Qualcomm

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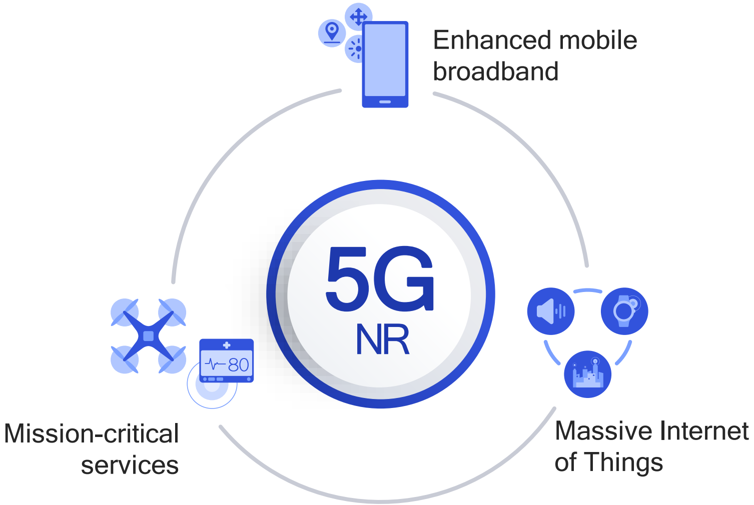
September 2018

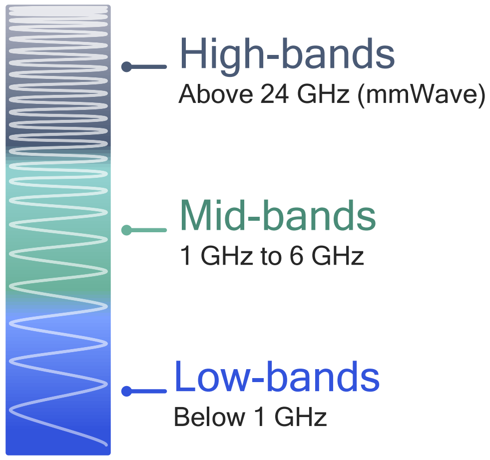
Designing 5G NR

The 3GPP Release 15 global standard for a unified, more capable 5G air interface

Designing a unified, more capable 5G air interface



Diverse services



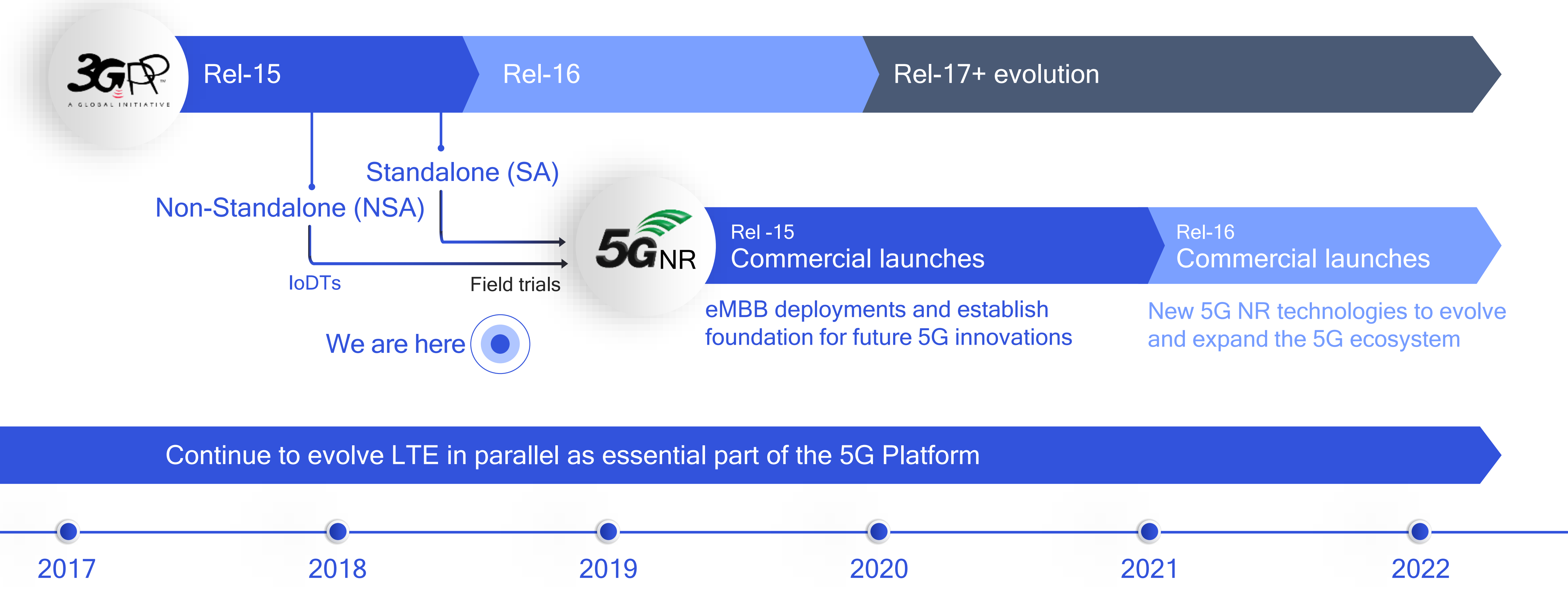
Licensed/shared/unlicensed

Diverse spectrum

Diverse deployments

Existing, emerging, and unforeseen services - a platform for future innovation

Driving the 5G roadmap and ecosystem expansion



5G NR pioneering advanced 5G NR technologies

To meet an extreme variation of 5G NR requirements

Mission-critical services

Cellular Vehicle-to-Everything (C-V2X)

Drone communications | Private Networks

Ultra Reliable Low Latency Comms (URLLC)

Enhanced mobile broadband

Spectrum sharing | Flexible slot-based framework

Scalable OFDM | Massive MIMO | Mobile mmWave

Dual Connectivity | Advanced channel coding

Massive Internet of Things

Enhanced power save modes

Deeper coverage | Grant-free UL

Narrow bandwidth | Efficient signaling

10x Decrease in end-to-end latency

10x Experienced throughput

3x Spectrum efficiency

100x Traffic capacity

100x Network efficiency

10x Connection density

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

The R&D engine fueling the 5G industry

Early system-level R&D investments

Designing/testing 5G for many years with best-in-class prototype systems

3GPP standards and technology leadership

Our system-level inventions are foundational to 5G NR standard

Global network experience and ecosystem collaborations

Industry-leading demos, simulations, testing and trials on path to commercialization

Qualcomm

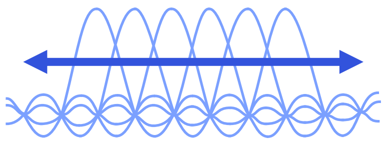
Building on our LTE technology leadership

5G NR design and technologies

3GPP Release-15

Our technology inventions drove Rel-15 specifications

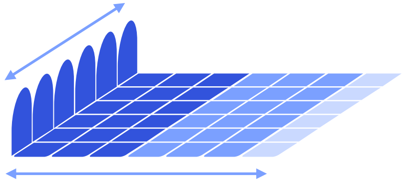
Scalable OFDM-based air interface



Scalable OFDM numerology

Address diverse services, spectrum, deployments

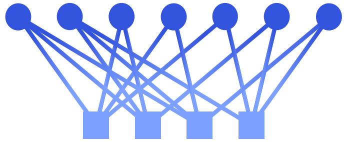
Flexible slot-based framework



Self-contained slot structure

Low latency, URLLC, forward compatibility

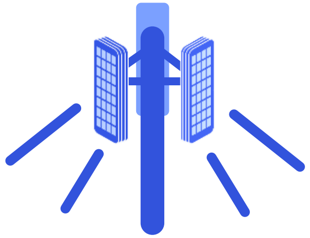
Advanced channel coding



Multi-Edge LDPC and CRC-Aided Polar

Support large data blocks, reliable control channel

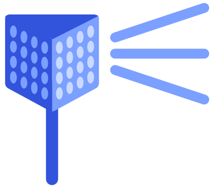
Massive MIMO



Reciprocity-based MU-MIMO

Large # of antennas to increase coverage/capacity

Mobile mmWave



Beamforming and beam-tracking

For extreme capacity and throughput

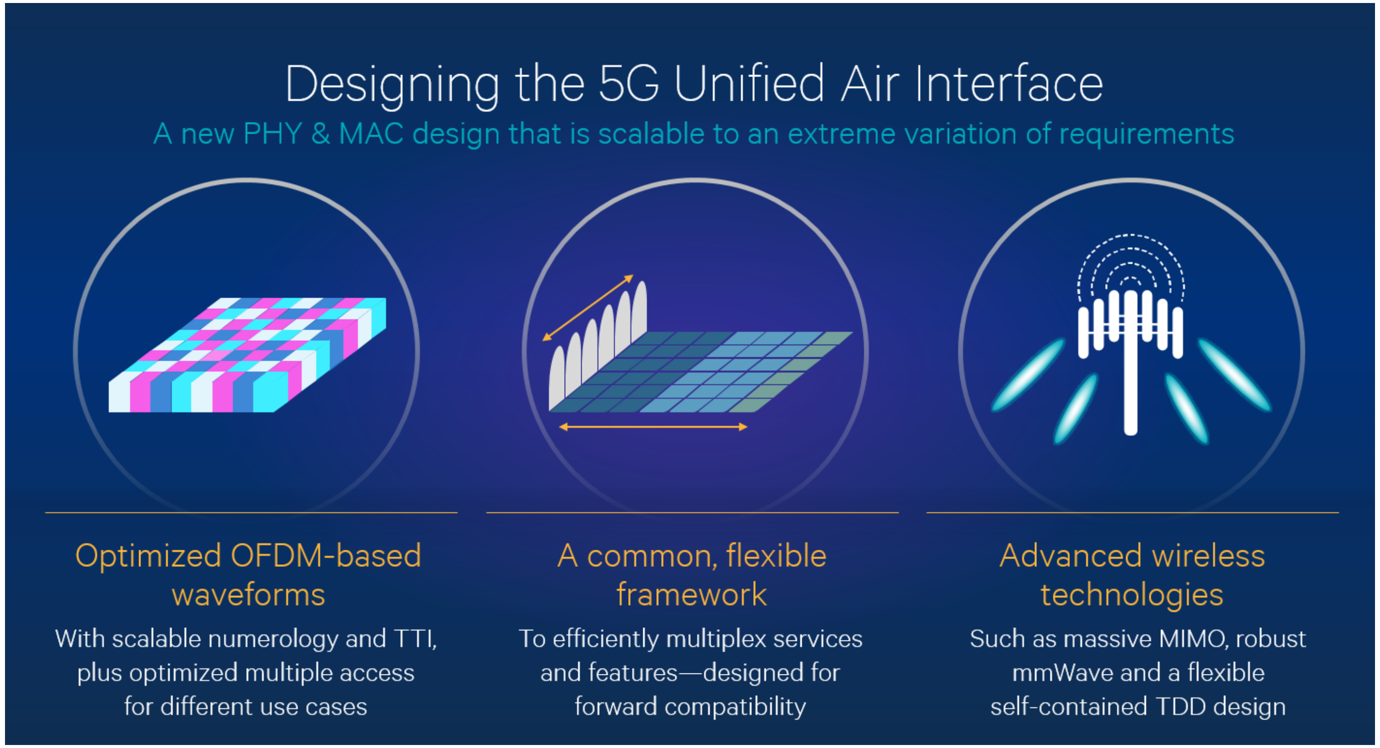
Early R&D investments | Best-in-class prototypes | Fundamental contributions to 3GPP

