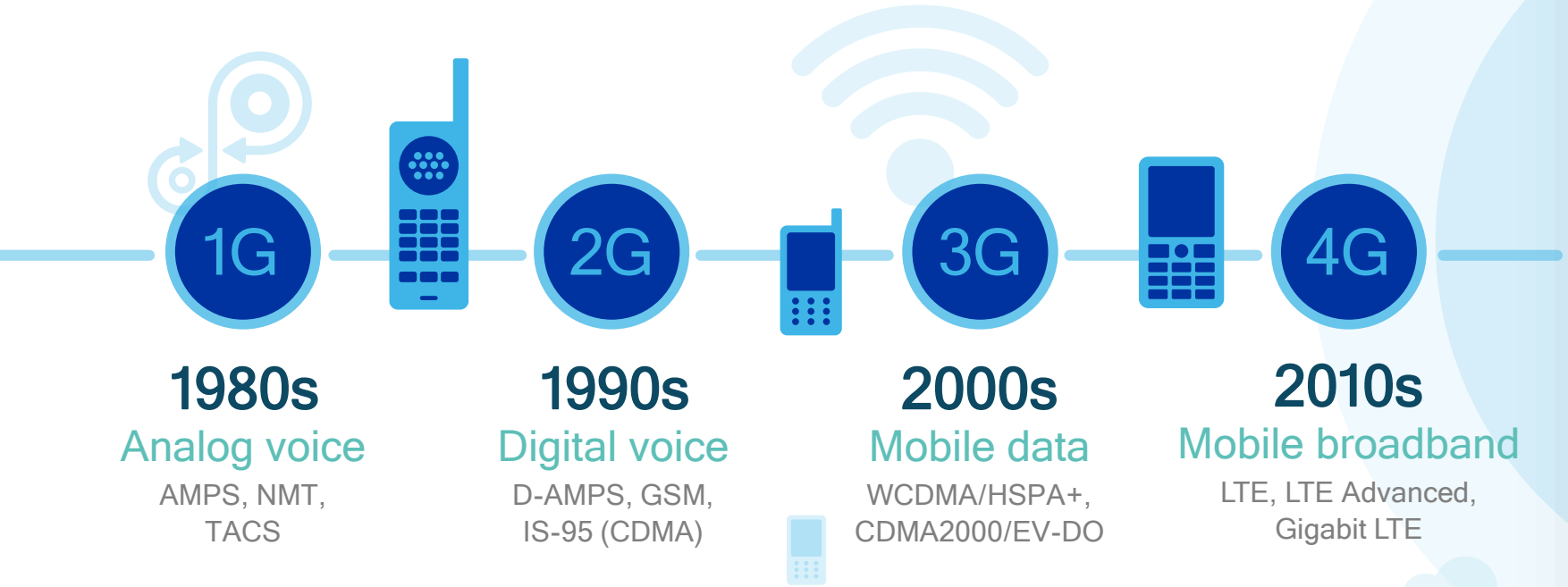
Making 5G NR a Commercial Reality

A unified, more capable 5G air interface

December 2017

@qualcomm_tech

Mobile is the largest technology platform in human history

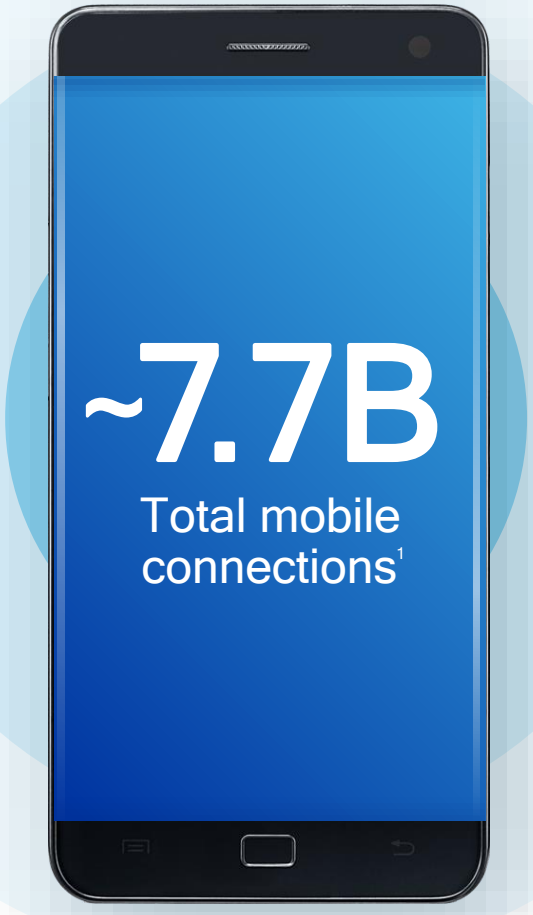


1980s
Analog voice
AMPS, NMT, TACS

1990s
Digital voice
D-AMPS, GSM, IS-95 (CDMA)

2000s
Mobile data
WCDMA/HSPA+, CDMA2000/EV-DO

2010s
Mobile broadband
LTE, LTE Advanced, Gigabit LTE



[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

Source: Nokia Bell Labs Consulting Report, 2016

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

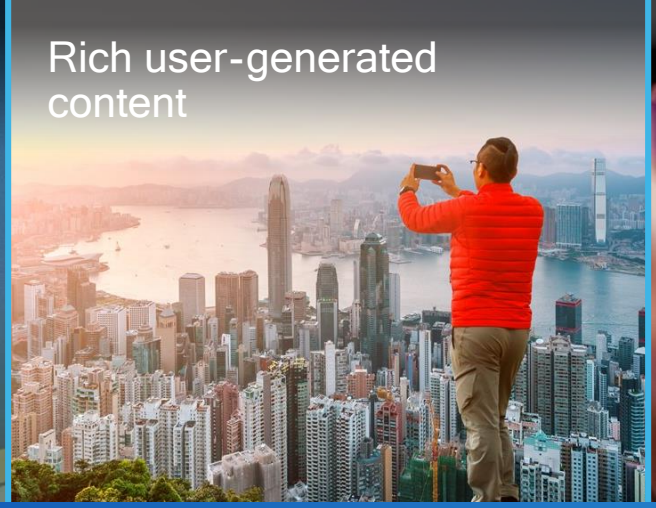
Top 3 reasons for 5G:

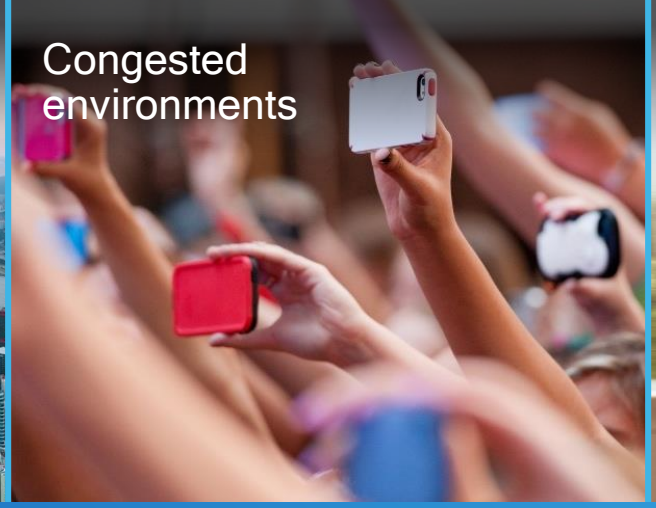
10x faster speeds

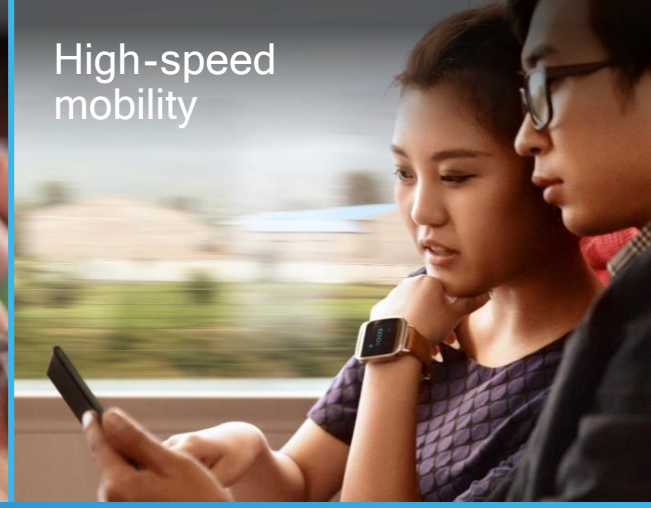
10x quicker response time

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.



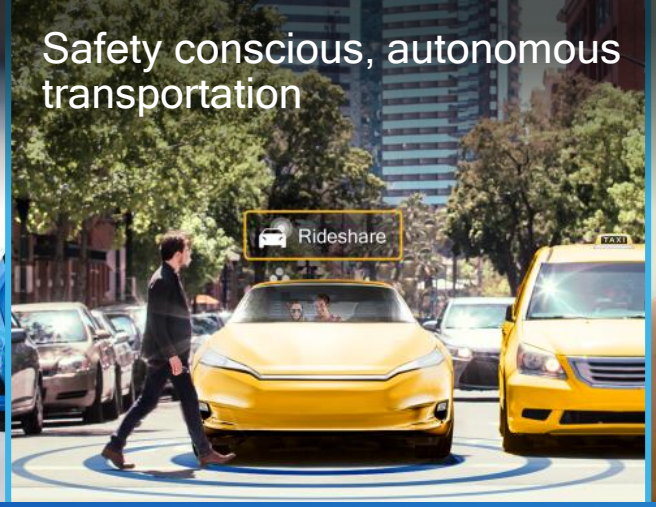


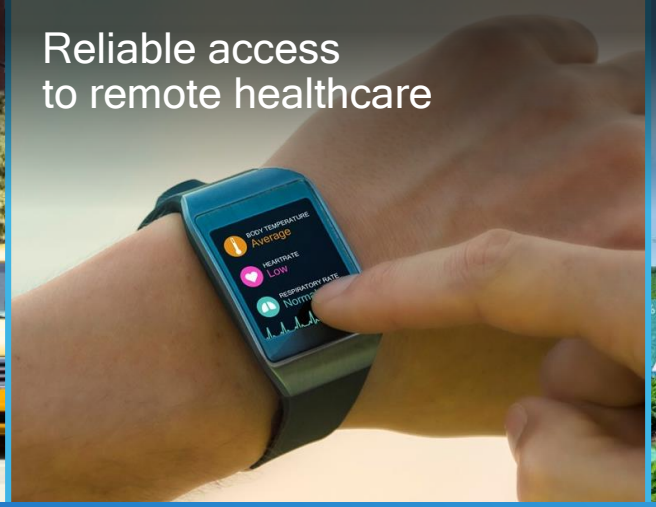


5G

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





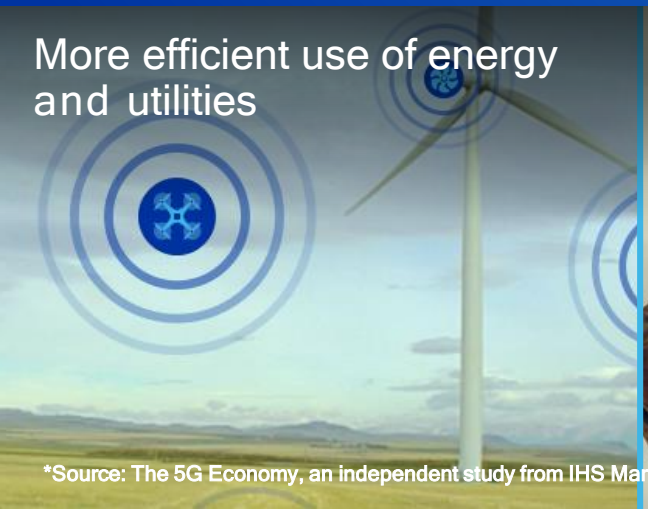
5G

5G will expand the mobile ecosystem to new industries

Powering the digital economy

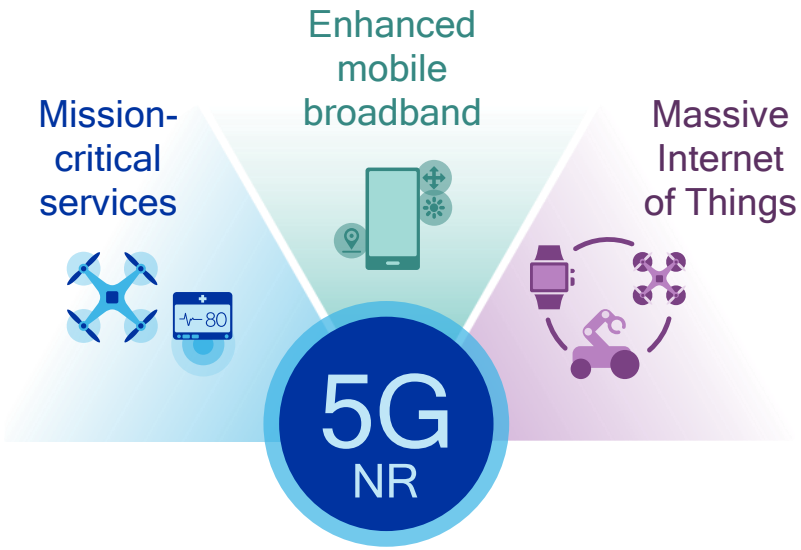
>$12 Trillion

in goods and services by 2035*



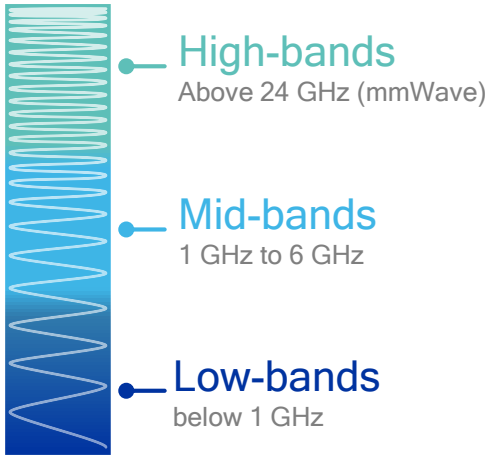
*Source: The 5G Economy, an independent study from IHS Markit, Penn Schoen Berland and Berkeley Research Group, commissioned by Qualcomm

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

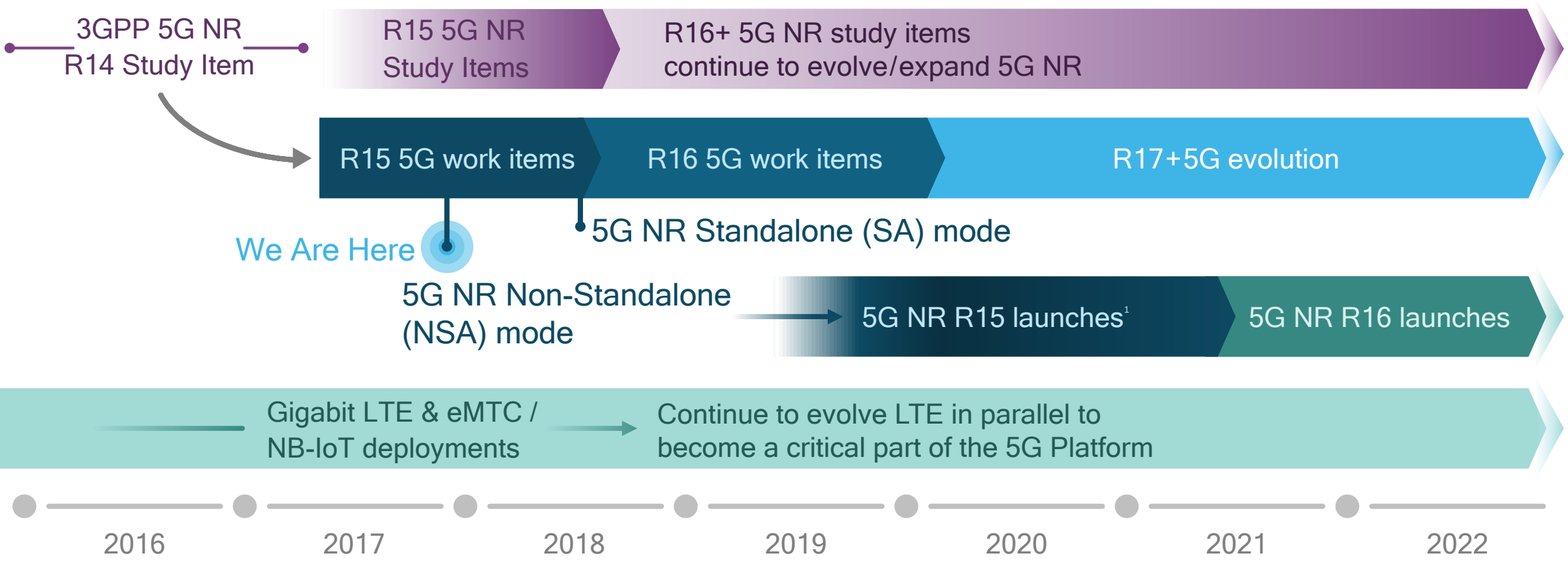
Diverse deployments

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

Flexible slot-based framework

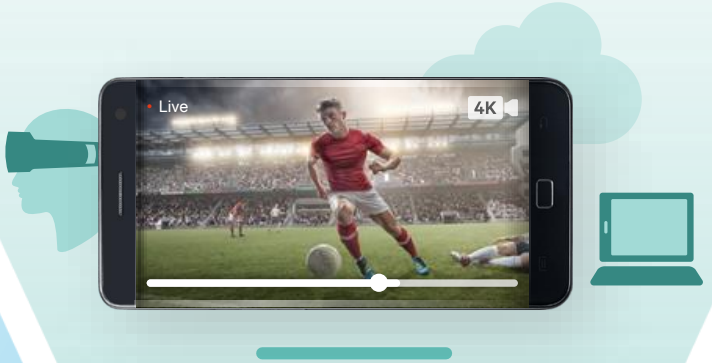
Scalable OFDM

Massive MIMO

Mobile mmWave

Dual Connectivity

Advanced channel coding



Enhanced mobile broadband

Enhanced power save modes

Deeper coverage

Grant-free UL

Narrow bandwidth

Efficient signaling

Massive Internet of Things

To meet an extreme variation of 5G NR requirements

10x	10x	3x	100x	100x	10x
Decrease in end-to-end latency	Experienced throughput	Spectrum efficiency	Traffic capacity	Network efficiency	Connection density

Based on ITU vision for IMT-2020 compared to IMT-advanced; URLLC: Ultra-Reliable Low-Latency Communications; IAB: Integrated Access & Backhaul

Making 5G NR a commercial reality for 2019

For standard-compliant networks and devices

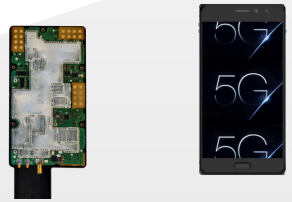
Best-in-class 5G prototype systems

Designing and testing 5G technologies for many years

3GPP™ A GLOBAL INITIATIVE

5G NR standards and technology leadership

Our technology inventions are driving the 5G NR standard



at&t · 中国移动 China Mobile · NTT docomo · SK telecom · Sprint · T · verizon · vodafone · ERICSSON · NOKIA · ZTE中兴

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

QUALCOMM®

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.

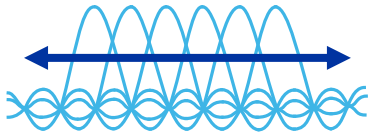
Designing 5G New Radio (NR)

3GPP Release 15

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

For enhanced mobile broadband and beyond

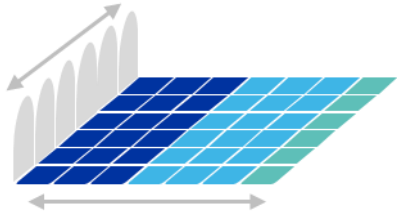
Scalable OFDM-based air interface



Scalable OFDM numerology

Efficiently address diverse spectrum, deployments and services

Flexible slot-based framework



Self-contained slot structure

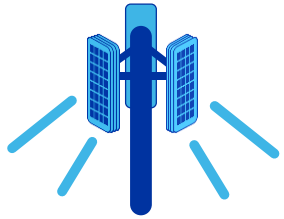
Key enabler to low latency, URLLC and forward compatibility

Advanced channel coding

ME-LDPC and CA-Polar[1]

Efficiently support large data blocks and a reliable control channel

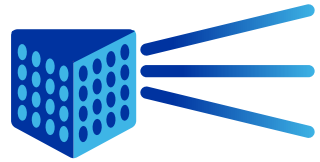
Massive MIMO



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

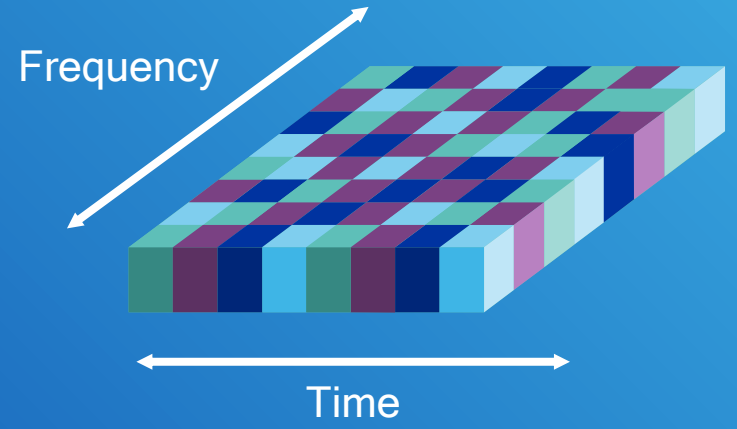
QUALCOMM®

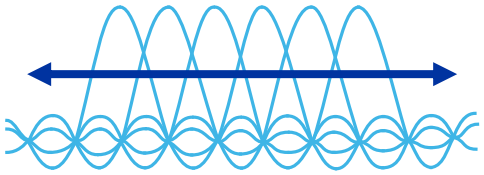
Our technology inventions are driving Rel-15 specifications

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

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

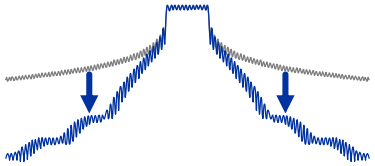
Scalable OFDM-based 5G NR air interface





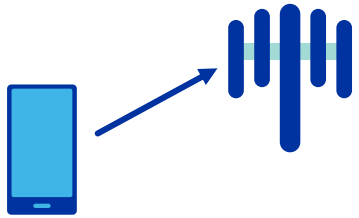
Scalable numerology

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



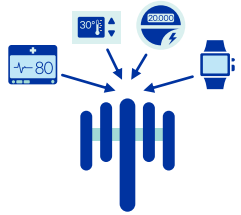
Frequency localization

Windowing[1] can effectively minimize in-band and out-of-band emissions



Lower power consumption

Single-carrier[2] OFDM utilized for efficient uplink transmissions



Asynchronous multiple access

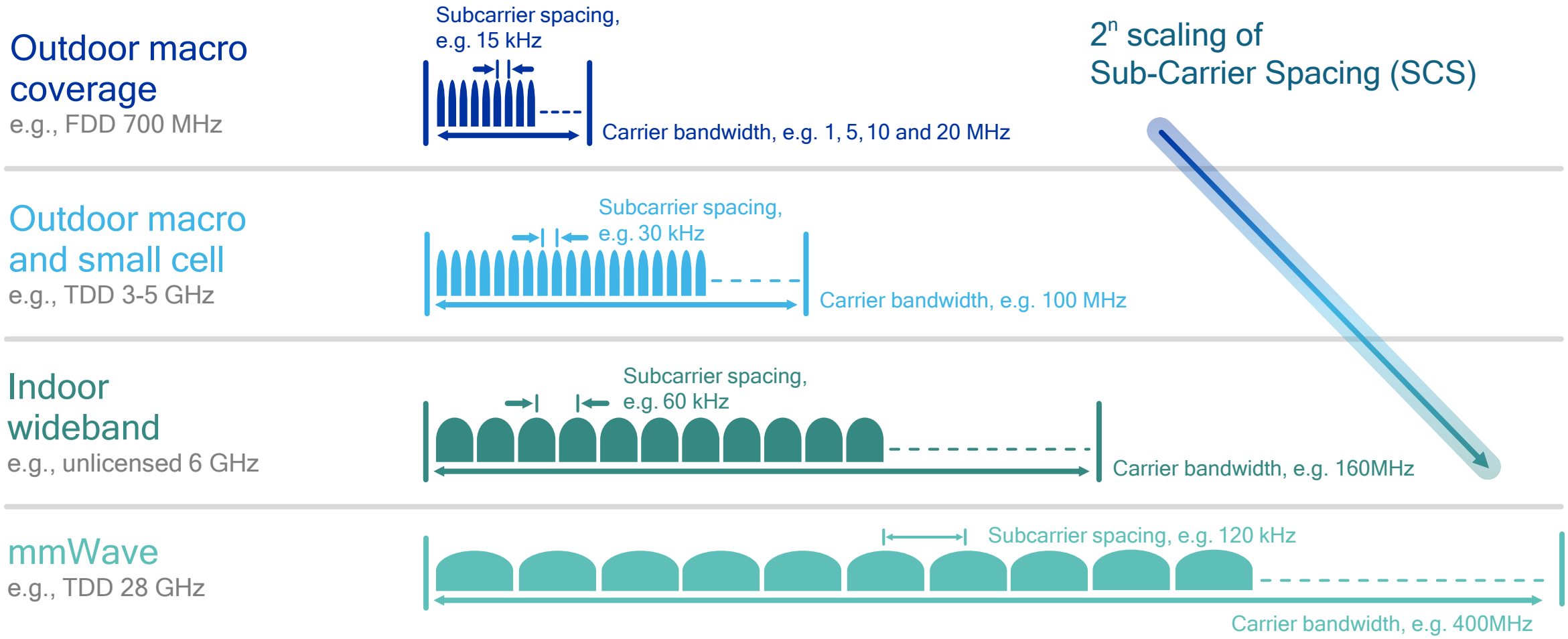
Can co-exist with optimized waveforms and multiple access for IoT UL[3]

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

Qualcomm Research is a division of Qualcomm Technologies, Inc.

