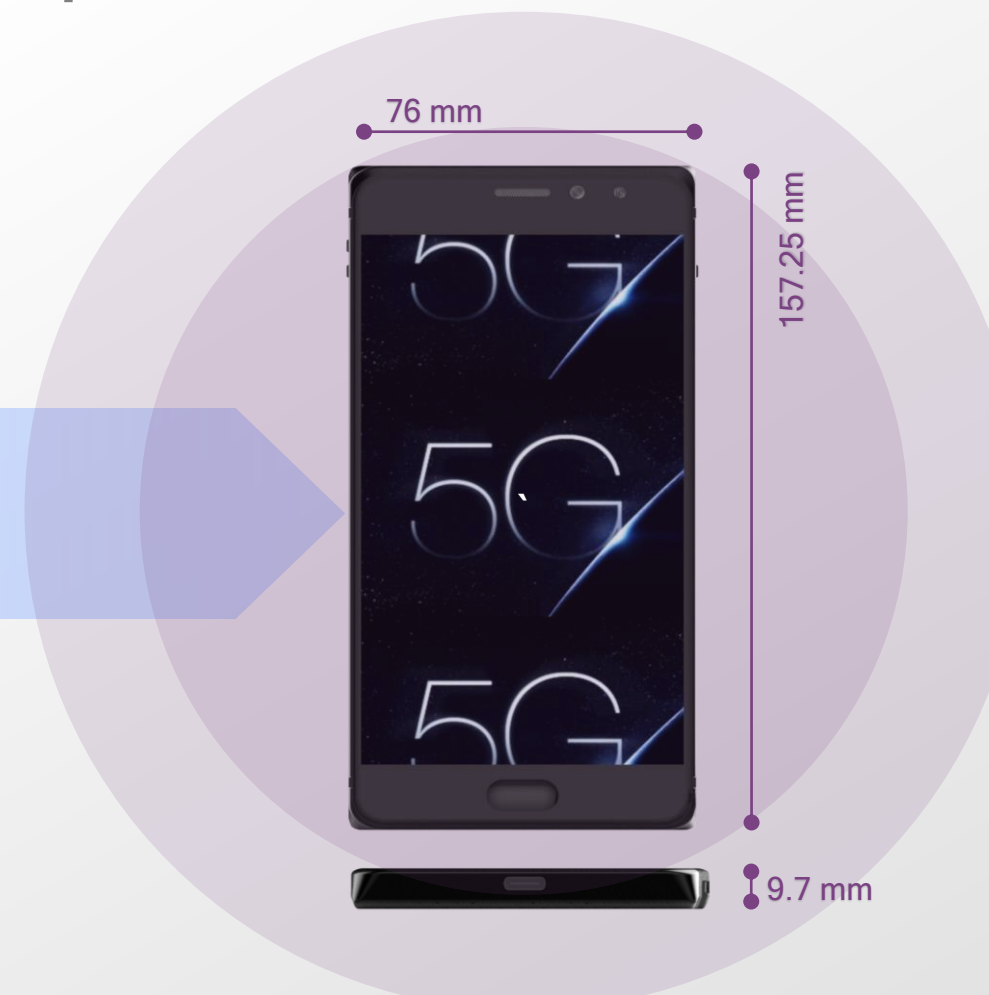


11ad in Asus Zenfone 4 Pro

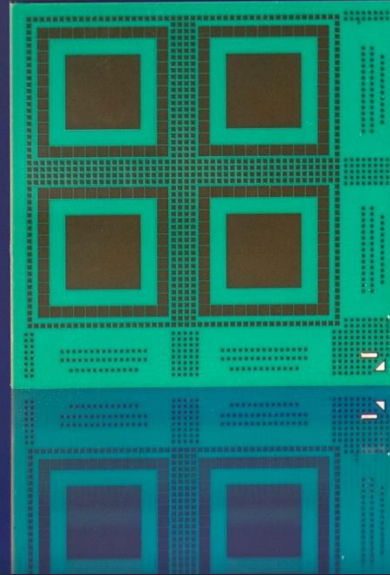
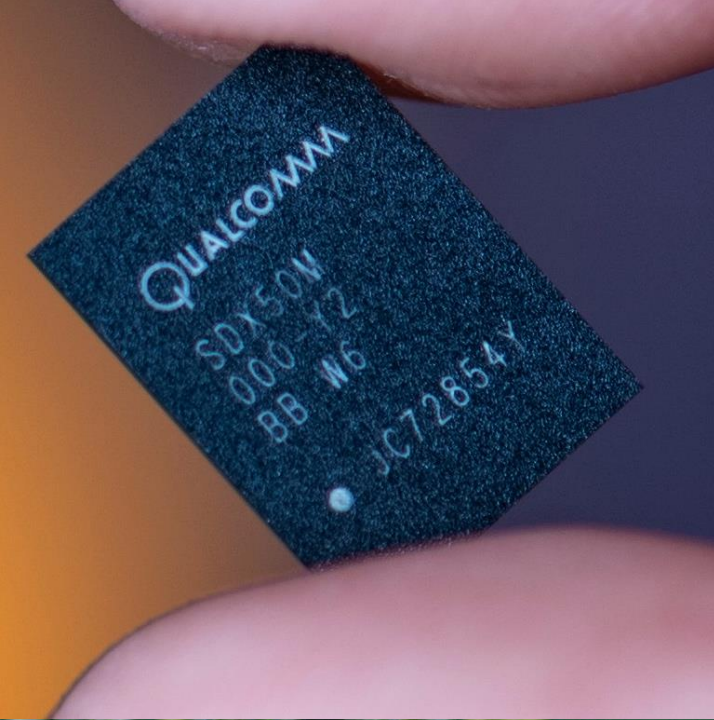
mmWave (60 GHz) viability
in handset form factor



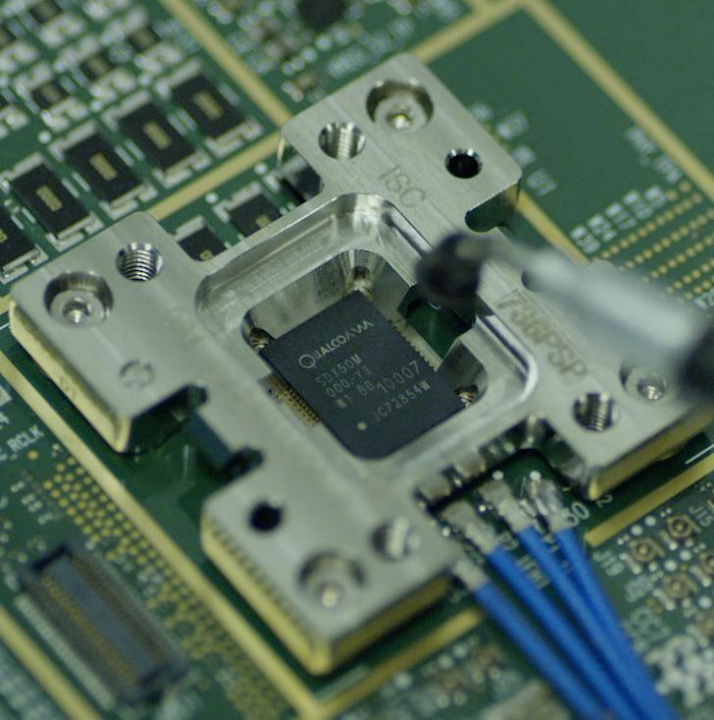
Qualcomm 5G NR mmWave prototype



5G NR mmWave
Qualcomm Reference Design



The world's first announced
**5G connection on
a mobile chipset**



Qualcomm®
snapdragon 

X50
5G MODEM

Qualcomm[®]
snapdragon



X50

5G Modem family

World's first 5G-NR
multimode modems

2G / 3G / 4G / 5G in a single chip

Sub-6 + mmWave

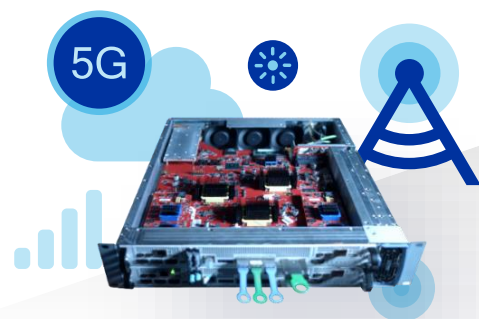
Premium-tier smartphones in 2019

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.