5G NR standard aligned with our early 5G design

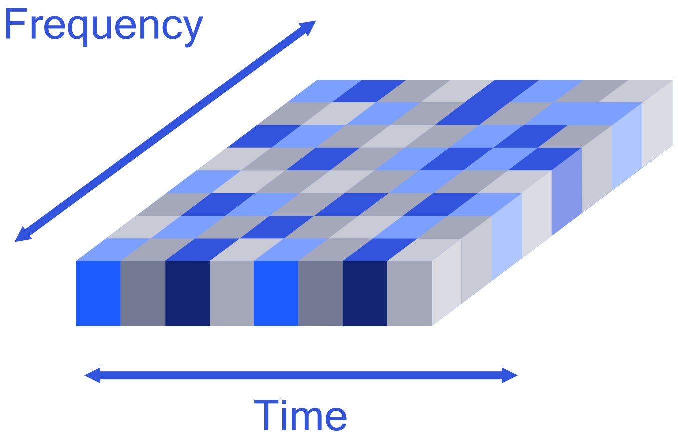
A testament to the impact of our early 5G R&D and fundamental contributions to 3GPP

November 2015

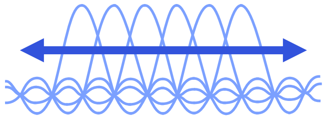
Qualcomm Technologies' 5G Analyst Day



Scalable OFDM-based 5G NR air interface

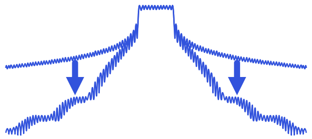


Scalable numerology



2^n scaling of sub-carrier 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]

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)

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

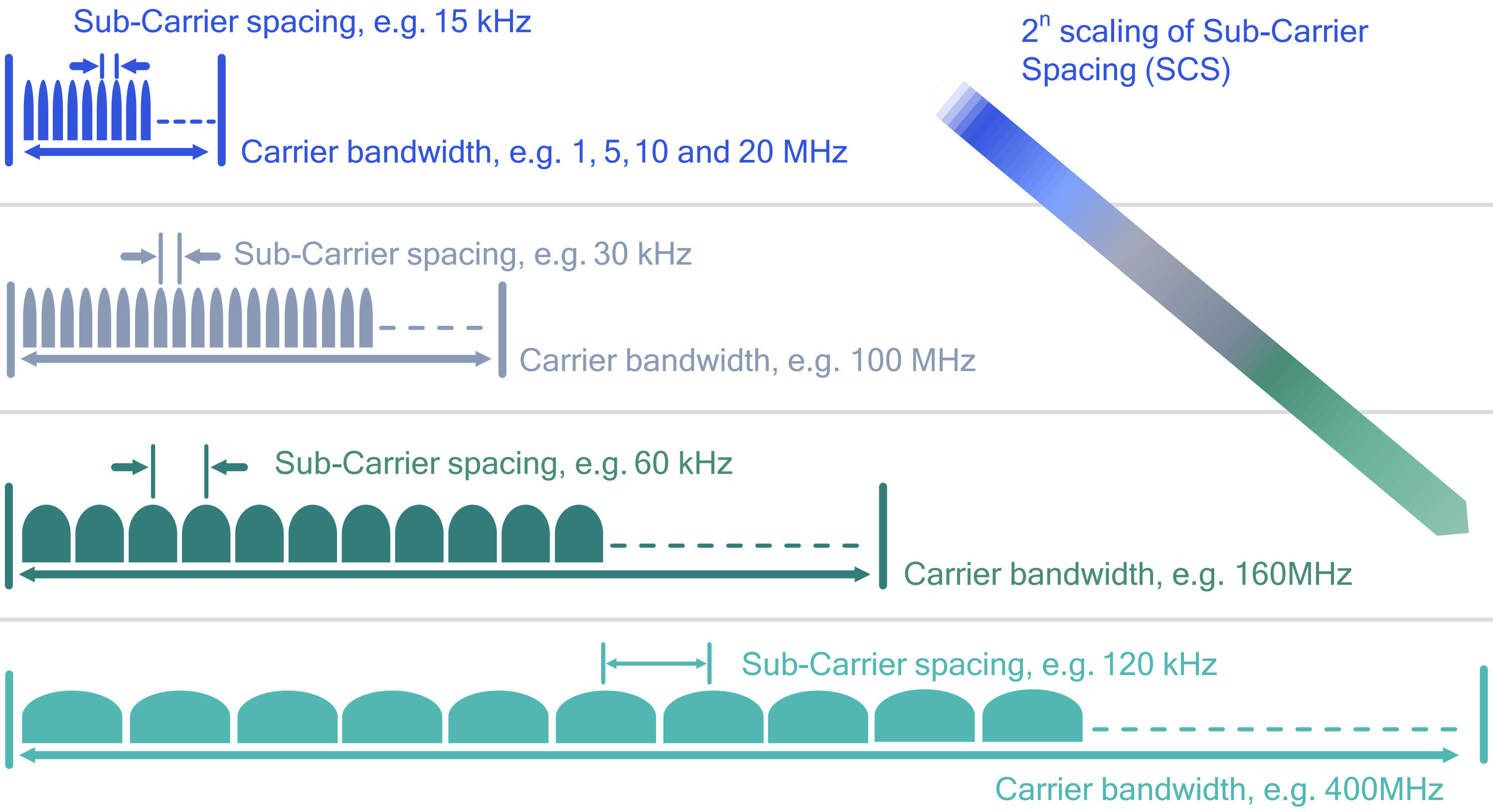
Scalable 5G NR OFDM numerology—examples

Outdoor macro coverage
e.g., FDD 700 MHz

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

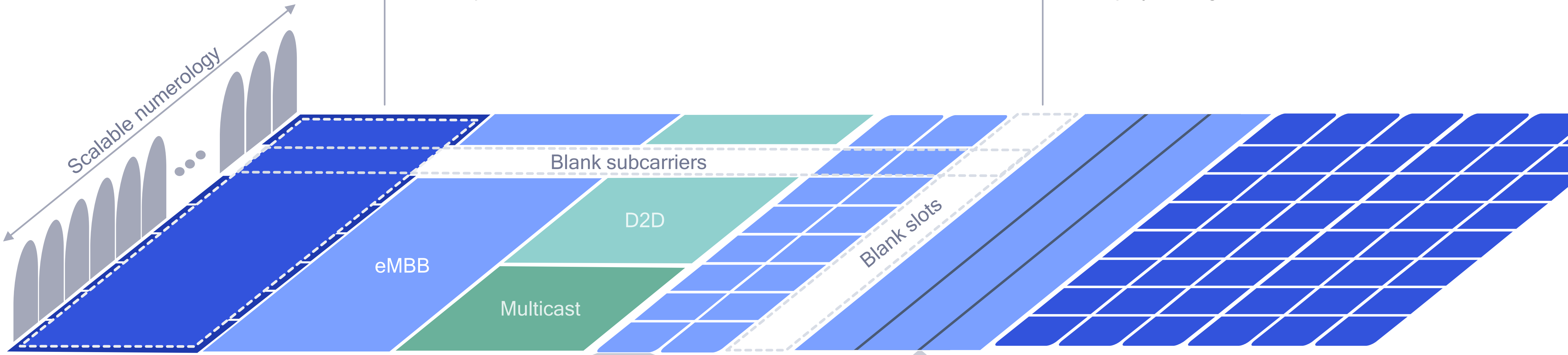
Efficiently multiplex envisioned and future 5G services on the same frequency