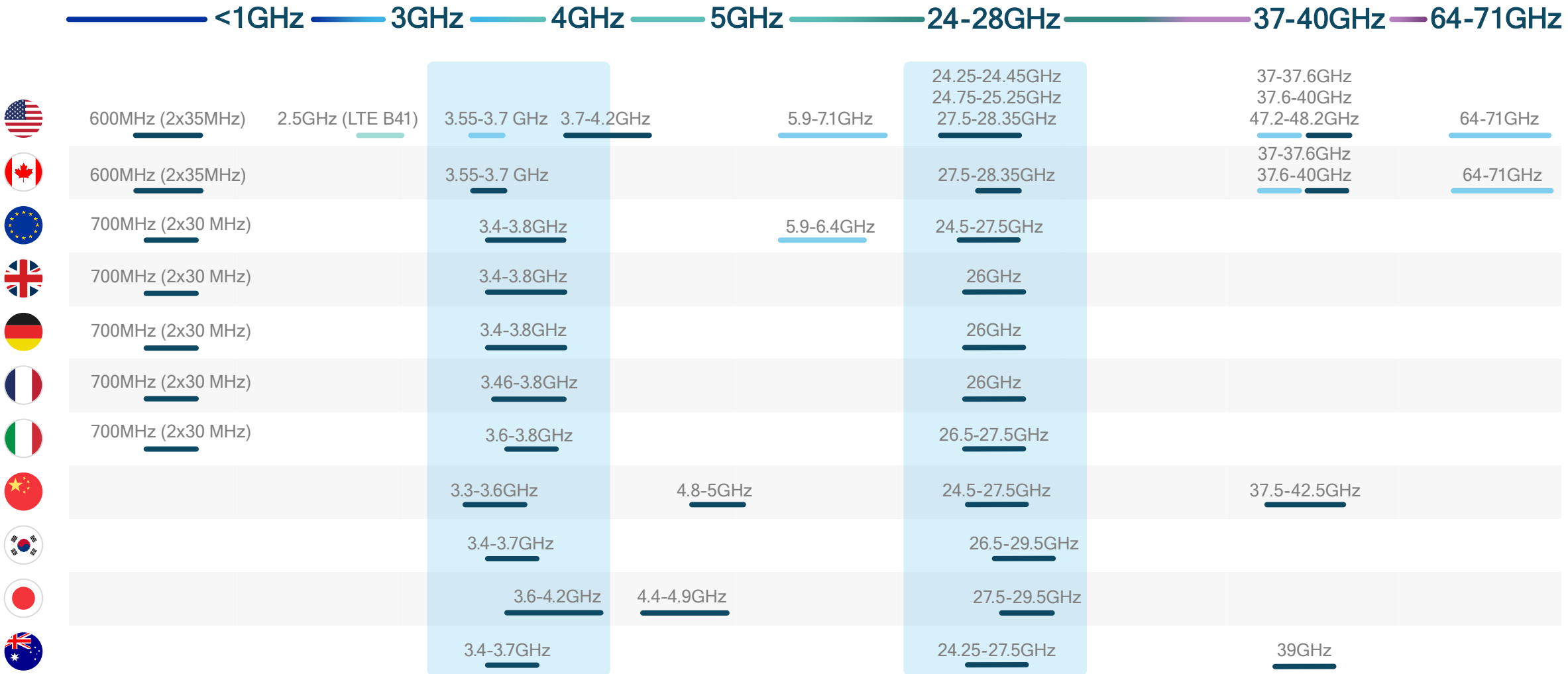
1. Such as Weighted Overlap Add (WOLA) utilized in LTE systems today. 2. DFT-Spread (DFT-S) OFDM. 3. Such as non-orthogonal Resource Spread Multiple Access (RSMA)

Scalable 5G NR OFDM numerology—examples



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

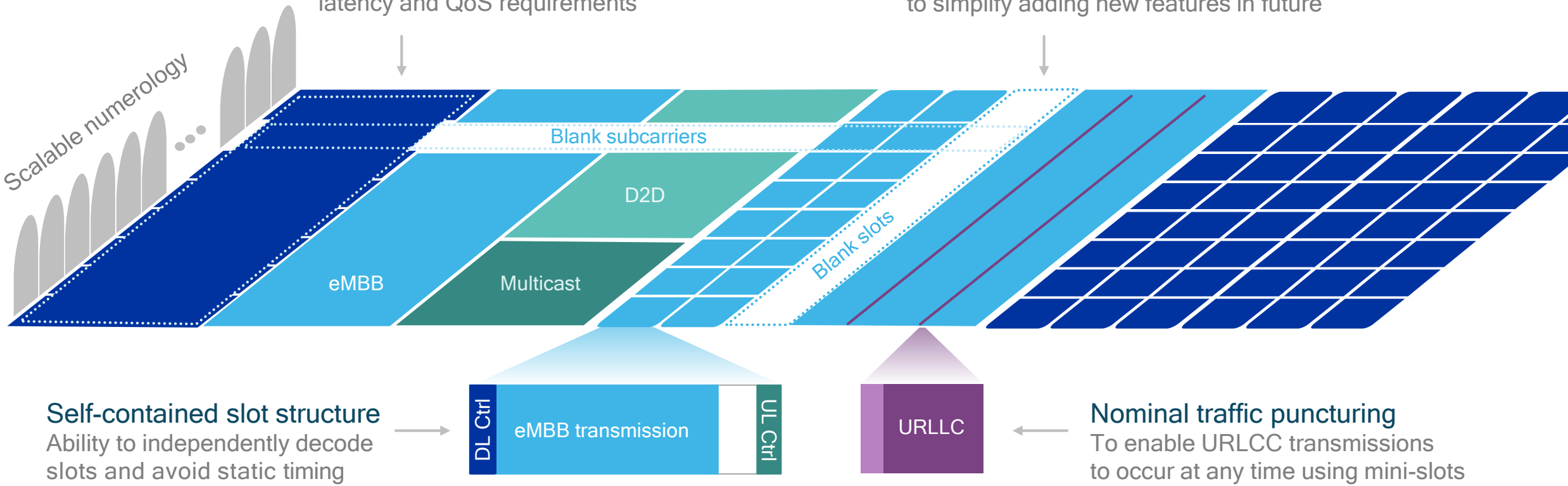
Existing band

Flexible slot-based 5G NR framework

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

Scalable slot duration
Efficient multiplexing of diverse latency and QoS requirements

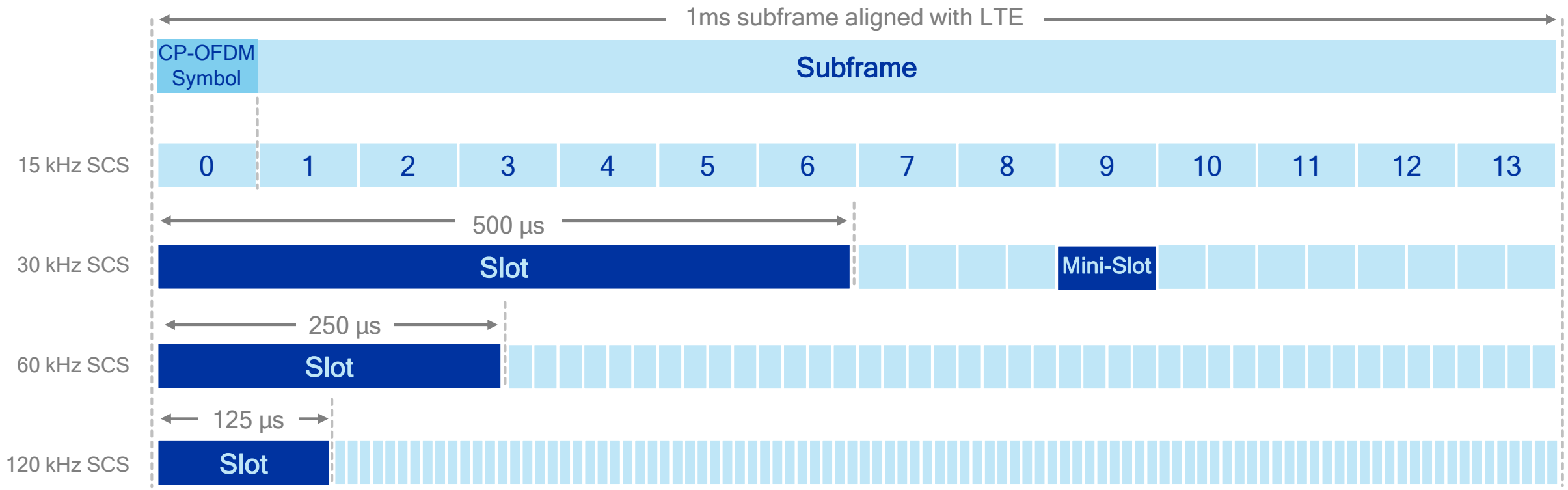
Forward compatibility
Transmissions well-confined in time/frequency to simplify adding new features in future



Self-contained slot structure
Ability to independently decode slots and avoid static timing relationships across slots

Nominal traffic puncturing
To enable URLCC transmissions to occur at any time using mini-slots

Scalable 5G NR slot duration for diverse latency/QoS



14 OFDM symbols per slot with mini-slot (2, 4, or 7 symbols) for shorter transmissions[1]

Supports slot aggregation for data-heavy transmissions

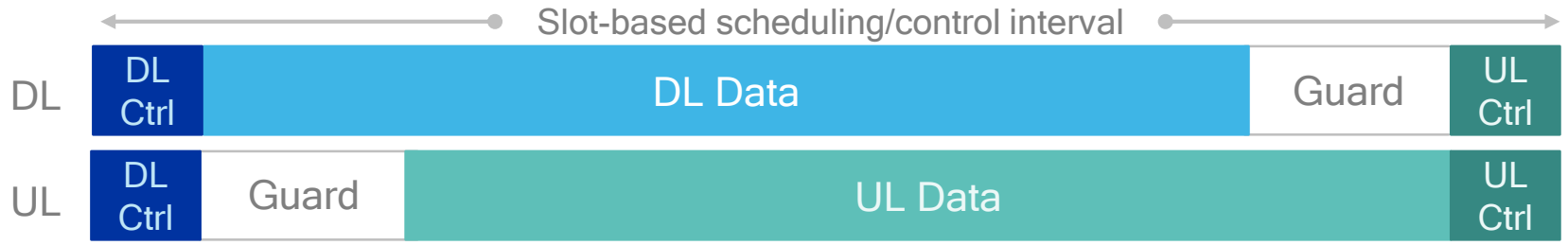
Efficient multiplexing of long and short transmissions[2]

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

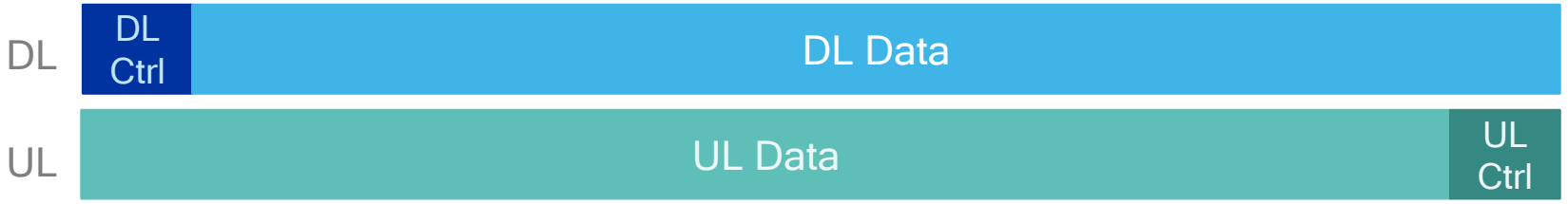
TDD Self-Contained

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



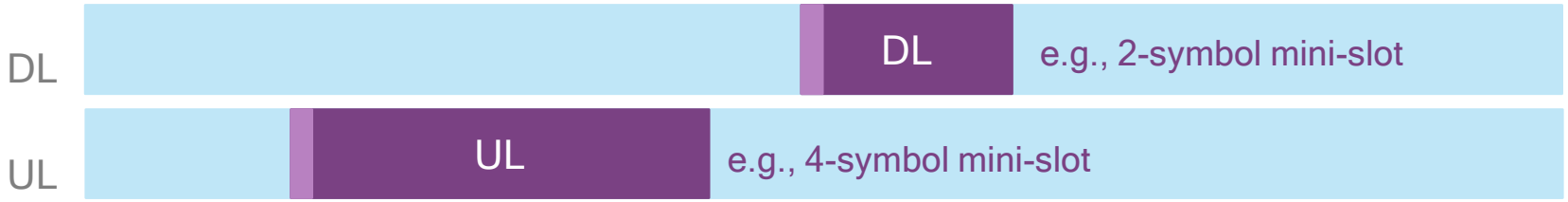
Data-centric

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

DL reference signals (DL DMRS) & UL Reference + Sounding (UL DSMR, SRS) not showed for simplicity

Benefits of the 5G NR TDD self-contained slot

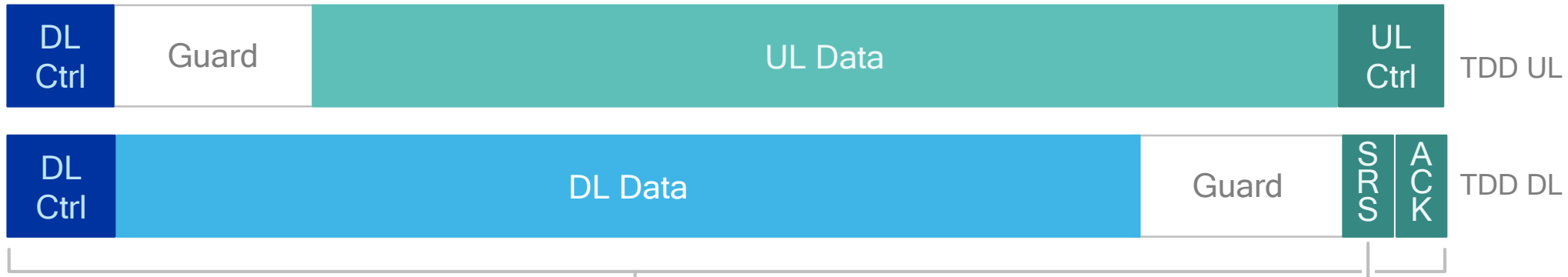
Much faster, more flexible TDD switching and turn around than 4G LTE

Flexibility for additional headers

E.g., channel reservation header for unlicensed/shared spectrum

More adaptive UL/DL

Faster TDD switching allows for more flexible capacity allocation



Low-latency

Faster TDD turn-around, with opportunity for UL/DL scheduling, data and ACK in the same slot

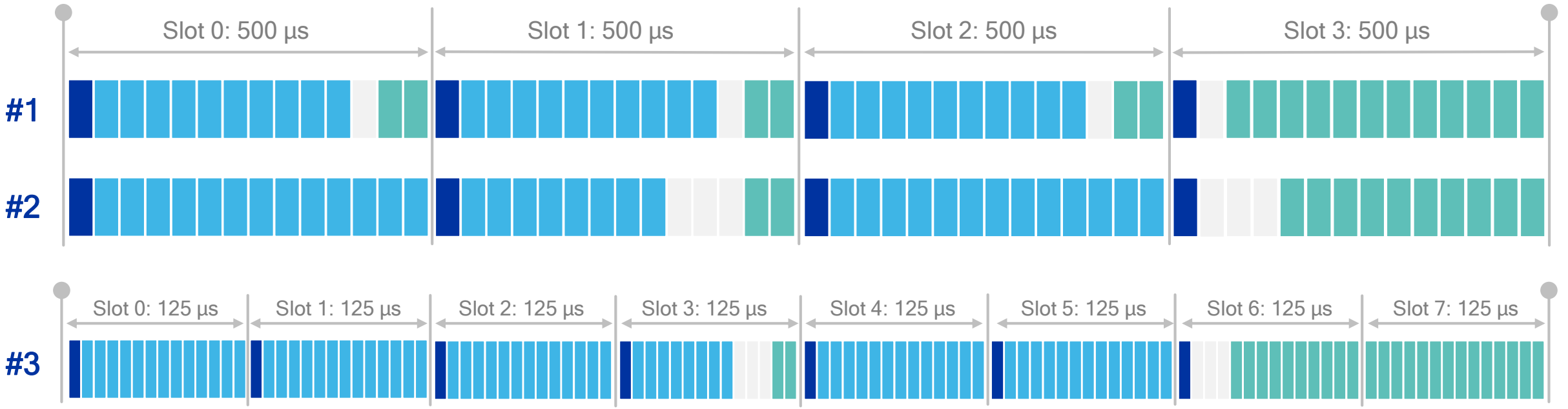
Efficient massive MIMO

Optimized TDD channel reciprocity with opportunity for SRS[1] every slot

1. Sounding Reference Signal

5G NR TDD self-contained slot structure in action

Three examples showcasing faster TDD switching for low latency



#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

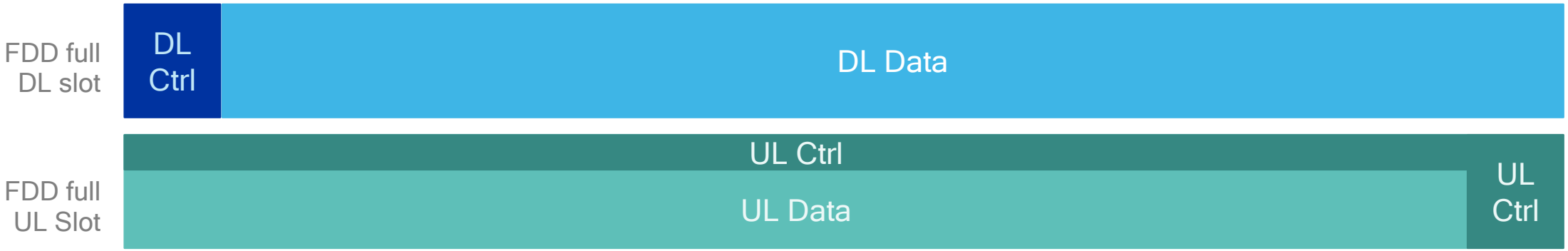
- Larger guard for outdoor deployment
- 6:2 configuration every 1ms (120kHz SCS)
- Slot 3 opportunity for ultra-low latency
- Bulk of UL traffic goes on Slots 6 & 7

DL reference signals (DL DMRS) & UL Reference + Sounding (UL DSMR, SRS) not showed for simplicity

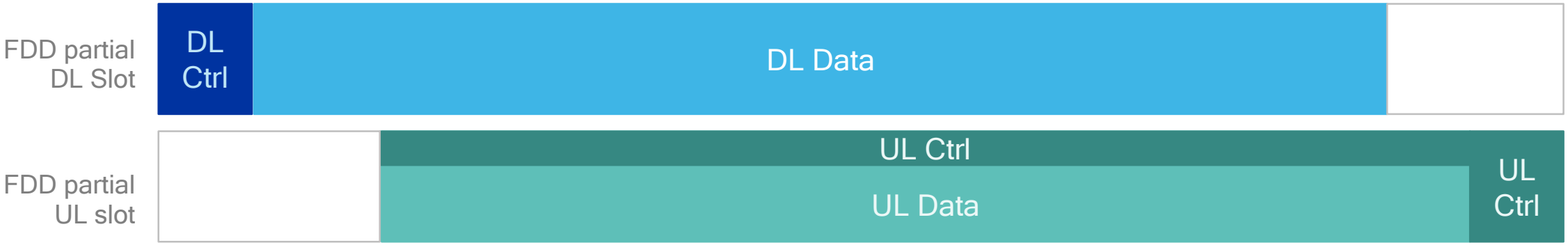
5G NR flexible FDD slot structure

Delivering low latency, extended coverage, and forward compatibility

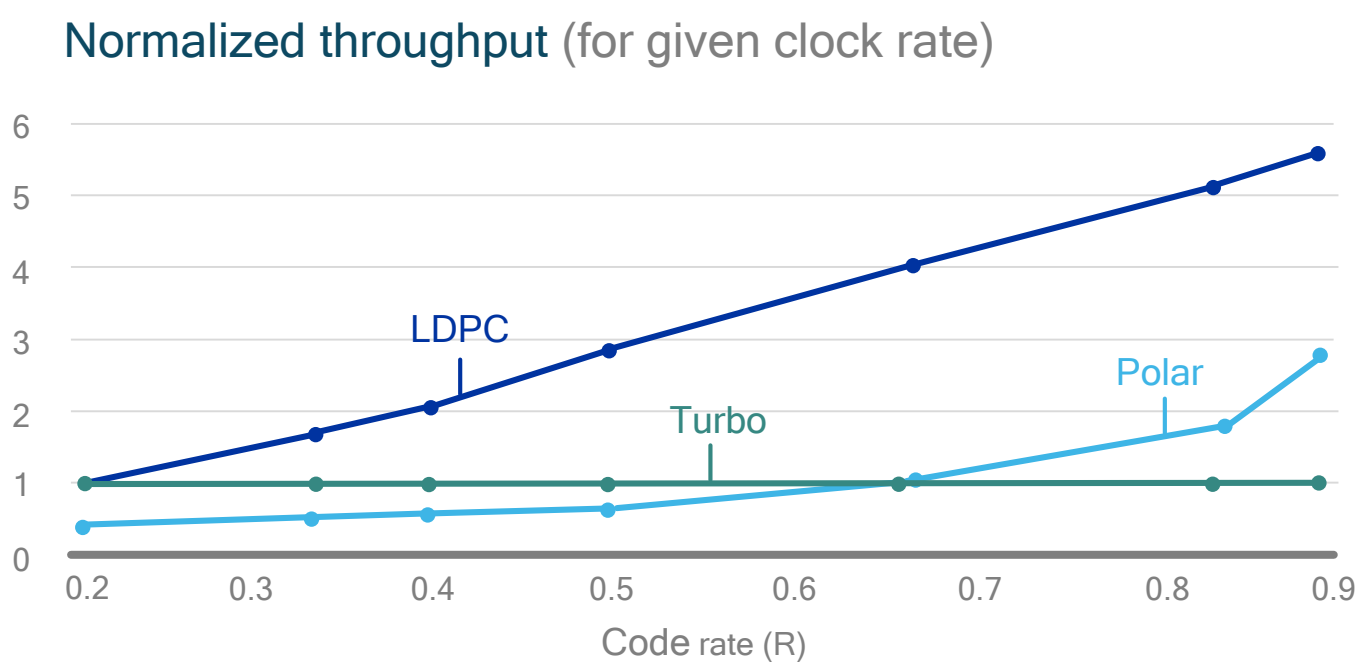
FDD baseline for continuous transmission and extended coverage