Making 5G NR a commercial reality for 2019

For standard-compliant networks and devices



Best-in-class 5G prototype systems

Designing and testing 5G technologies for many years



5G NR standards and technology leadership

Our technology inventions are driving the 5G NR standard



5G NR interoperability testing and trials

Utilizing prototype systems and our global network experience



Modem, RFFE and platform leadership

Snapdragon X50 5G modem supporting anticipated 2019 mobile device launches

LTE foundational technologies



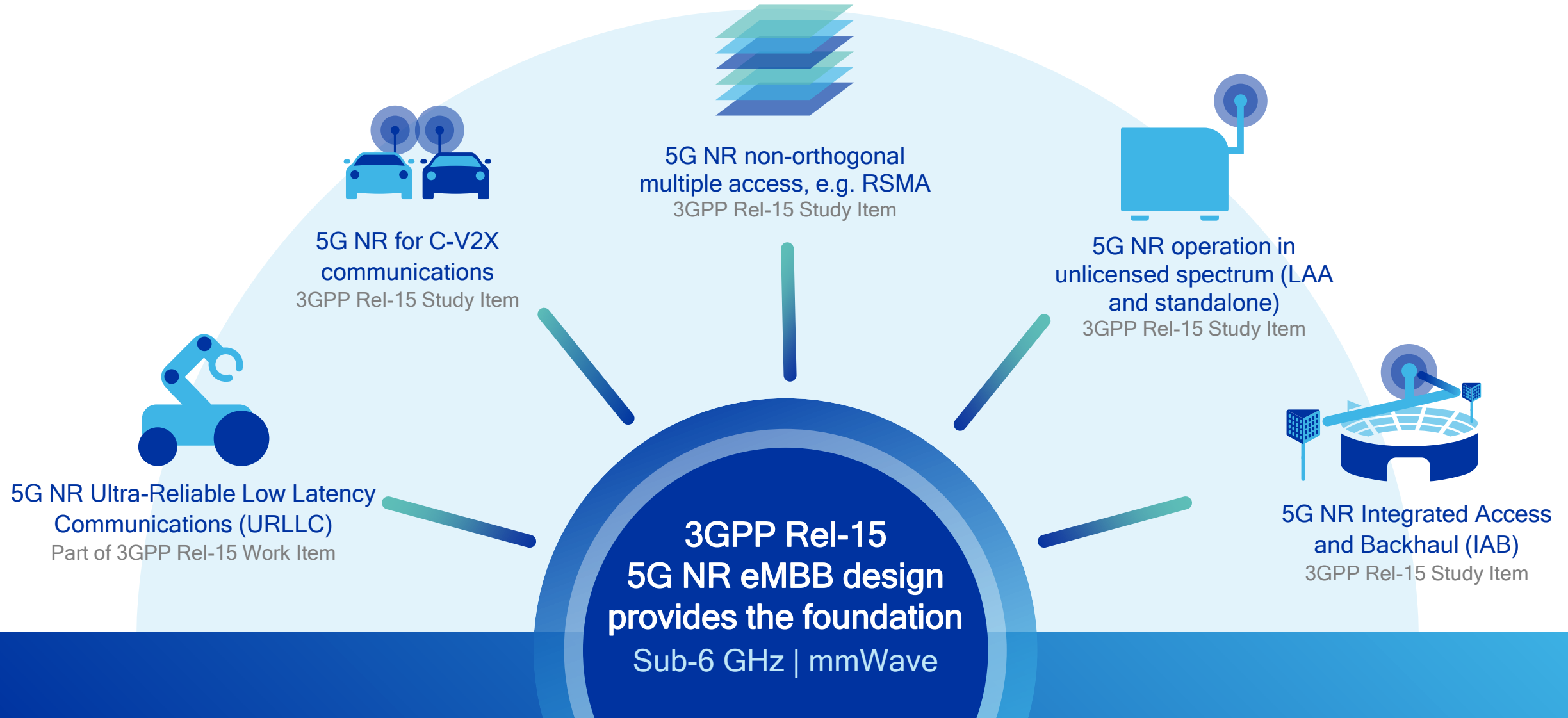
Expanding 5G NR beyond enhanced mobile broadband

3GPP Release 15 and beyond



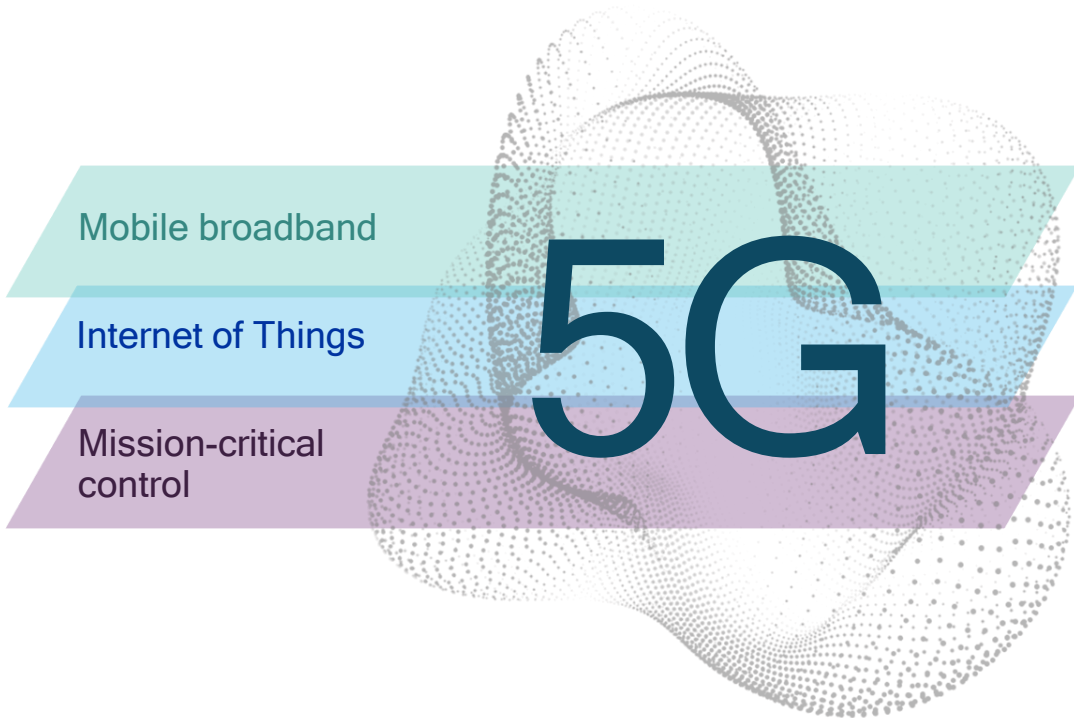
5G NR evolution and expansion beyond eMBB

URLLC part of Rel-15 Work Item + new Rel-15 5G NR Study Items approved



5G Next Gen Core (NGC) also part of 3GPP Rel-15

Increased flexibility through NFV and SDN – essential to 5G NR expansion



- Configurable end-to-end connectivity per vertical
- Modular, specialized network functions per service
- Flexible subscription models
- Dynamic control and user planes with more functionality at the edge

Better cost/energy
efficiency

Optimized
performance

Flexible biz models
and deployments

Dynamic creation
of services



5G NR URLLC for new mission- critical services

Ultra-low 1 ms e2e latency

Faster, more flexible frame structure; also new non-orthogonal uplink access

High reliability targeting 10-5 BLER¹

Ultra-reliable transmissions that can be time multiplexed with nominal traffic through puncturing

High availability

Simultaneous links to both 5G and LTE for failure tolerance and extreme mobility

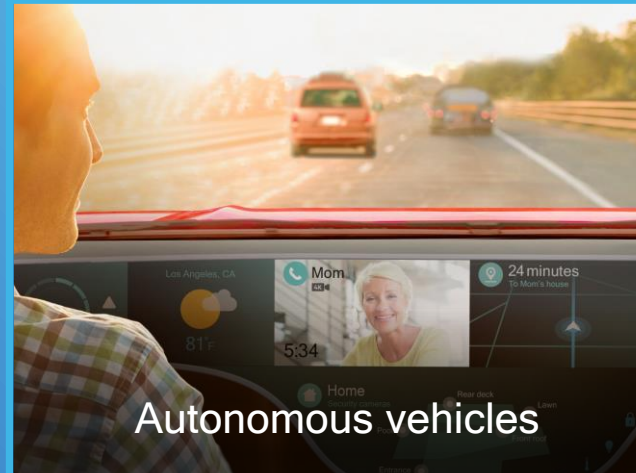
A platform for tomorrow's more autonomous world