Scalable 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



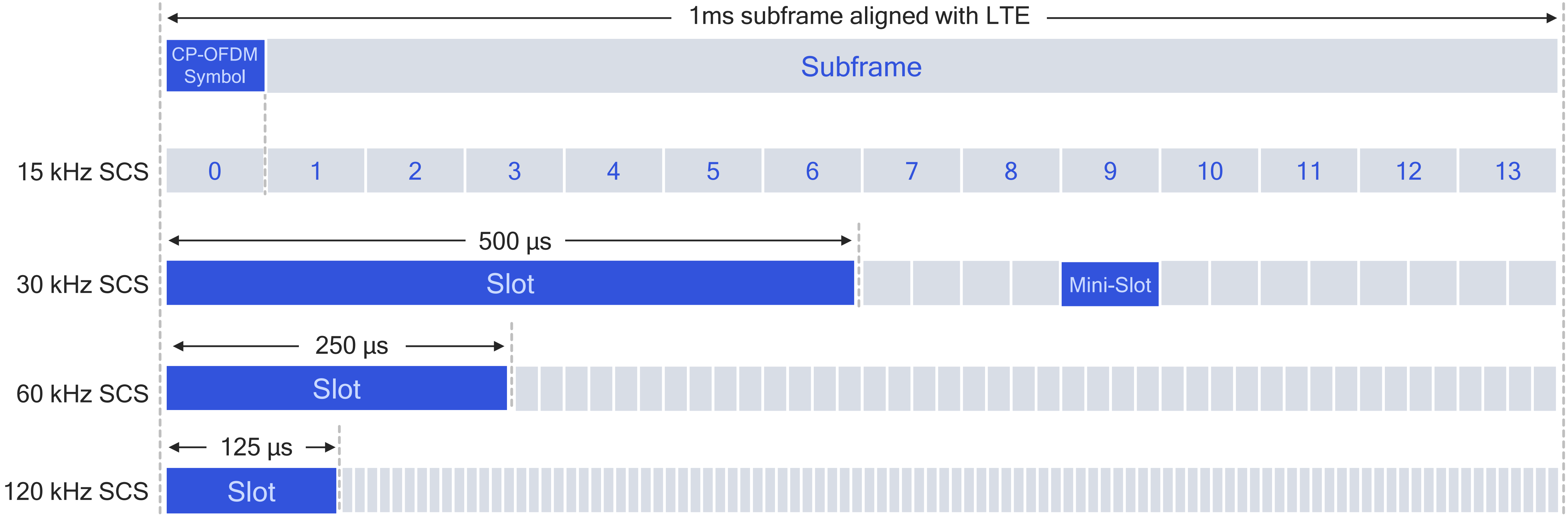
Self-contained slot structure

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 – Examples

TDD Self-Contained

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

Data-centric

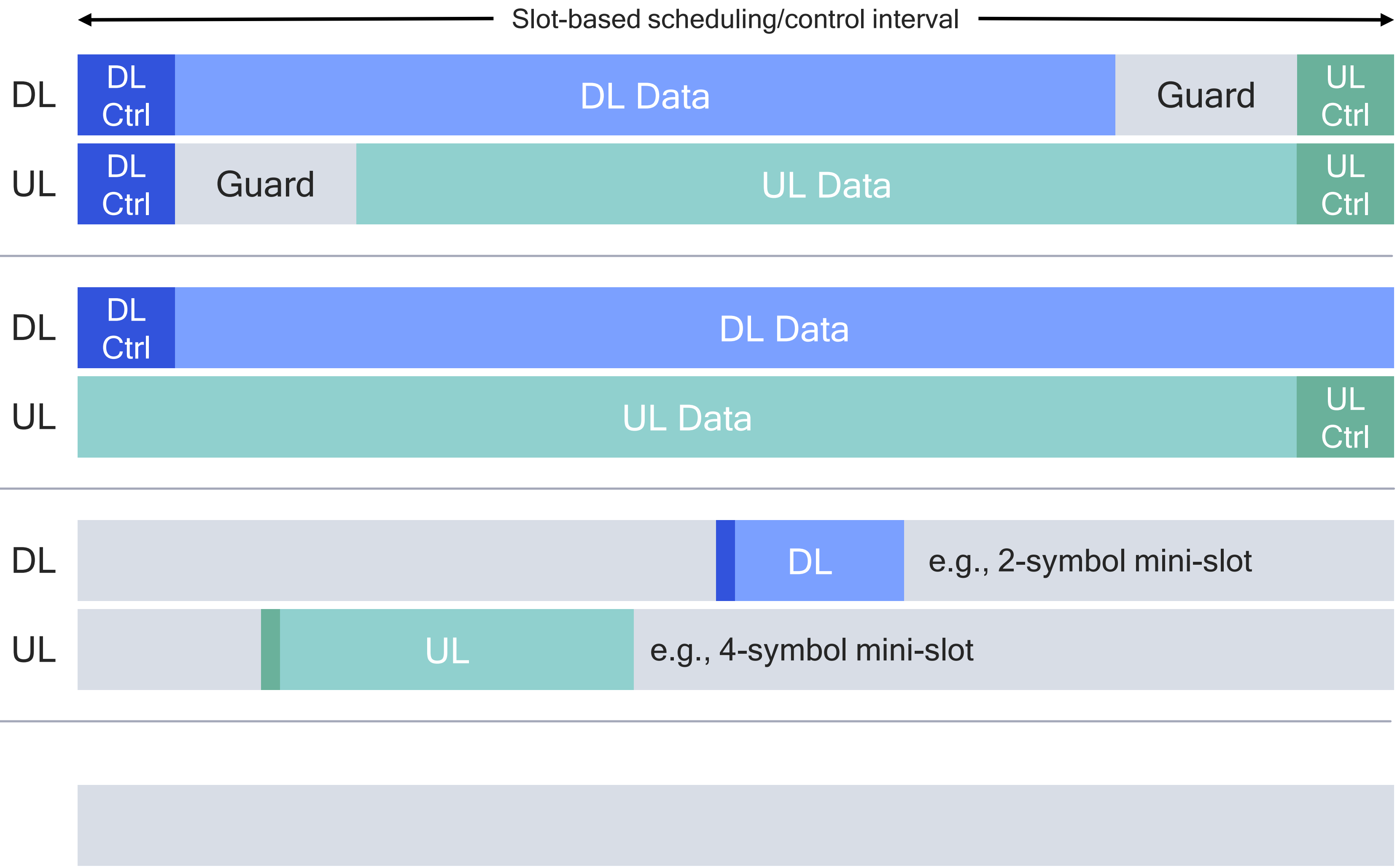
More relaxed TDD timing configurations + FDD operation

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

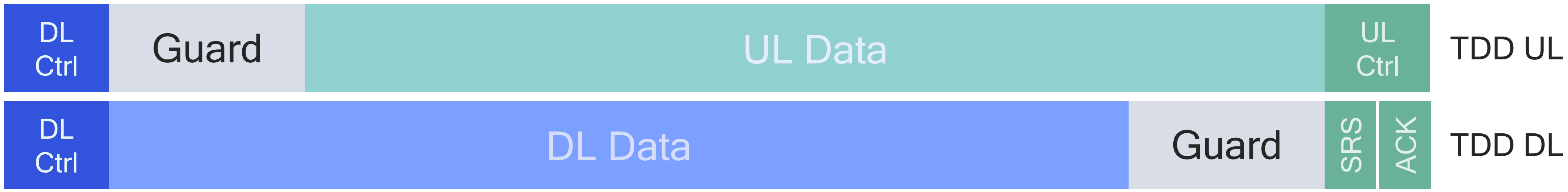
Much faster, more flexible TDD switching and turn-around than 4G LTE

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

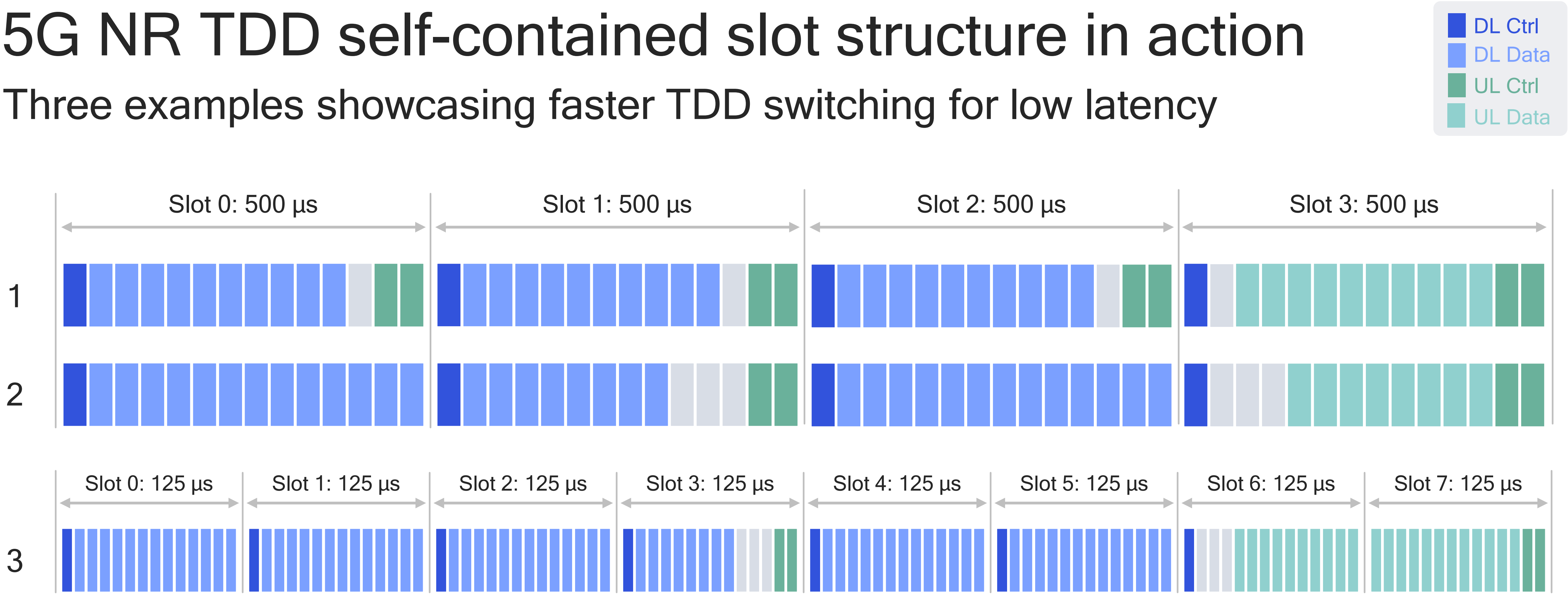
Efficient massive MIMO

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



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

1. Indoor (sub-6 or mmWave)

- Shorter guard for indoor deployment
- Fast turn-around (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