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



Advanced ME-LDPC[1] channel coding is more efficient than LTE Turbo code at higher data rates



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

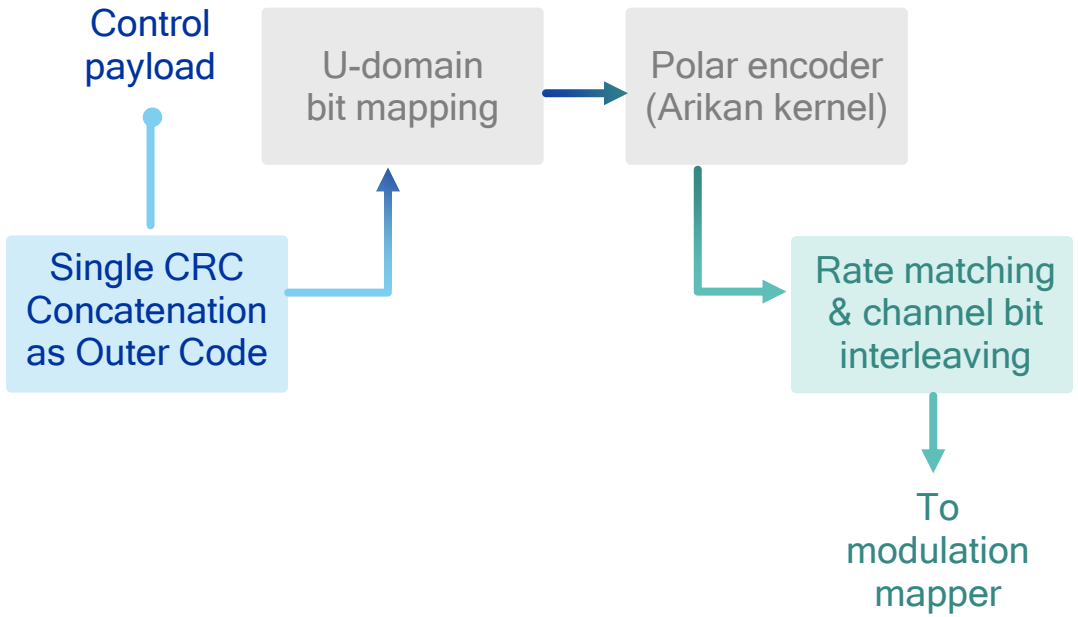
Selected as 5G NR eMBB data channel as part of 3GPP Release-15

1. Multi-Edge Low-Density Parity-Check

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

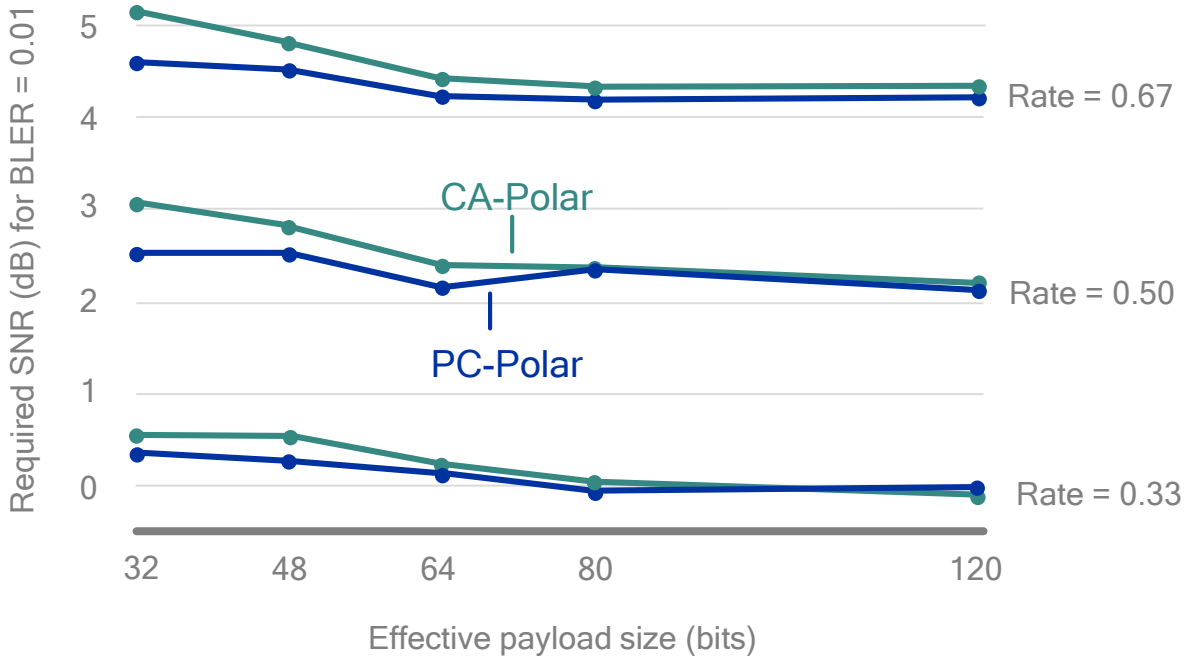
5G NR CRC-Aided (CA-Polar) design

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



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

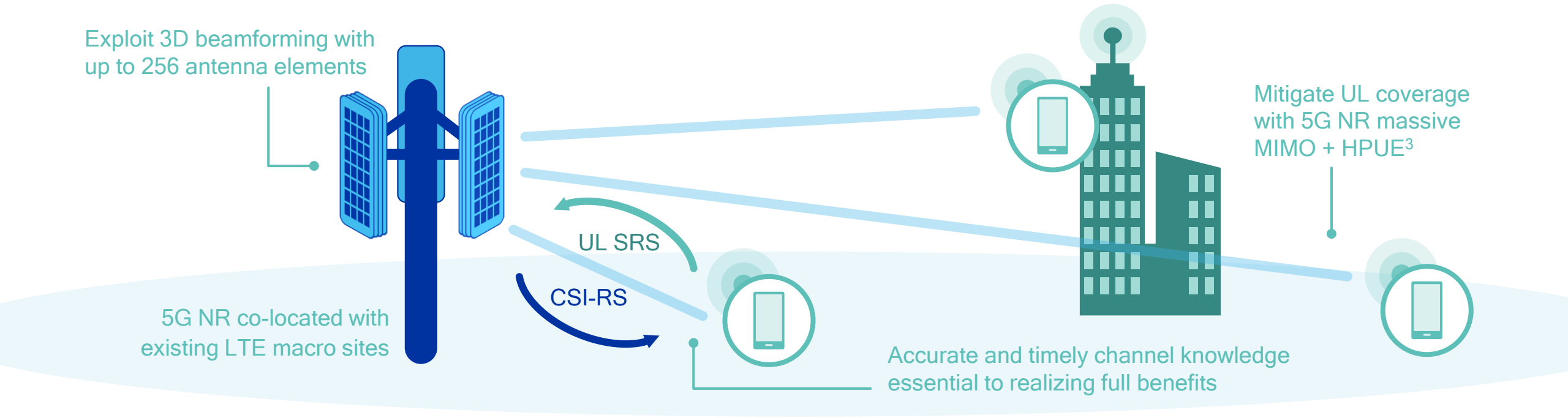
Versus PC-Polar[1] (lower is better)



1. Parity-Check Polar channel coding

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 SRS[1]

Enhanced CSI-RS[2] design and reporting mechanism

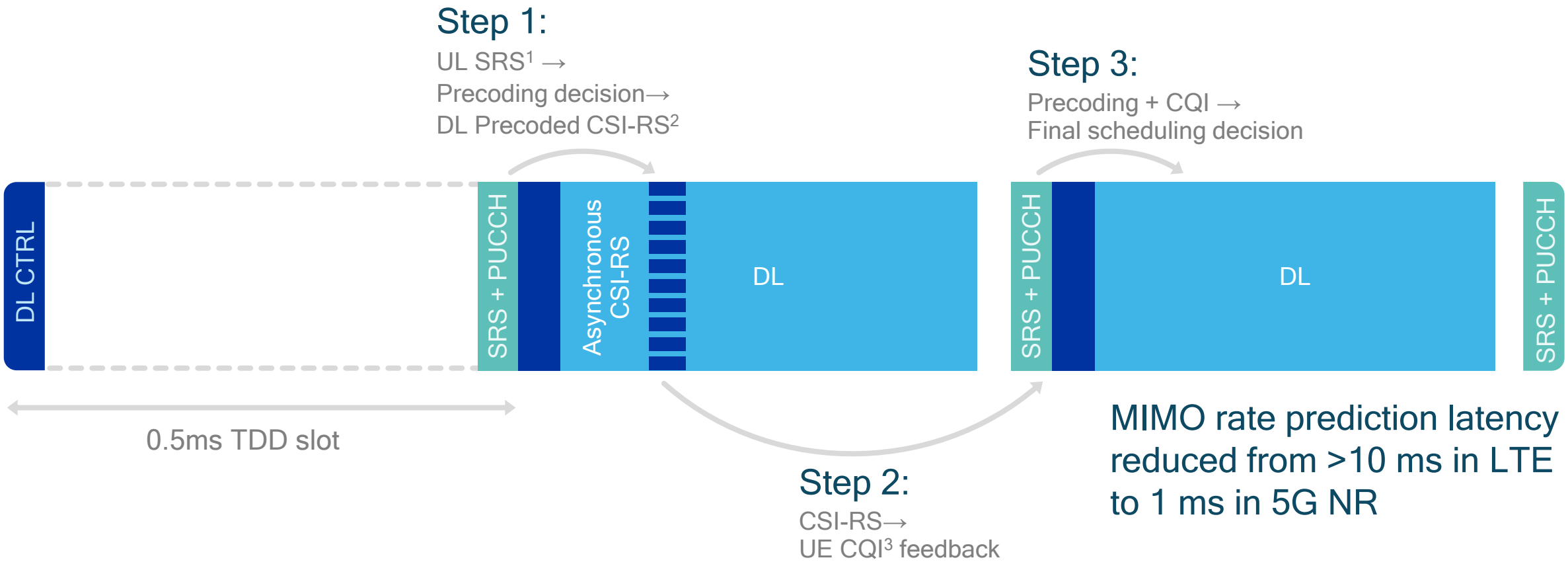
Advanced, high-spatial resolution codebook supporting up to 256 antennas

New features, such as distributed MIMO

1. Sounding Reference Signal. 2. Channel State Information Reference Signal; 3. High-Power User Equipment (HPUE) Tx power gains

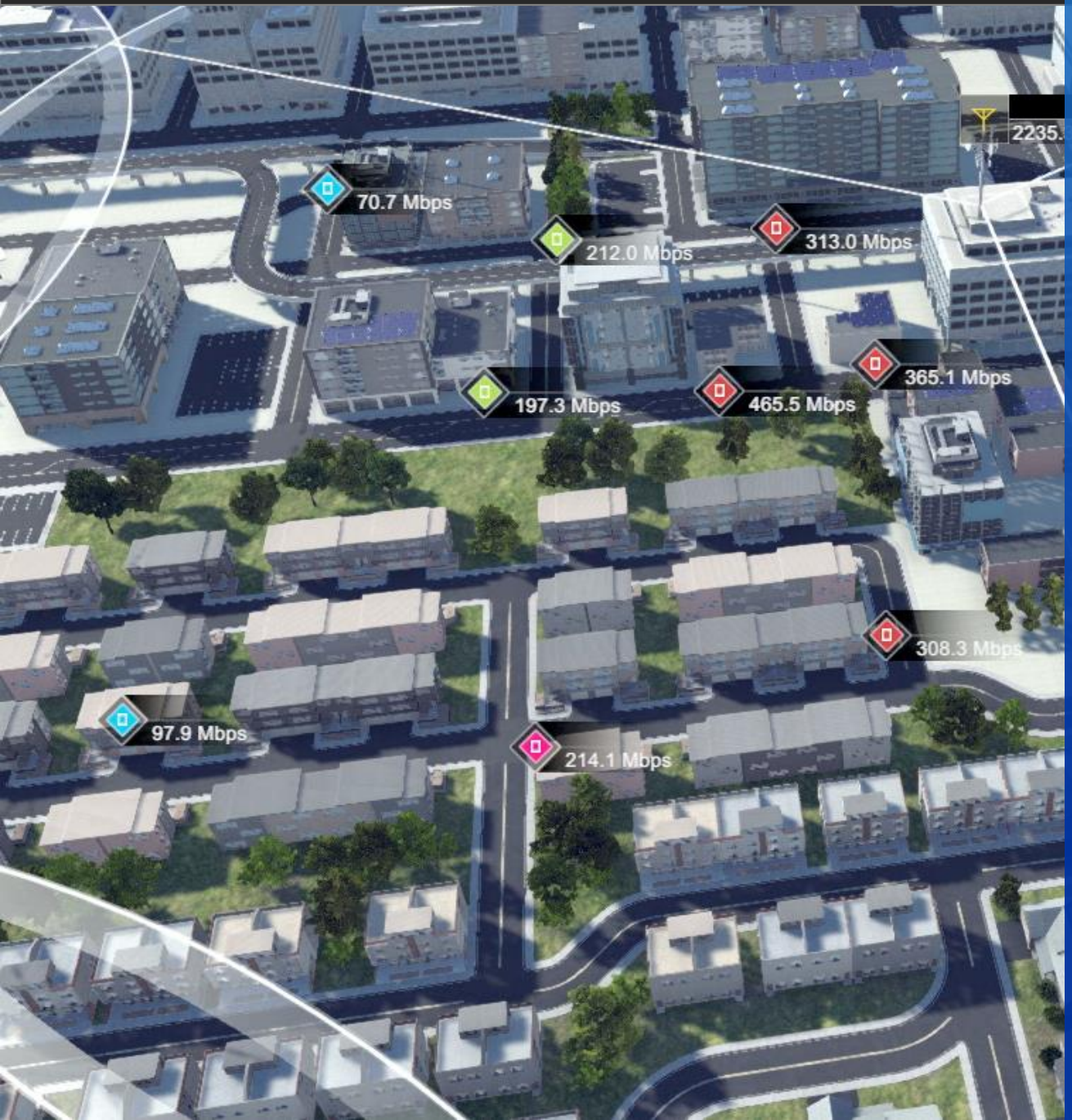
5G NR optimized design for TDD reciprocity procedures

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



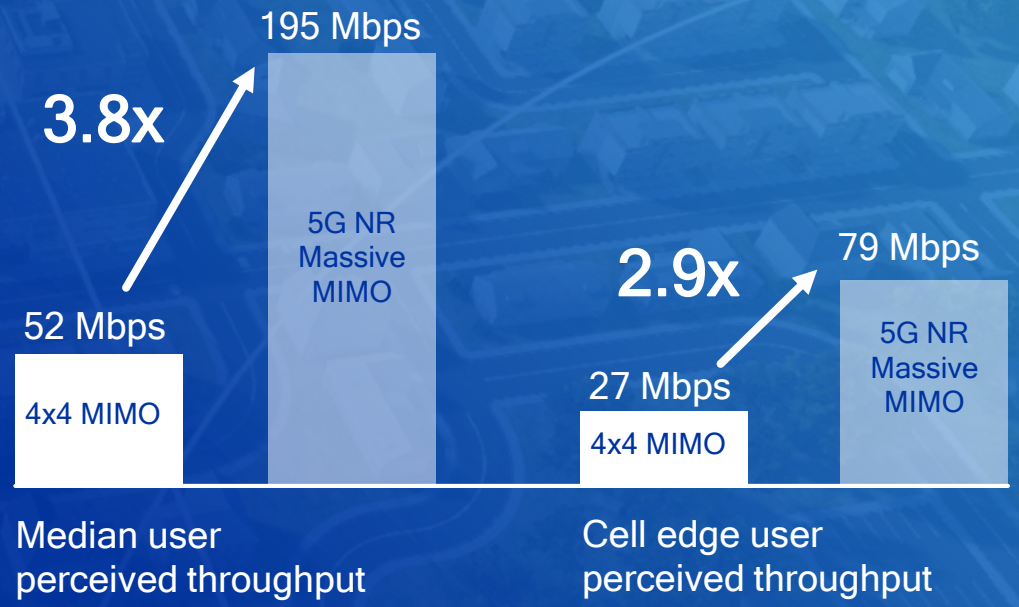
*Sub 6 GHz, macro cell numerology, 30 kHz tone spacing; Channel sounding opportunity increases from <= 200 Hz with LTE to 2 kHz with 5G NR. 1. Sounding Reference Signal. 2. Channel State Information Reference Signal. 3. Channel Quality Indicator

QUALCOMM 5G NR Sub-6 GHz Massive MIMO Simulation



5G NR massive MIMO increases coverage & capacity

Faster, more uniform data rates throughout cell



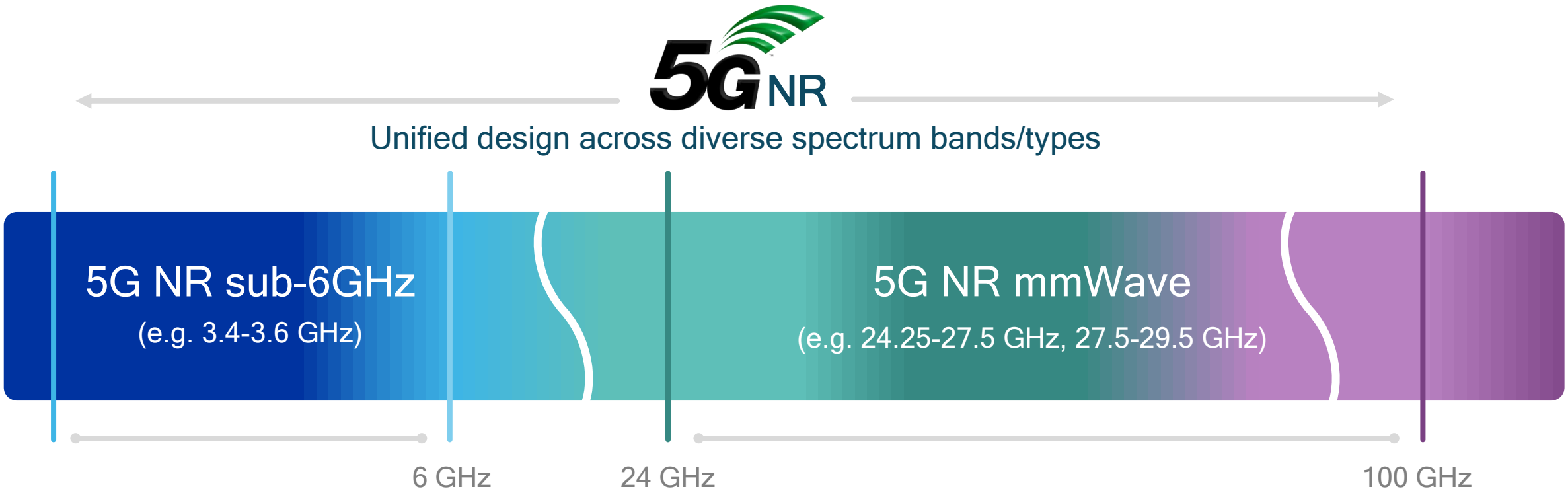
Median user perceived throughput

Cell edge user perceived throughput

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

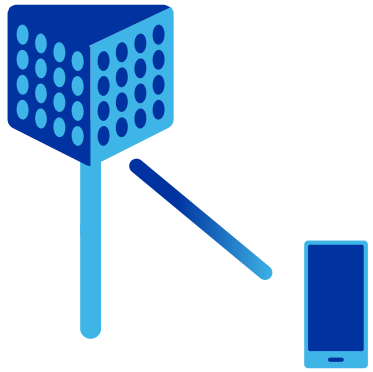


Multi-Gbps data rates
With large bandwidths (100s of MHz)

Much more capacity
With dense spatial reuse

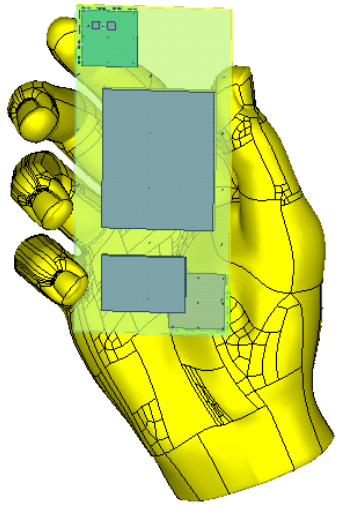
Flexible deployments
Opens up new opportunities

Overcoming numerous challenges to mobilize mmWave



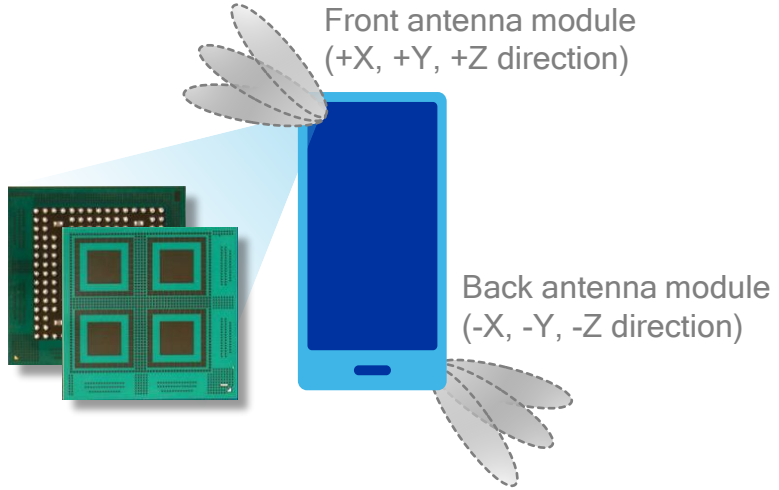
Coverage

Innovations to overcome significant path loss in bands above 24 GHz



Robustness

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

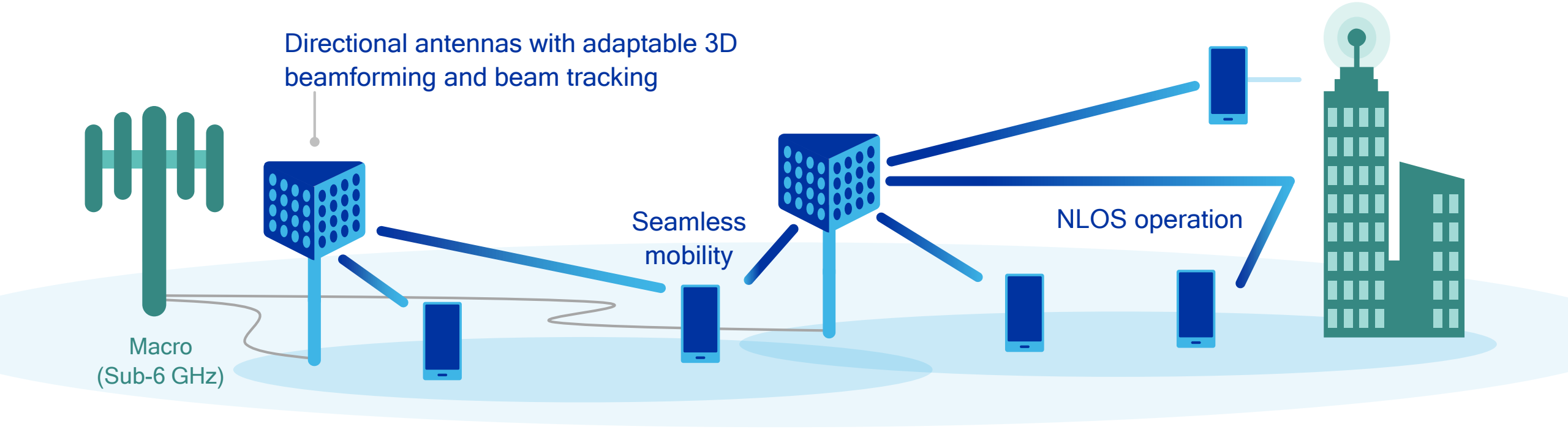


Device size/power

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

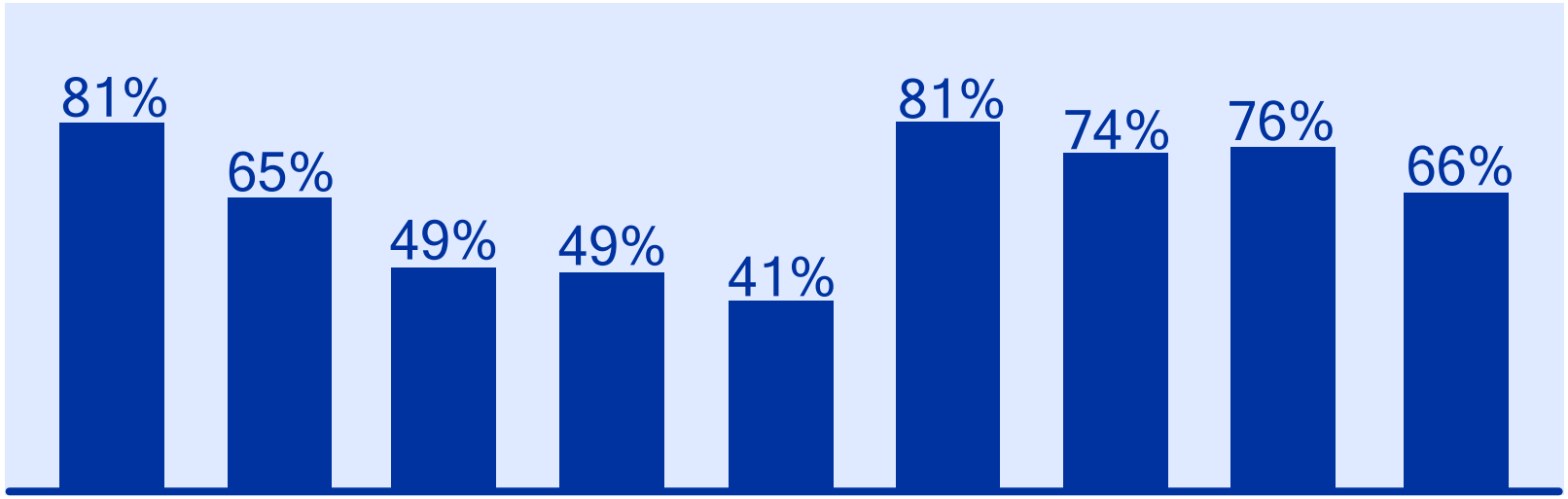
Qualcomm Research simulations based on extensive testing and measurements