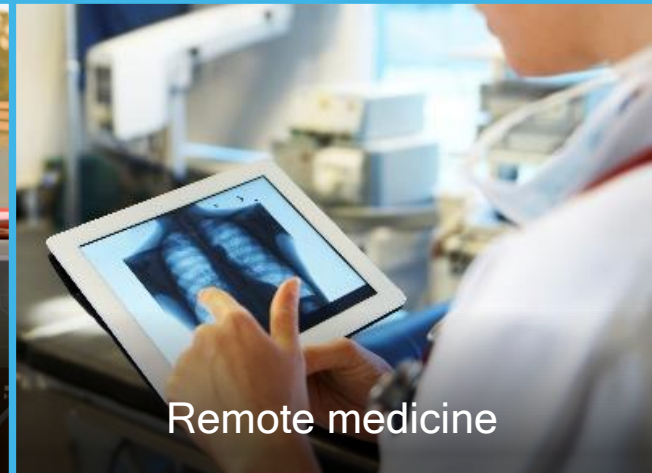
Aviation and public safety



Industrial automation



Autonomous vehicles



Remote medicine



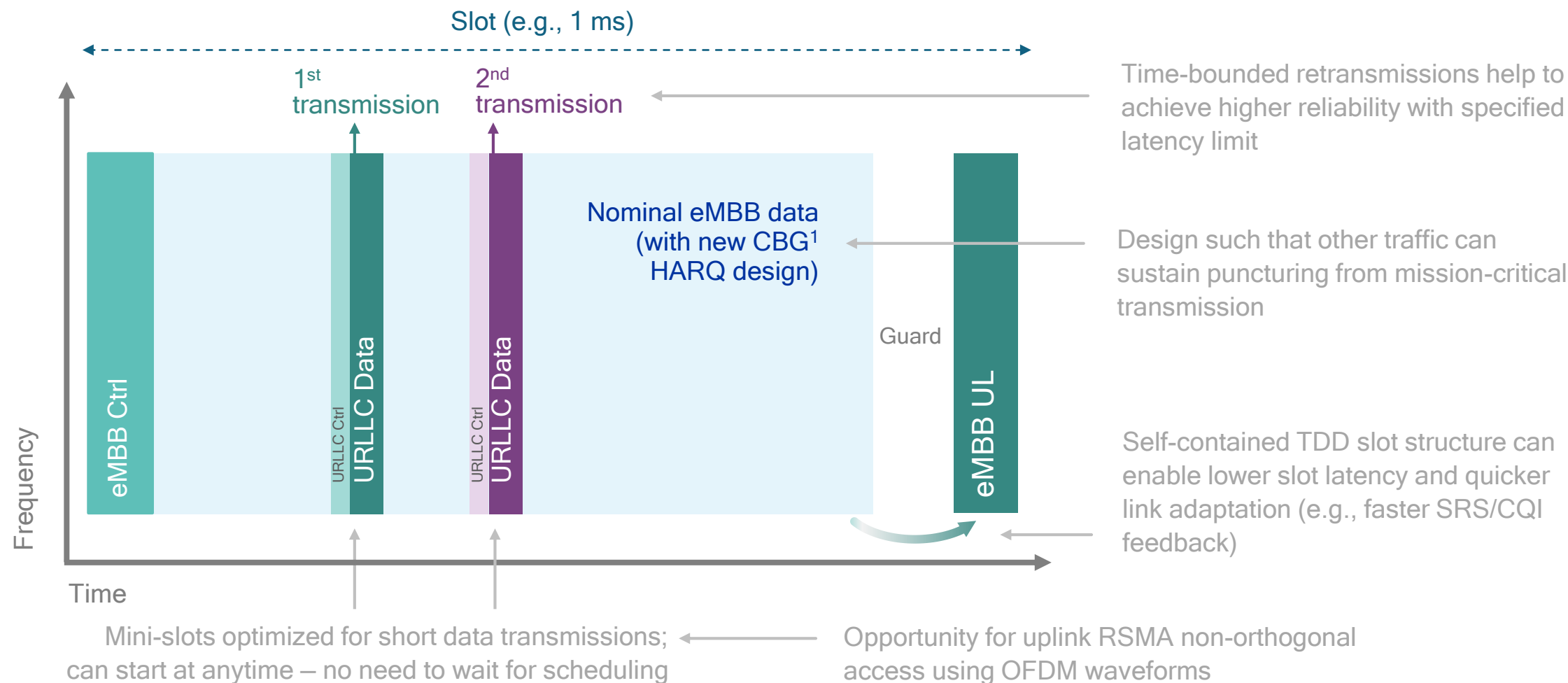
Robotics



Smart grid/energy

New slot structure enables low-latency communication

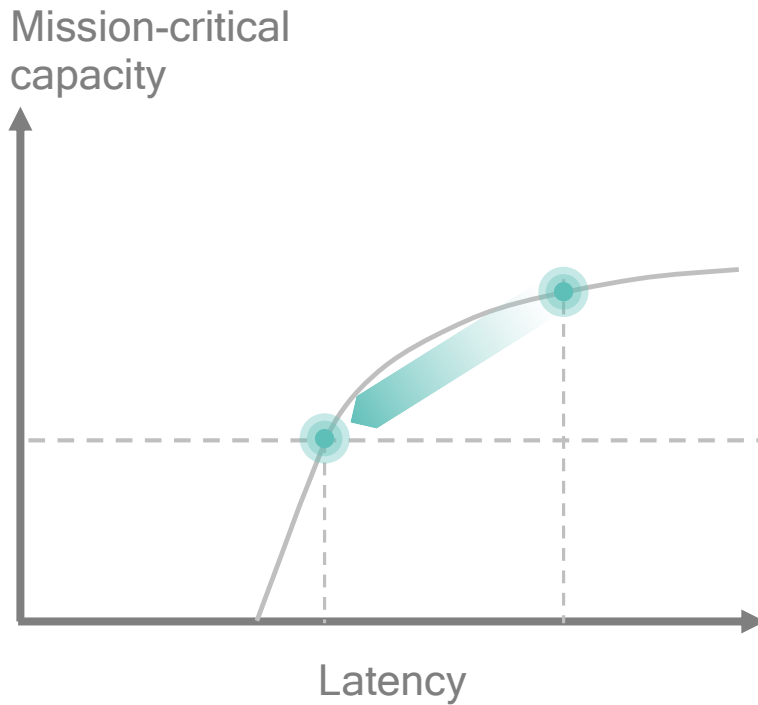
Efficient multiplexing with other services – more flexible than dedicated resources



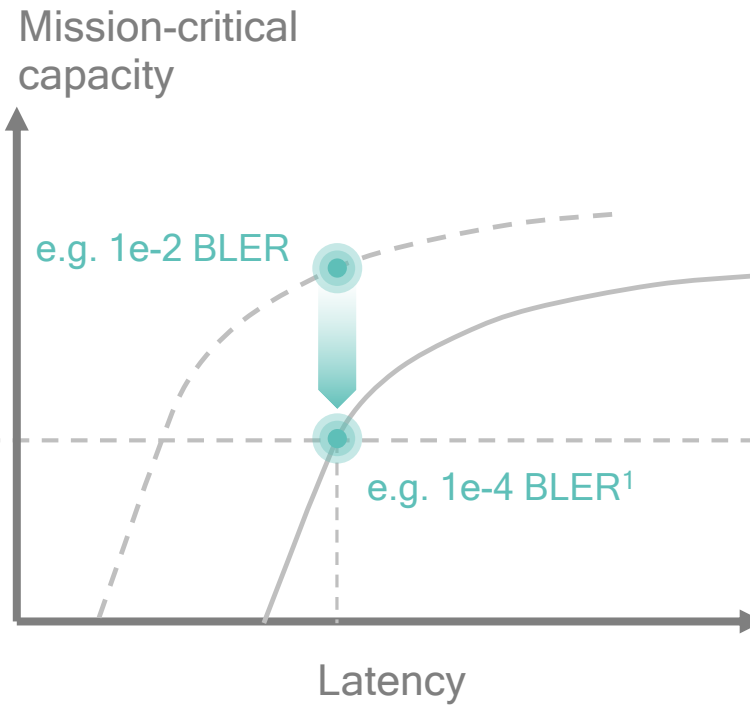
New 5G NR design allows for optimal trade-offs