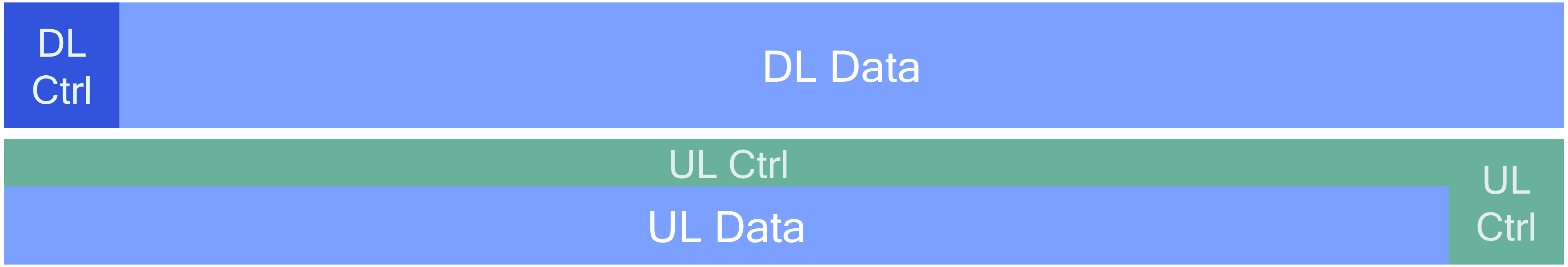
5G NR flexible FDD slot structure

Delivering low latency, extended coverage, and forward compatibility

FDD baseline for continuous transmission and extended coverage

FDD full DL Slot

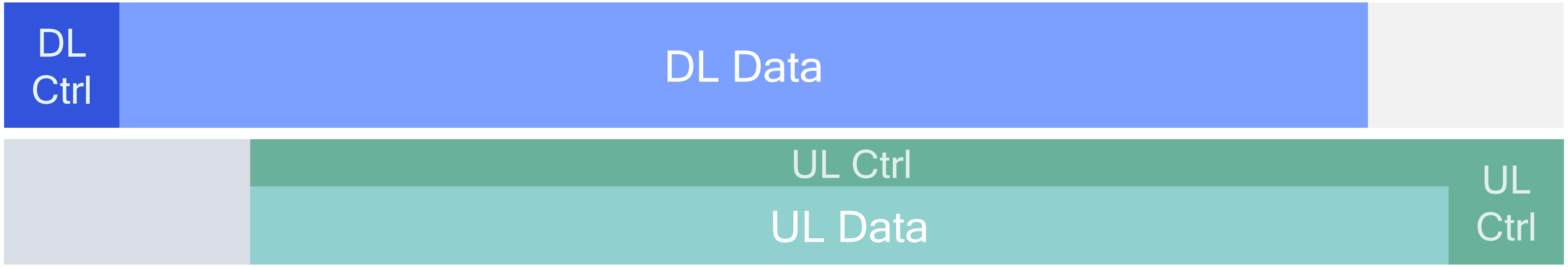
FDD full UL Slot



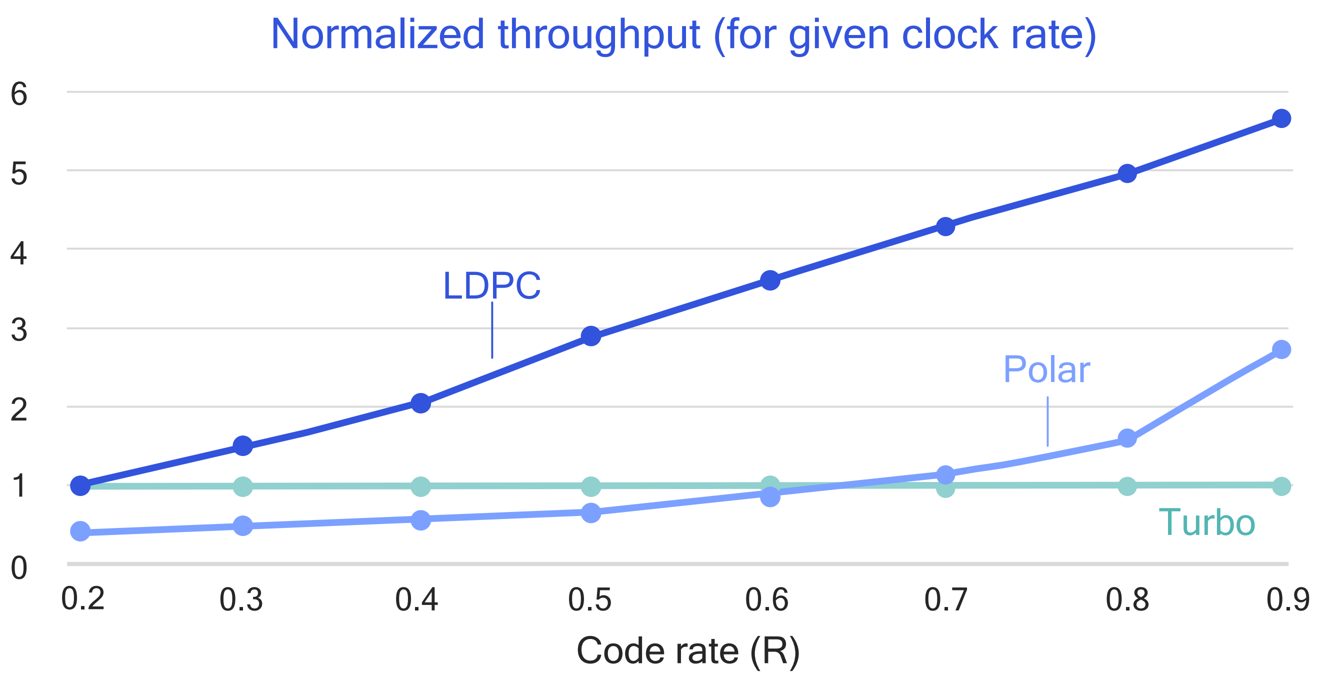
FDD partial slot for faster DL/UL turn-around and efficient half-duplex FDD implementation