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



	US City 1	US City 2	US City 3	US City 4	EU City 1	Korea City 1	Korea City 2	Hong Kong	Japan City 1
Total	48	36	32	31	28	41	31	39	37
Macro	0	8	15	14	7	33	31	39	37
Small	48	28	17	17	21	8	0	0	0

City site density (per km^2)

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

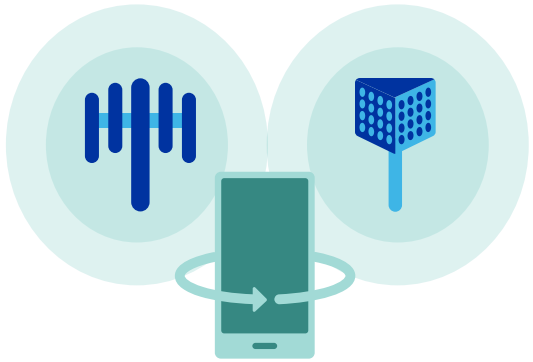
Qualcomm Research is a division of Qualcomm Technologies, Inc.

Assumptions: 3GPP 38.900 Umi/Uma propagation models, 256 x2 (V&H) antennas at gNodeB, 133 dB Maximum Allowable Path-Loss, 0.4 bps/Hz spectral efficiency.

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

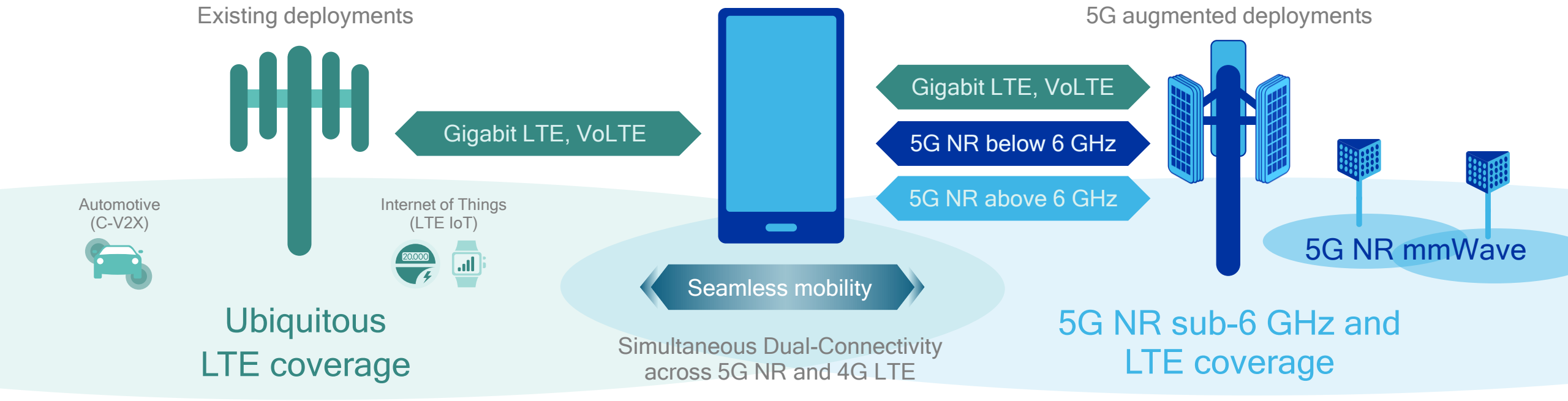
E.g., Licensed and unlicensed with 5G NR Licensed Assisted Access (LAA) – approved Rel-15 Study Item

Building on solid LTE CA and Dual Connectivity foundation

LTE Rel-10+
- Supplemental DL
- FDD/TDD CA
- LAA CA
- Dual Connectivity

5G NR Rel-15+
- LTE/5G NR NSA
- Supplemental UL
- Supplemental DL
- FDD/TDD CA
- NR LAA CA
- Dual Connectivity

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.

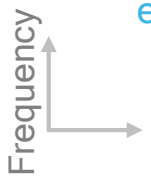
5G NR FDD/TDD CA to support mid-band deployments

Low-band FDD can help increase 5G NR TDD UL data rate/range[1]

5G NR mmWave
e.g., TDD 28 GHz

5G NR mid-band
e.g., TDD 3-5 GHz

Low-band
e.g., FDD 700 MHz



Non-Standalone (NSA)

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

e.g. <1 GHz | LTE Anchor | NR TDD, e.g. 3.5 GHz

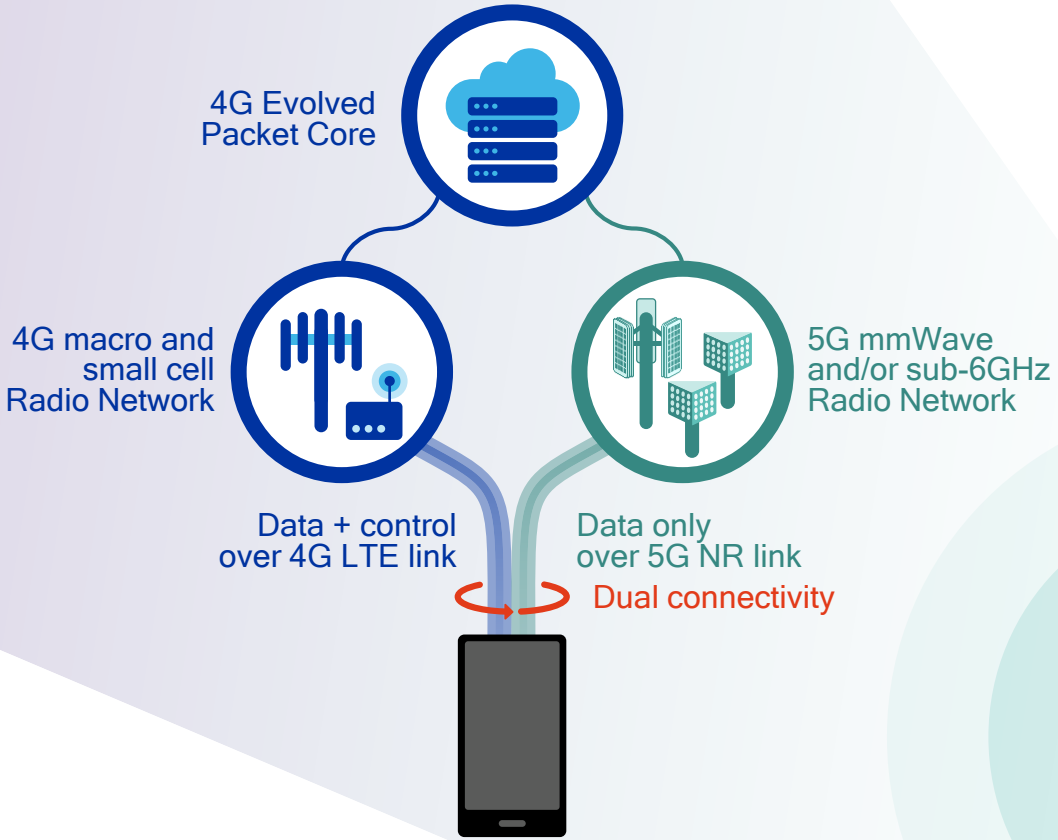
Standalone (SA)

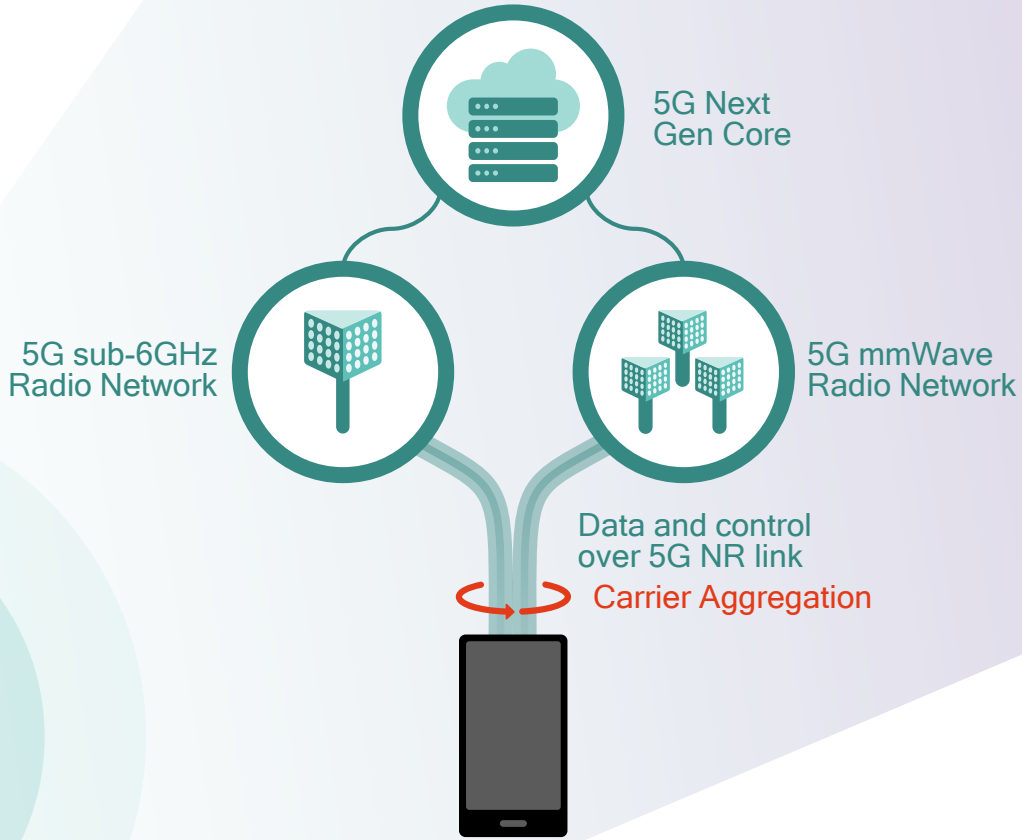
NR low band can carry NR uplink control and data for edge cell users

e.g. <1 GHz | NR TDD, e.g. 3.5 GHz

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





5G NR

Non-Standalone (NSA) option

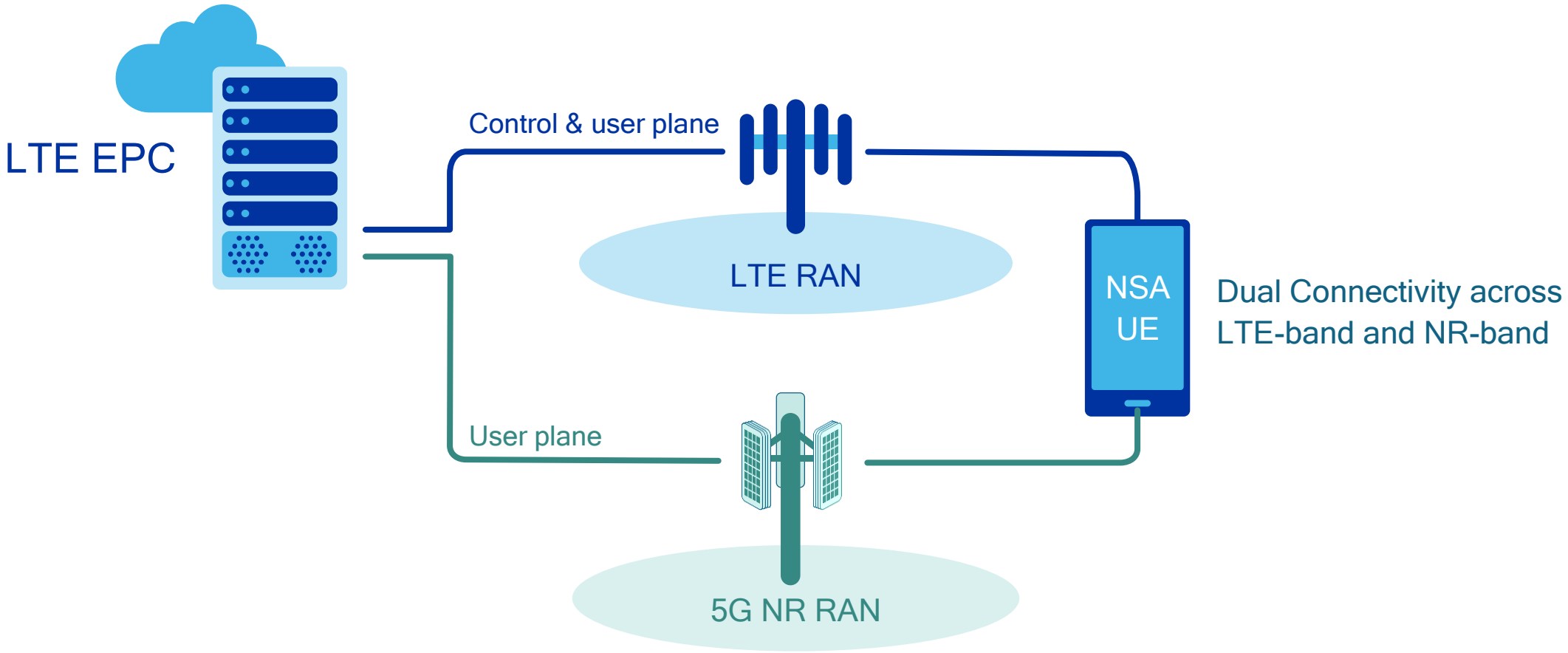
Fast-to-launch | Higher BW & UX* | VoLTE & CS voice

Standalone (SA) option

Network slicing | New services | VoNR & 4G fallback

*Initial NSA bandwidth and user experience in 2019-2020 5G NR launches as compared to SA launches in the same timeframe. Source: Qualcomm Technologies, Inc.

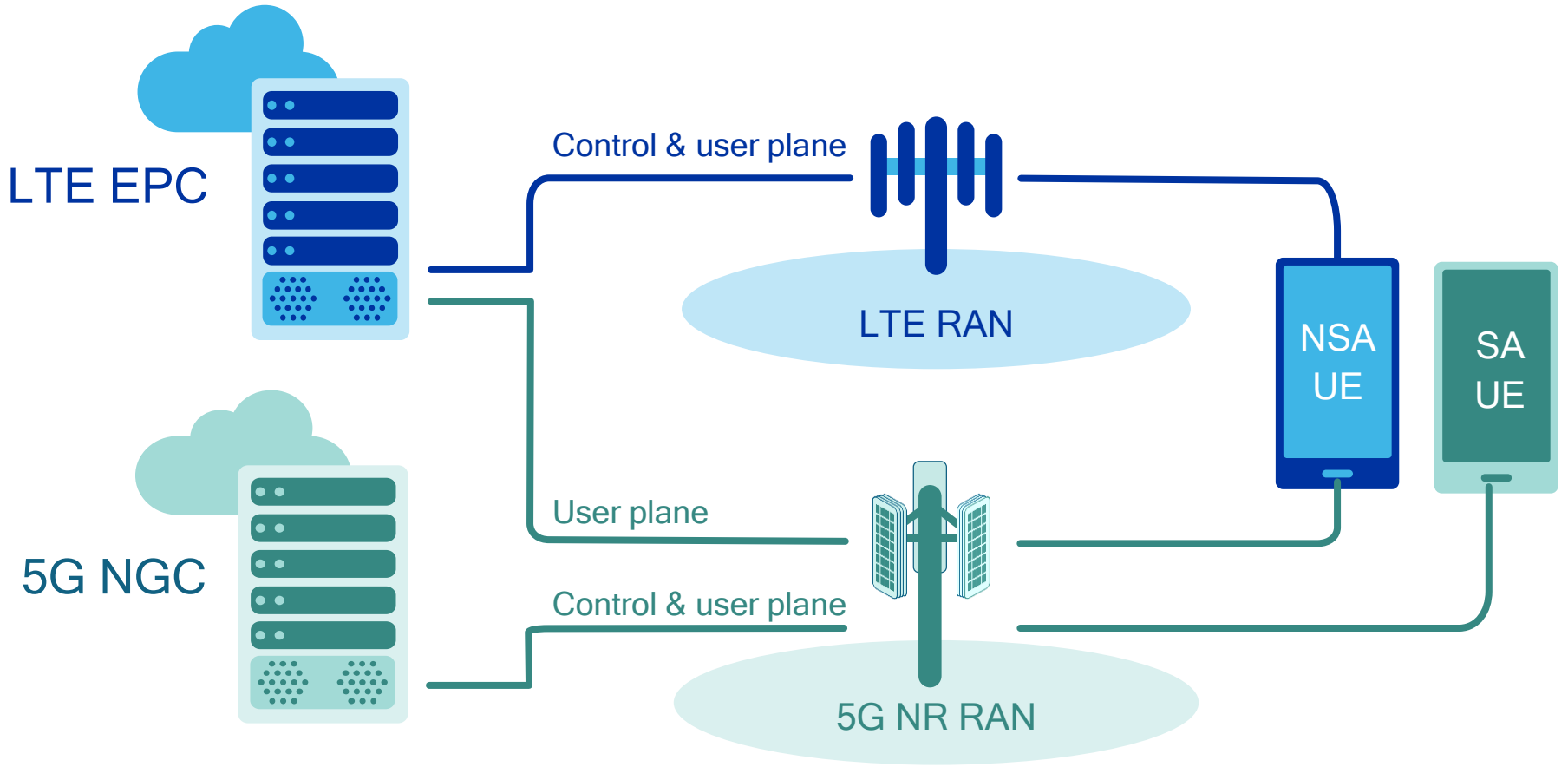
NSA 5G NR is accelerating 5G NR deployments for 2019



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



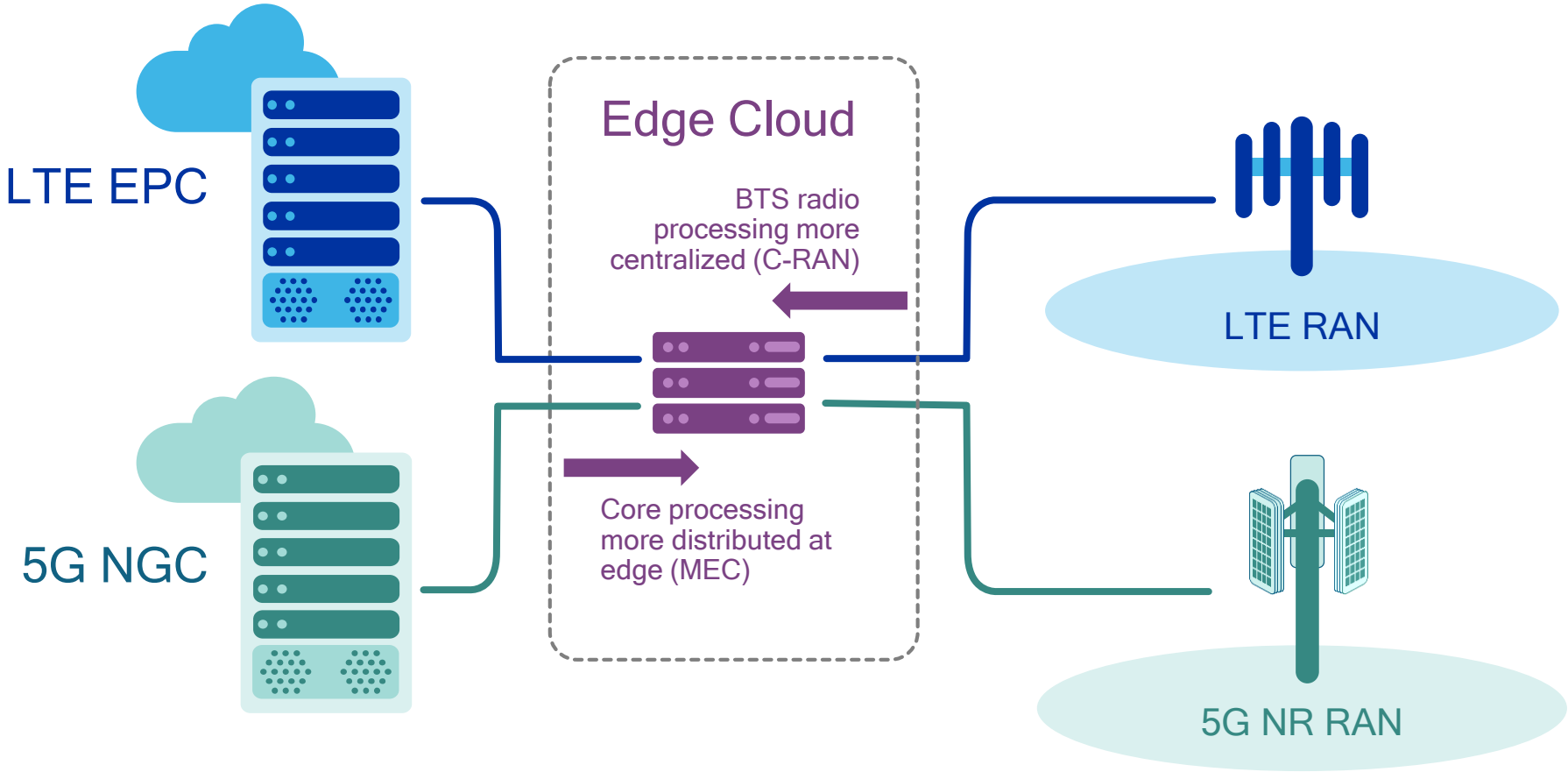
SA provides full user/control plane capability for 5G NR, seamlessly coexisting with NSA UEs