E.g., leveraging wider bandwidths to offset mission-critical capacity reductions

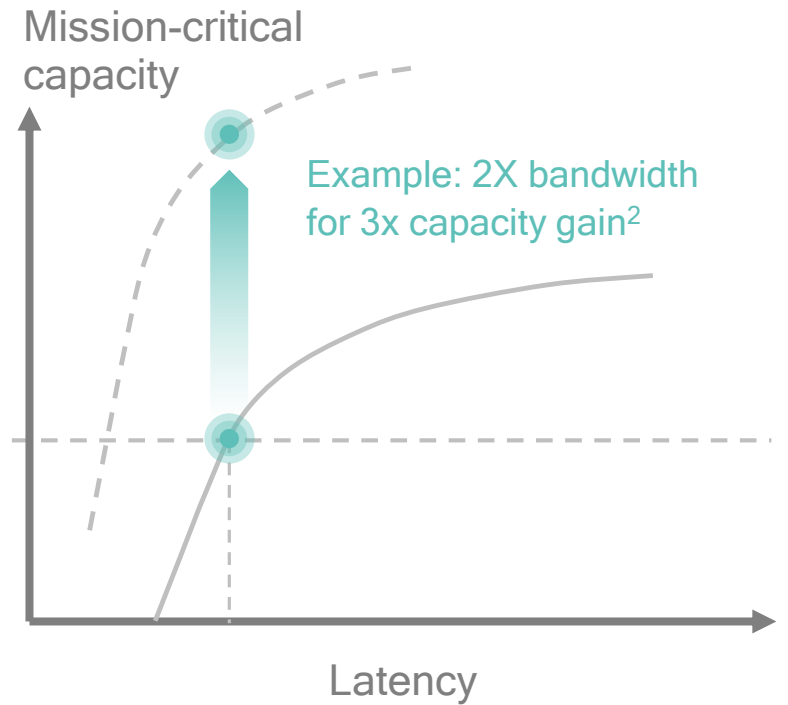
Latency vs. capacity...



Reliability vs. capacity...



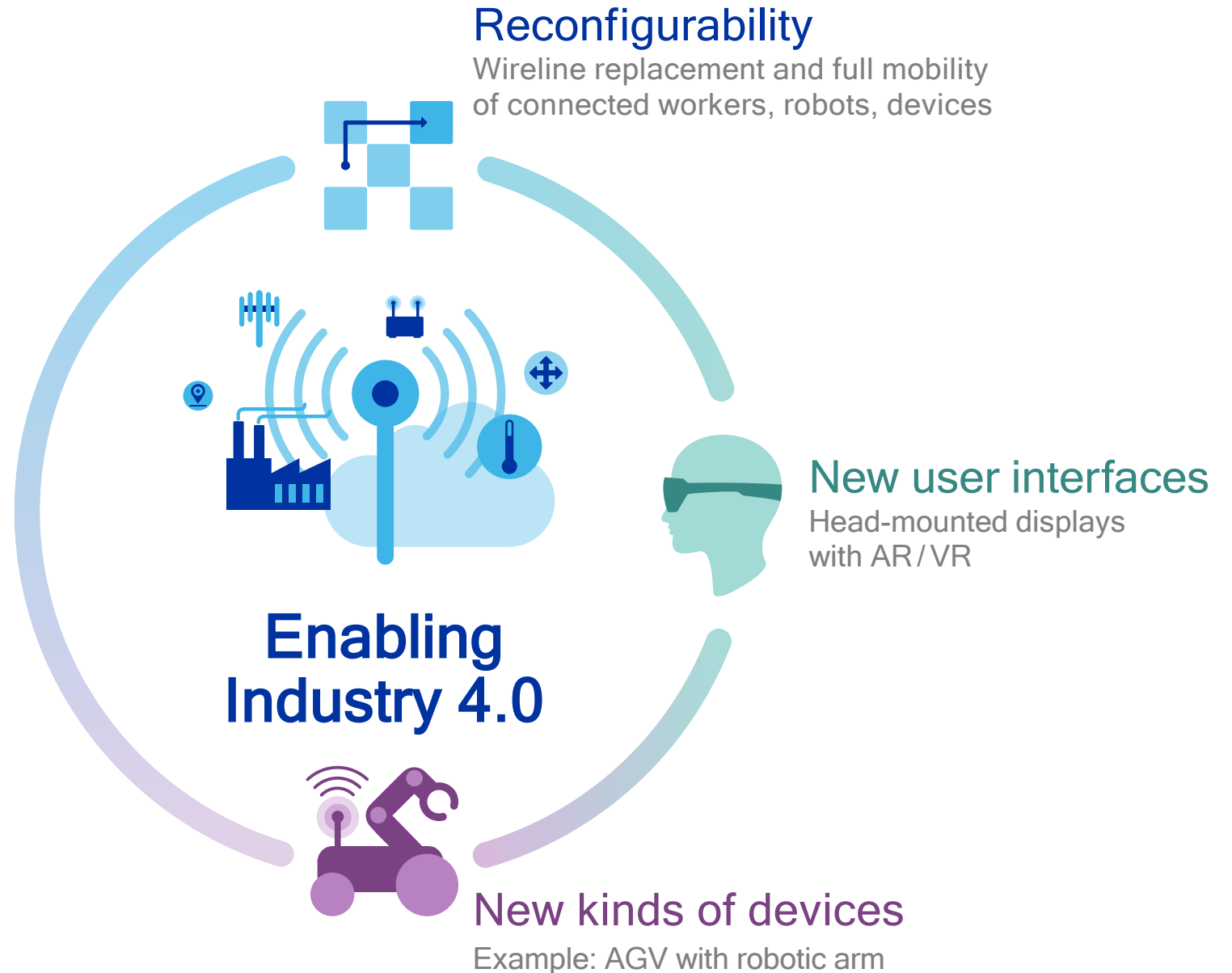
But wider bandwidth can offset reductions



¹ Low BLER Block Error Rate, required to achieve high-reliability with a hard delay bound; ² All data based on Qualcomm simulations with approximate graphs and linear scales; 3x gain when increasing from 10 to 20MHz for 1e-4 BLER

5G NR URLLC enables advanced industrial IoT applications

- Single network for entire factory
- Ultra reliable low latency
- Deterministic latency
- Unified and global ecosystem
- Licensed and unlicensed spectrum
- Sub-6 GHz and mmWave spectrum



