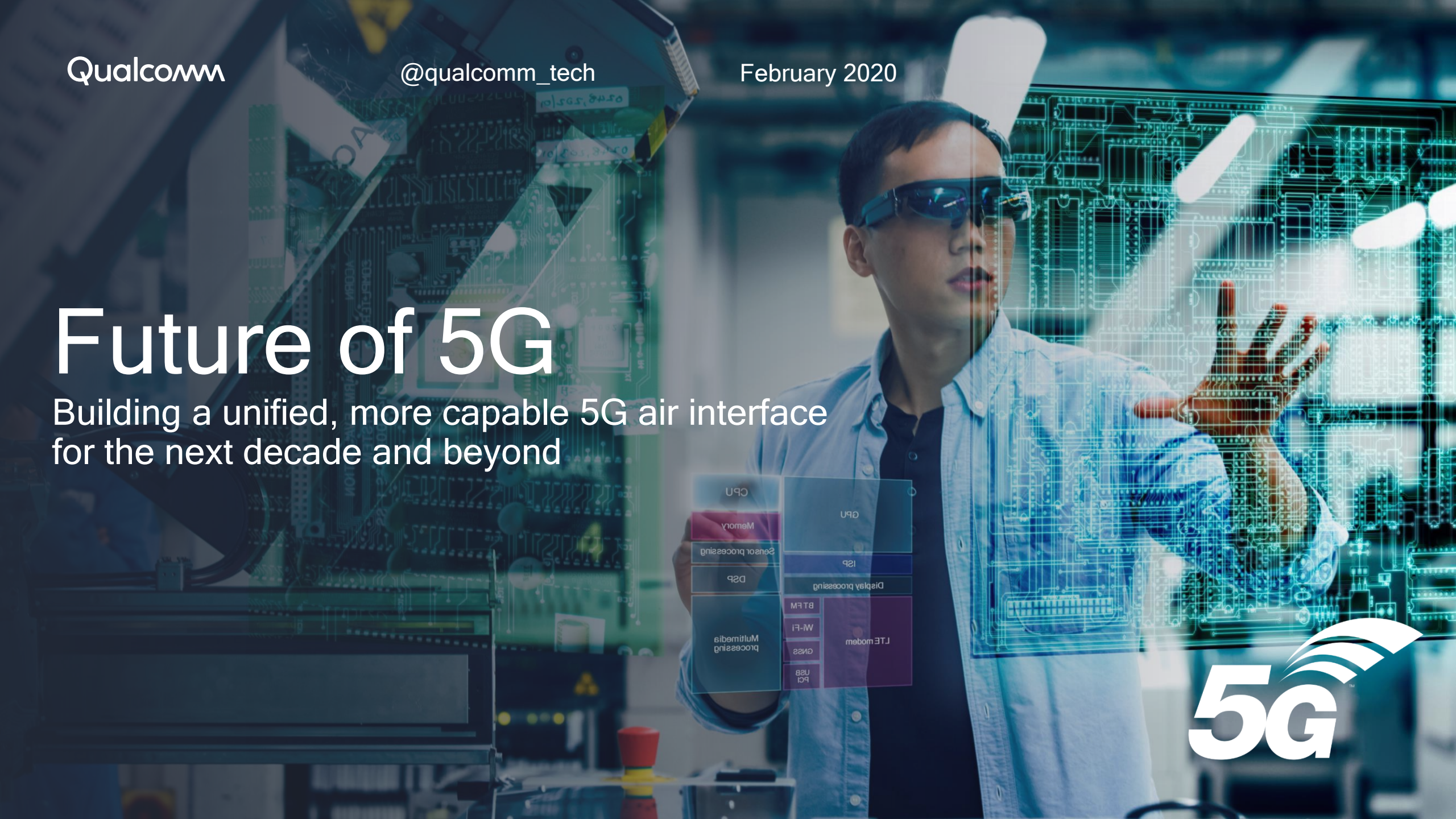
Qualcomm @qualcomm_tech February 2020

Future of 5G

Building a unified, more capable 5G air interface for the next decade and beyond



Mobile has made a leap every ~10 years

Mobile voice communication

1G

1980s

Analog voice

AMPS, NMT, TACS

Efficient voice to reach billions

2G

1990s

Digital voice

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

Focus shifts to mobile data

3G

2000s

Wireless Internet

CDMA2000/EV-DO WCDMA/HSPA+,

Mobile broadband and emerging expansion

4G

2010s

Mobile broadband

LTE, LTE Advanced, Gigabit LTE

A unified future-proof platform

2020s

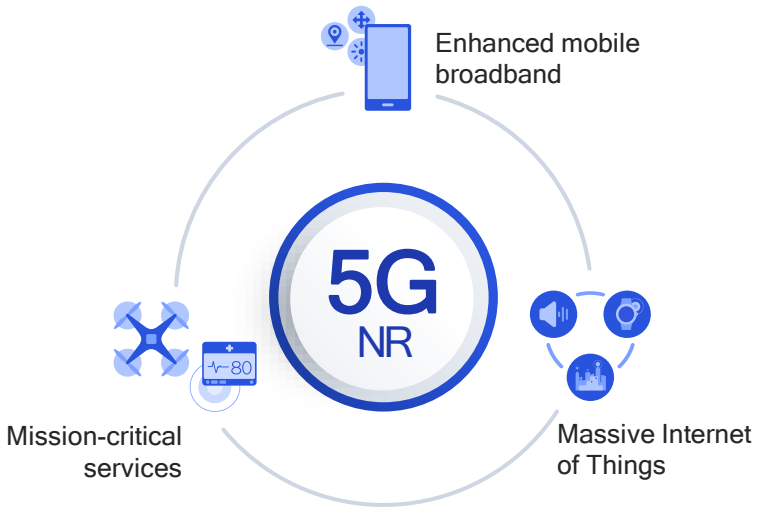
Wireless Edge

5G New Radio (NR)

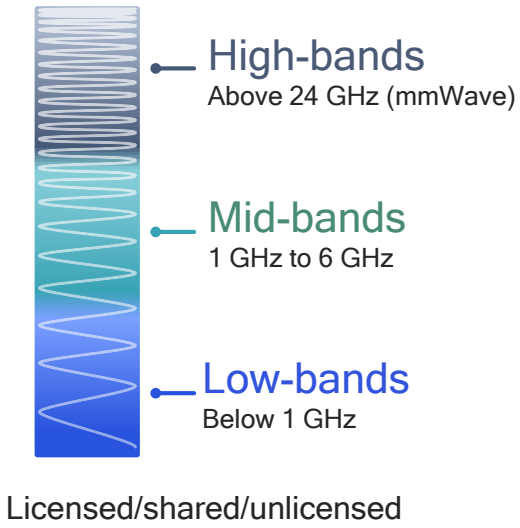
Delivering on the 5G vision

Where virtually everyone and everything is intelligently connected

5G NR is a unified, more capable air interface



Diverse services



Licensed/shared/unlicensed

Diverse spectrum

Diverse deployments

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

5G will address the insatiable demand for mobile broadband

Over 60x growth in mobile data traffic from 2013 to 2024

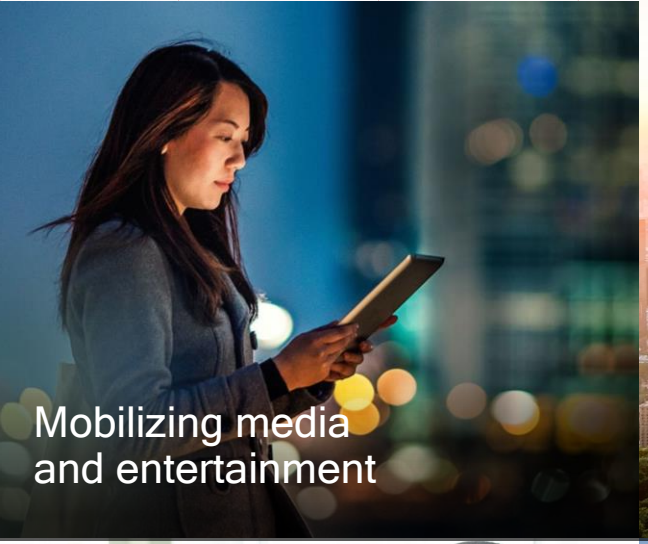
~131B Gigabytes

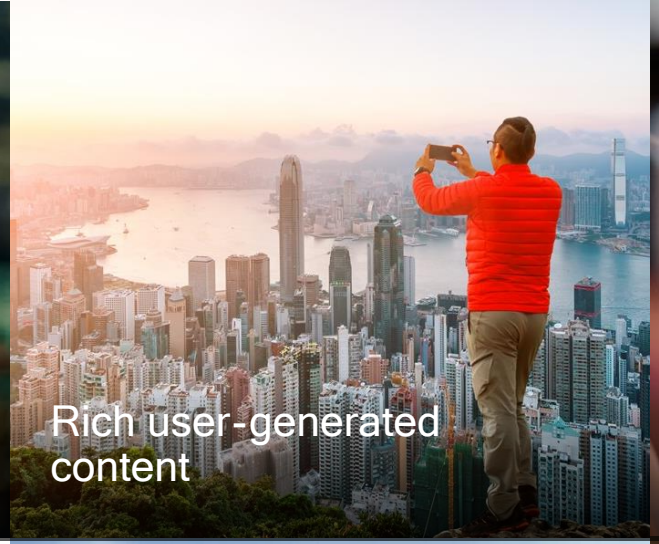
Monthly global mobile data traffic in 2024

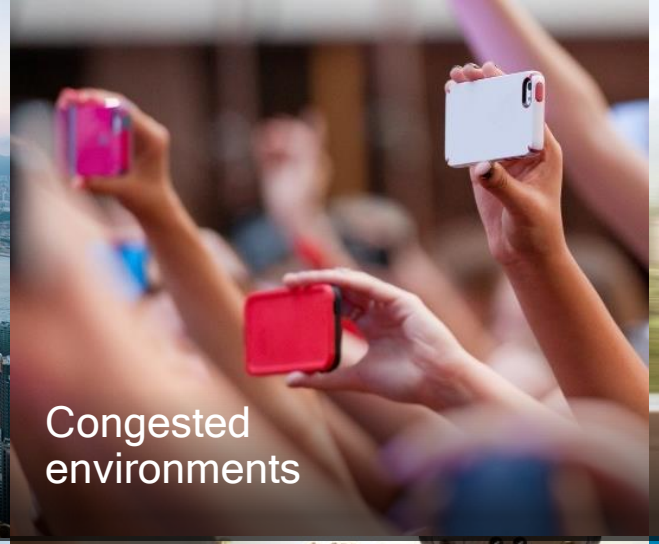
In 2024, ~75% of mobile data traffic from multi-media creation & consumption

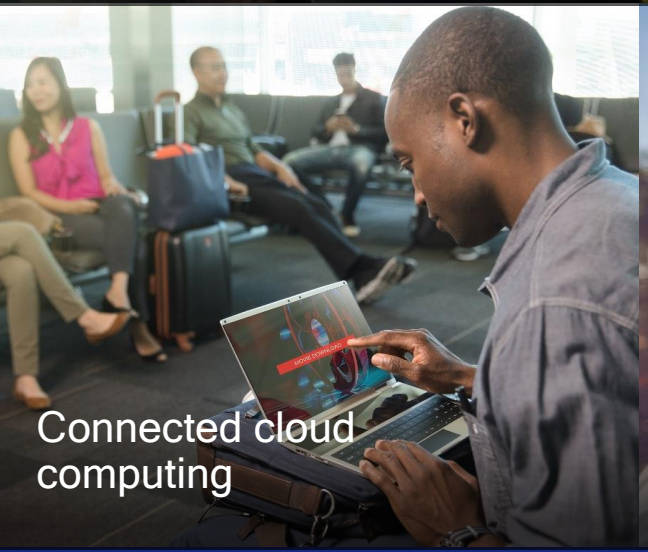
In 2024, 25% of mobile data traffic will be carried by 5G networks – 1.3x more than 4G/3G/2G traffic today