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

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®

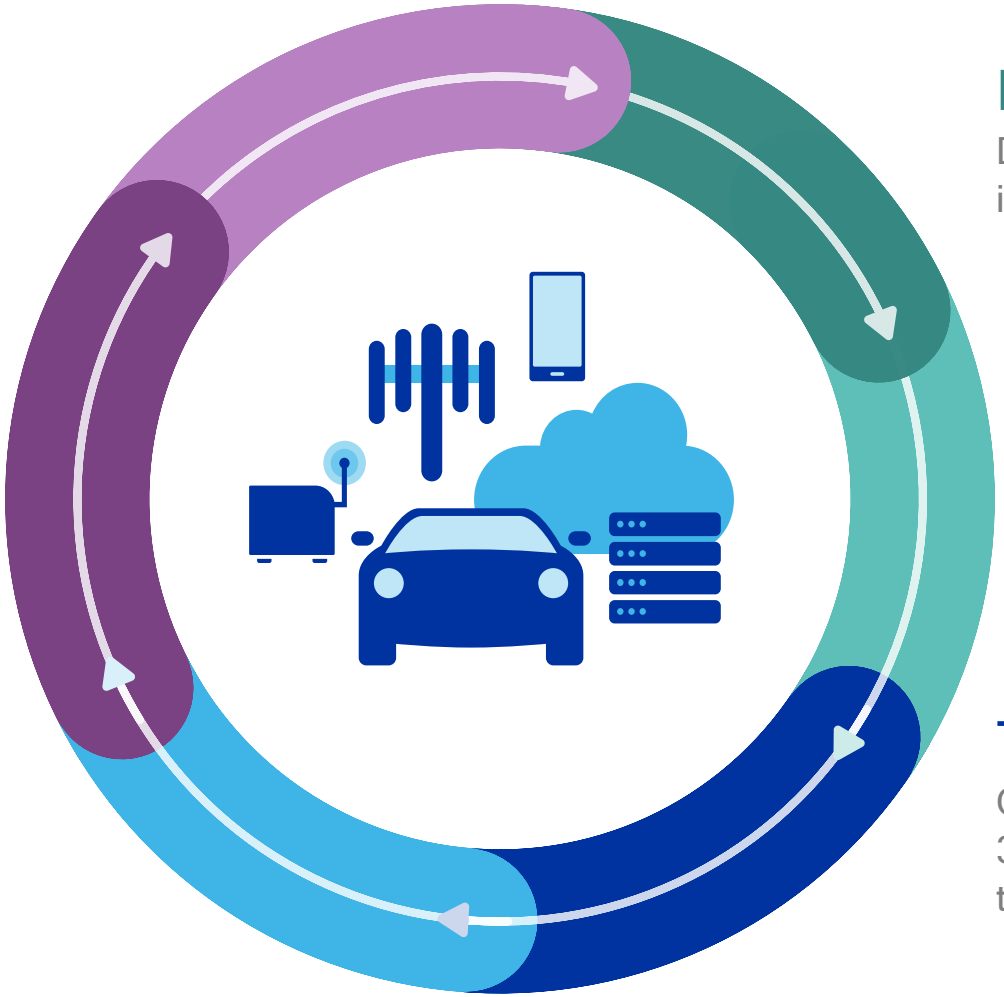
*Cumulative expenditures to date since 1985

Foundation to 5G leadership is technology leadership

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

Invention
Invent new technologies and e2e system architecture

Proof-of-concept
Deliver end-to-end prototypes and impactful demonstrations



Vision
Identify a problem or need; establish requirements

Standardization
Drive e2e design with ecosystem and through standards process

Commercialization
Engage with global network operators to deploy new features with standards-compliant infrastructure and devices

Trials
Collaborate on OTA field trials that track 3GPP standardization and drive ecosystem towards rapid commercialization

Qualcomm has led the evolution and expansion of LTE

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

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

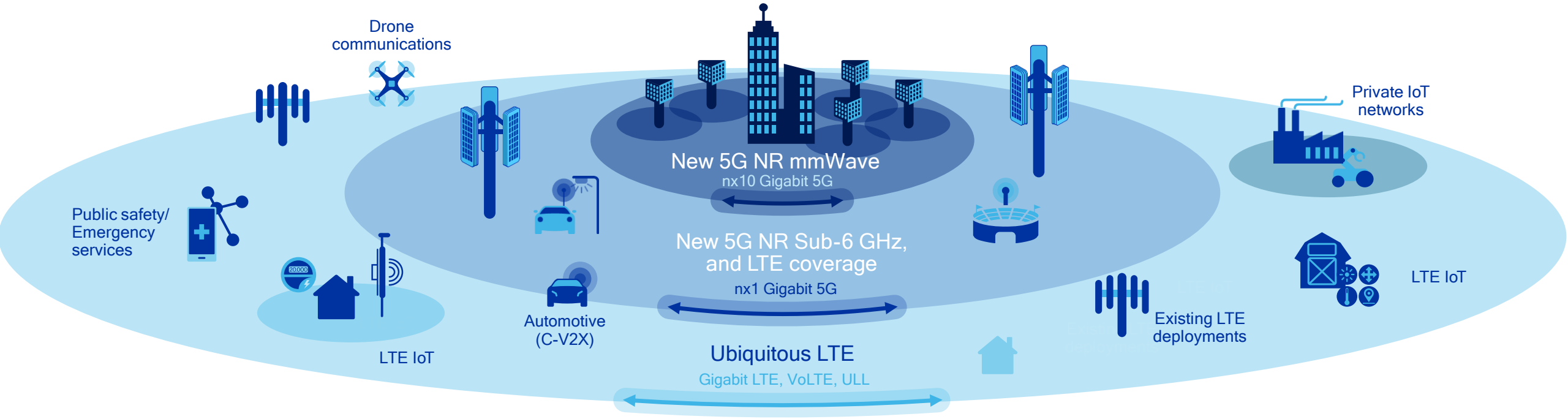
Small cell self-configuration techniques

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

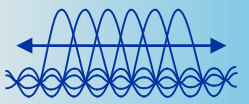
LTE IoT, C-V2X, etc. are expanding the mobile ecosystem today

LTE will be submitted with 5G NR to meet IMT-2020 requirements[1]

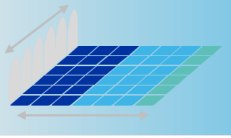
5G NR will fully leverage LTE investments for a phased roll-out

1. ITU Recommendation ITU-R M.2083-0, September, 2015

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

5G NR

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

First successful 5G NR interoperable connection

3GPP
A GLOBAL INITIATIVE

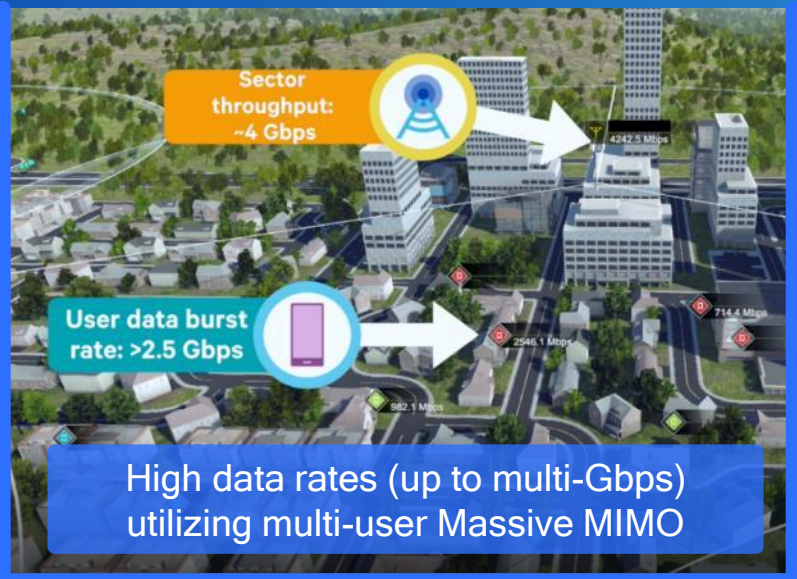
Fundamental contributions to 3GPP standardization

Technologies part of 5G NR Release-15

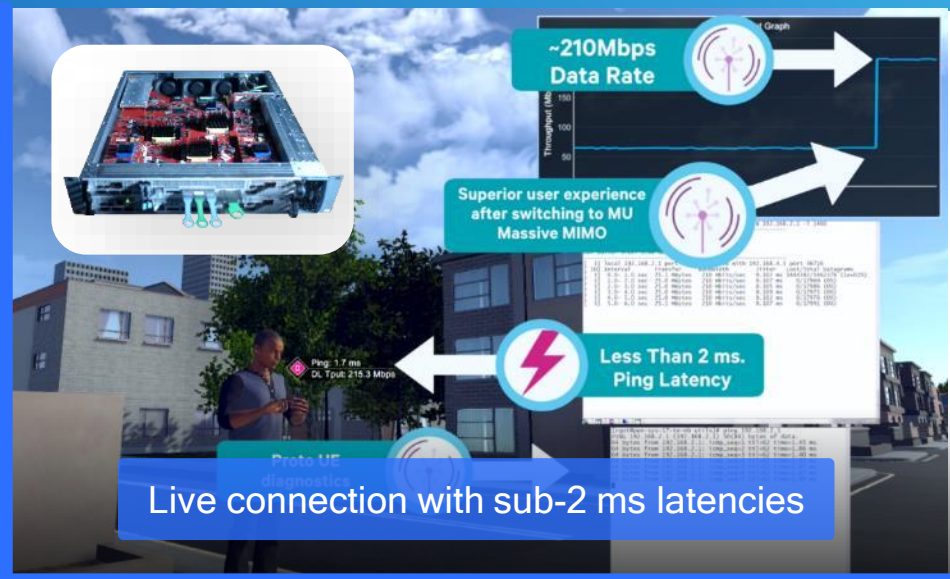
Qualcomm Research 5G NR Sub-6 GHz Prototype

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

Wide area coverage at 3.3-3.8 GHz band with multiple simultaneous users



High data rates (up to multi-Gbps) utilizing multi-user Massive MIMO



Live connection with sub-2 ms latencies

Kpis	MIMO	MU-MIMO
Downlink Datarate (Gain %)	12.84 Mbps	32.47 Mbps (+152.88 %)
MIMO SINR	3.46 dB	4.97 dB
Modulation Order	QPSK	QPSK
Base Station Rank	2	11

Faster, more uniform data rates both outdoor and indoor

Self-contained TDD operation

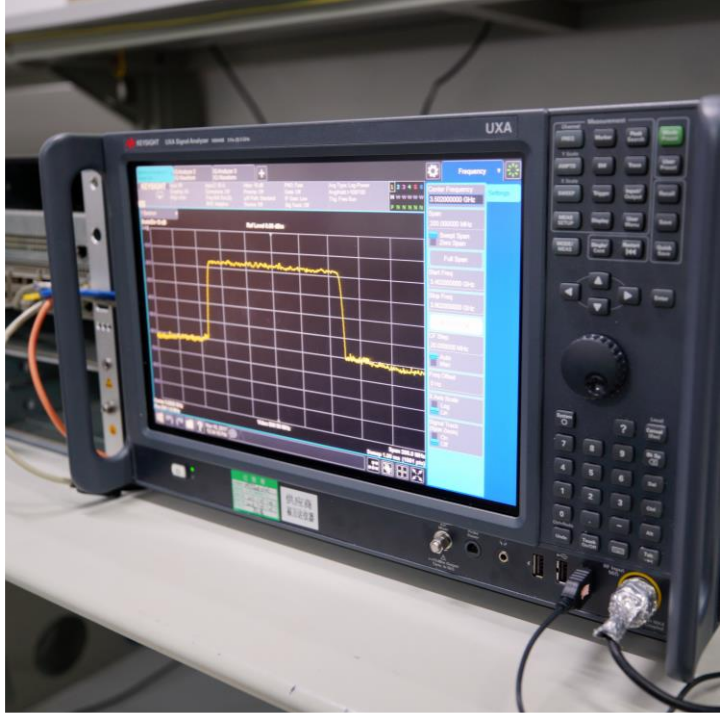
The world's first

end-to-end 5G NR sub-6 GHz interoperable connection based on 3GPP standard

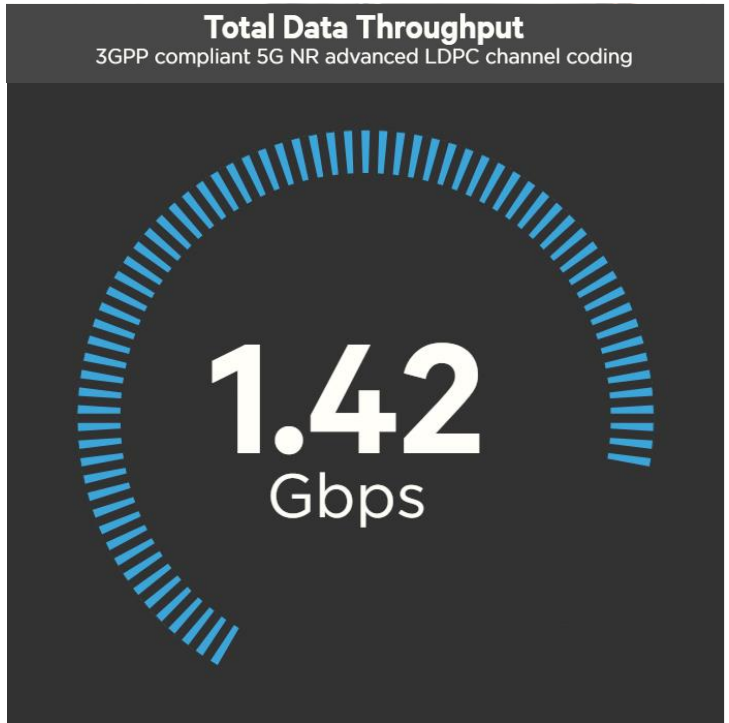
中国移动 China Mobile ZTE中兴 QUALCOMM

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

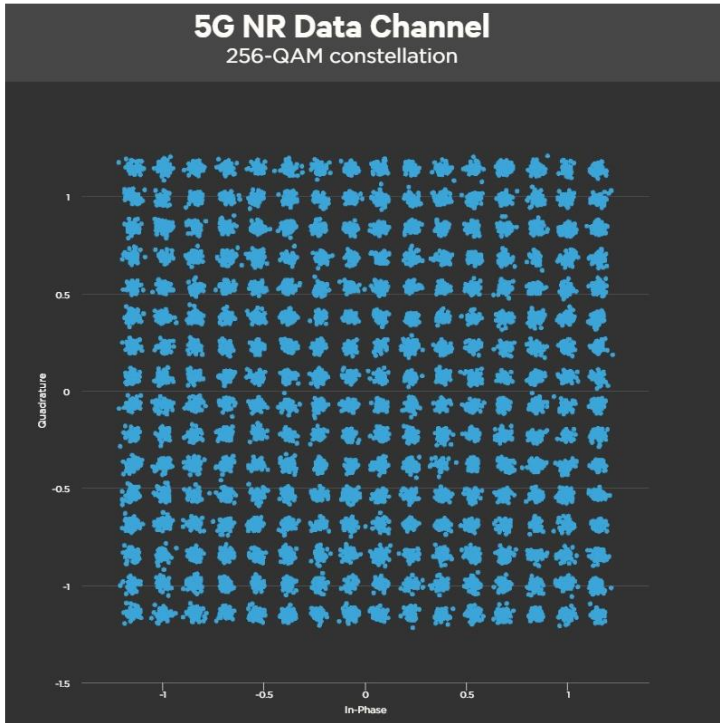
- ☑ 5G NR scalable OFDM air interface
- ☑ 5G NR low-latency slot-based framework
- ☑ 5G NR advanced channel coding
- ☑ 100 MHz bandwidth, operating at 3.5 GHz



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

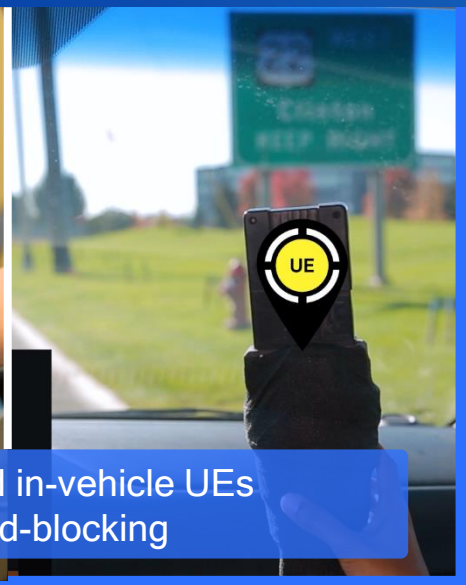


5G NR Data Channel
256-QAM constellation



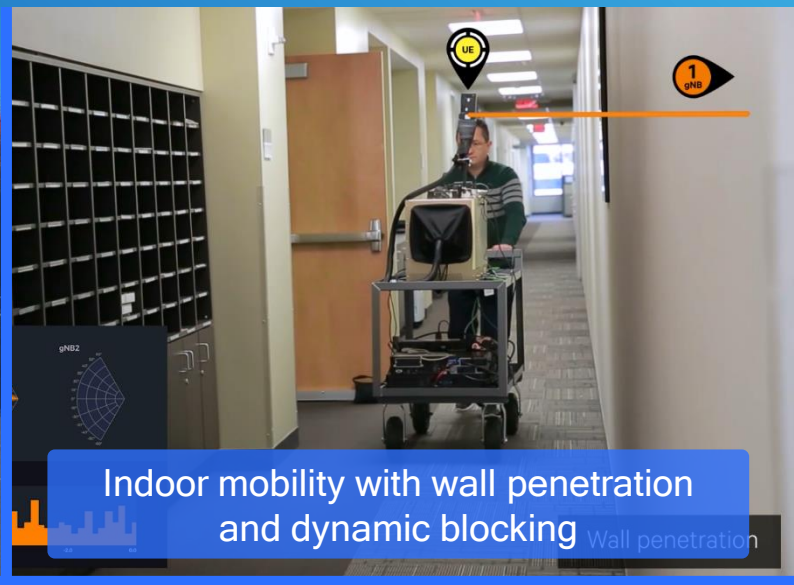
Qualcomm Research 5G mmWave prototype

Showcasing robust mobile communications in real-world OTA testing

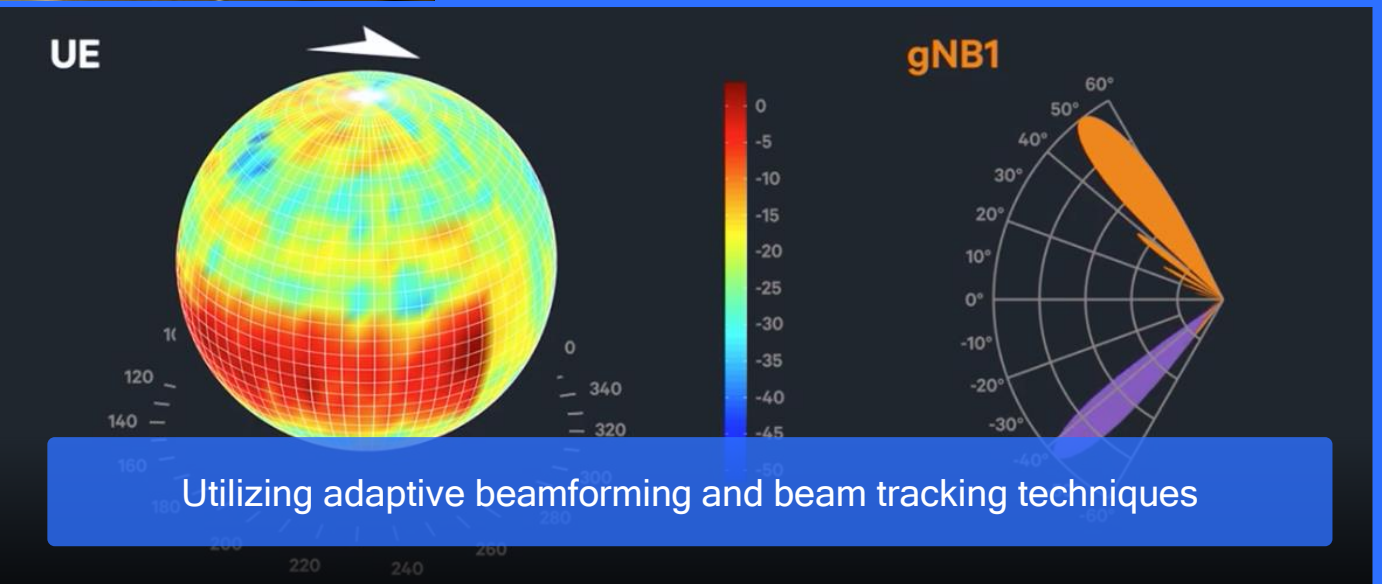


Handheld and in-vehicle UEs with hand-blocking

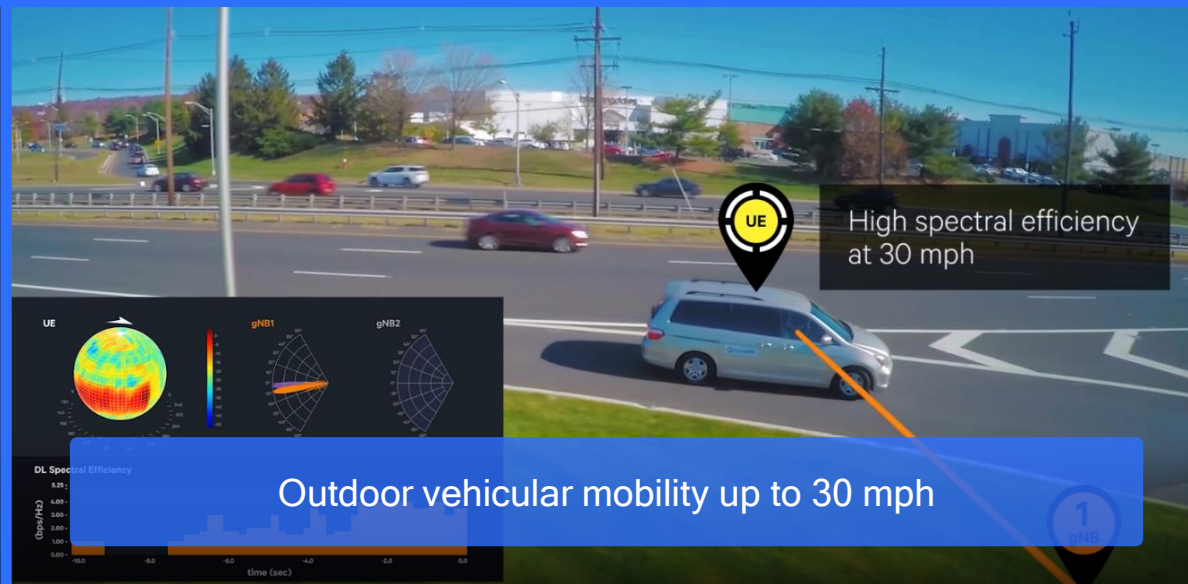
Multiple gNodeBs with seamless handovers