C-V2X

Intelligently connecting
the car to surroundings
and cloud

V2V



Vehicle-to-vehicle

e.g. collision avoidance safety systems

V2P



Vehicle-to-pedestrian

e.g. safety alerts to pedestrians, bicyclists

V2N



Vehicle-to-network

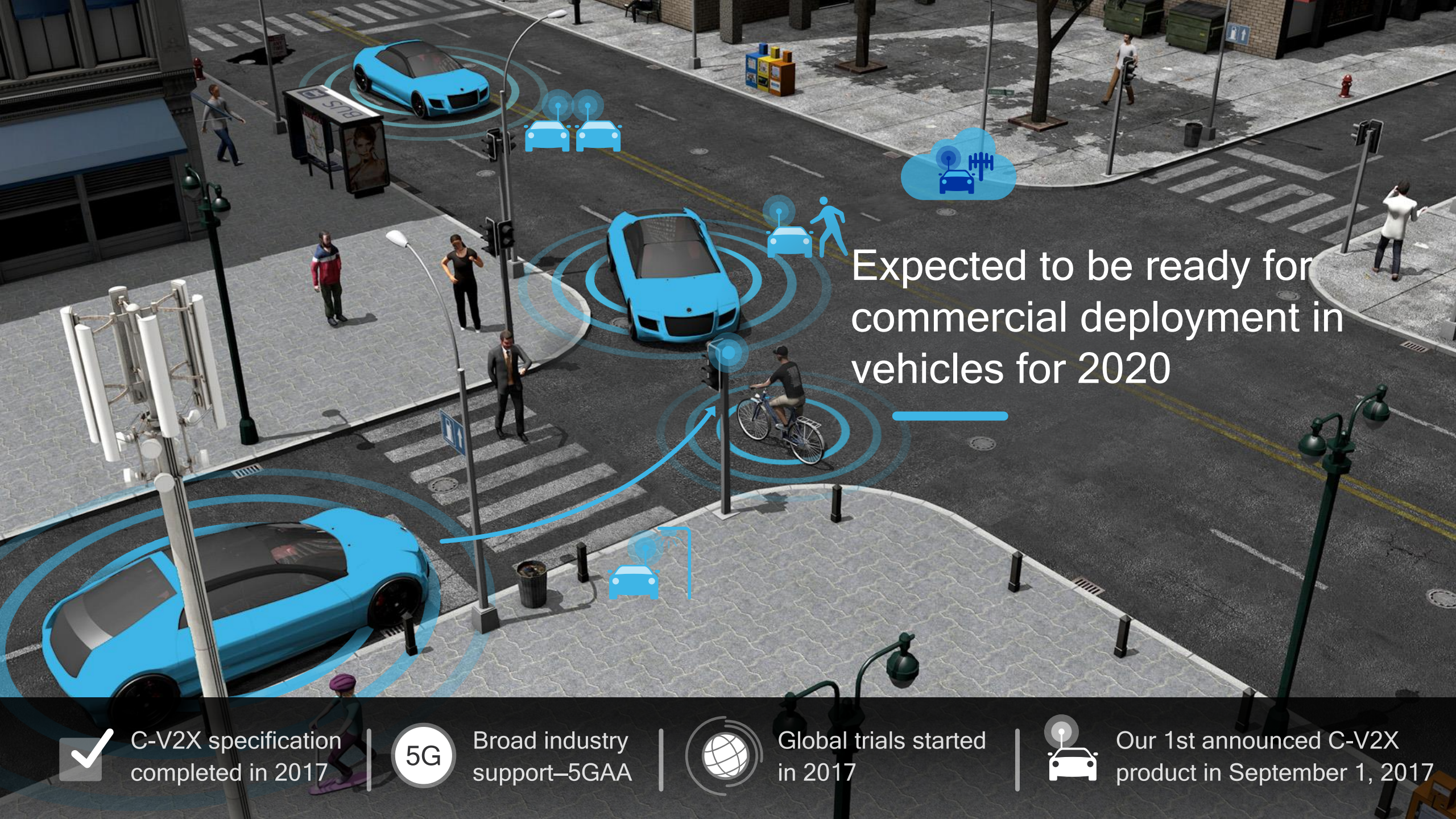
e.g. real-time traffic / routing, cloud services

V2I



Vehicle-to-infrastructure

e.g. traffic signal timing/priority



Expected to be ready for commercial deployment in vehicles for 2020



C-V2X specification completed in 2017



Broad industry support—5GAA



Global trials started in 2017



Our 1st announced C-V2X product in September 1, 2017

C-V2X has a strong evolution path towards 5G NR

While maintaining backward capabilities

Evolution to 5G NR, while being backward compatible
C-V2X R14 is necessary and operates with R16

Basic and enhanced safety
C-V2X R14/R15 with enhanced range and reliability

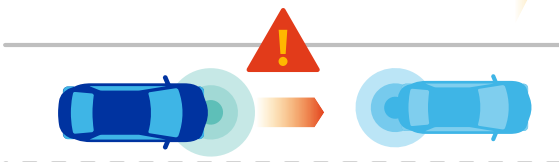
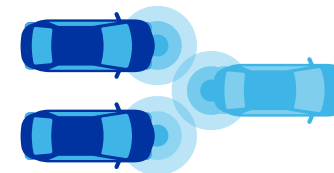
Basic safety
IEEE 802.11p

Advanced safety
C-V2X R16 (building upon R14)

Backward compatible with R14 enabled vehicles

Higher throughput Wideband ranging/positioning

Higher reliability Lower latency



5G V2X brings new capabilities for the connected vehicle

While maintaining backward compatibility



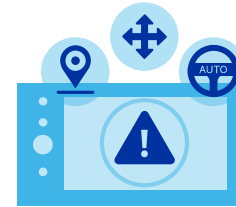
High throughput sensor sharing

High throughput and low-latency to enable the exchange of raw or processed data gathered



Intention / trajectory sharing

High throughput and low-latency to enable planned trajectory sharing



Wideband ranging and positioning

Wideband carrier support to obtain accurate positioning and ranging for cooperated and automated use cases



Local high definition maps / "bird's eye view"

High throughput to build local, dynamic maps based on camera and sensor data; and distribute them at street intersections

Ubiquitous connectivity

To reach challenging locations by achieving device link budget of 164 dB¹

Ultra energy efficiency

To realize 10+ year device battery life² and 100x network energy efficiency³

Evolving LTE IoT

for the massive
Internet of Things

Massive scale

To efficiently support dense connections of 1+ million devices/km²

Extreme simplicity

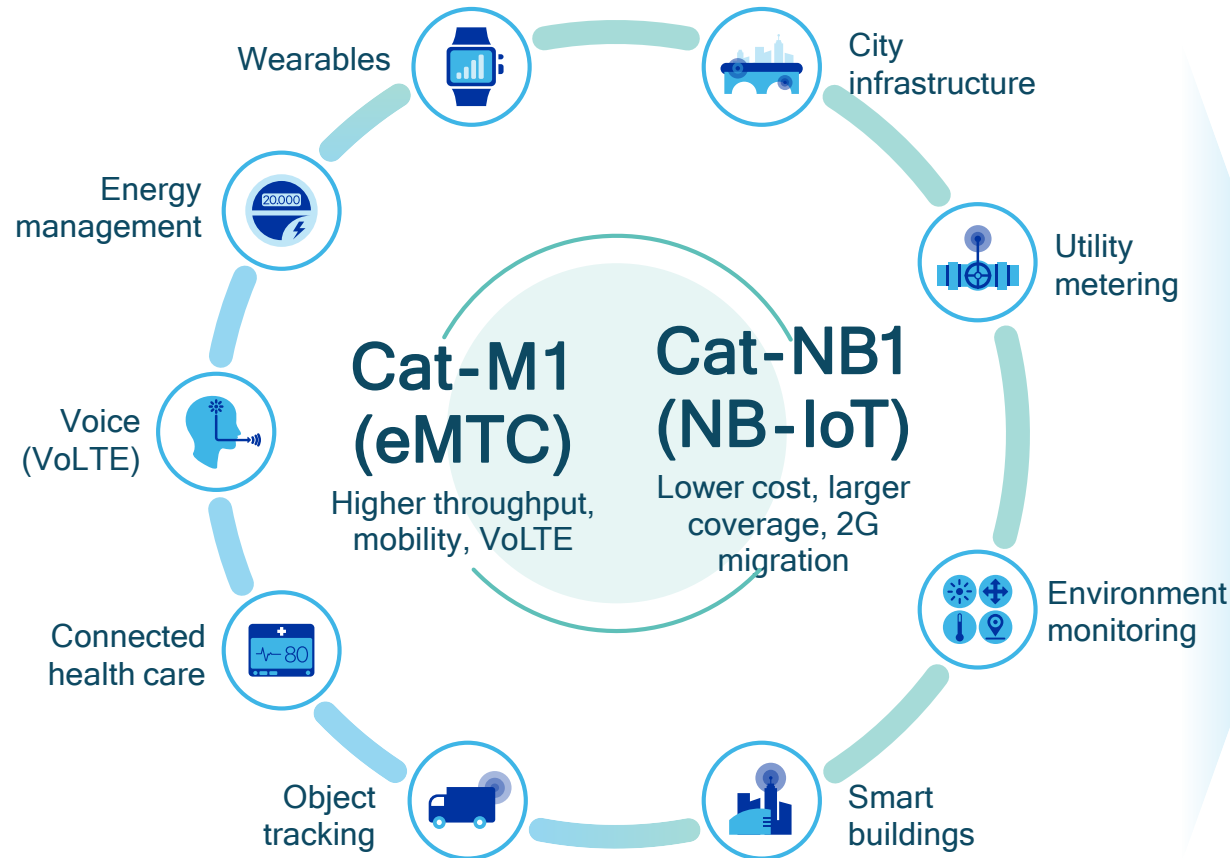
To allow scaling to the lowest-end use cases with e.g., single Rx antenna

Addressing the growing needs of low-power, wide-area IoT use cases

1. Maximum Coupling Loss, assuming data rate of 160bps; 2. Assuming 200B UL + 20B DL per day at 164 MCL with 5Wh battery; 3. Compared to IMT-Advanced

LTE IoT starts to connect the massive IoT today

Over 35 mobile operators committed to deploy Cat-M1 and/or Cat-NB1 networks



MDM9206

Flexible LTE IoT chipset platform for Cat-M1 / Cat-NB1 / E-GPRS

- Global dual-mode solution – single SKU
- Pre-certified modules commercially available today
- Multiple design wins across industry-leading OEMs