FDD partial DL Slot

FDD partial UL Slot



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

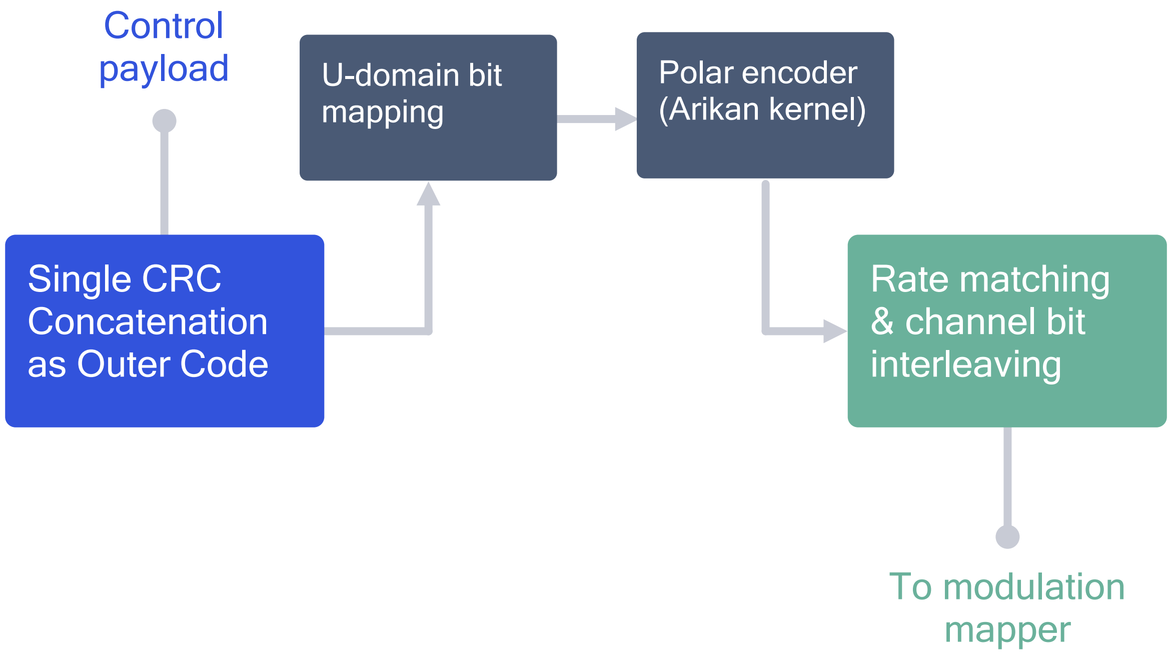
1. Multi-Edge Low-Density Parity-Check

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

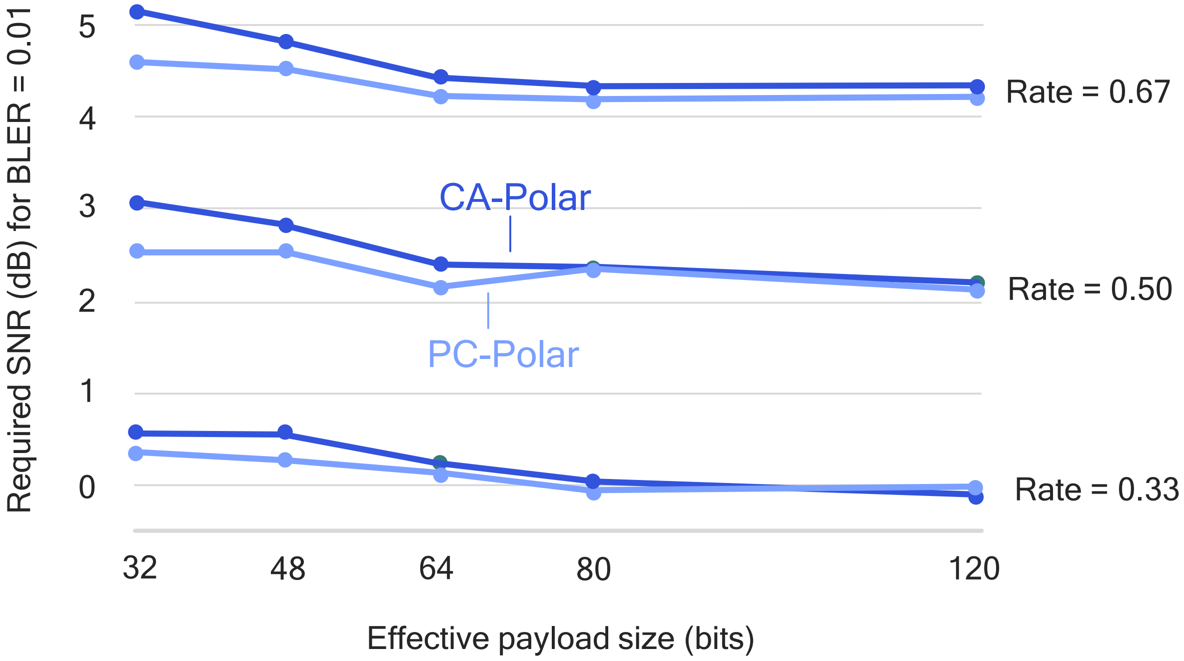
5G NR CRC-Aided (CA-Polar) design

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



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

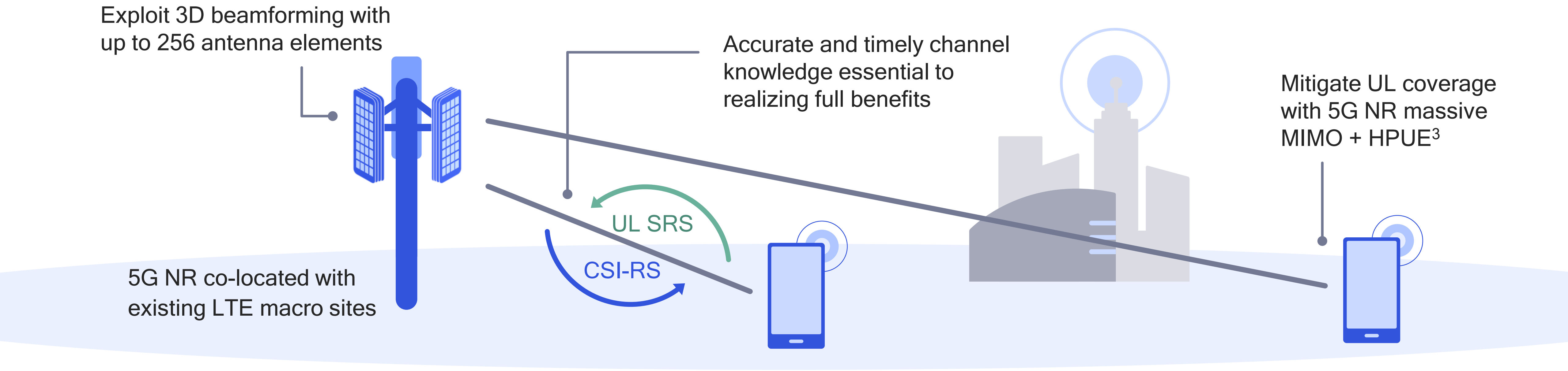
Versus PC-Polar[1] (lower is better)



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



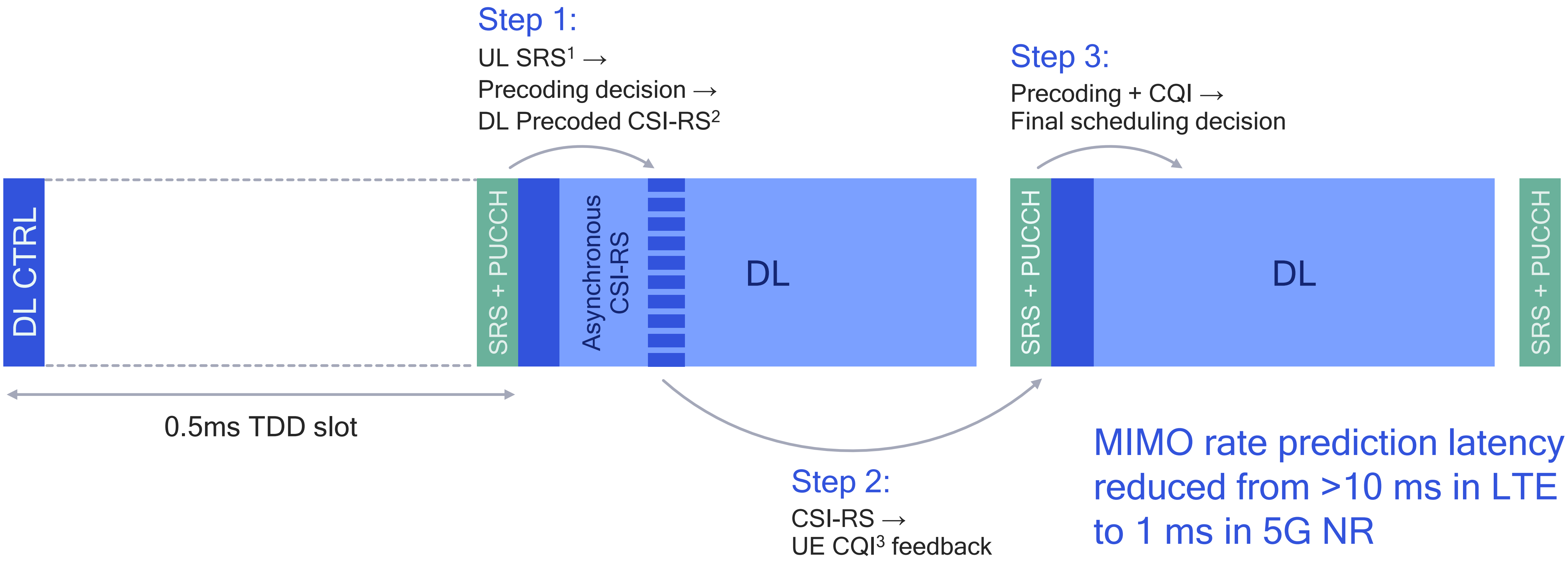
Enabled through an advanced 5G NR end-to-end Massive MIMO design (network and device)

- 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

C1. 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

5G NR slot structure and enhanced Ref Signals enable fast/accurate feedback

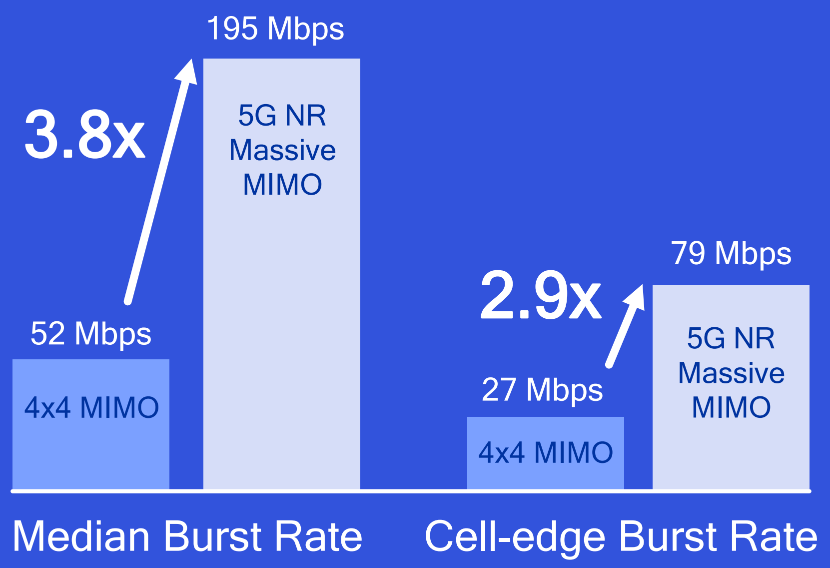


MIMO rate prediction latency reduced from >10 ms in LTE to 1 ms in 5G NR

*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



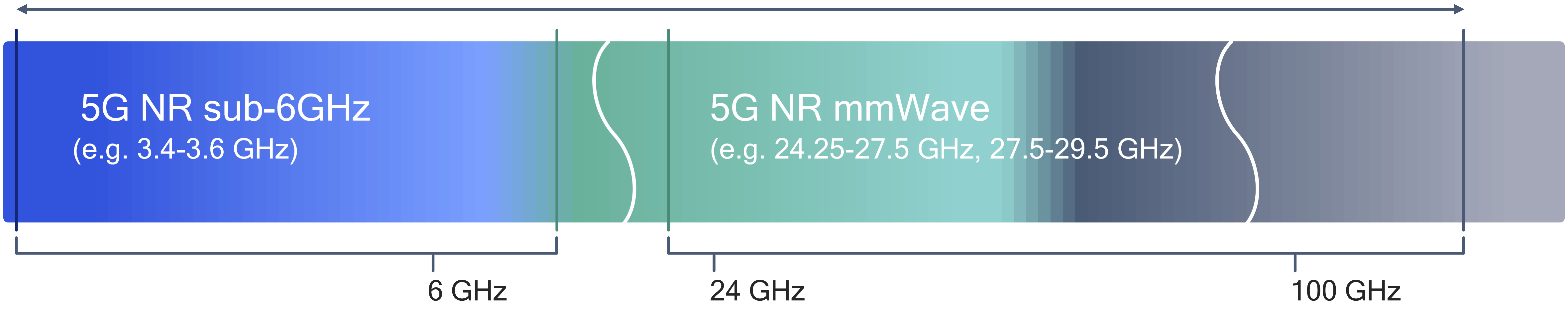
Assumptions: carrier frequency 4GHz; 200m ISD, 200MHz total bandwidth; base station: 256 antenna elements (x-pol), 48dBm Tx power; UE: 4 Tx/Rx antenna elements, 23dBm max. Tx power; full buffer traffic model, 80% indoor and 20% outdoor UEs.