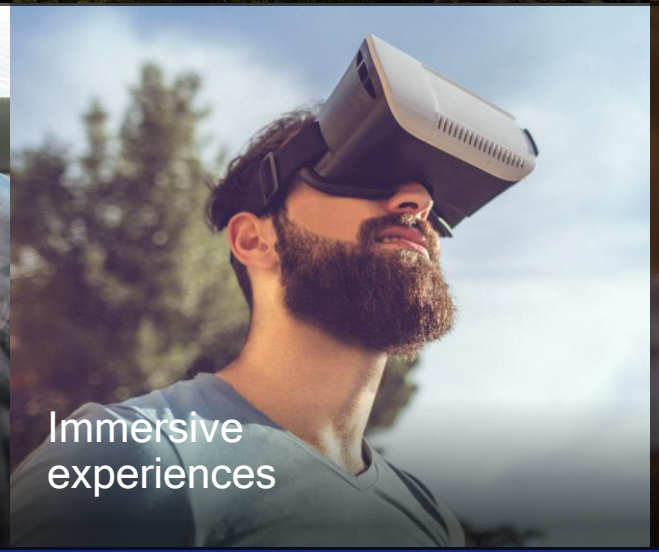
Source: Ericsson Mobility Report June 2019







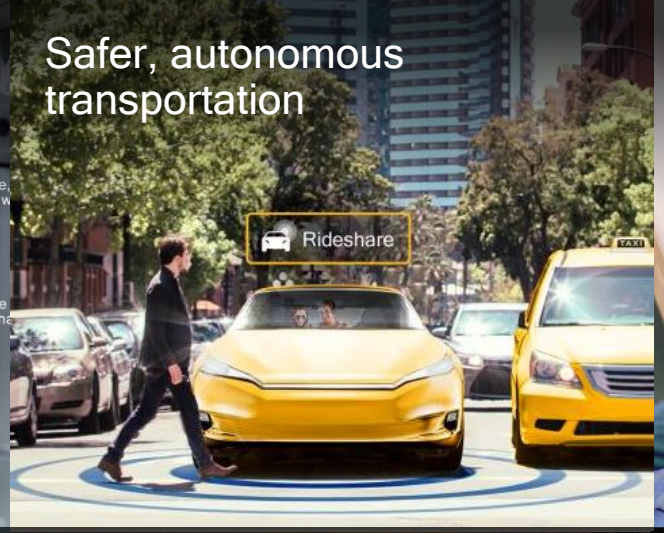


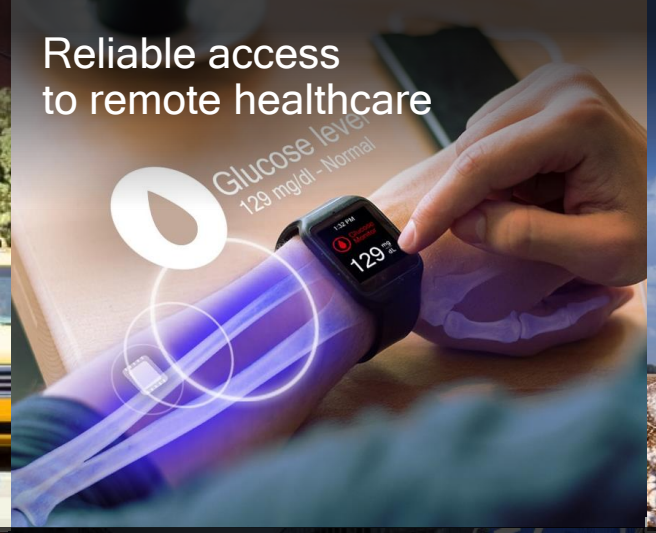


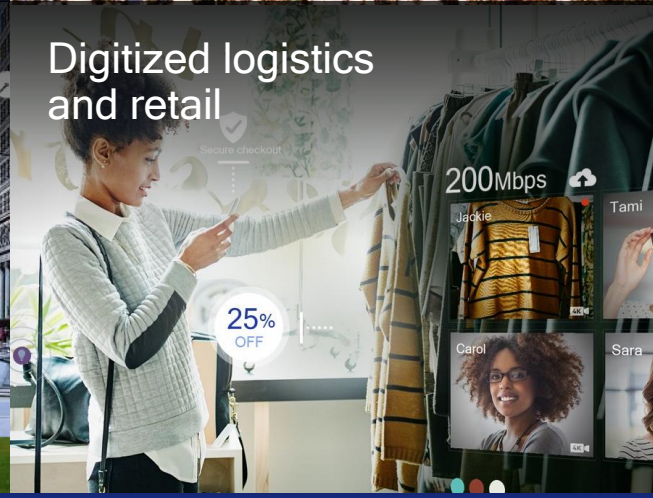
5G

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

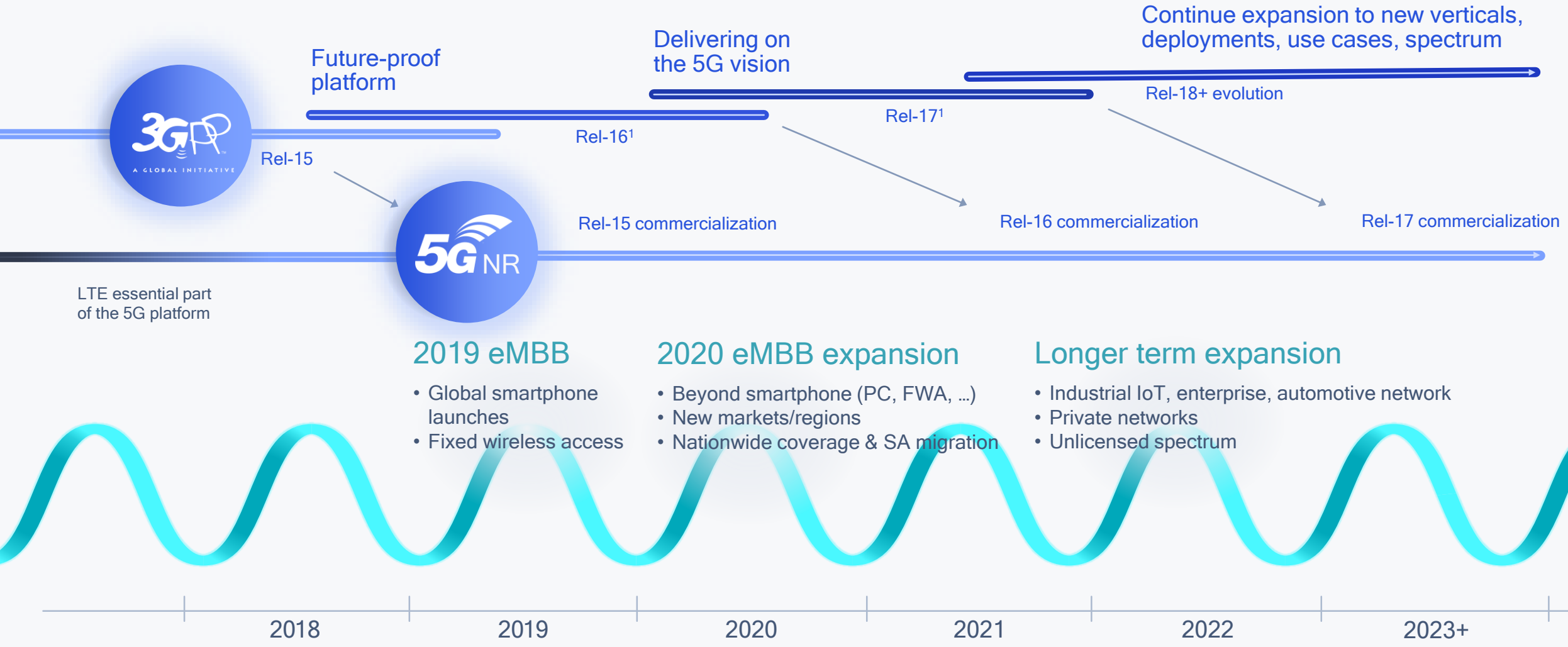
Powering the digital economy

$13.2 Trillion

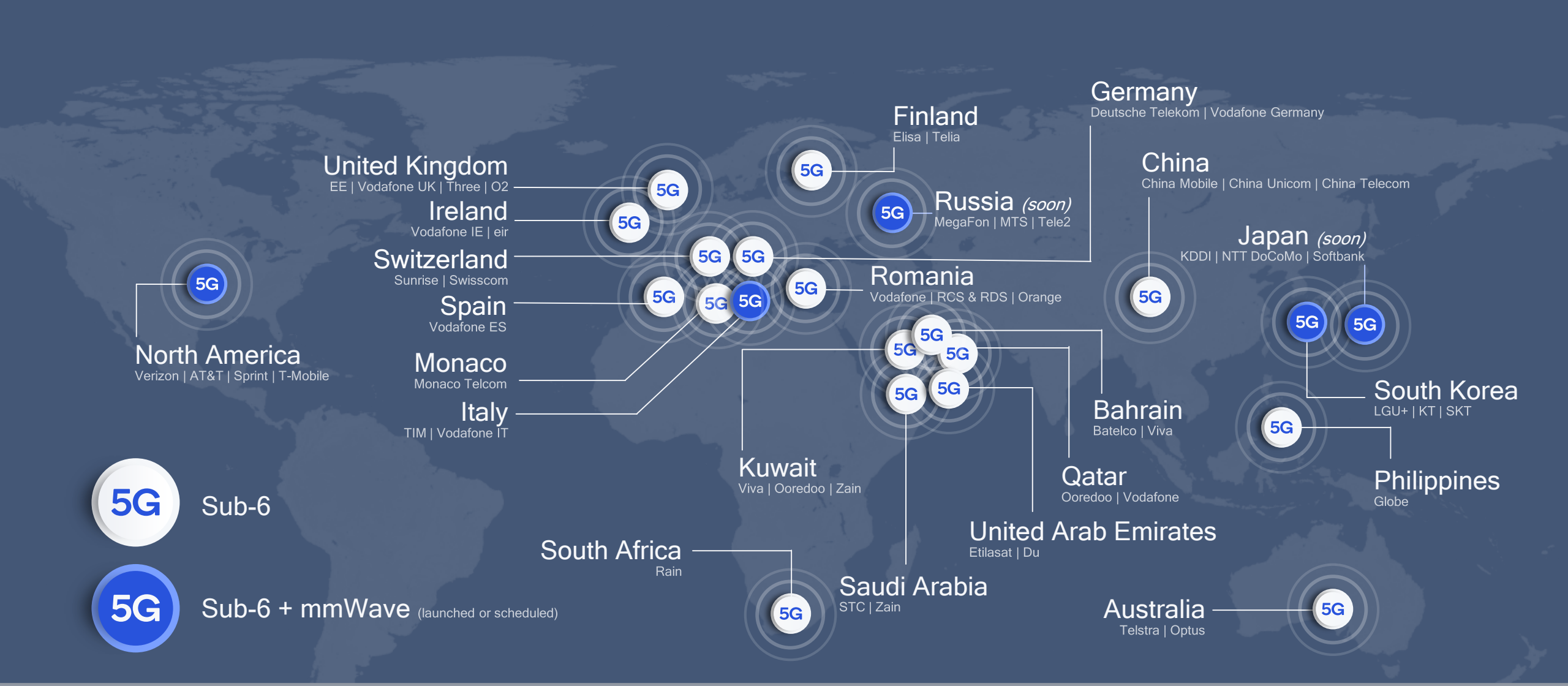
In goods and services by 2035*

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

Driving the 5G expansion



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



Comparison of Year 1 announcements

4G

4 Operators launched
3 OEMs launched

5G

40+ Operators launching
40+ OEMs launching

5G smartphones

Lenovo
Z6 Pro 5G

LG
V50 ThinQ
5G

Motorola
moto z^4/z^3
+ 5G moto mod

Nubia
Mini 5G

OnePlus
7 Pro 5G

OPPO
Reno 5G


Samsung
Galaxy
S10 5G


Samsung
Galaxy Fold


Samsung
Galaxy
Note10+ 5G


Samsung
A90 5G

Vivo
iQOO
5G Edition


Vivo
NEX 3 5G


Xiaomi
Mi MIX 5G

Xiaomi
Mi MIX Alpha

Xiaomi
Mi 9 Pro 5G

ZTE
Axon 10 Pro
5G

Hotspots and CPEs

Askey HTC Netgear WNC
Inseego Netcomm Nokia ZTE

5G modules

Compal Longsung Sierra SIMcom
Fibocom Quectel Wireless Telit

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

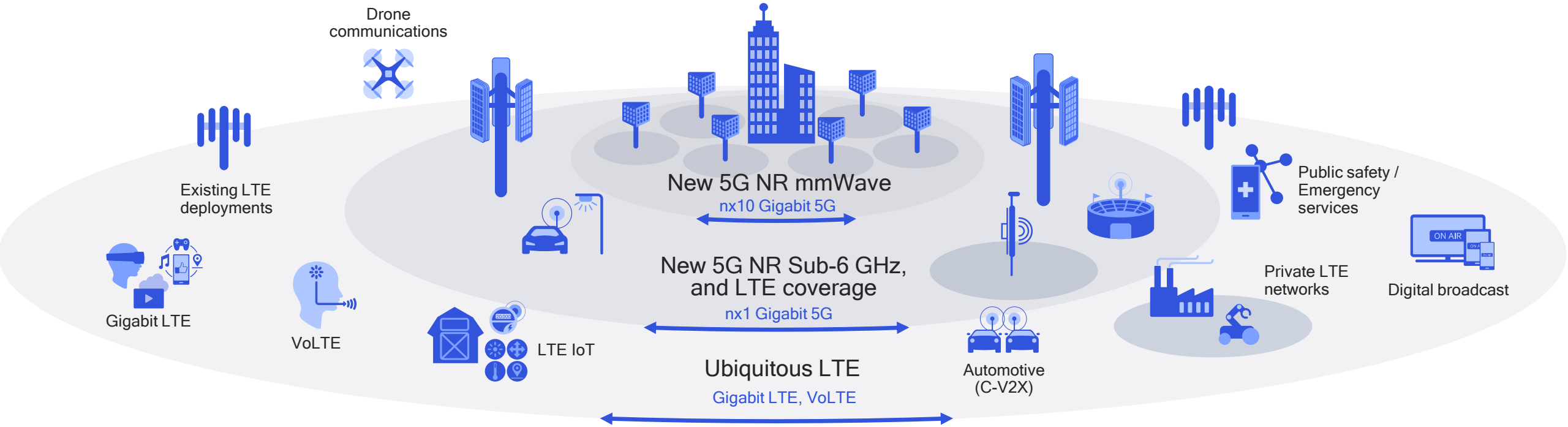
Qualcomm snapdragon

230+

5G devices launched or in development

Our LTE advancements are essential to 5G