Indoor mobility with wall penetration and dynamic blocking



Utilizing adaptive beamforming and beam tracking techniques

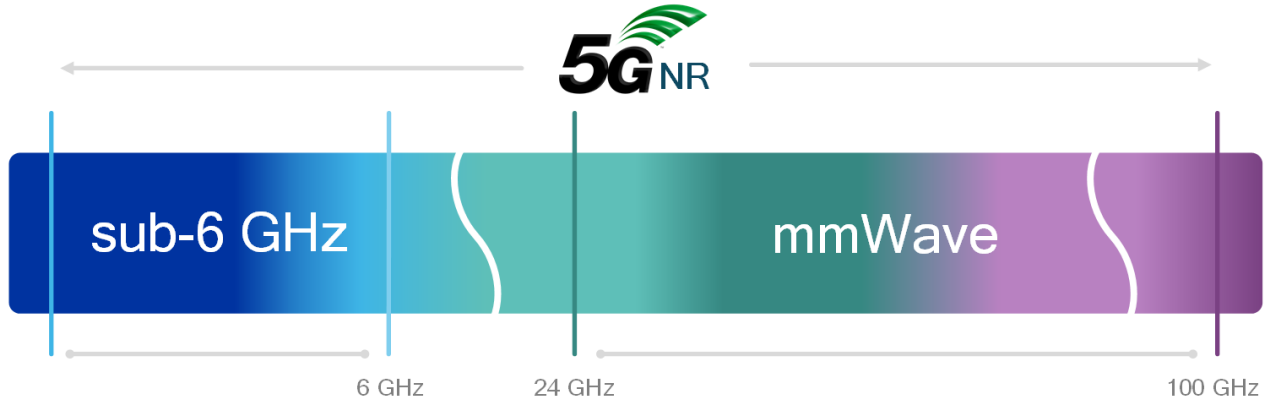


Outdoor vehicular mobility up to 30 mph

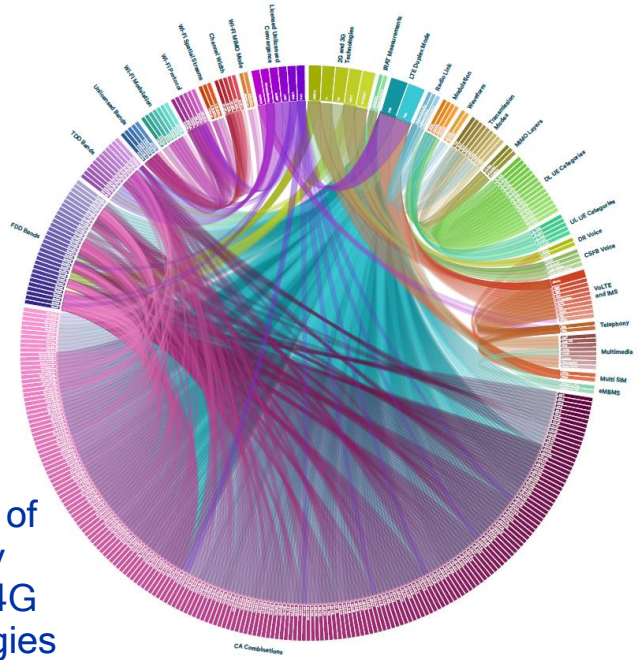
Complexity of mobile systems is accelerating

5G NR massively impacts RF front end design

Extremely wide spectrum range

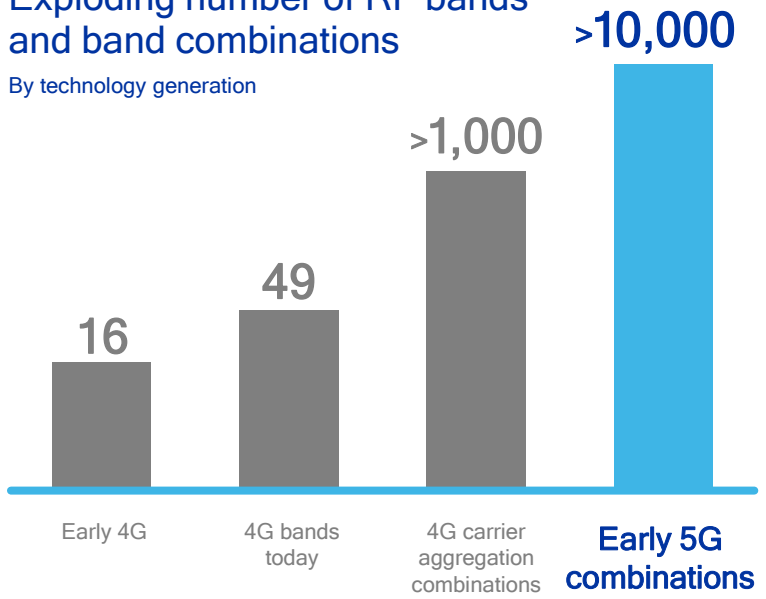


Support of legacy 2G/3G/4G technologies



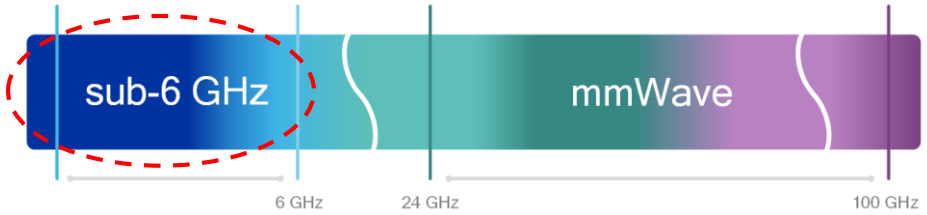
Exploding number of RF bands and band combinations

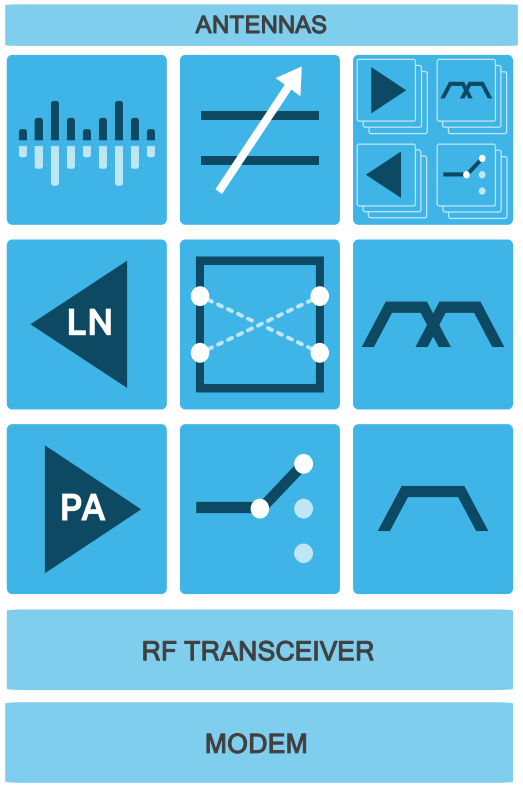
By technology generation



Source: Qualcomm Technologies, Inc. internal analysis

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

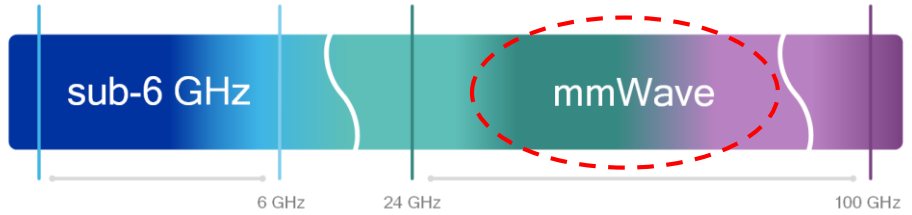
RFFE capabilities

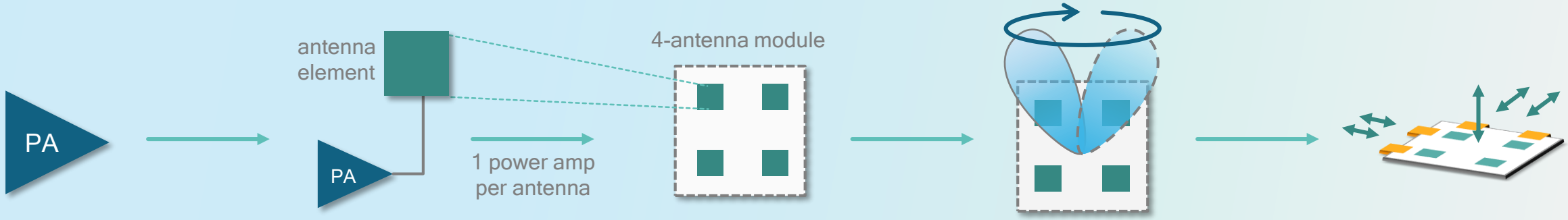
RFFE enhancements

*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

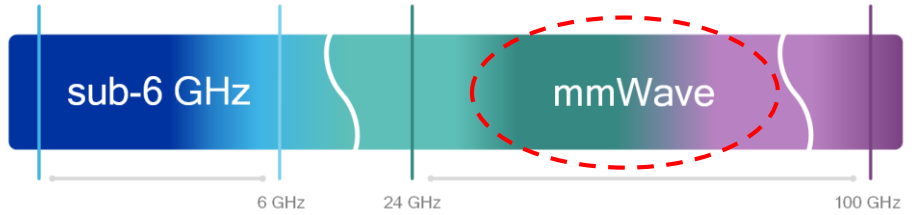
# of PAs and antennas determines max EIRP[1]

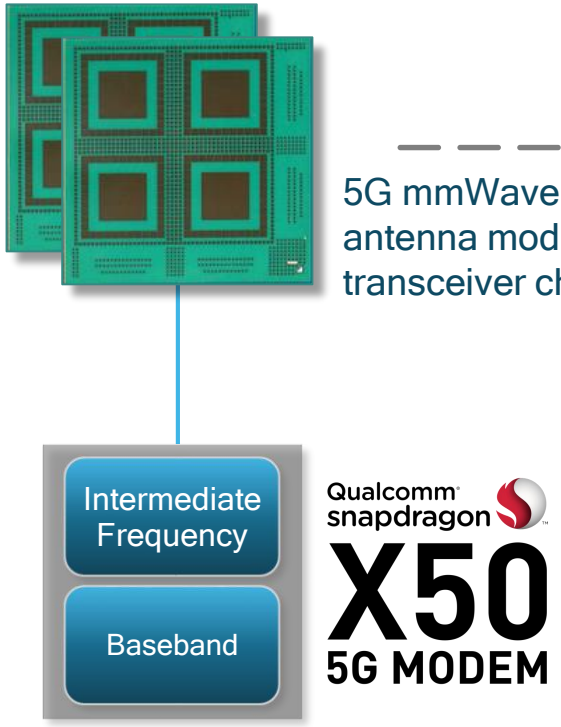
Beamforming and directional architectures allow more gain

Effective directional transmit power (aka EIRP[1])

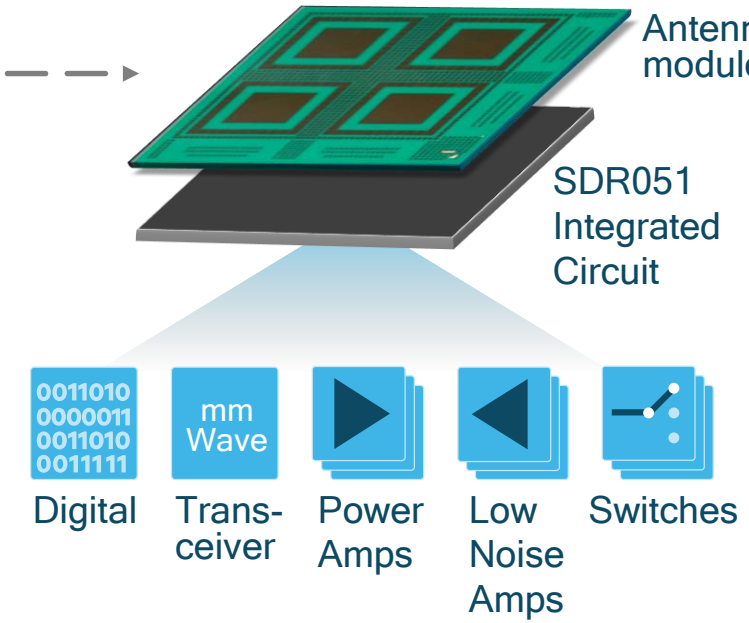
[1] EIRP = Effective Isotropic Radiated Power. Represents peak directional power transmitted from the antenna array relative to an isotropic transmission

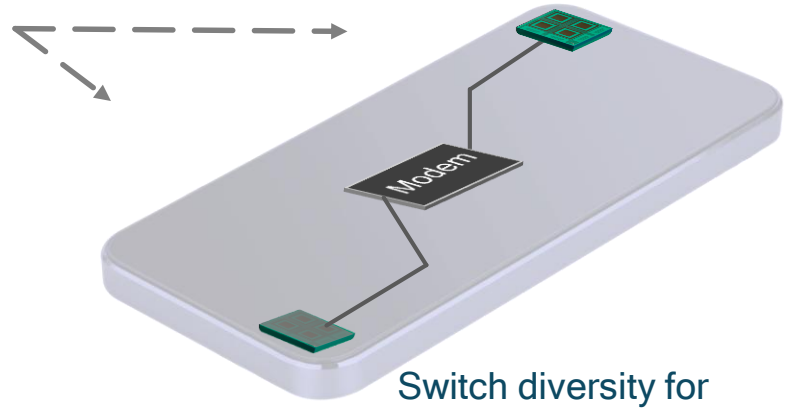
Snapdragon X50 mmWave solution





5G mmWave antenna modules & transceiver chips





Switch diversity for mmWave coverage

Snapdragon X50 5G mmWave architecture

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

Architecture allows flexible placements and multiple modules

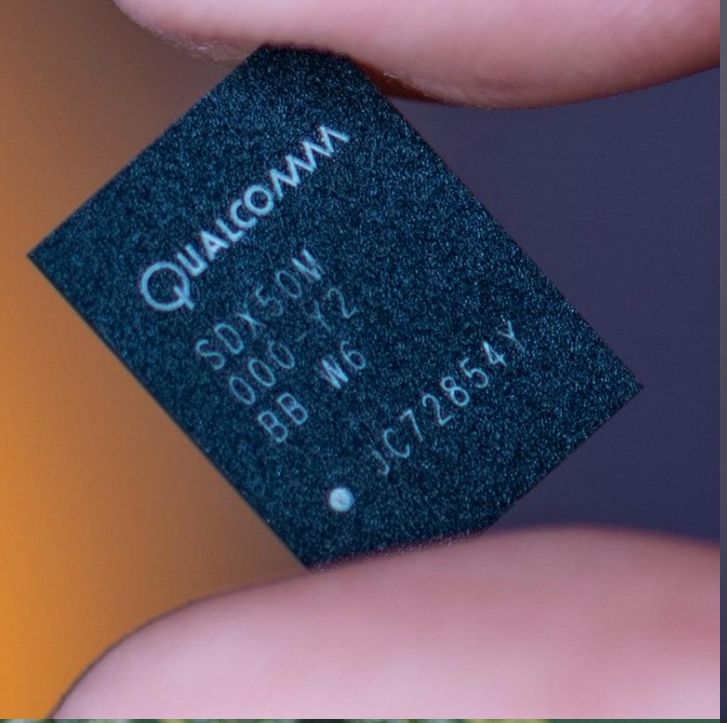
Commercializing mmWave in a smartphone form factor

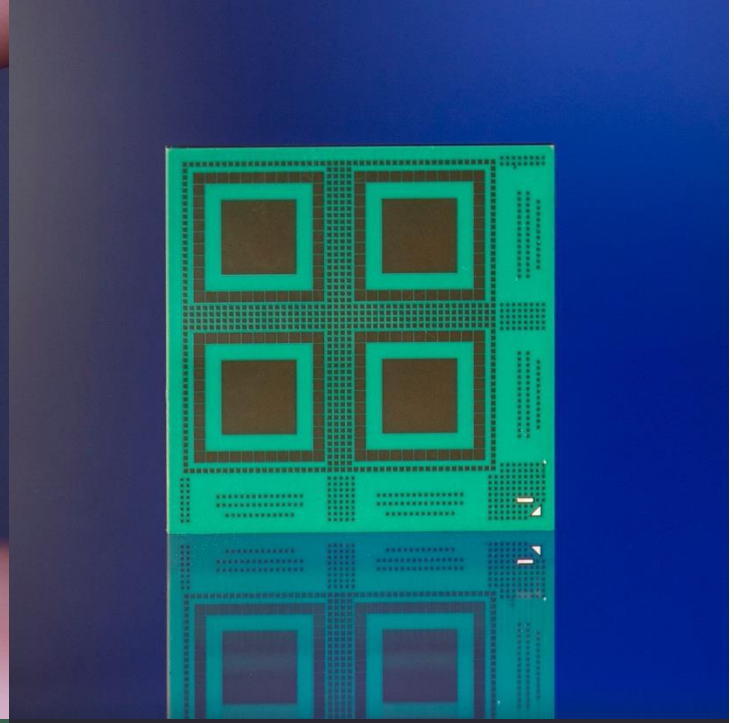
11ad in Asus Zenfone 4 Pro

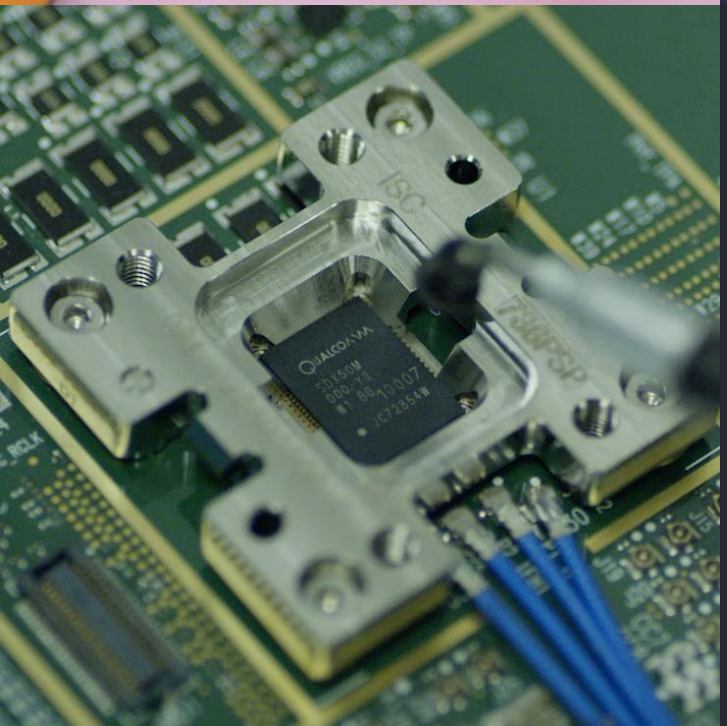
mmWave (60 GHz) viability in handset form factor

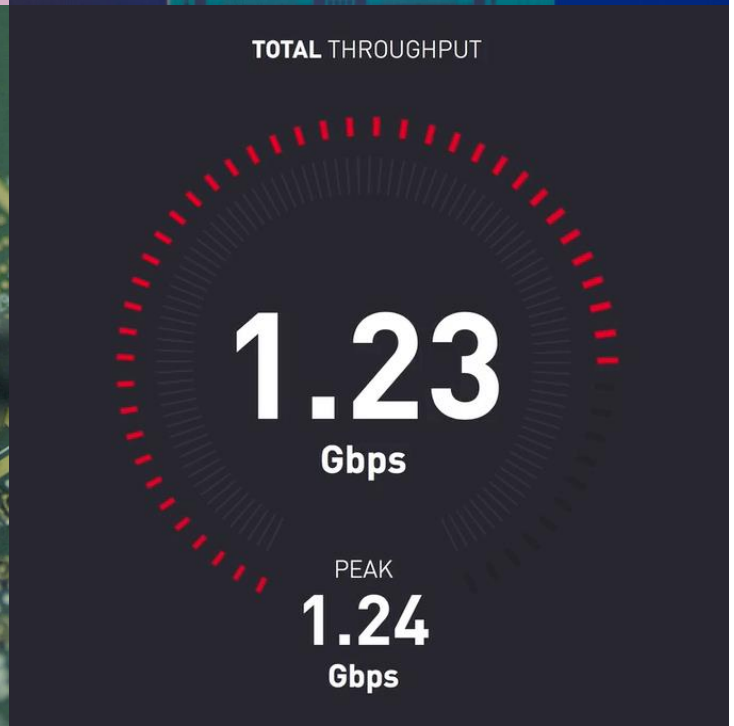
Qualcomm 5G NR mmWave prototype

5G NR mmWave Qualcomm Reference Design









The world's first announced

5G connection on a mobile chipset

Qualcomm® snapdragon™

X50

5G MODEM

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.

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

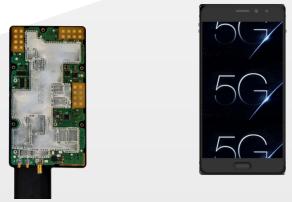
Best-in-class 5G prototype systems

Designing and testing 5G technologies for many years

3GPP™ A GLOBAL INITIATIVE

5G NR standards and technology leadership

Our technology inventions are driving the 5G NR standard



at&t · 中国移动 China Mobile · NTT docomo · SK telecom · Sprint · T · verizon · vodafone · ERICSSON · NOKIA · ZTE中兴

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

QUALCOMM®

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.