The large bandwidth opportunity for mmWave

The new frontier of mobile broadband

5G NR

Unified design across diverse spectrum bands/types

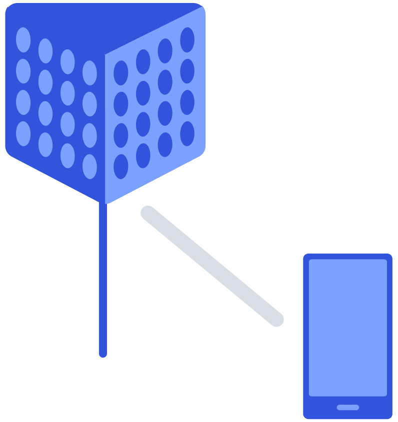


Multi-Gbps data rates
With large bandwidths (100s of MHz)

Much more capacity
With dense spatial reuse

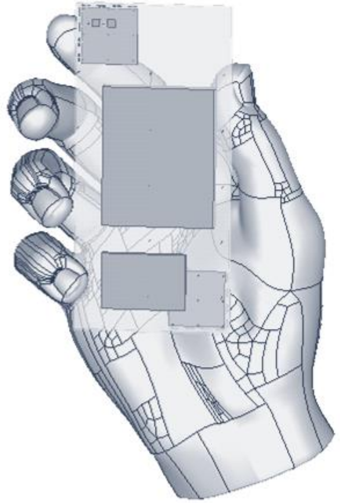
Lower latency
Opens up new opportunities

Overcoming numerous challenges to mobilize mmWave



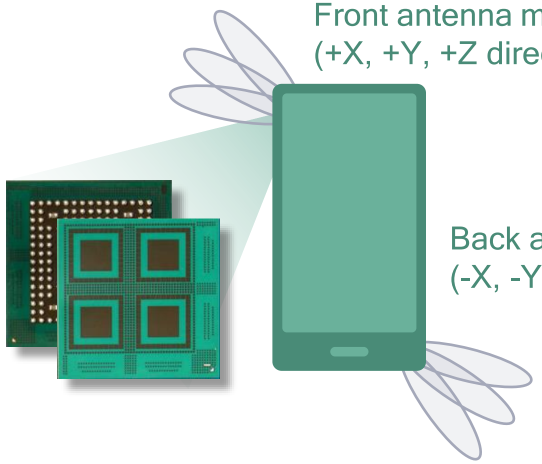
Coverage

Analog beamforming with narrow beamwidth to overcome significant path loss in bands above 24 GHz



Robustness

Adaptive beam steering and switching to overcome blockage from hand, head, body and foliage

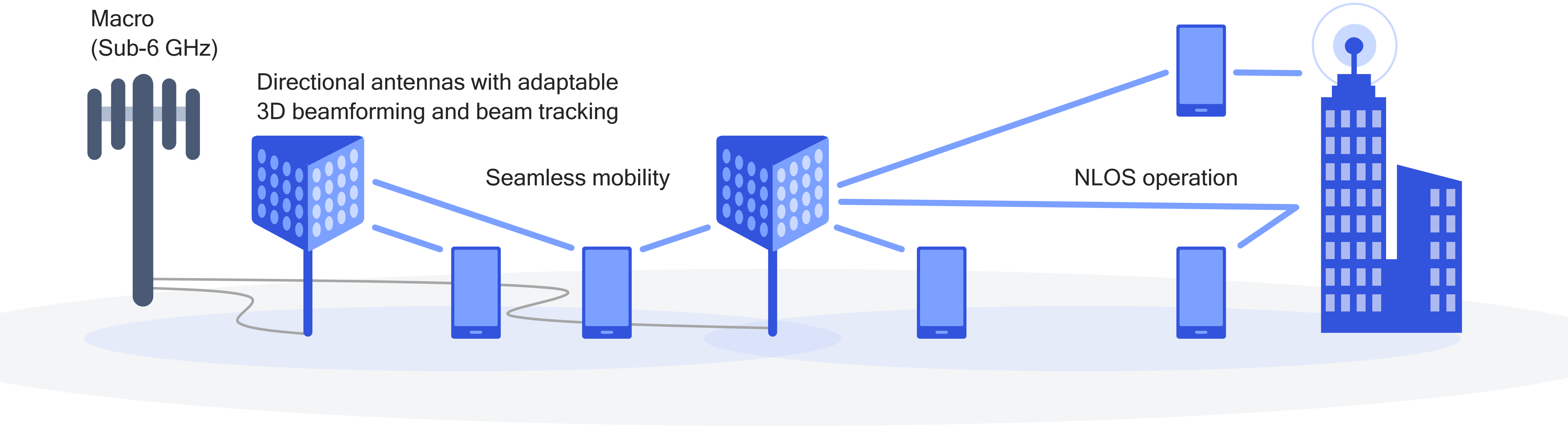


Device size/power

Different antenna configurations (face/edge) 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

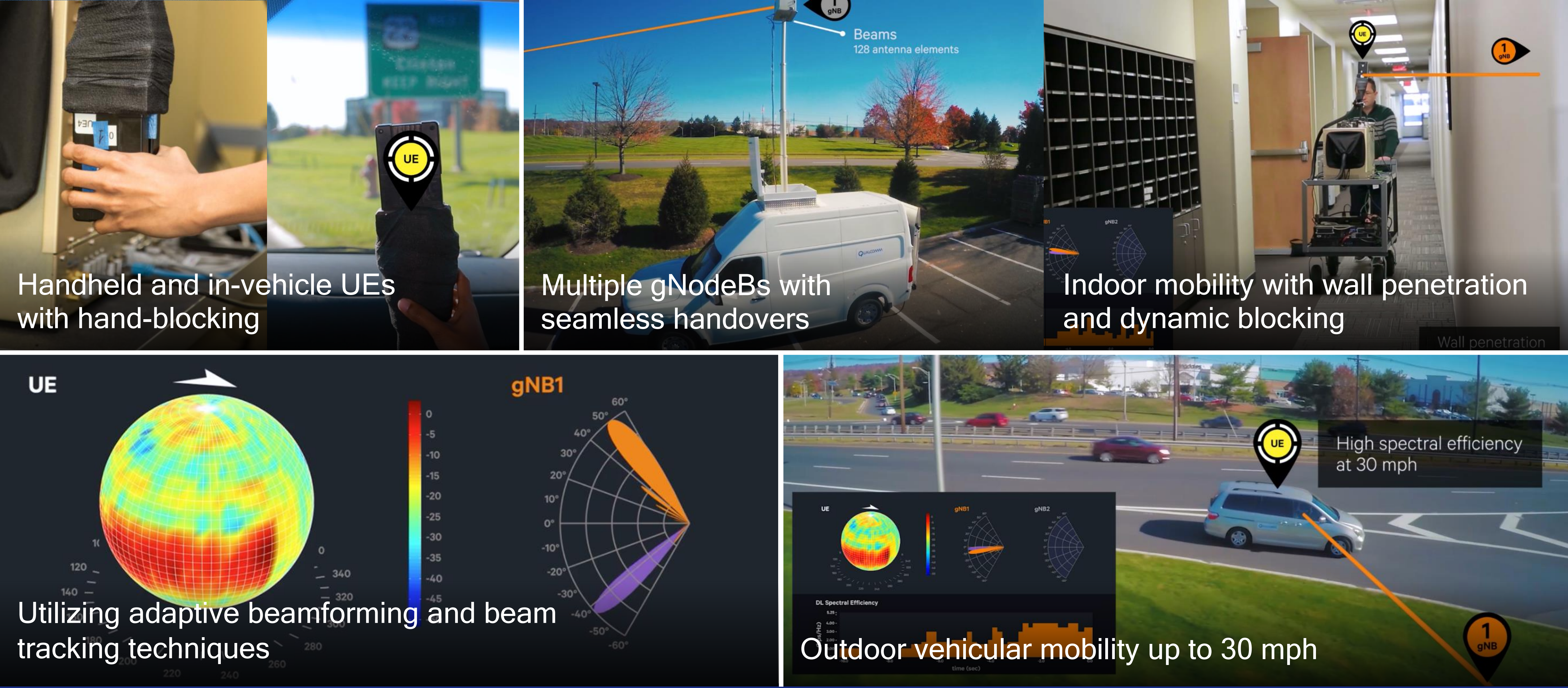


Very dense network topology and spatial reuse (~150-200m ISD)

Fast beam steering and switching within an access point

Architecture that allows for fast beam switching across access points

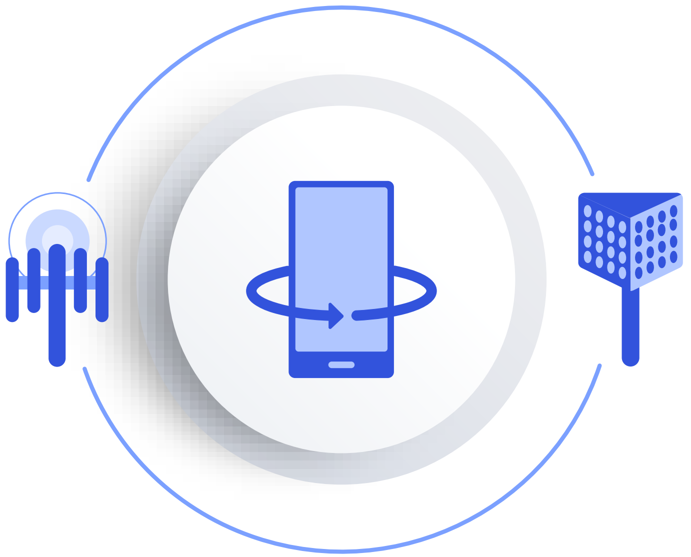
Tight integration with sub-6 GHz (LTE or NR)