Providing ubiquitous coverage and essential services that complement 5G NR



Gigabit LTE is here now and delivers a virtually seamless 5G mobile experience

LTE IoT, private LTE network, C-V2X are enabling new mobile use cases today

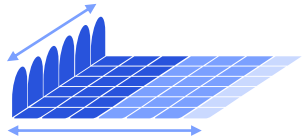
LTE Advanced Pro leadership is essential to success in the 5G Era

5G NR design and technologies

3GPP Release-15

Our technology inventions drove 5G Rel-15 specifications

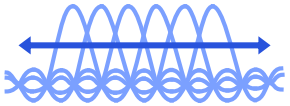
Flexible slot-based framework



Scalable OFDM numerology

Low latency, URLLC, forward compatibility

Scalable OFDM-based air interface



Self-contained slot structure

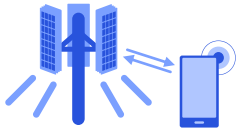
Address diverse services, spectrum, deployments

Advanced channel coding

Multi-Edge LDPC and CRC-Aided Polar

Support large data blocks, reliable control channel

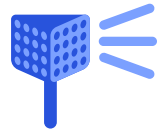
Massive MIMO



Reciprocity-based MU-MIMO

Large # of antennas to increase coverage/capacity

Mobile mmWave

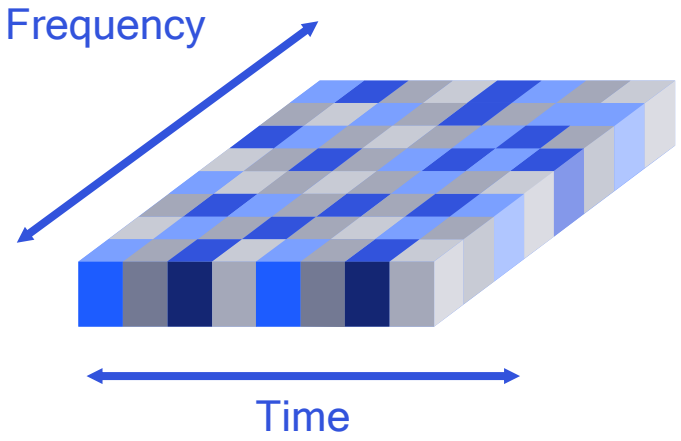


Beamforming and beam-tracking

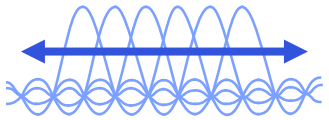
For extreme capacity and throughput

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

Scalable OFDM-based 5G NR air interface

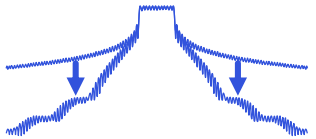


Scalable numerology



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]