Expanding 5G NR beyond enhanced mobile broadband

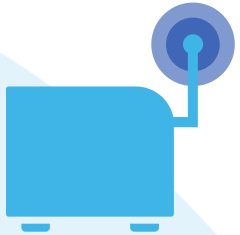
3GPP Release 15 and beyond

5G NR evolution and expansion beyond eMBB

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

5G NR non-orthogonal multiple access, e.g. RSMA
3GPP Rel-15 Study Item

5G NR for C-V2X communications
3GPP Rel-15 Study Item



5G NR operation in unlicensed spectrum (LAA and standalone)
3GPP Rel-15 Study Item

5G NR Ultra-Reliable Low Latency Communications (URLLC)
Part of 3GPP Rel-15 Work Item

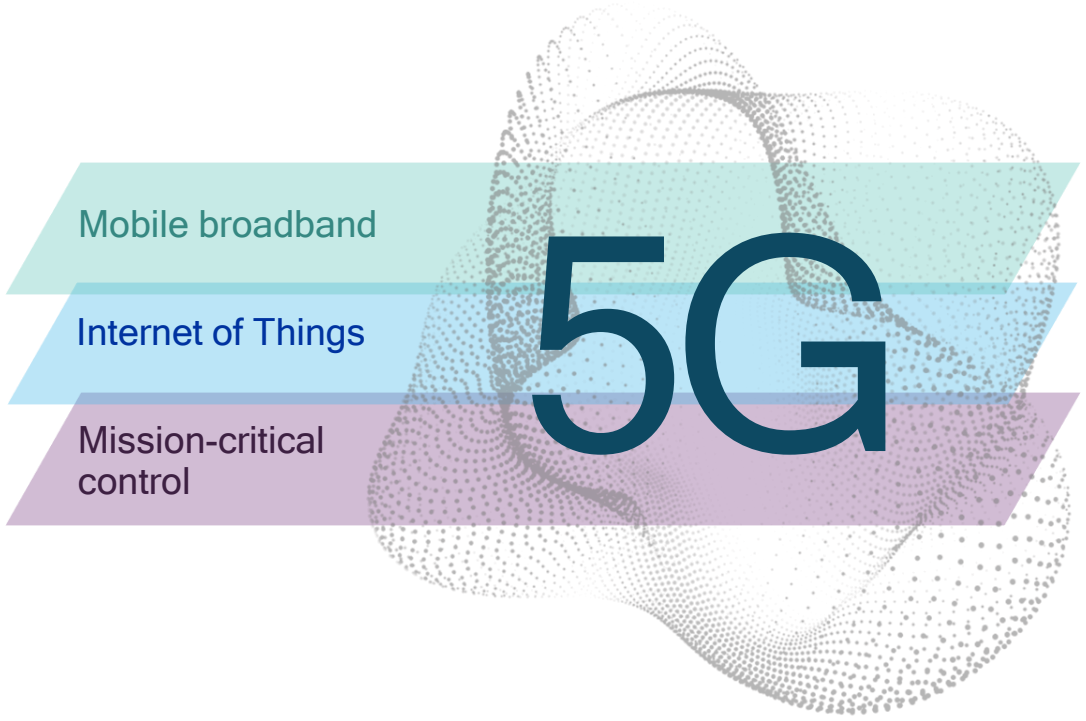
5G NR Integrated Access and Backhaul (IAB)
3GPP Rel-15 Study Item

3GPP Rel-15 5G NR eMBB design provides the foundation

Sub-6 GHz | mmWave

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

NFV: Network Functions Virtualization; SDN: Software Defined Networking

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

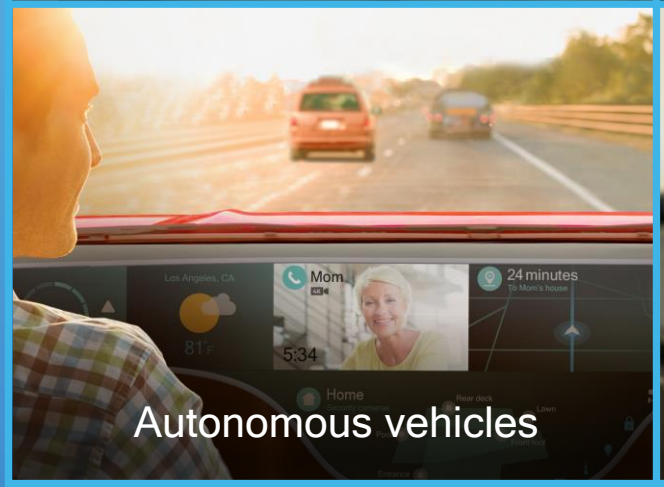
High reliability targeting 10-5 BLER[1]

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

High availability

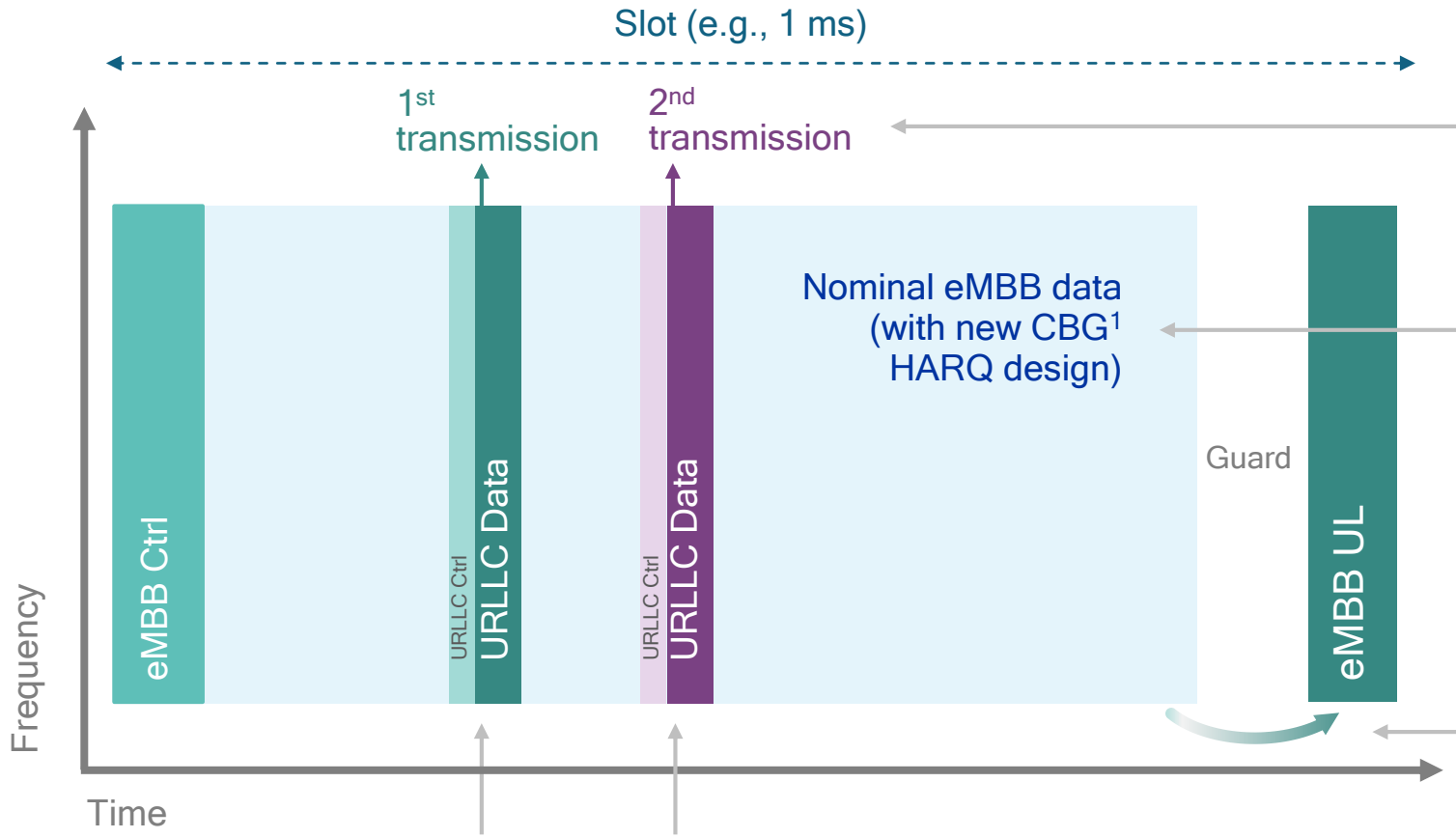
Simultaneous links to both 5G and LTE for failure tolerance and extreme mobility

A platform for tomorrow's more autonomous world



New slot structure enables low-latency communication

Efficient multiplexing with other services – more flexible than dedicated resources



Time-bounded retransmissions help to achieve higher reliability with specified latency limit

Design such that other traffic can sustain puncturing from mission-critical transmission

Self-contained TDD slot structure can enable lower slot latency and quicker link adaptation (e.g., faster SRS/CQI feedback)

Mini-slots optimized for short data transmissions; can start at anytime – no need to wait for scheduling

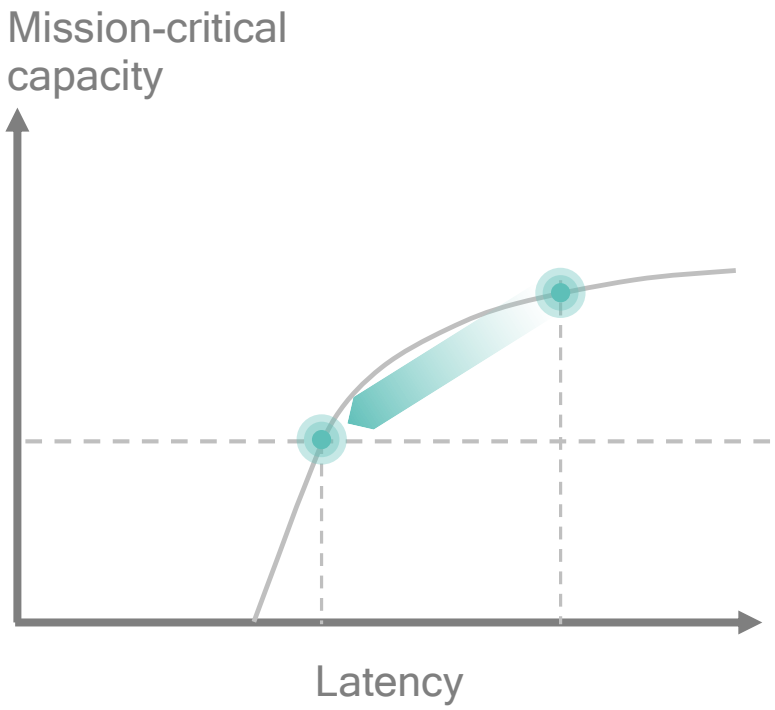
Opportunity for uplink RSMA non-orthogonal access using OFDM waveforms

1 Code Blog Group

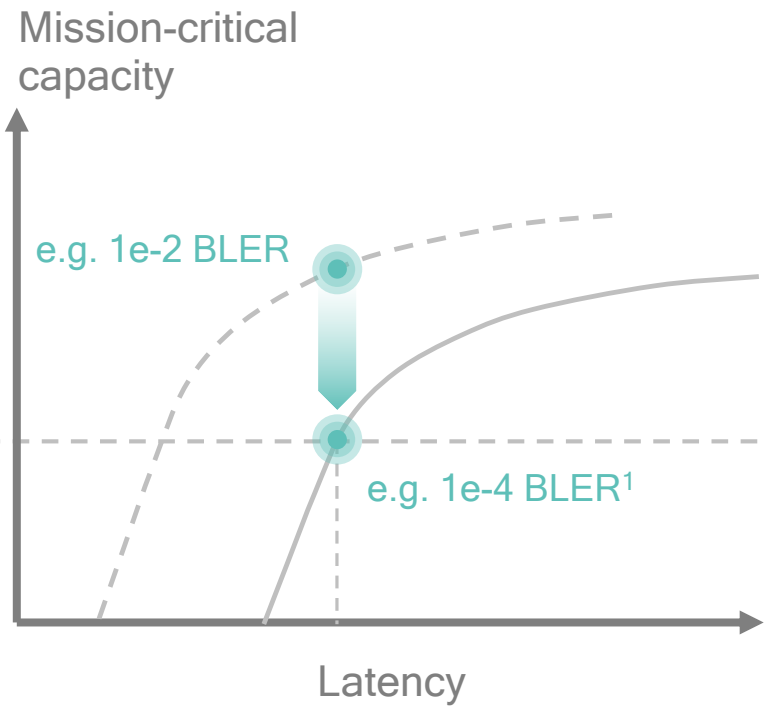
New 5G NR design allows for optimal trade-offs

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

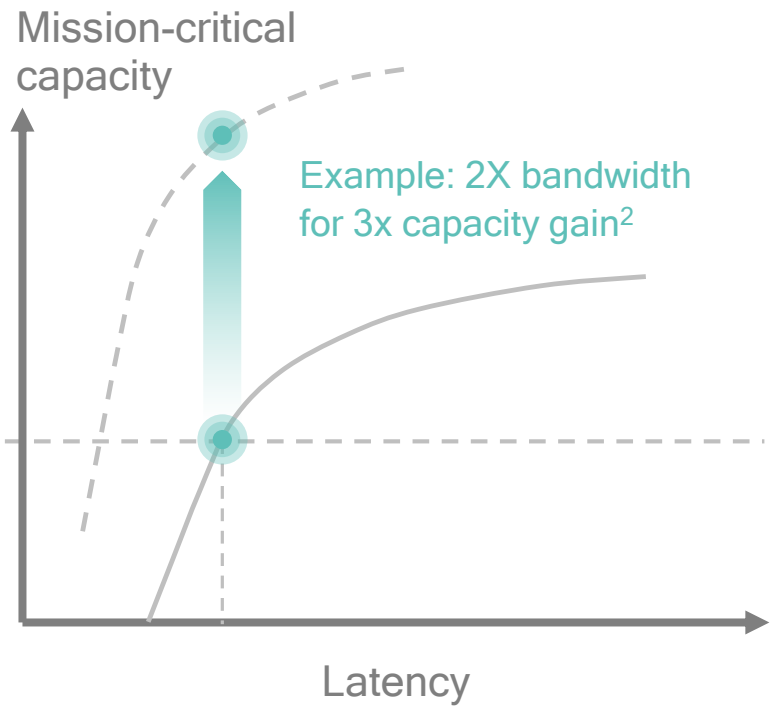
Latency vs. capacity…



Reliability vs. capacity…



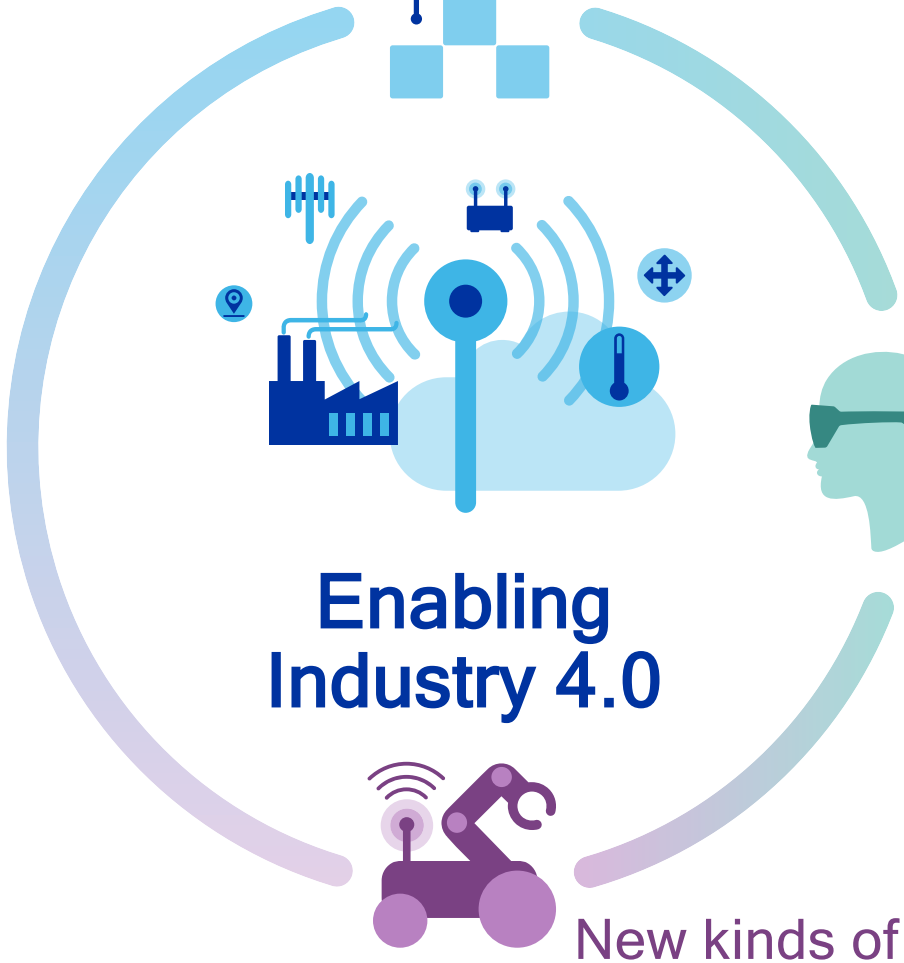
But wider bandwidth can offset reductions



[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



Reconfigurability

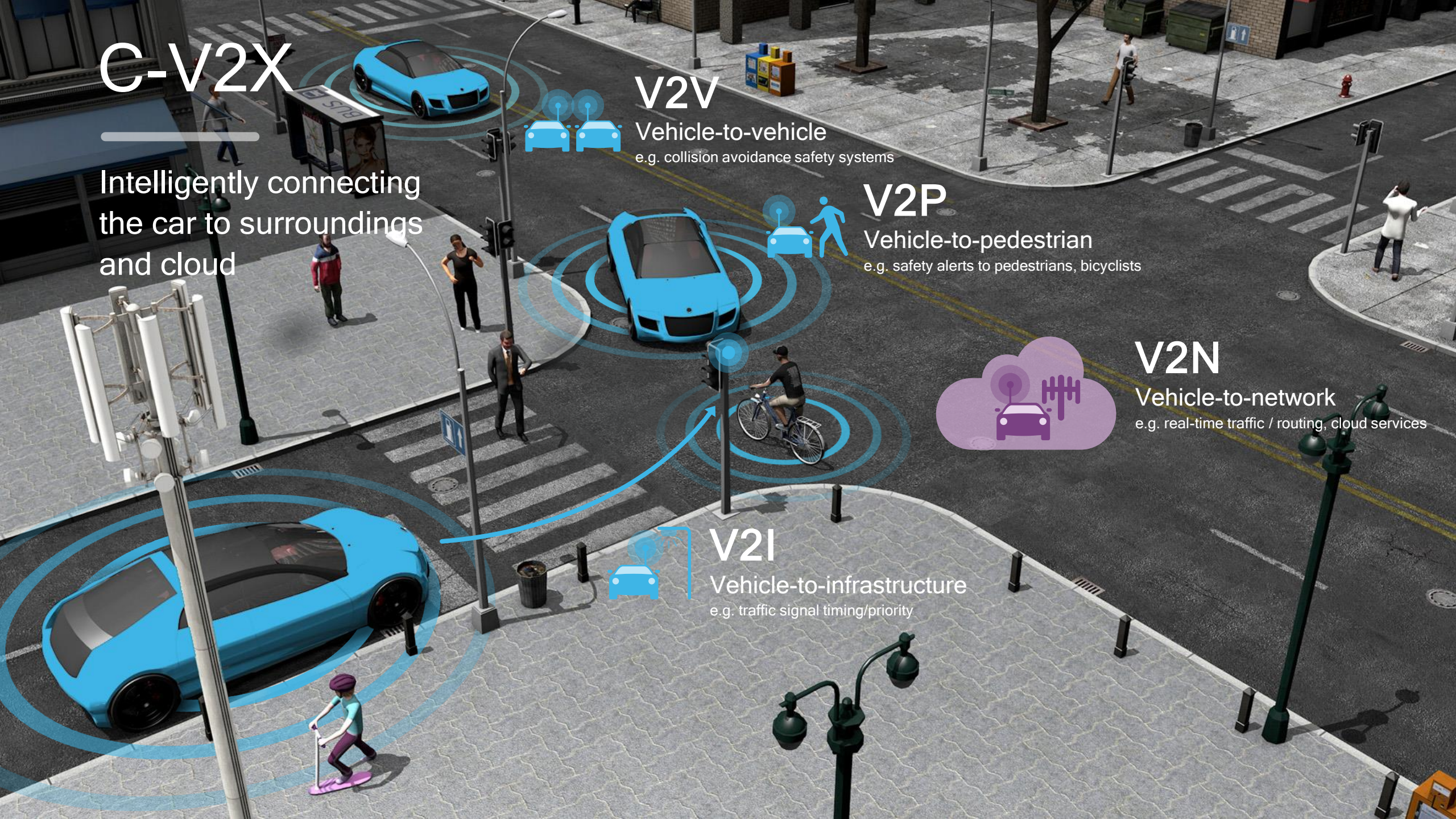
Wireline replacement and full mobility of connected workers, robots, devices

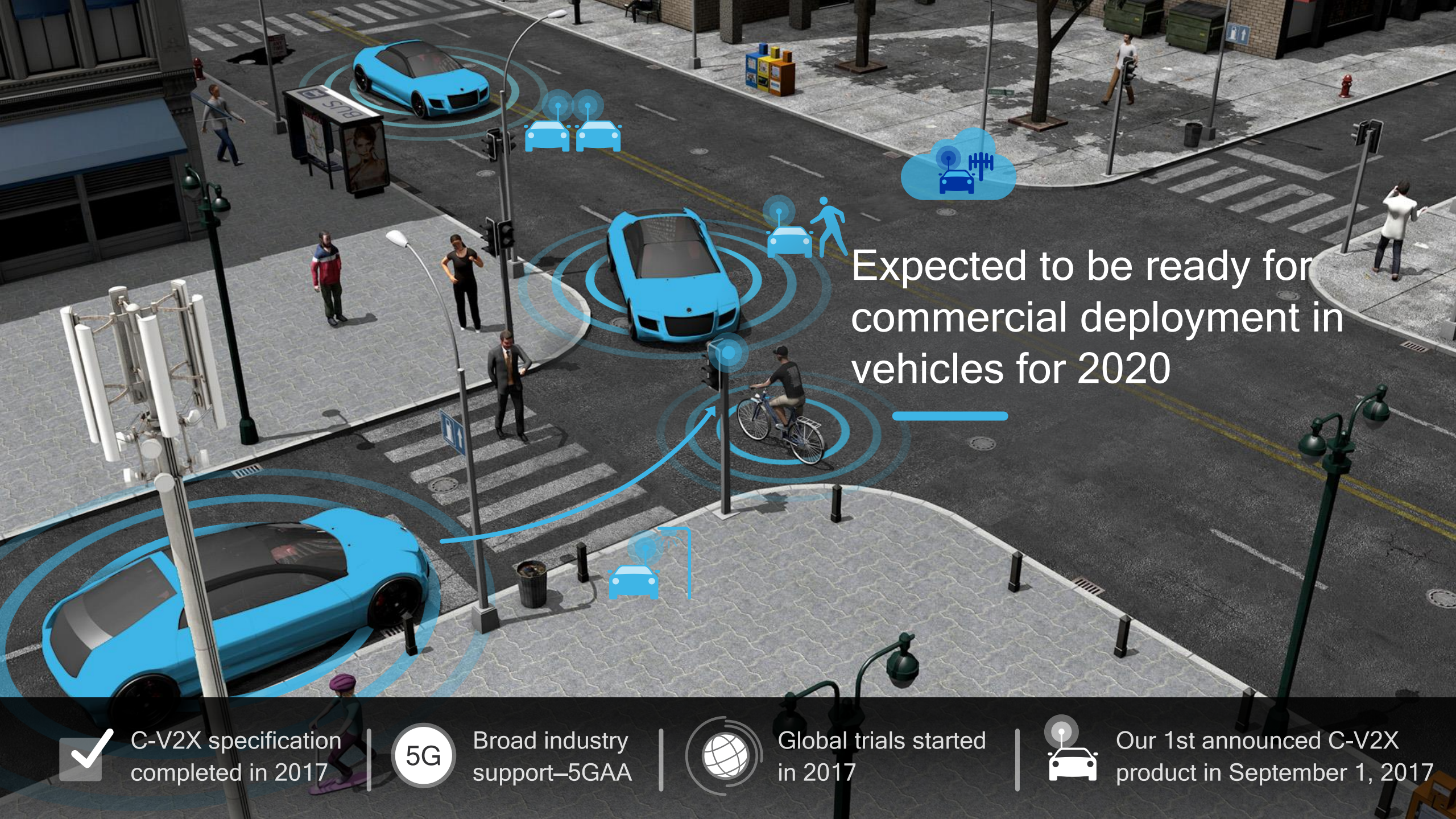
New user interfaces

Head-mounted displays with AR / VR

New kinds of devices

Example: AGV with robotic arm


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

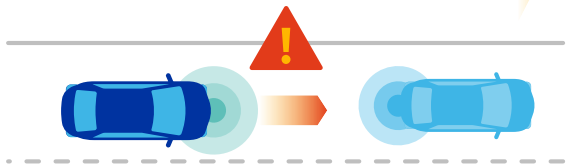

Expected to be ready for commercial deployment in vehicles for 2020
C-V2X specification completed in 2017
5G
Broad industry support–5GAA
Global trials started in 2017
Our 1st announced C-V2X product in September 1, 2017

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 safety
IEEE 802.11p

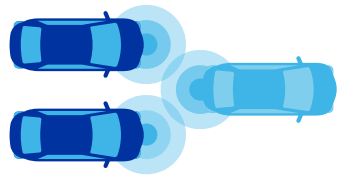


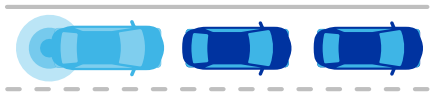
Basic and enhanced safety
C-V2X R14/R15 with enhanced range and reliability

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

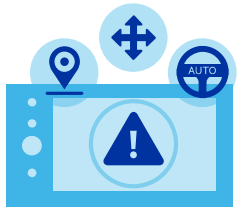
While maintaining backward compatibility

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

Wideband carrier support | High throughput | Ultra-low latency | Ultra-high reliability | Strong security

Ubiquitous connectivity

To reach challenging locations by achieving device link budget of 164 dB[1]

Ultra energy efficiency

To realize10+ year device battery life[2] and 100x network energy efficiency[3]