Qualcomm Research 5G mmWave prototype

Showcasing robust mobile communications in real-world OTA testing

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

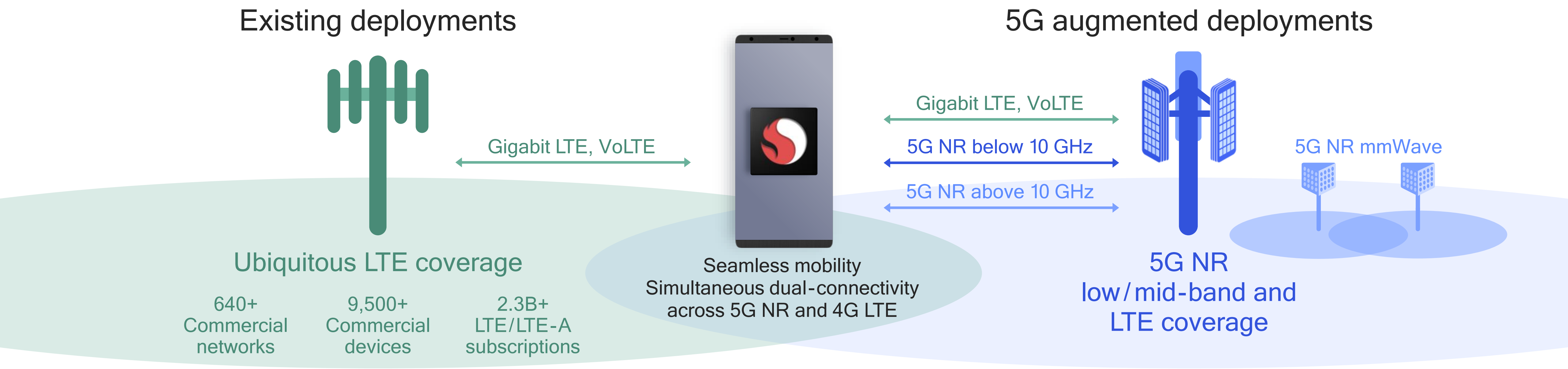
CA across spectrum types

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

Gigabit LTE provides the coverage foundation for 5G eMBB



Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. Source: GSA (www.gsacom.com)—Oct 2017 on network launches, Oct 2017 on subscriptions, Nov 2017 on commercial devices

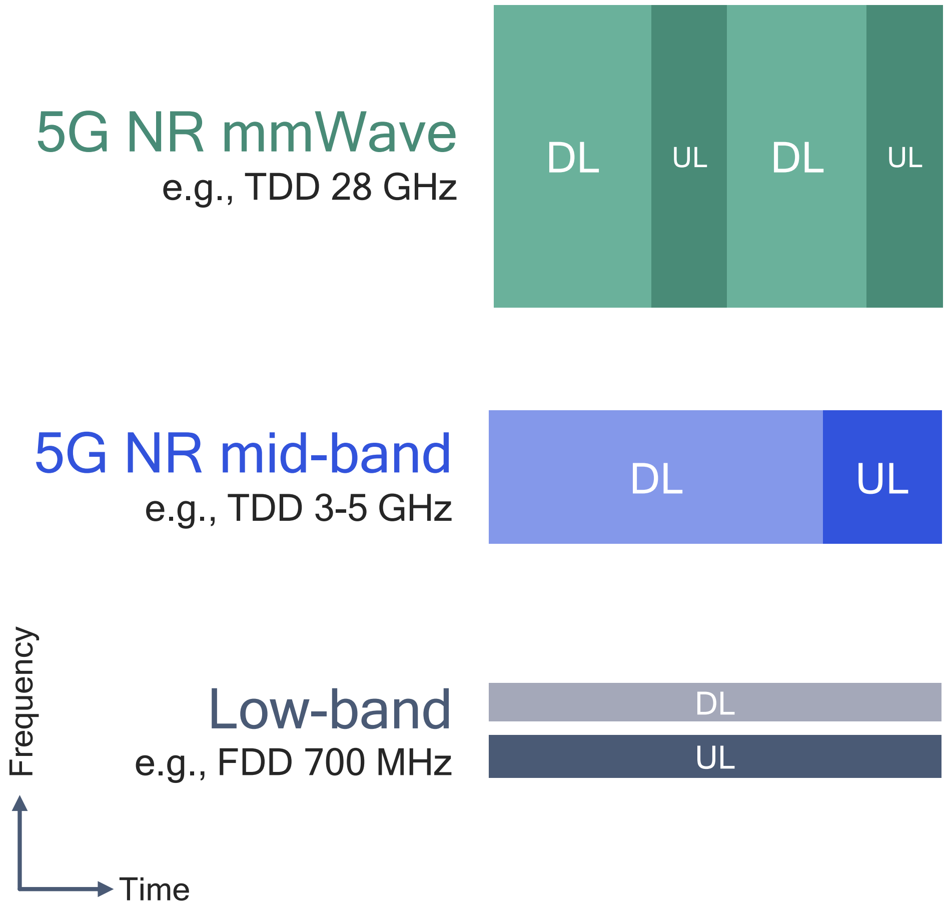
Enabling gigabit experiences everywhere

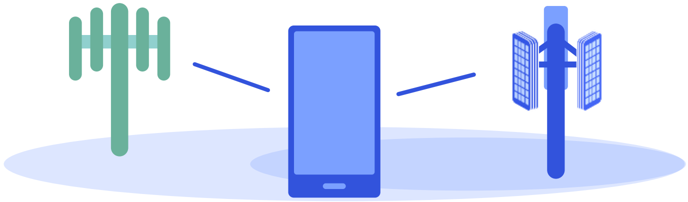
Providing VoLTE leveraging LTE's ubiquitous coverage

Supplementing 5G NR mid-band and mmWave

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

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





Non-Standalone (NSA)

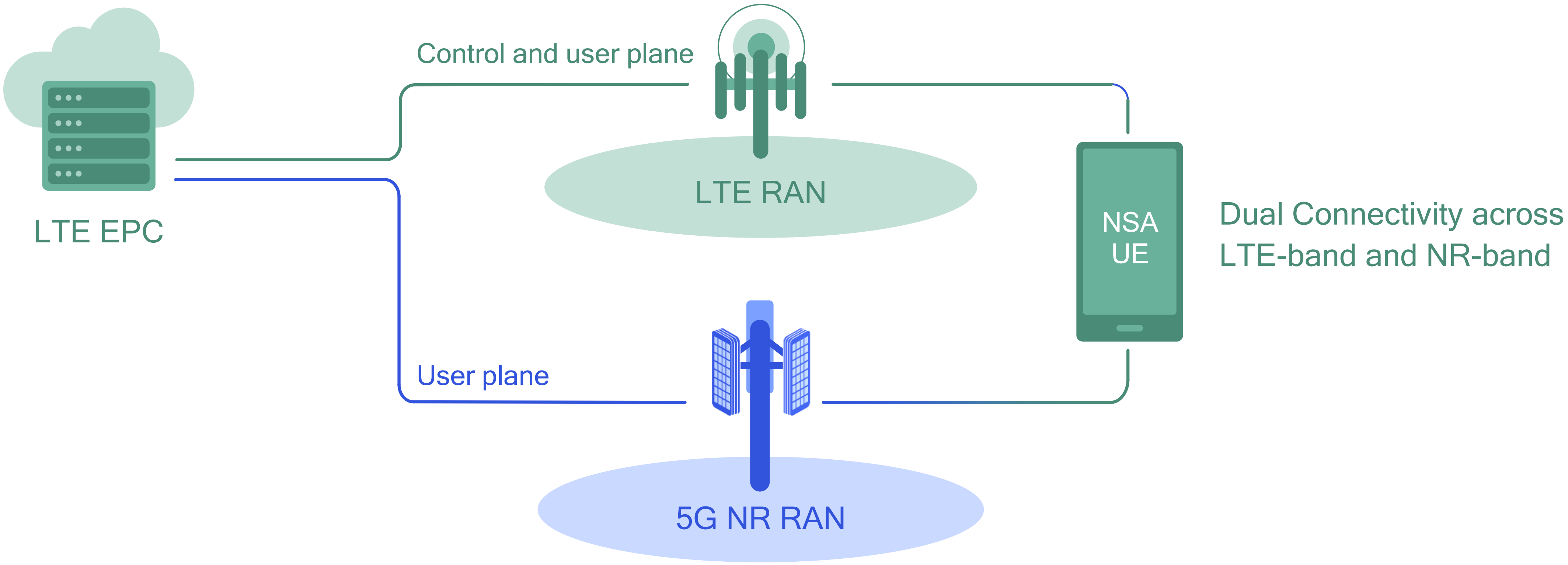
Low-band LTE or NR UL can help increase UL data rate/range

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

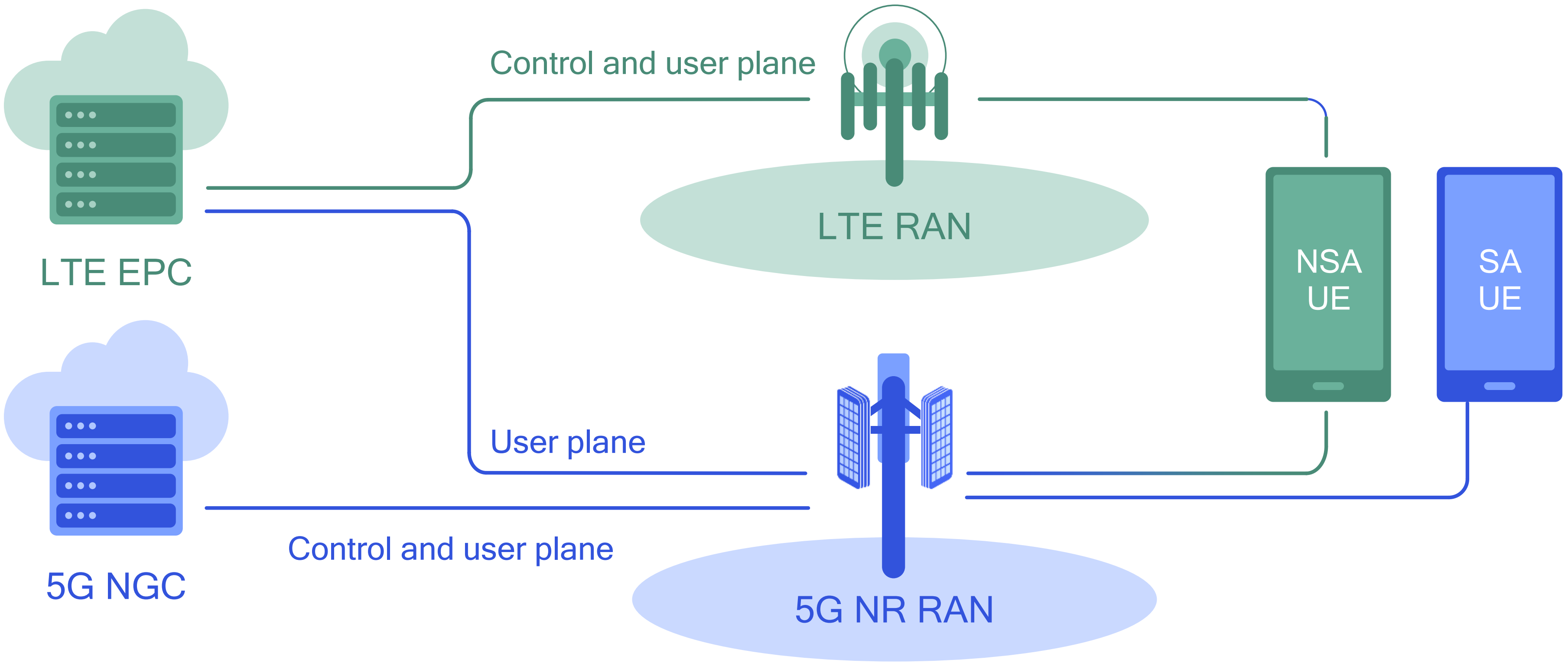
NSA 5G NR is accelerating 5G NR deployments for 2019