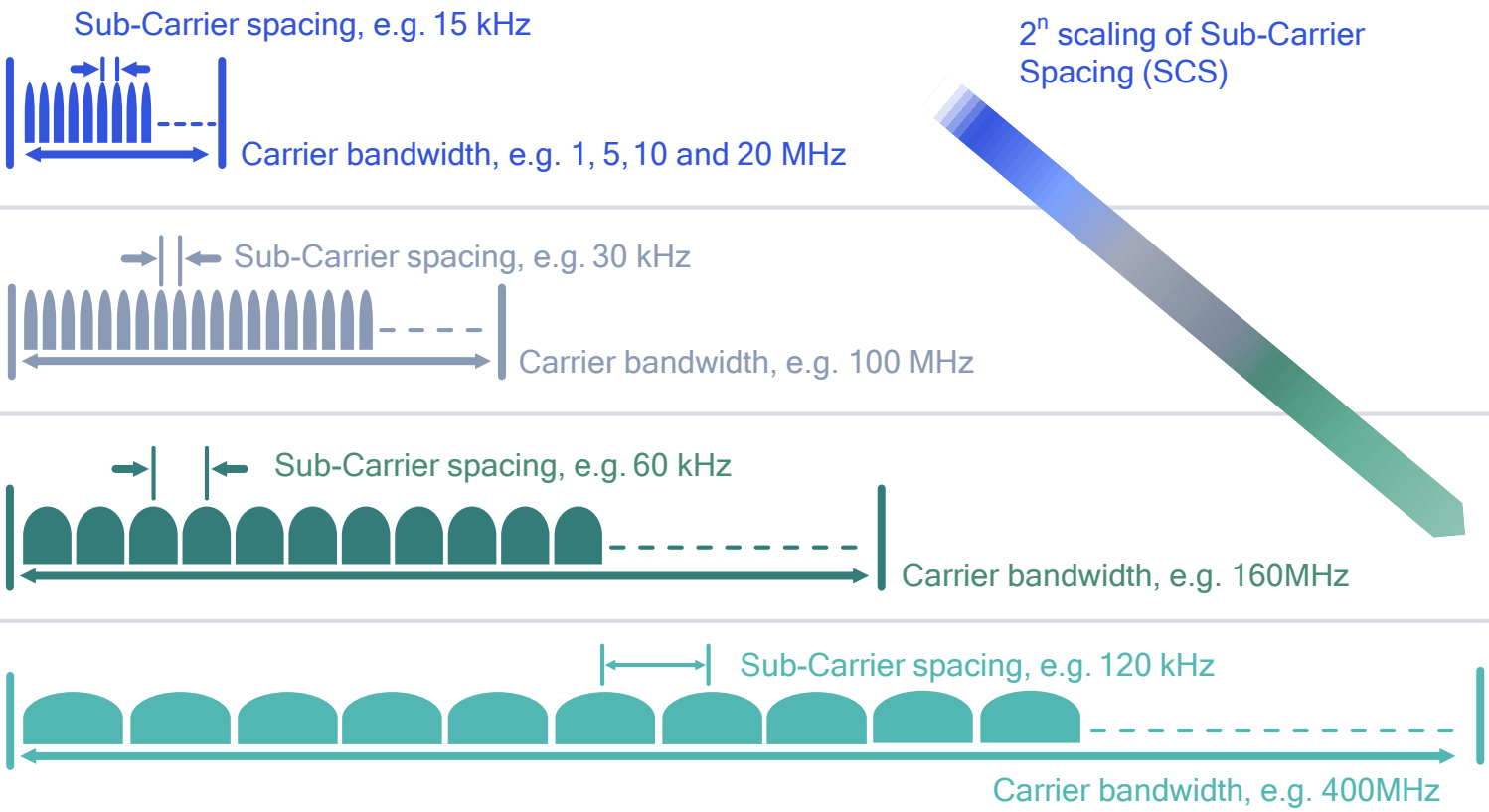
Scalable 5G NR OFDM numerology–examples

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

Global snapshot of allocated/targeted 5G spectrum

5G is being designed for diverse spectrum types/bands

New 5G band

- Licensed
- Unlicensed/shared
- Existing band

Expanding 5G with the flexible slot-based framework

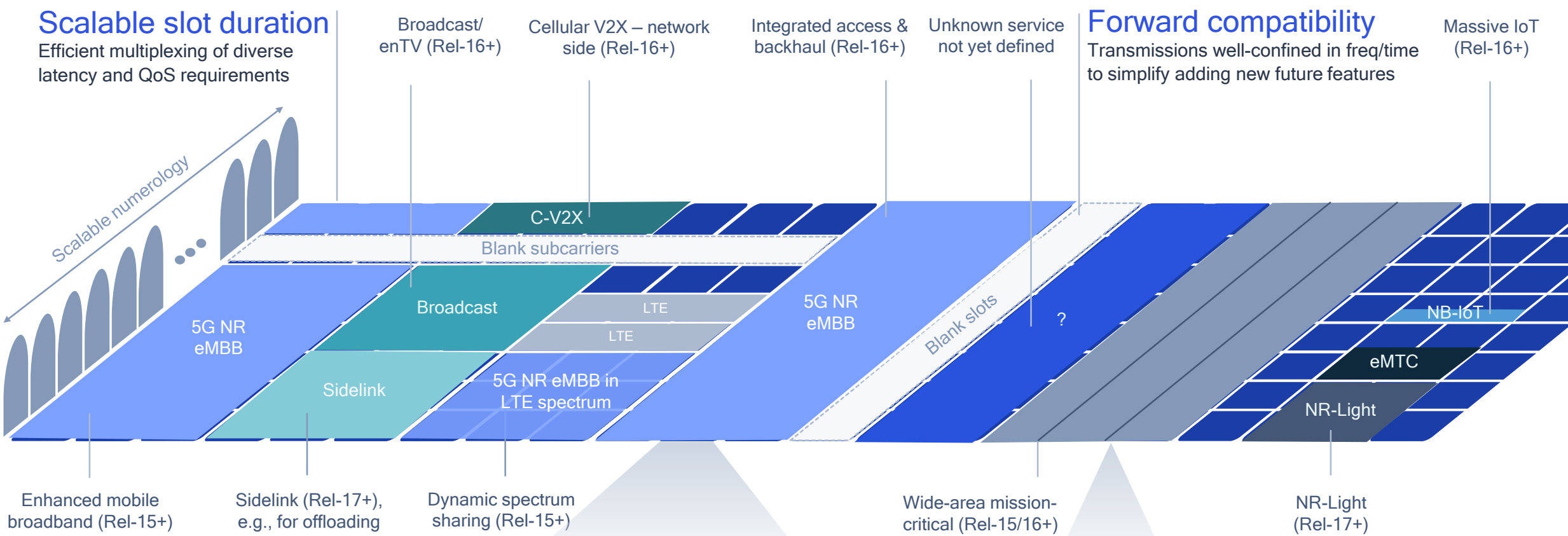
Efficiently multiplex envisioned and future 5G services on the same frequency

Scalable slot duration

Efficient multiplexing of diverse latency and QoS requirements

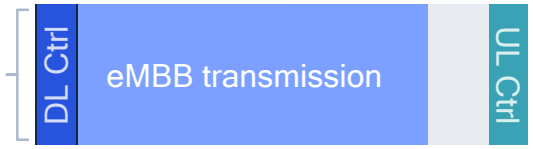
Forward compatibility

Transmissions well-confined in freq/time to simplify adding new future features



Self-contained slot structure

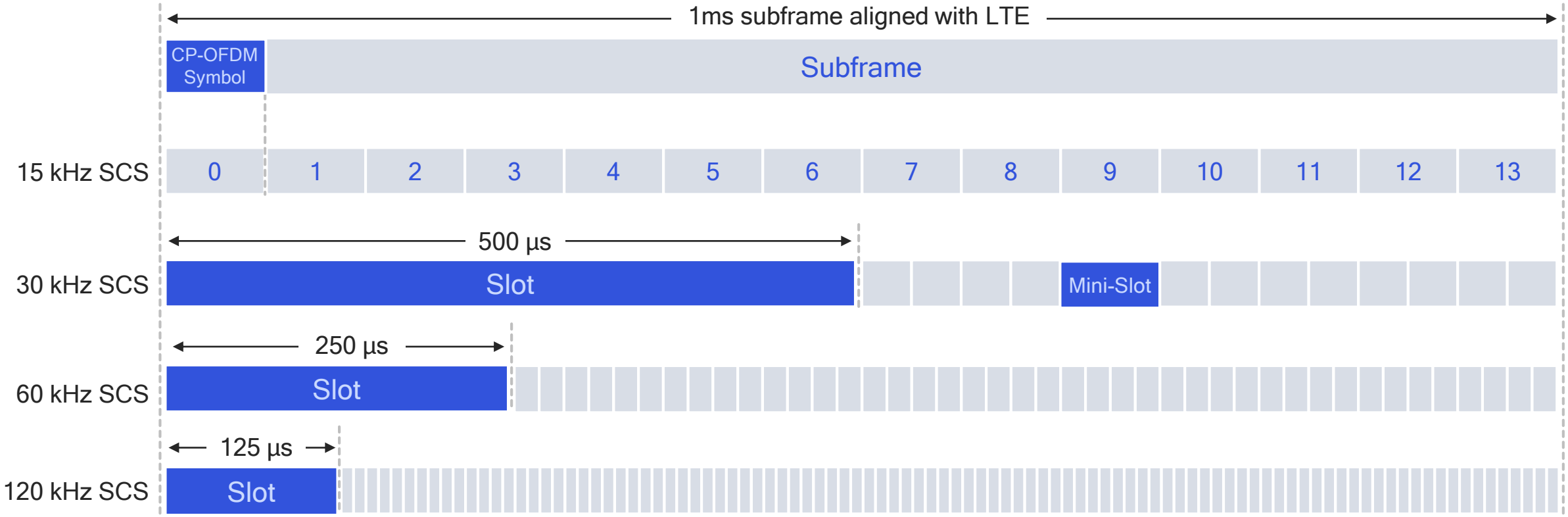
Ability to independently decode slots and avoid static timing relationships across slots



Nominal traffic puncturing

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

Scalable 5G NR slot duration for diverse latency/QoS



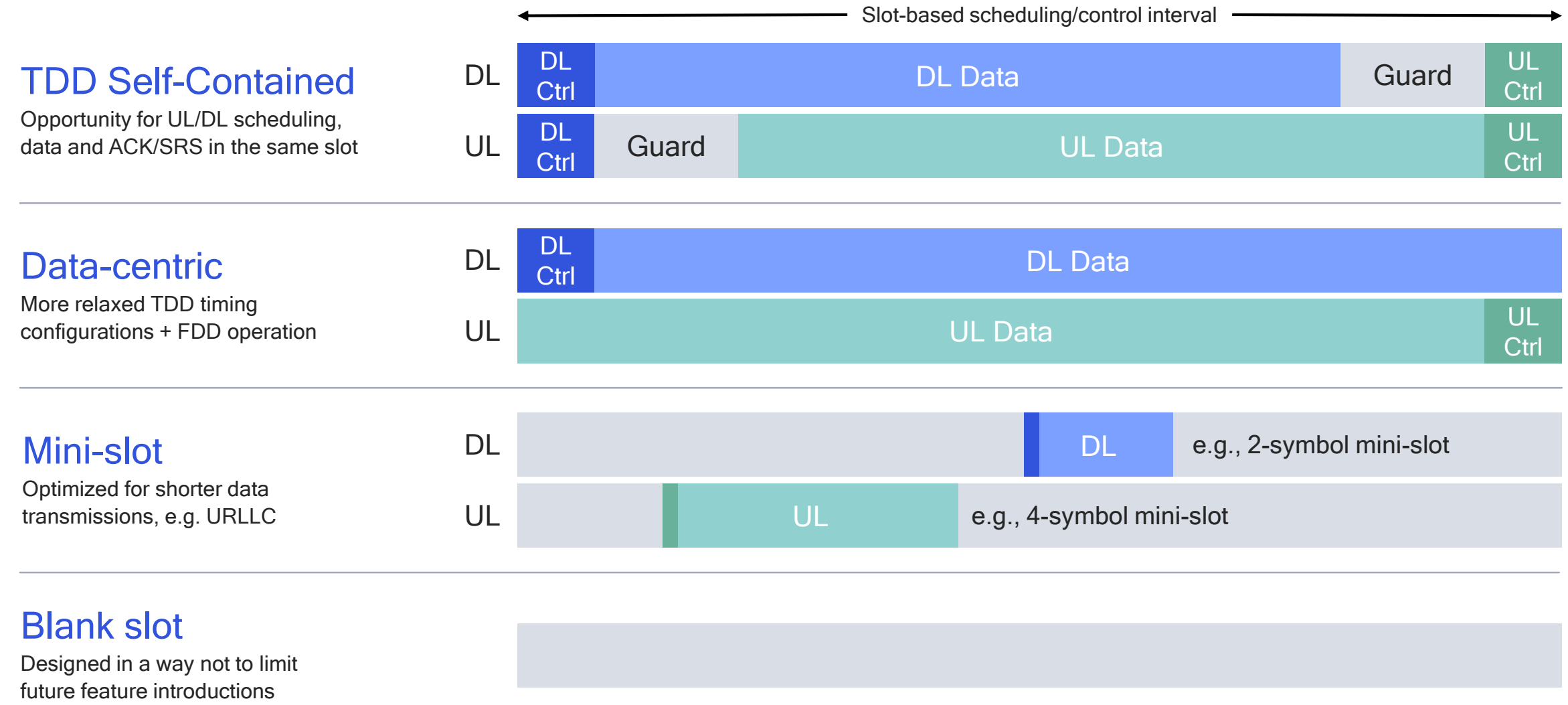
14 OFDM symbols per slot with mini-slot (2, 4, or 7 symbols) for shorter transmissions[1]

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



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

Benefits of the 5G NR TDD self-contained slot

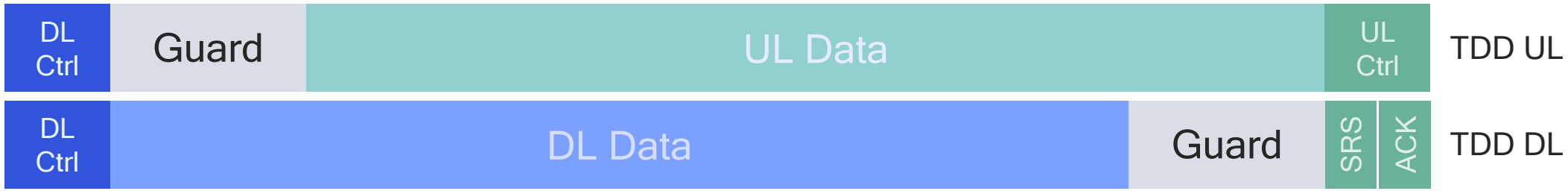
Much faster, more flexible TDD switching and turn-around than 4G LTE