QUECTEL
Wireless Module Expert

LONG UNG
龙尚科技

MobileTek

ZTEWelink

Neoway 有方

u-blox

WNC

Telit

SIM.Com
A company of SIM Tech

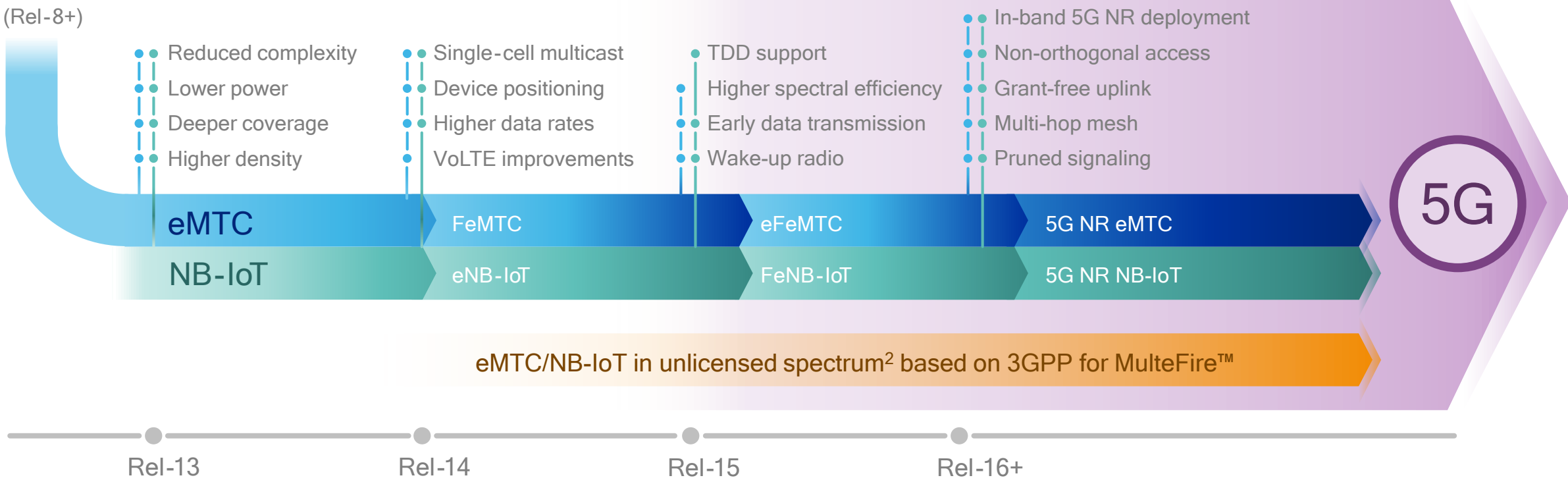
MOBIKE
移动科技

...and many more

Continued evolution to meet tomorrow's massive IoT needs

Essential to 5G Platform¹

LTE Cat-1
and above
(Rel-8+)



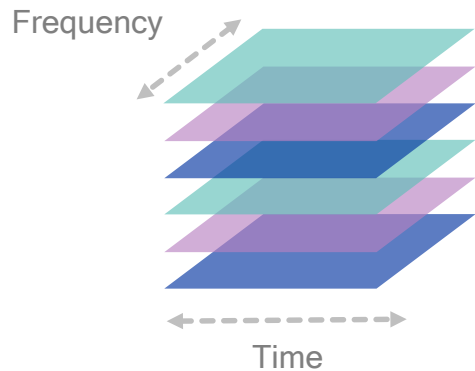
1. LTE IoT, part of LTE Advanced Pro, will be submitted with 5G NR to meet IMT-2020 requirements per defined in ITU Recommendation ITU-R M.2083-0, September, 2015; 2. Standardization in MulteFire Alliance

Pioneering tomorrow's massive IoT technologies

Applies to LTE IoT and 5G NR IoT evolution – potential for 3GPP Rel-16+

Non-orthogonal multiple access

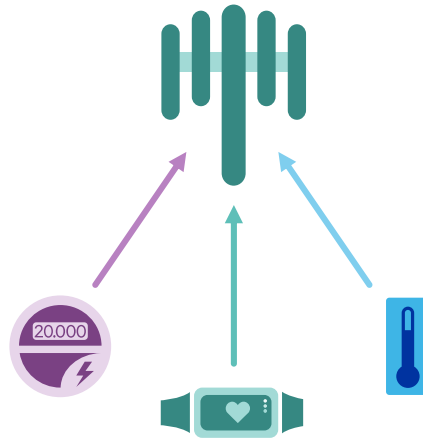
Resource Spread Multiple Access (RSMA)



- NOMA is part of 5G NR Rel-15 Study Item
- Can be either scheduled or grant-free
- Increases device density & network efficiency

Grant-free uplink

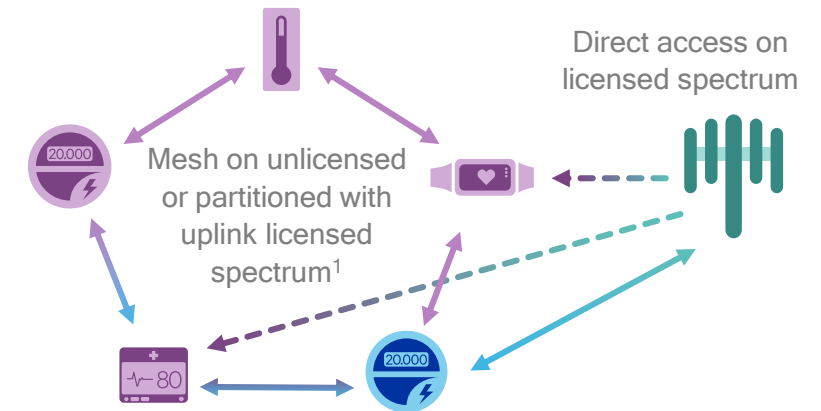
Autonomous mode transmission



- Contention-based access for IoT devices
- For sporadic uplink of small data bursts
- Also key enabler of mission-critical communication

Mesh networking

Multi-hop mesh with WAN management



- For low-power devices with challenging placements
- Especially uplink data relayed via nearby devices
- Expands on LTE Device-to-Device (D2D)

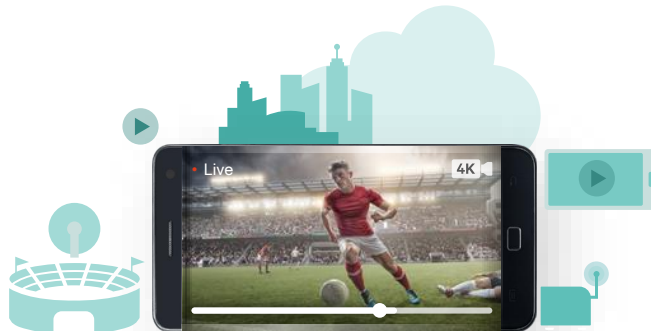
1. Greater range and efficiency when using licensed spectrum, e.g. protected reference signals. Network time synchronization improves peer-to-peer efficiency

Spectrum sharing valuable for wide range of deployments



Licensed spectrum aggregation

Better user experience with higher speeds



Enhanced local broadband

Neutral host, neighborhood network



Private 5G networks

Industrial IoT, Enterprise



Enhancing existing deployments,

Examples today: Gigabit LTE with LAA¹

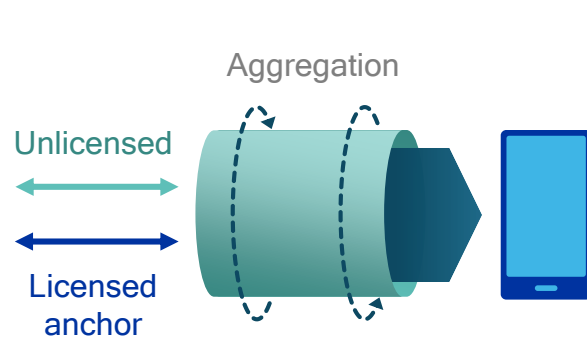
New types of deployments,

Examples today: Private LTE networks

1. Licensed-Assisted Access (LAA);

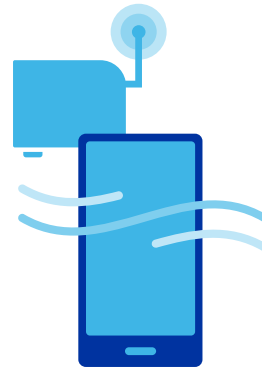
3GPP study on 5G NR operation in unlicensed spectrum

First time 3GPP studies cellular technology operating stand-alone in unlicensed¹



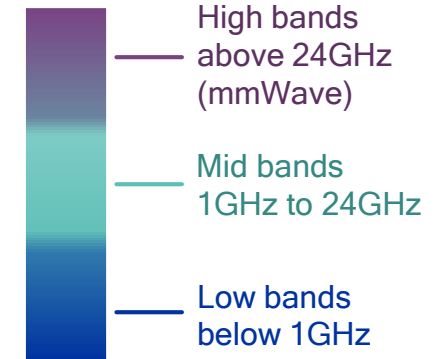
NR-based LAA

NR in unlicensed aggregated with LTE (dual-connectivity) or NR (carrier-aggregation) in licensed spectrum



Stand-alone unlicensed

NR operating standalone in unlicensed spectrum. This will become the MulteFire™ evolution path to 5G.