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

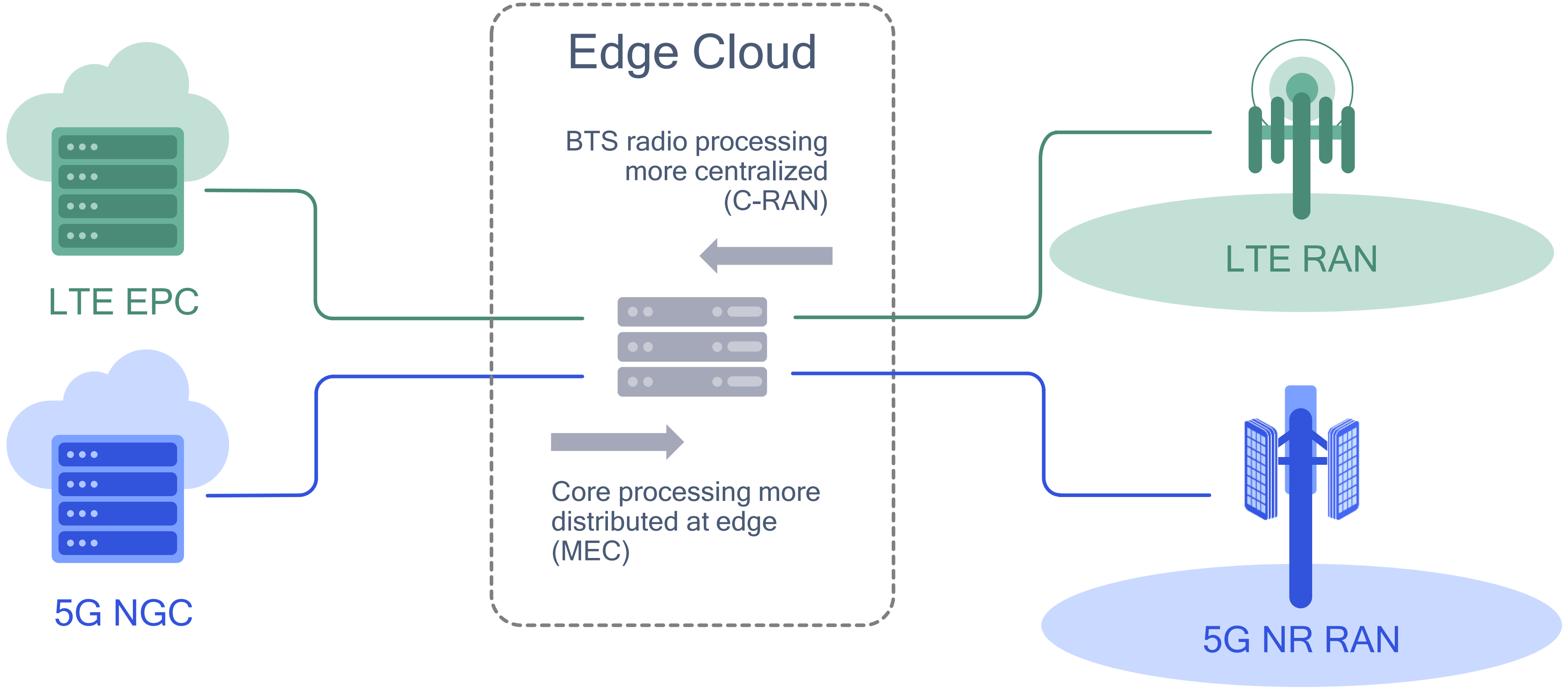


SA provides full user/control plane capability for 5G NR, seamlessly coexisting with NSA UEs

Standalone (SA) 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



Increased cloud-based RAN

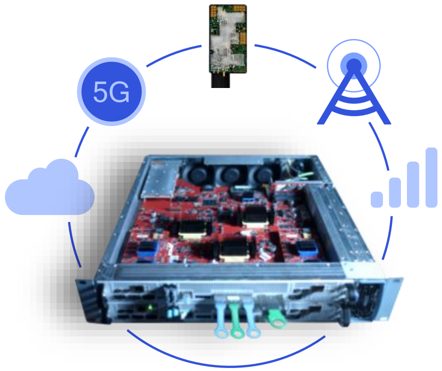
Trend starting today to help minimize changes to RAN for 5G NR evolution

Increased edge-based computing

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

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

Making 5G NR a commercial reality for 2019



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

Leveraging prototype systems and our leading global network experience

Qualcomm snapdragon X50 5G modem

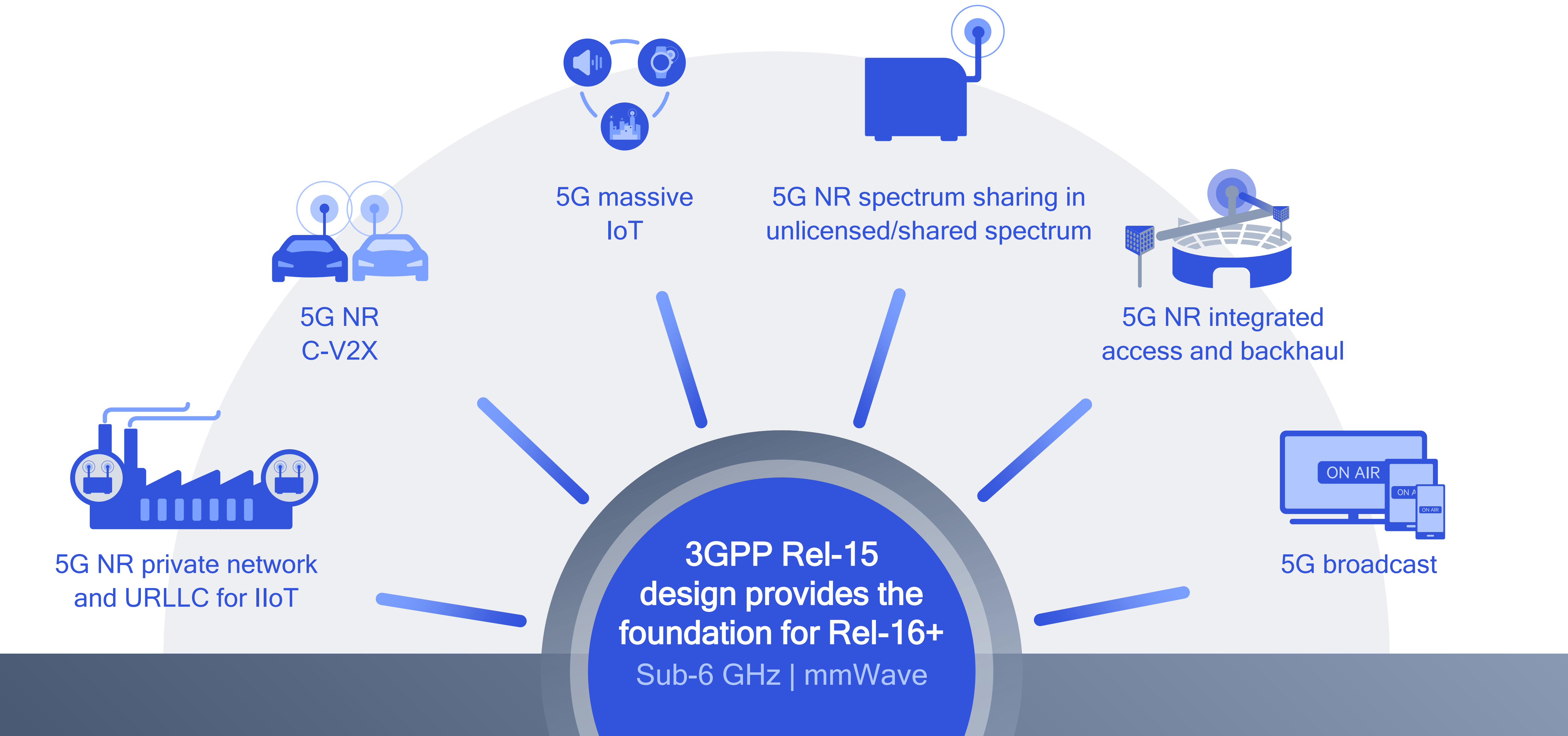
Modem and RFFE leadership

Announced the Qualcomm Snapdragon X50 5G modem family

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. and/or its subsidiaries

LTE foundational technologies

Driving a rich 5G roadmap in Release 16 and beyond



Qualcomm

5G NR

5G is the foundation to what's next.
We are the foundation to 5G.

Learn more at www.qualcomm.com/5G

Making 5G NR a commercial reality for 2019 eMBB deployments

Driving the expansion of 5G NR ecosystem and opportunity

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