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

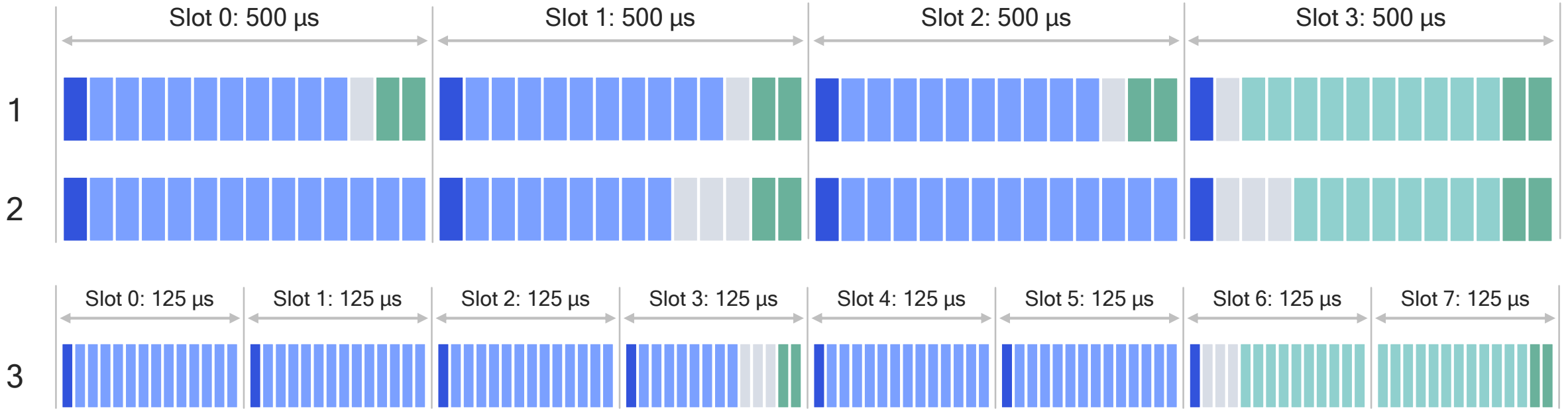
Efficient massive MIMO

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

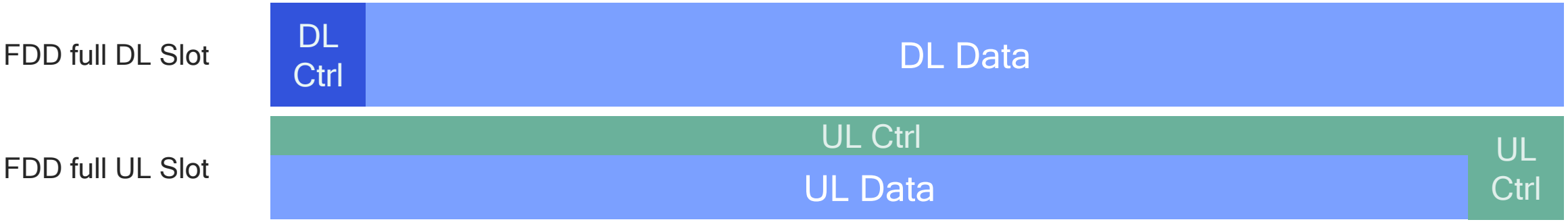
3. Outdoor mmWave

- 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

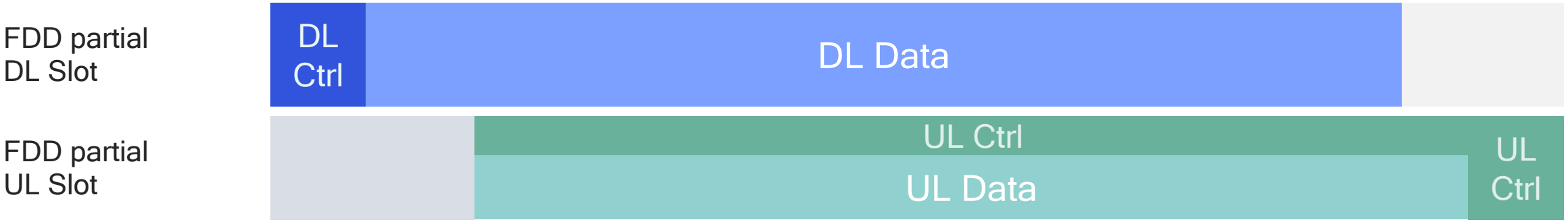
5G NR flexible FDD slot structure

Delivering low latency, extended coverage, and forward compatibility

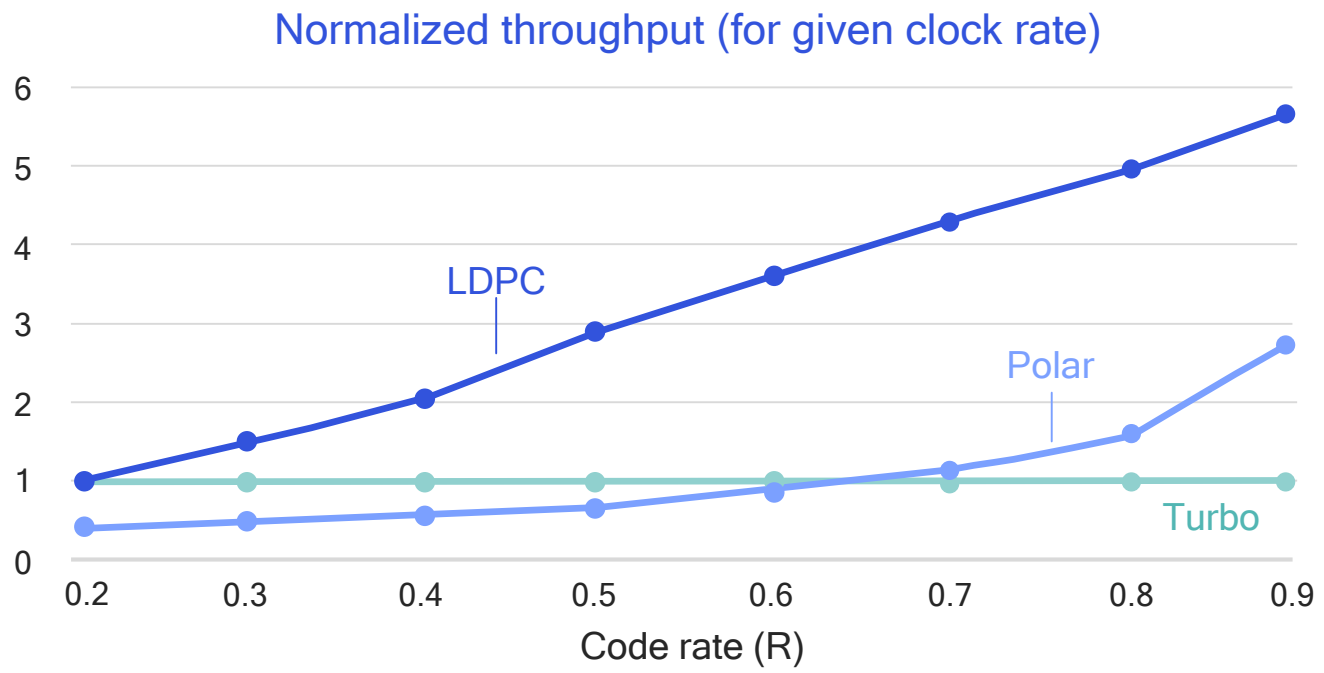
FDD baseline for continuous transmission and extended coverage