Evolving LTE IoT

for the massive Internet of Things

Massive scale

To efficiently support dense connections of 1+ million devices/km^2

Extreme simplicity

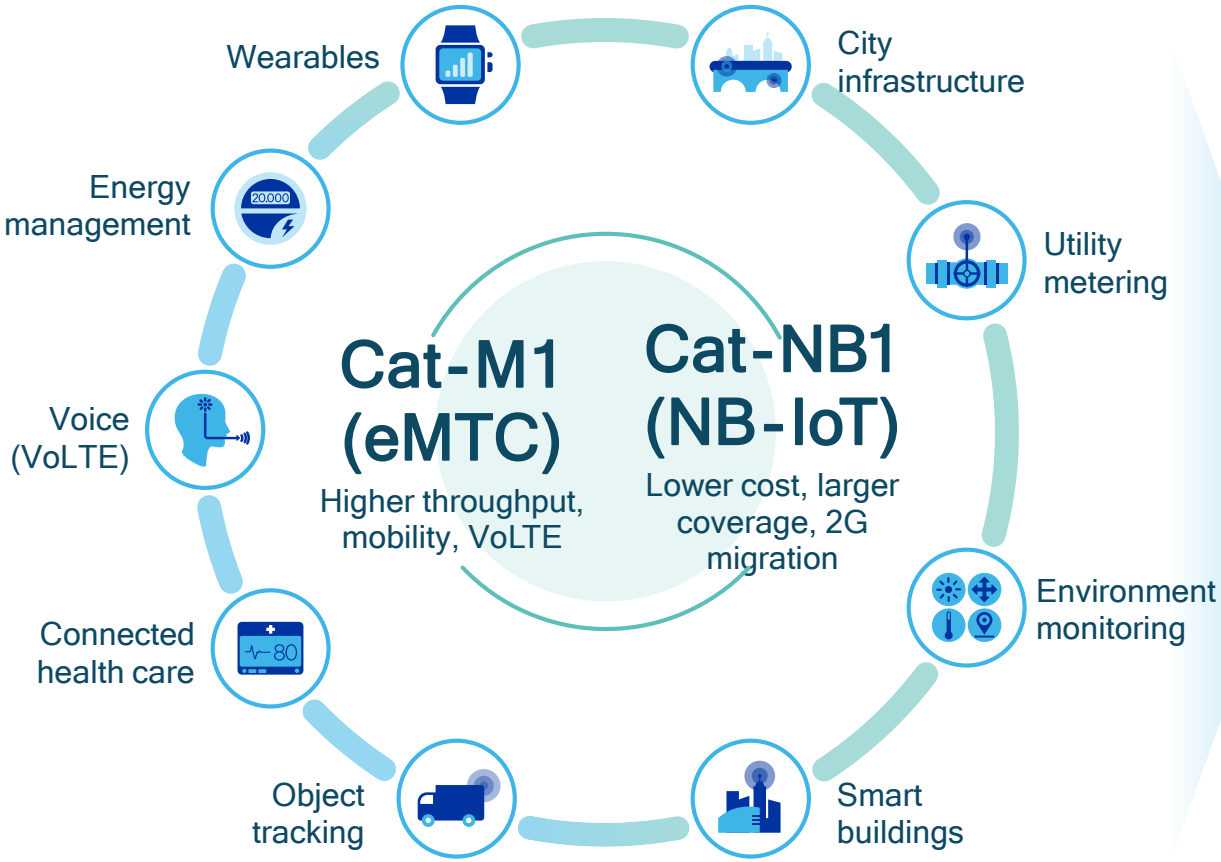
To allow scaling to the lowest-end use cases with e.g., single Rx antenna

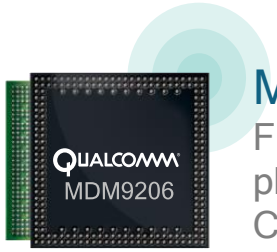
Addressing the growing needs of low-power, wide-area IoT use cases

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

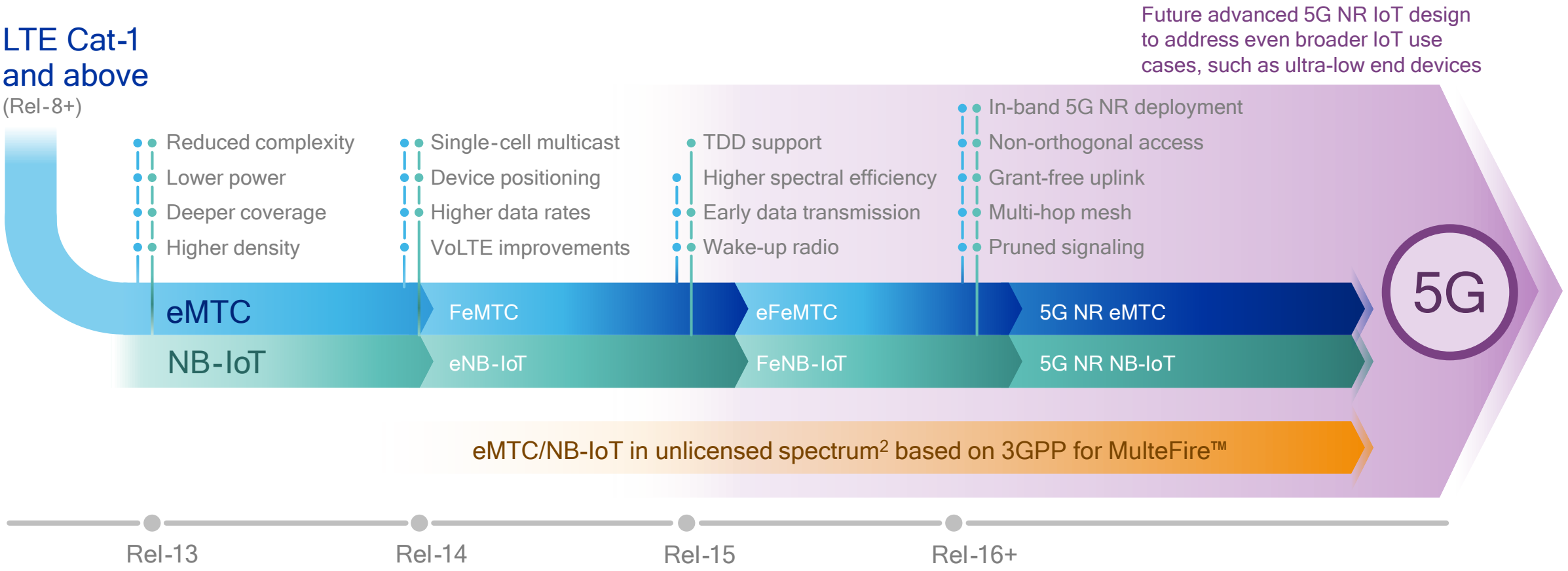
- Global dual-mode solution – single SKU
- Pre-certified modules commercially available today
- Multiple design wins across industry-leading OEMs

QUECTEL Wireless Module Expert
ZTE Welink
Telit
LONG UNG 龙尚科技
Neoway 有方
SIMCom A company of SIM Tech
MobileTek
u-blox
WNC
mobike

...and many more

Continued evolution to meet tomorrow's massive IoT needs

Essential to 5G Platform[1]

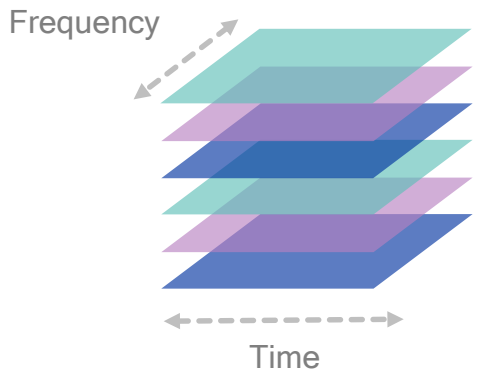


1. LTE IoT, part of LTE Advanced Pro, will be submitted with 5G NR to meet IMT-2020 requirements per defined in ITU Recommendation ITU-R M.2083-0, September, 2015; 2. Standardization in MulteFire Alliance

Pioneering tomorrow's massive IoT technologies

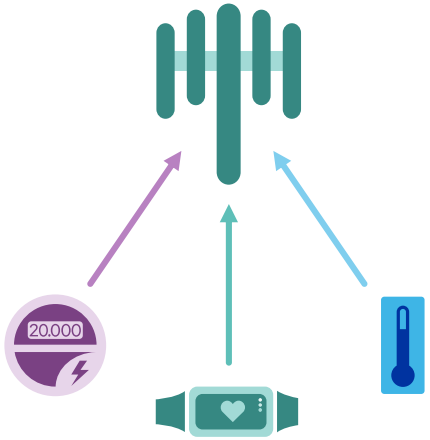
Applies to LTE IoT and 5G NR IoT evolution – potential for 3GPP Rel-16+

Non-orthogonal multiple access
Resource Spread Multiple Access (RSMA)



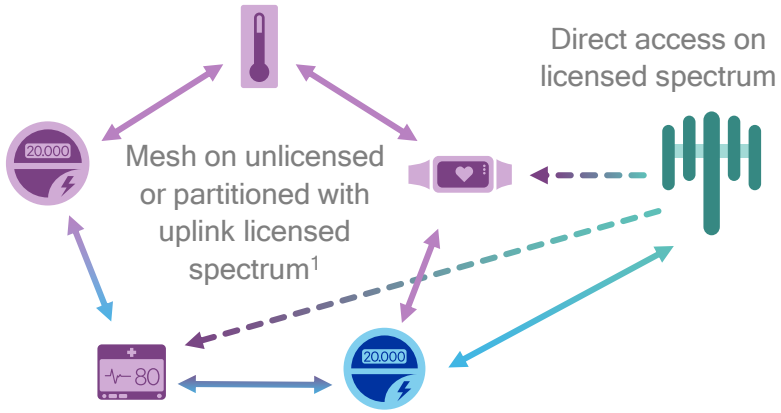
- NOMA is part of 5G NR Rel-15 Study Item
- Can be either scheduled or grant-free
- Increases device density & network efficiency

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

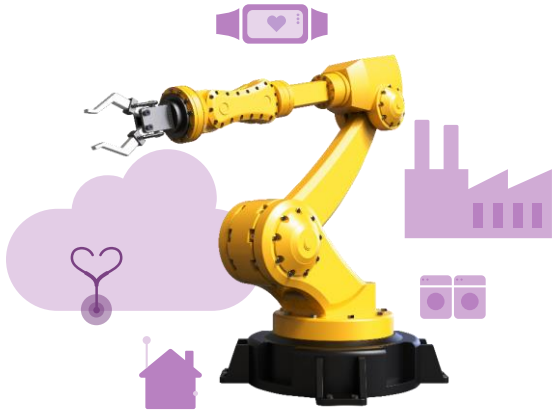
Spectrum sharing valuable for wide range of deployments

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 LAA[1]

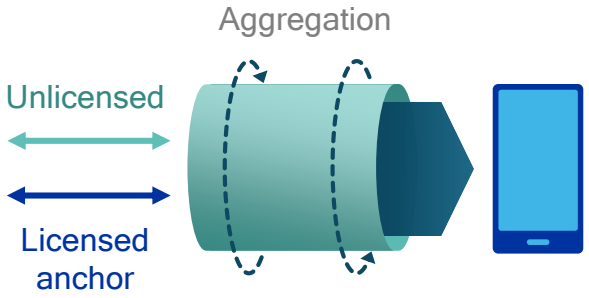
New types of deployments,

Examples today: Private LTE networks

1. Licensed-Assisted Access (LAA);

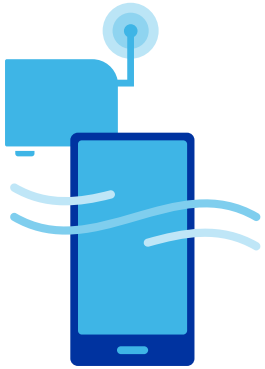
3GPP study on 5G NR operation in unlicensed spectrum

First time 3GPP studies cellular technology operating stand-alone in unlicensed[1]



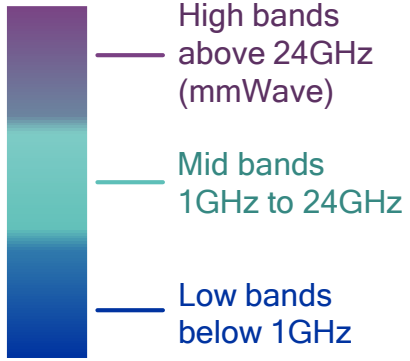
NR-based LAA

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

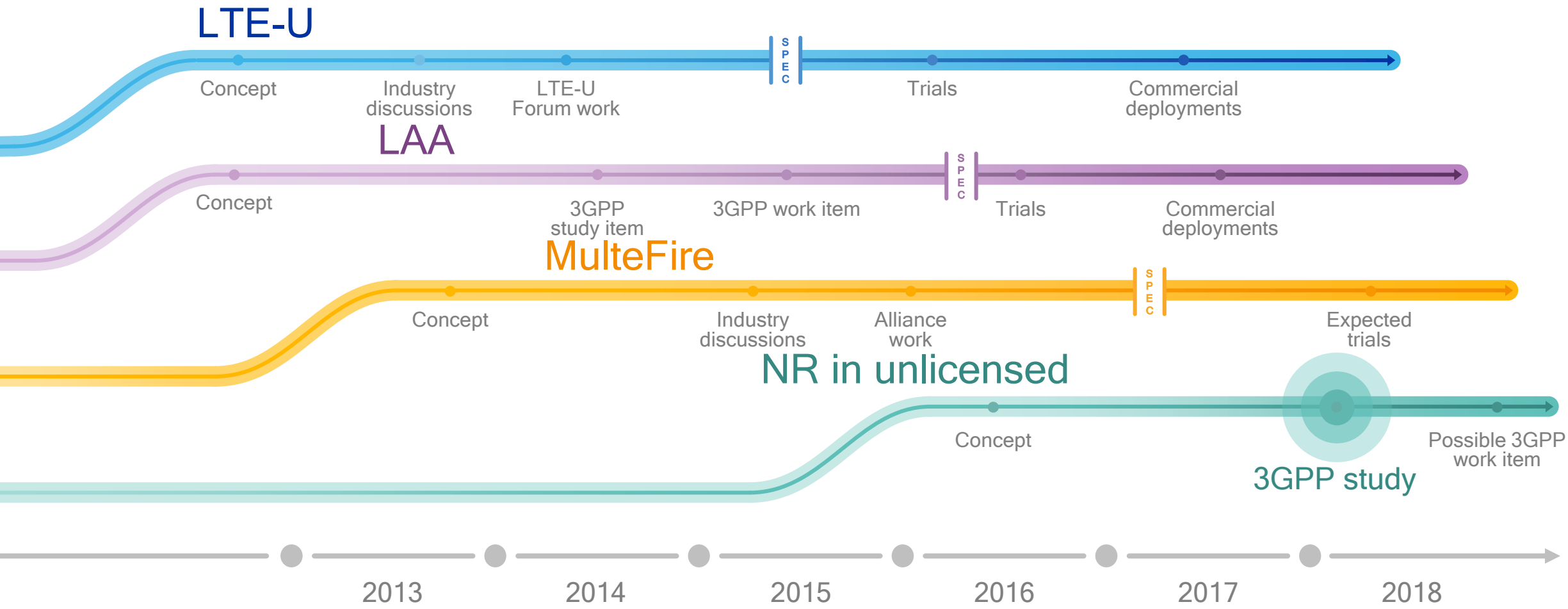
Both below and above 6 GHz, e.g., 5GHz, 37GHz, 60GHz* (*assuming no change to waveform)

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

NR-SS[1]

Flexible NR framework

- Flexible slot-based framework
- Scalable OFDM-based air interface
- Network MIMO
- TDD self-contained slot structure

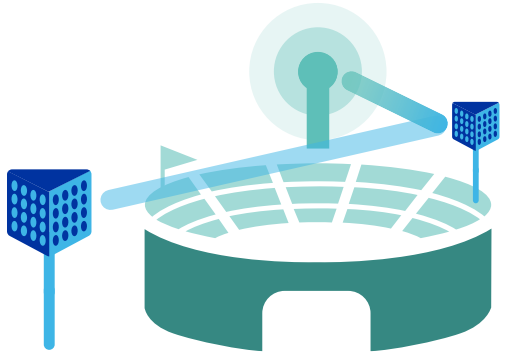
- Mobile mmWave

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

1) 5G NR Spectrum Sharing (NR-SS)

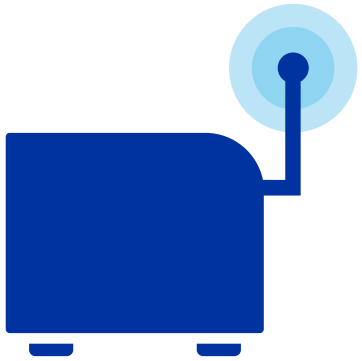
5G NR mmWave continuing to evolve beyond R15

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

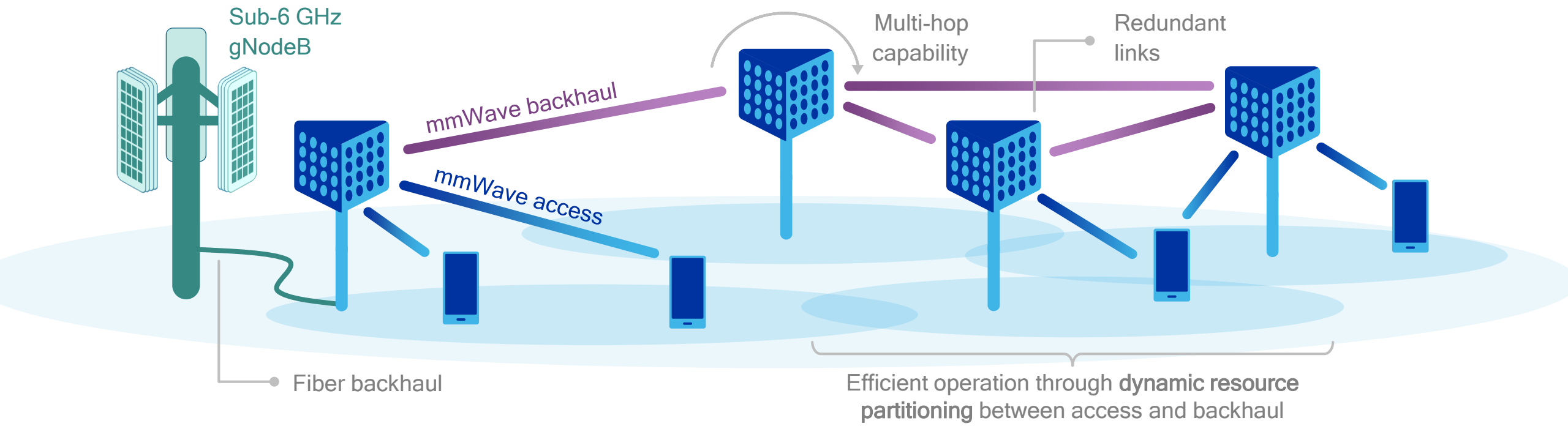
Rel-15 Study Item for both LAA and standalone operation (aka 5G MulteFire™) in sub-6 GHz and mmWave spectrum bands

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 IAB[1] for cost-efficient dense deployments

Improves coverage and capacity, while limiting backhaul cost



Traditional fiber backhaul can be expensive for mmWave cell sites

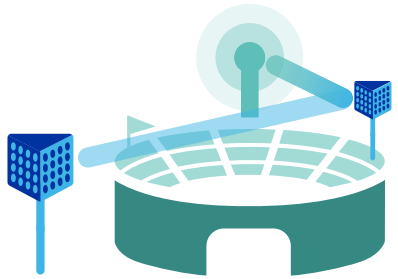
- mmWave access inherently requires small cell deployment
- Running fiber to each cell site may not be feasible and can be cost prohibitive
- mmWave backhaul can have longer range compared to access

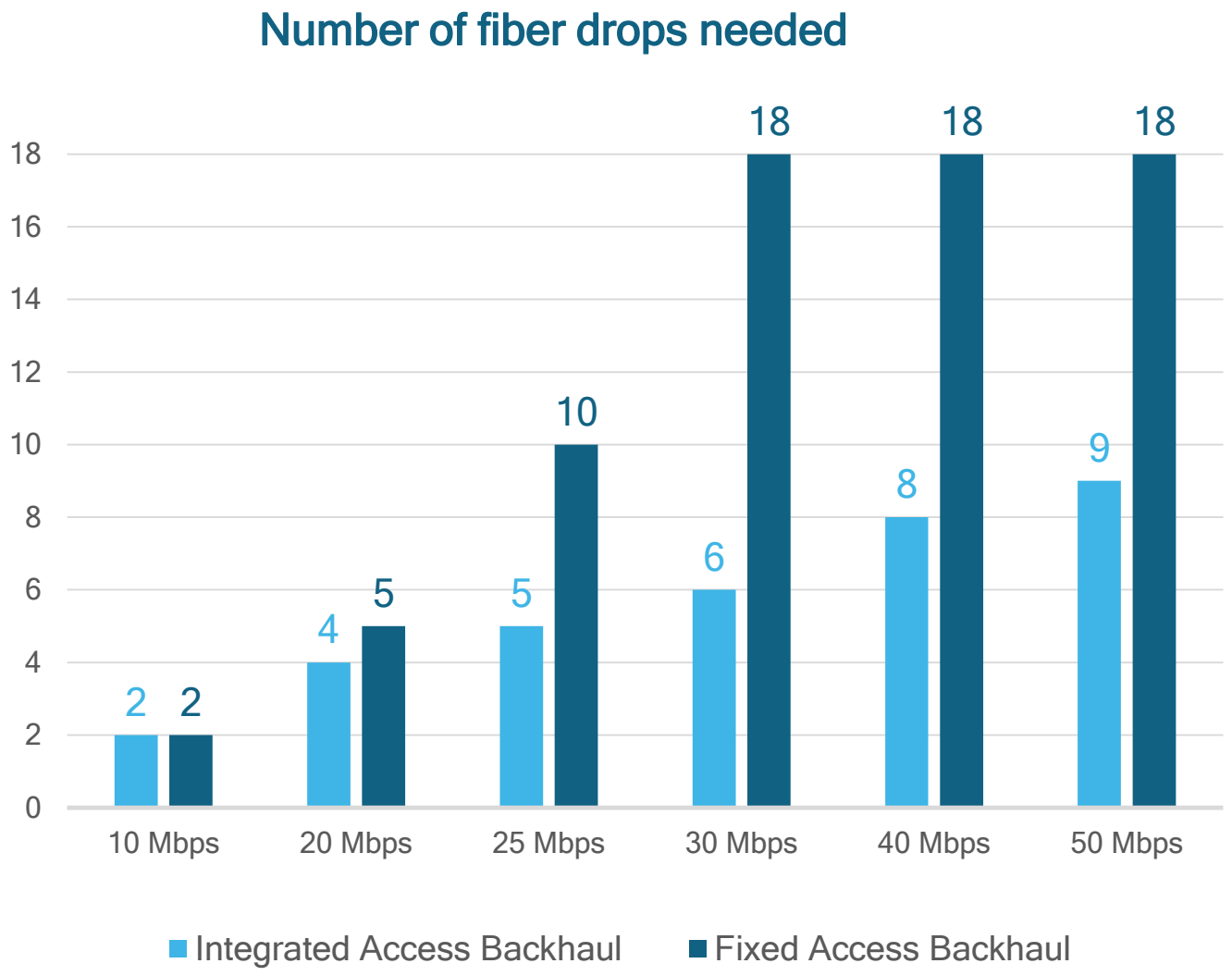
[1] Integrated Access & Backhaul

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





*Assumptions: 28 GHz band, 1GHz b/w, 18 base-stations; 200m ISD; 600 devices, uniform distribution; results obtained without any constraint on the number of hops

Anyone can talk about 5G.
We are making it a reality.

QUALCOMM®

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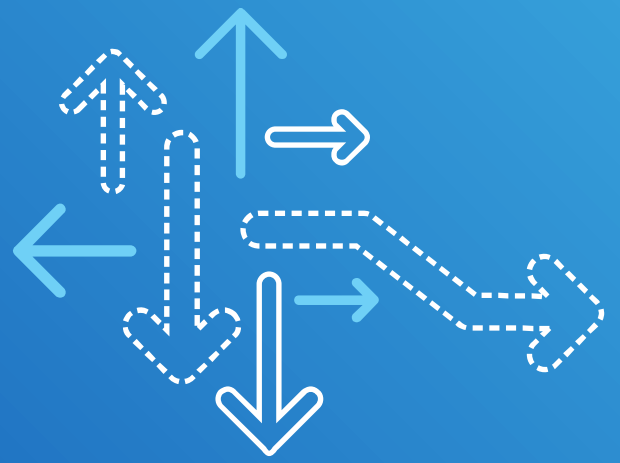
http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp

http://www.slideshare.net/qualcommwirelessevolution



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