Across spectrum bands

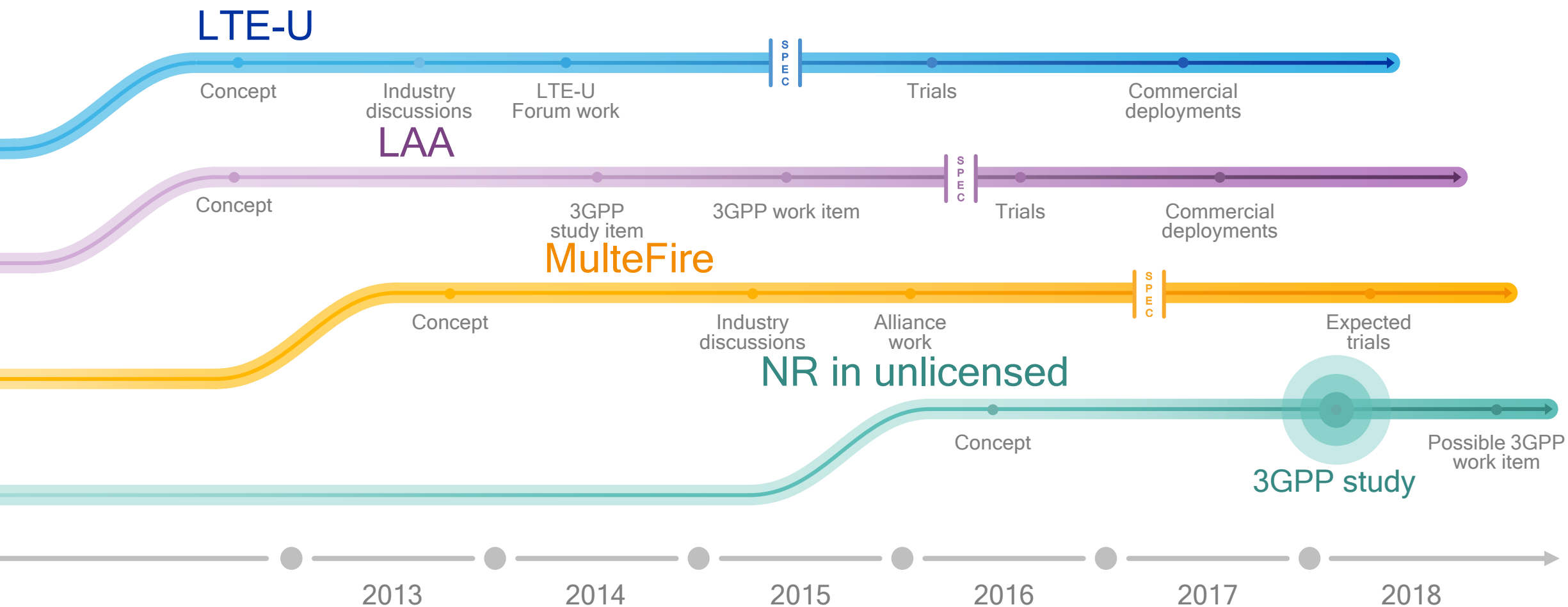
Both below and above 6 GHz, e.g., 5GHz, 37GHz, 60GHz*
(*assuming no change to waveform)

Designing with fair co-existence in any unlicensed spectrum: NR/NR, NR/LTE, NR/Wi-Fi

¹ Study item in Rel. 15 (RP-170828), which could be followed by a work item that is completed in Rel. 16.

Many years in the making to lead up to NR in unlicensed

Work started over 5 years ago when we first envisioned LTE in unlicensed



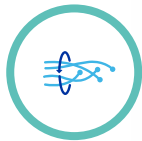
Flexible NR framework supports new sharing paradigms

Building on spectrum sharing technologies that we are pioneering today for LTE

Today's spectrum sharing technologies



LTE-U / LAA



LWA

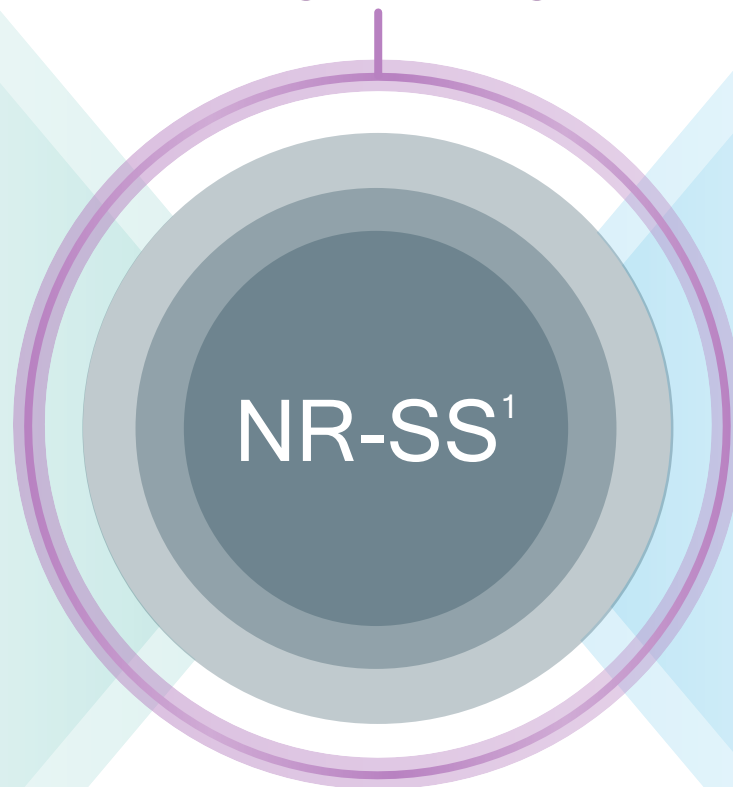


MulteFire



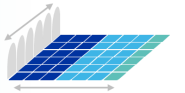
CBRS / LSA

Introducing new sharing paradigms



Flexible NR framework

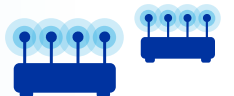
Flexible slot-based framework



Scalable OFDM-based air interface



Network MIMO



TDD self-contained slot structure



Mobile mmWave

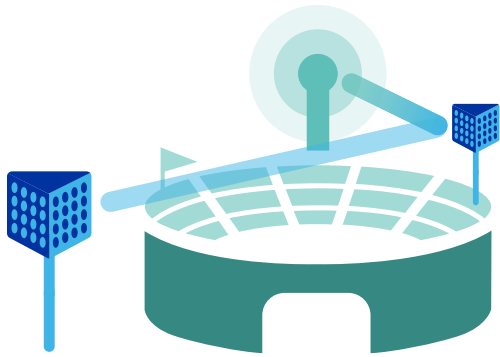


Learn more at:

www.qualcomm.com/invention/technologies/5g-nr/spectrum-sharing

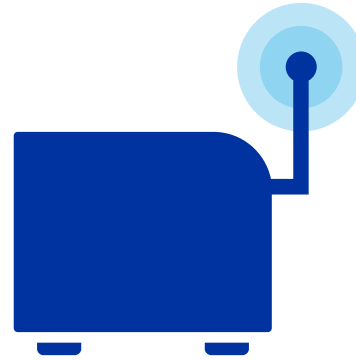
5G NR mmWave continuing to evolve beyond R15

Bringing new capabilities, new spectrum bands and new deployment opportunities



Integrated Access & Backhaul

Rel-15 Study Item on enabling easy/low-cost deployment of small cells using mmWave spectrum for access and backhaul