FDD 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

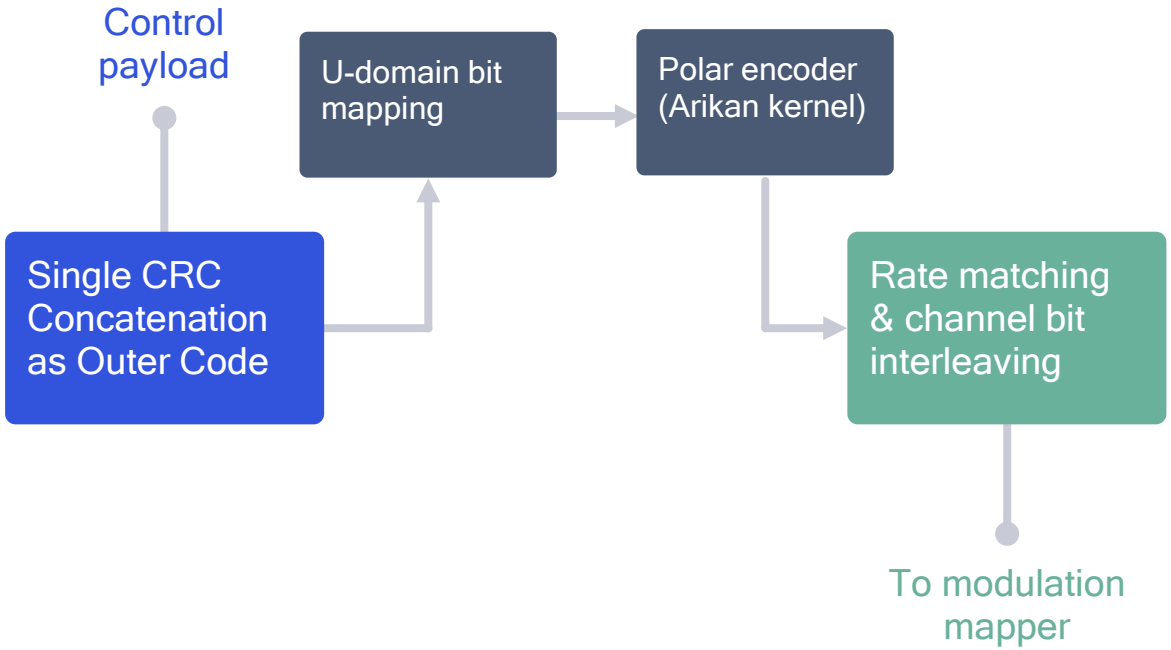
1. Multi-Edge Low-Density Parity-Check

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

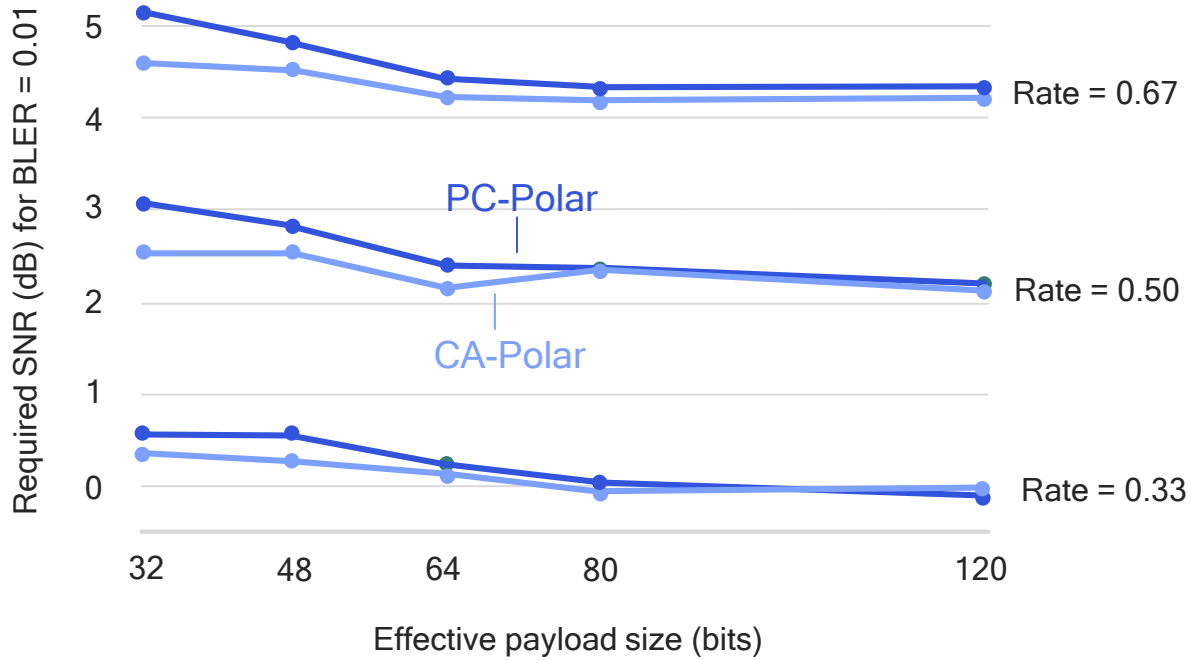
5G NR CRC-Aided (CA-Polar) design

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



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

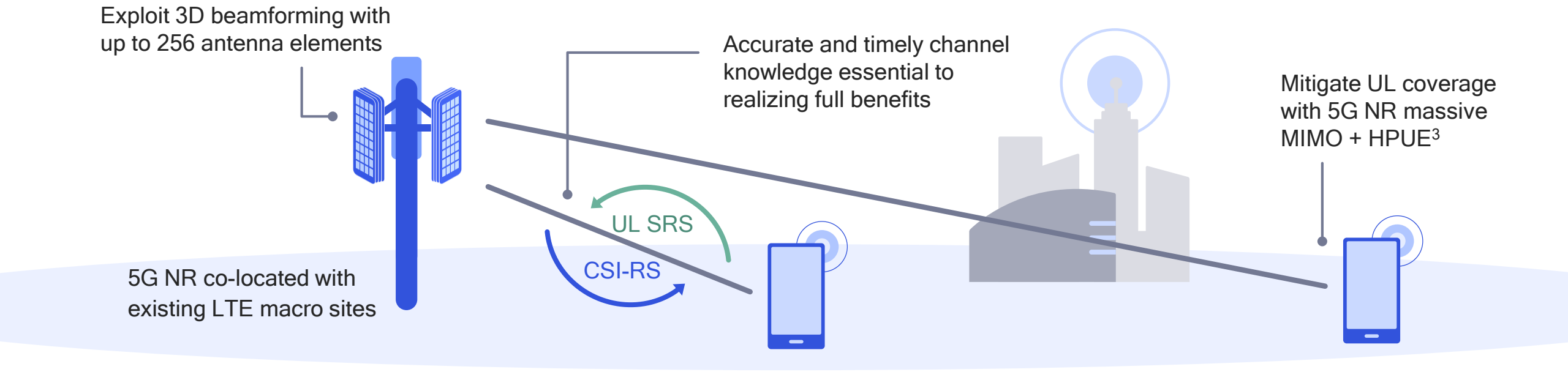
Versus PC-Polar[1] (lower is better)



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



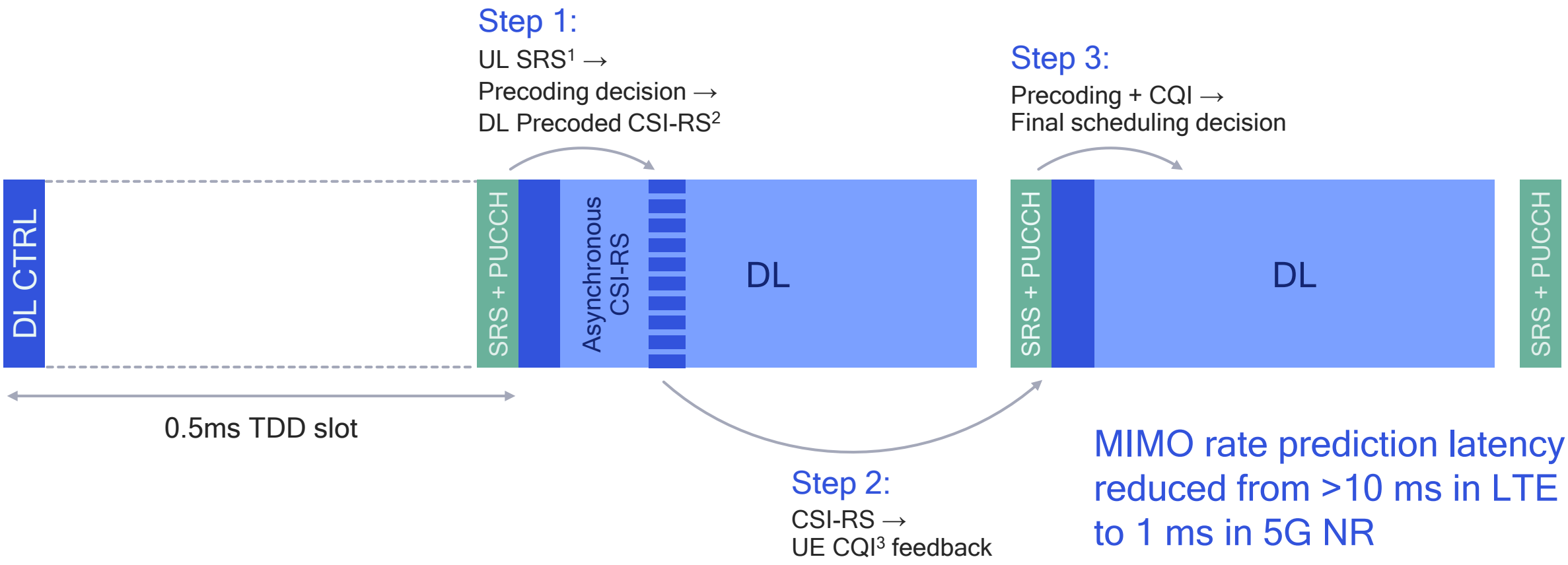
Enabled through an advanced 5G NR end-to-end Massive MIMO design (network and device)

- 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



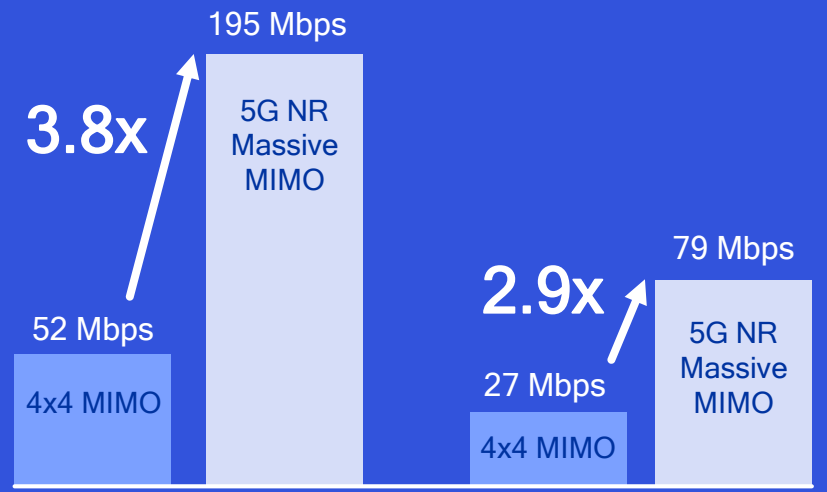
MIMO rate prediction latency reduced from >10 ms in LTE to 1 ms in 5G NR

*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

Qualcomm | 5G NR Massive MIMO

5G NR massive MIMO increases coverage & capacity

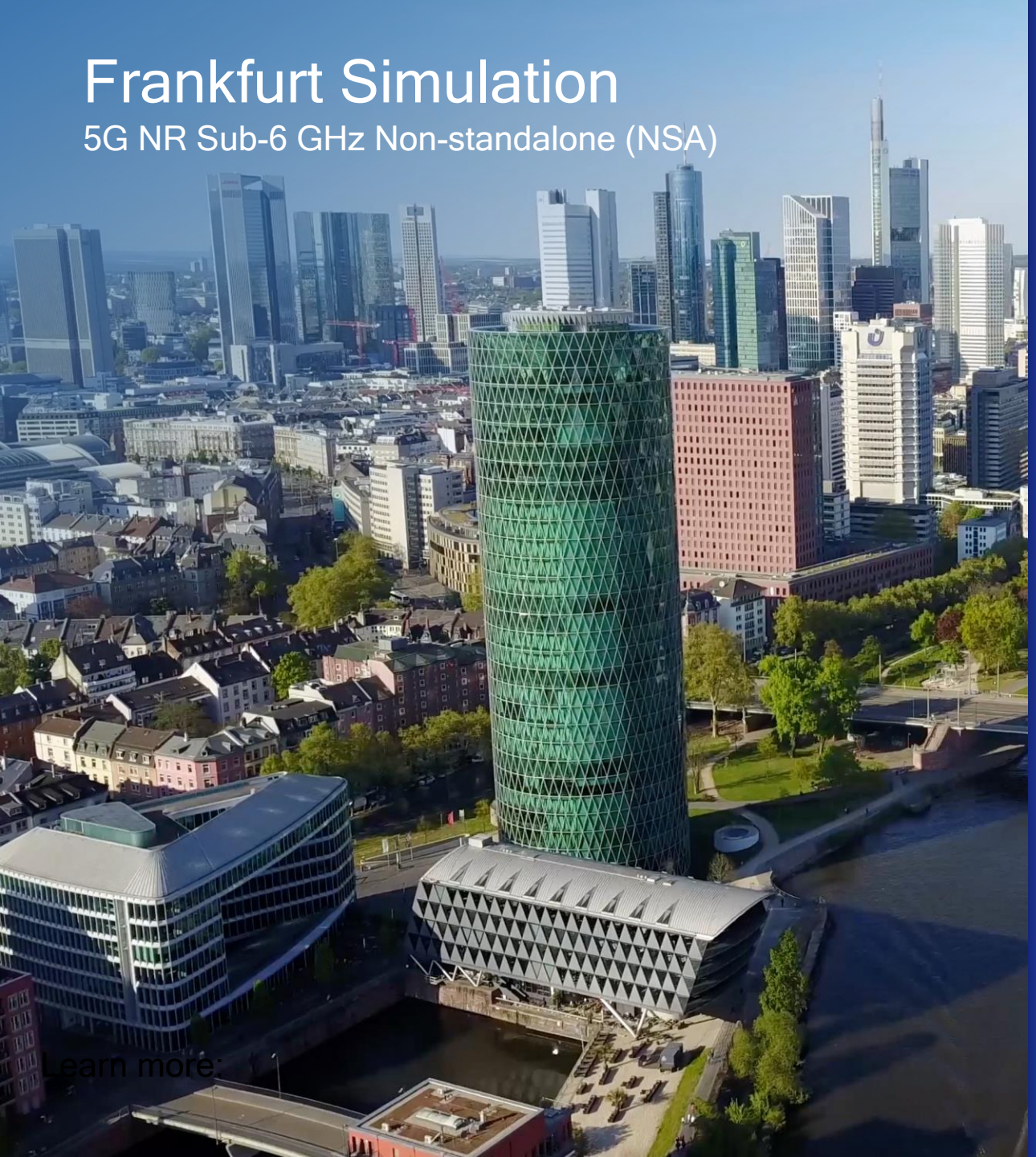
Faster, more uniform data rates throughout cell



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.

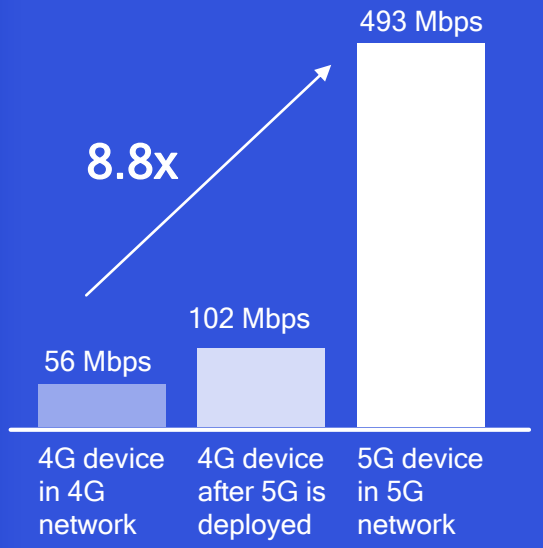
Frankfurt Simulation

5G NR Sub-6 GHz Non-standalone (NSA)

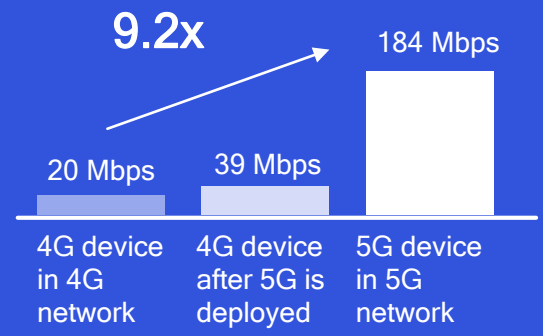


Learn more:

Industry-first simulation of real world performance reveals immense 5G user experience gains over 4G



Median burst rate



Cell-edge burst rate

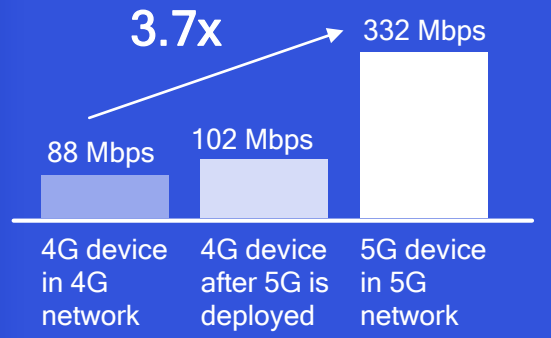
Assumptions: Actual Frankfurt city layout; Max LTE bandwidth 80 MHz (carrier frequencies ranging from 700 MHz to 2.7 GHz); 5G NR total bandwidth 100 MHz (carrier frequency 3.5 GHz); Mix of macro and small cell base stations; Bursty Poisson traffic model; 50% indoor and 50% outdoor UEs; 75% LTE only devices / 25% 5G NR capable devices; NR TDD 3:1 DL/UL slot configuration. Burst rate comparisons are betwee LTE Cat-9 mainstream devices and 5G NR devices

Tokyo Simulation

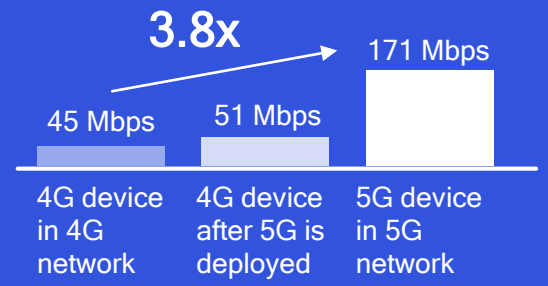
5G NR Sub-6 GHz Standalone (SA)

Industry-first simulation of 5G NR Standalone network

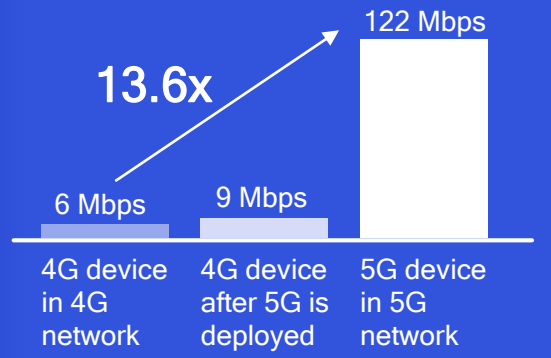
DL median burst rate



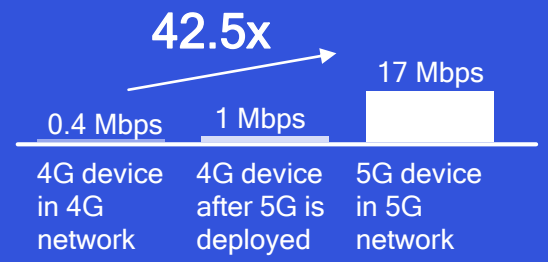
DL cell-edge burst rate



UL median burst rate



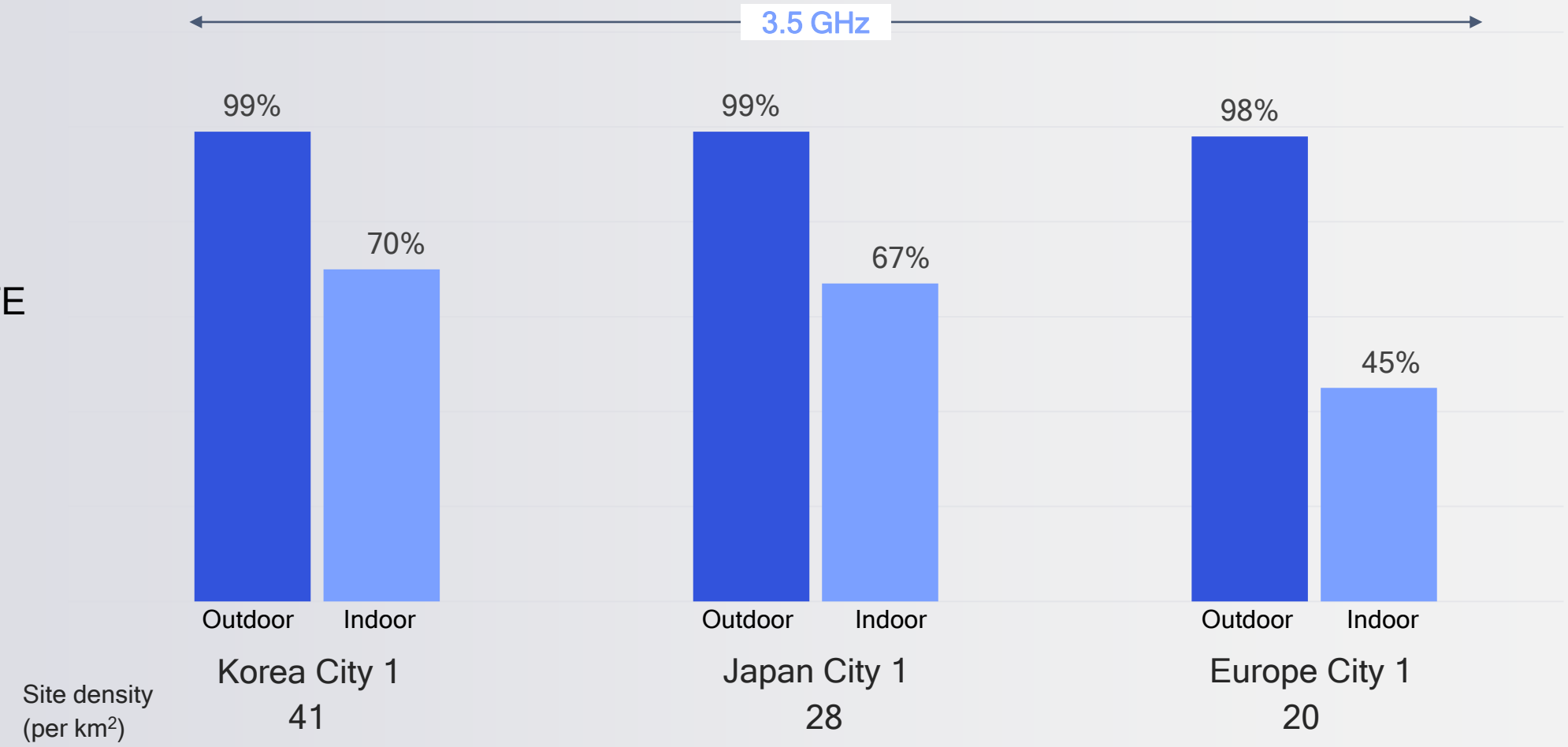
UL cell-edge burst rate



Assumptions: Actual Tokyo city layout; Max LTE bandwidth 60 MHz in 2.5 GHz; 5G NR total bandwidth 100 MHz (carrier frequency 3.5 GHz); Mix of macro and small cell base stations; Bursty Poisson traffic model; 50% indoor and 50% outdoor UEs; 75% LTE only devices / 25% 5G NR capable devices; NR TDD 3:1 DL/UL slot configuration. Burst rate comparisons are betwee LTE Cat-9 mainstream devices and 5G NR devices.

Downlink Coverage %

Co-siting with LTE

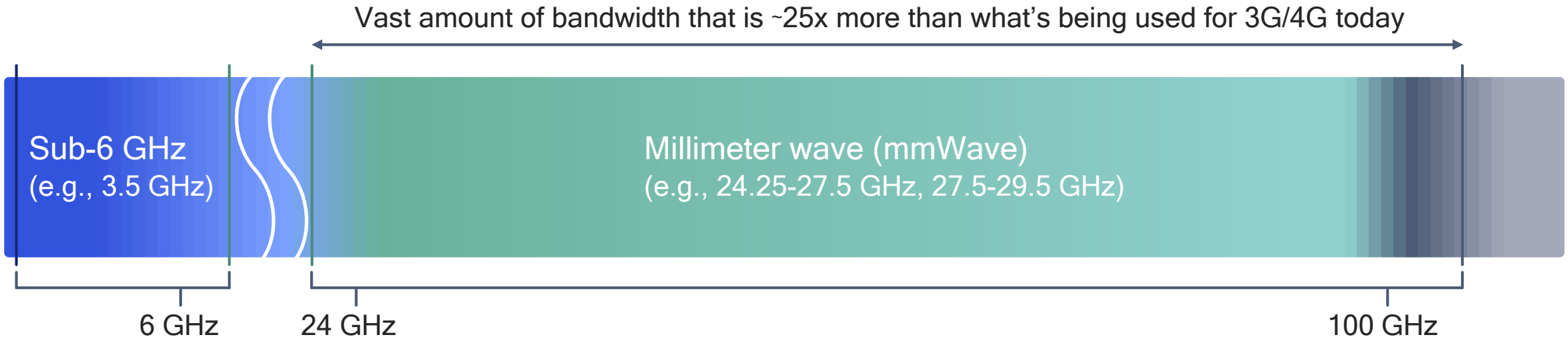


Assuming minimum spectral efficiency of 0.3 bps/Hz over 100 MHz = ~30 Mbps at cell edge; With LTE, outdoor/indoor coverage for Korea city :100%/96%, Japan city 100%/87%, Europe city 100%/80%

Significant 5G NR 3.5 GHz outdoor & indoor coverage via co-siting

Simulations based on over-the-air testing and channel measurements

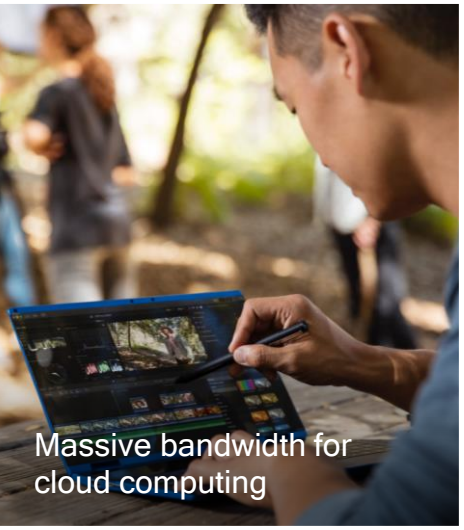
New frontier of mobile broadband – mobilizing mmWave

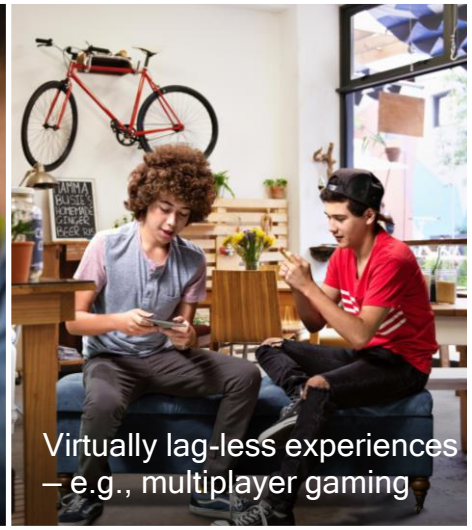


Multi-Gbps data rates
With large bandwidths (100s of MHz)

Much more capacity
With dense spatial reuse

Lower latency
Bringing new opportunities





5G

5G NR mmWave will support new and enhanced mobile experiences

- Fiber-like data speeds
- Low latency for real-time interactivity
- Massive capacity for unlimited data plans
- Lower cost per bit

We are overcoming the mobile mmWave challenge

Proving the skeptics wrong about mmWave can never be used for mobile

Limited coverage and too costly

Significant path loss means coverage limited to just a few hundred feet, thus requiring too many small cells

Significant coverage with co-siting

Analog beamforming w/ narrow beam width to overcome path loss. Comprehensive system simulations reusing existing sites.