Unlicensed Spectrum

Rel-15 Study Item for both LAA and standalone operation (aka 5G MulteFire™) in sub-6 GHz and mmWave spectrum bands

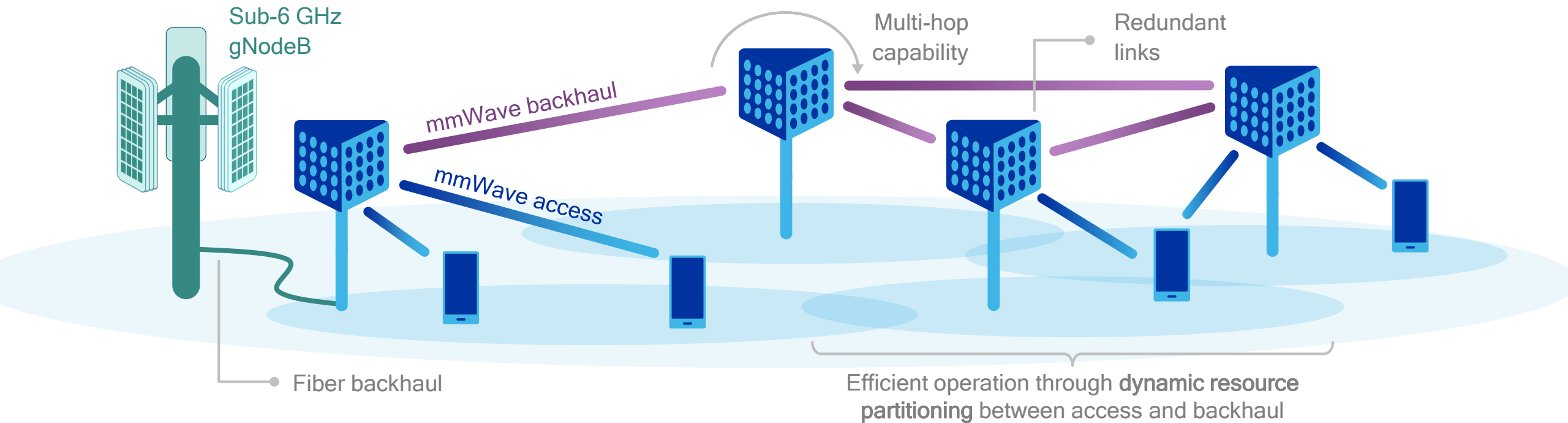


Higher spectrum bands

Exploring the use of spectrum bands above ~40 GHz, including unlicensed spectrum in the 57 GHz to 71 GHz band

5G NR mmWave IAB¹ for cost-efficient dense deployments

Improves coverage and capacity, while limiting backhaul cost



Traditional fiber backhaul
can be expensive for
mmWave cell sites

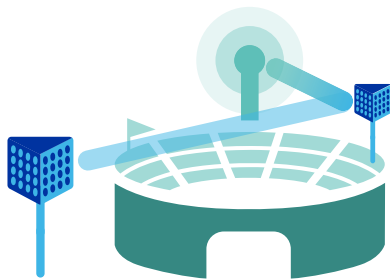
- mmWave access inherently requires small cell deployment
- Running fiber to each cell site may not be feasible and can be cost prohibitive
- mmWave backhaul can have longer range compared to access

¹ Integrated Access & Backhaul

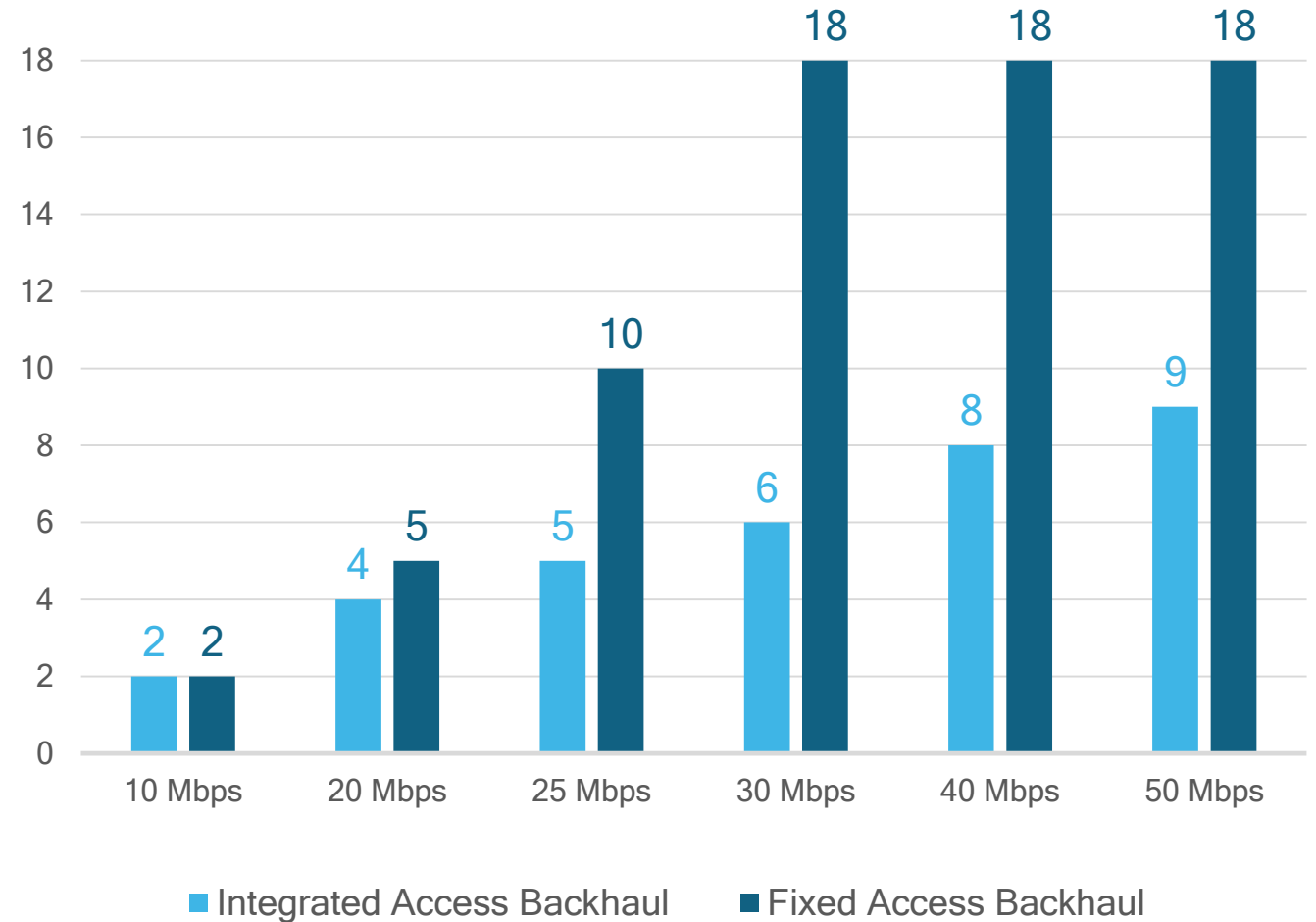
5G NR IAB supports more adaptive flexible deployments and reduces network cost

Fewer fiber drop points needed compared to fixed backhaul for a given traffic demand

Dynamically adjusts to changes in fiber drop locations and numbers



Number of fiber drops needed



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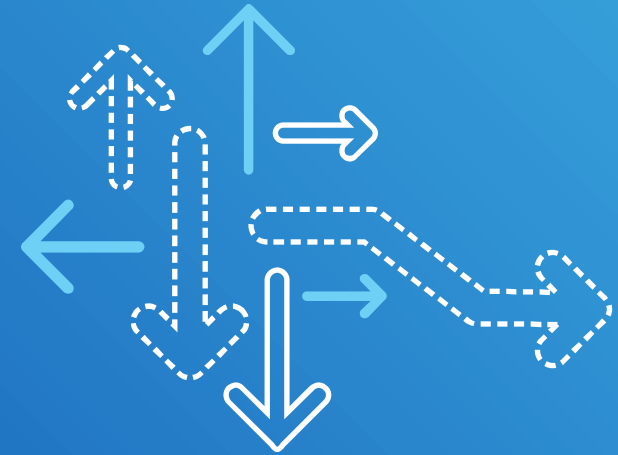
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