Works only line-of-sight (LOS)[1]

Blockage from hand, body, walls, foliage, rain etc. severely limits signal propagation

Operating in LOS and NLOS[1]

Pioneered advanced beamforming, beam tracking leveraging path diversity and reflections.

Only viable for fixed use

As proven commercial mmWave deployments are for wireless backhauls and satellites

Supporting robust mobility

Robustness and handoff with adaptive beam steering and switching to overcome blockage from hand, head, body, foliage.

Requiring large formfactor

mmWave is intrinsically more power hungry due to wider bandwidth with thermal challenges in small formfactor

Commercializing smartphone

Announced modem, RF, and antenna products to meet formfactor and thermal constraints, plus device innovations.

1 LOS: Line of sight, NLOS: Non-line-of-sight

Many milestones to mobilize 5G NR mmWave

1990+

Many years of foundational technology research on mmWave, MIMO, advanced RF

MWC 2016

Demonstrated Non-line of sight (NLOS) mmWave mobility with beam steering, first at 5G analyst day in October 2015

Oct. 2016

Introduced world's first announced 5G modem, the Qualcomm® Snapdragon™ X50, mmWave & sub-6 GHz

MWC 2017

Demonstrated NLOS van mobility with beam steering & switching across access points

Mar. 2017

Led way forward on accelerated 5G NR eMBB workplan, to enable mmWave launches in 2019

Sep. 2017

Launched world's first mmWave smartphone, Asus ZenFone, supporting 802.11ad 60 GHz

Sep. 2017

Showcased 5G NR mmWave coverage simulations announced prototype mmWave UE

Oct. 2017

Demonstrated world's first 5G mmWave connection based on Snapdragon X50; announced smartphone reference design

Dec. 2017

Achieved world's first 5G NR mmWave standards-compliant connection with partner

MWC 2018

Completed interoperability testing with multiple infrastructure vendors, showcased 5G network capacity simulations

ERICSSON
NOKIA
SAMSUNG

Jul. 2018

Launched the world's first 5G NR RF module for mobile devices

May 2018

Introduced FSM100xx, industry's first 5G NR solution for small cells and remote radio heads

Oct. 2018

Introduced even smaller 5G NR RF module that is 25% smaller in size

Sep. 2018

Announced first 3GPP-compliant 5G NR mmWave OTA call with a mobile form factor device

Feb. 2019

Announced our second generation multimode 5G modem, Qualcomm® Snapdragon™ X55

MWC 2019

Announced our indoor and outdoor mmWave e2e OTA test networks and showcased indoor mmWave simulations

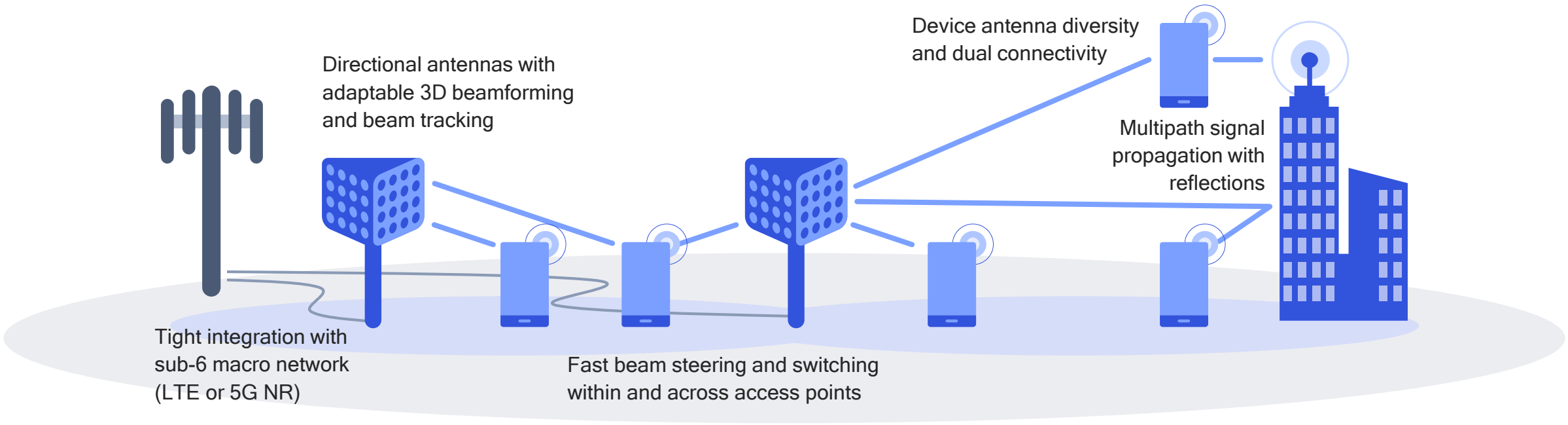
1H19+

Commercial 5G NR mmWave network and devices including data cards and smartphones

5G NR field trials with MNOs & infra vendors

Mobilizing mmWave with 5G NR technologies

Deploying a dense mmWave network with spatial reuse – ~150 - 200m ISD



Delivering robust NLOS connectivity

Supporting seamless mobility

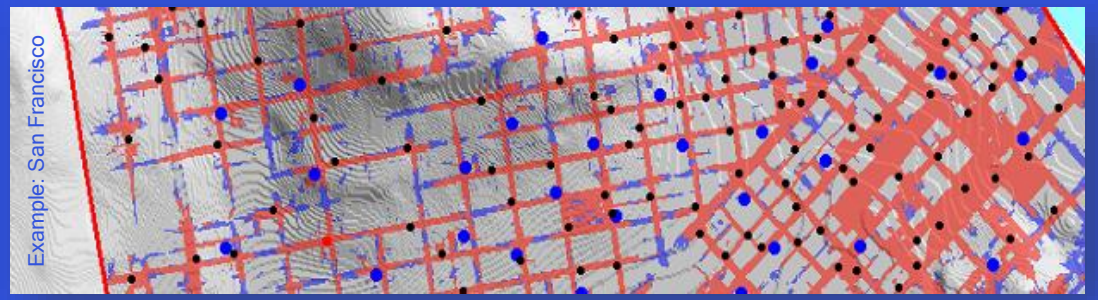
Complementing macro area coverage

Empowering the 5G ecosystem

Advanced 5G Simulations

for network planning based on our extensive over-the-air testing and channel measurements

Collaborating with global operators to demonstrate significant 5G NR mmWave capacity & coverage



62%
Outdoor coverage

5x
Increase in capacity[1]

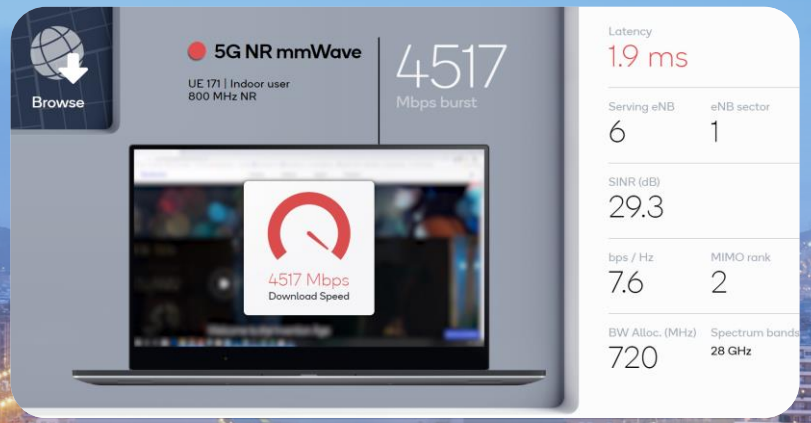
320 Mbps
Cell edge burst rate[2]

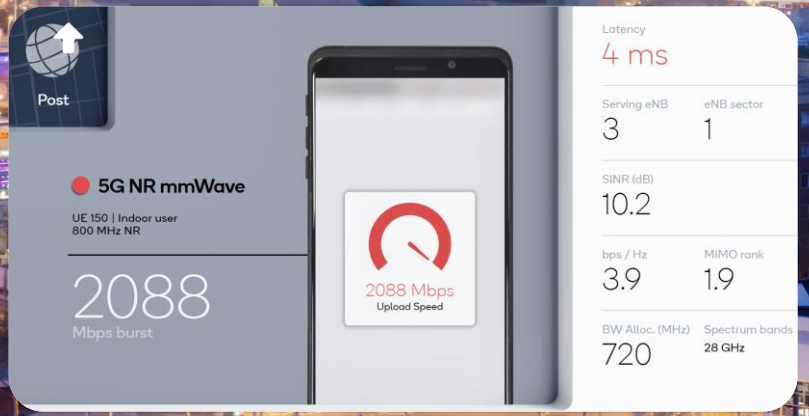
1.4 Gbps
Median burst rate

- Significant outdoor coverage, user experience and capacity gains utilizing existing LTE infrastructure (including LAA small cells for Gigabit LTE)
- Outdoor coverage only; frees up sub-6 GHz resources for out-to-indoor capacity
- Dual connectivity with LTE or aggregation with sub-6 GHz 5G NR ensures complete coverage

1 Compared to Gigabit LTE only with additional 800 MHz spectrum in 28 GHz; 2 Cell edge defined as 0.4 bps/Hz = 320 Mbps for 8x100 MHz channel bandwidth

Showcasing enhanced mobile mmWave user experiences





Simulation assumes 5G NR mmWave co-siting at actual LTE DAS locations in Fira Gran Via Hall 3, uses 800 MHz spectrum in 28 GHz, and is based on Qualcomm engineering simulation tools

Advanced Network Simulations

Deploying 28 GHz 5G NR mobile mmWave at Mobile World Congress venue

Ubiquitous coverage via co-siting

Virtually unlimited capacity

Multi-Gbps speed & low latency

More uniform user experience

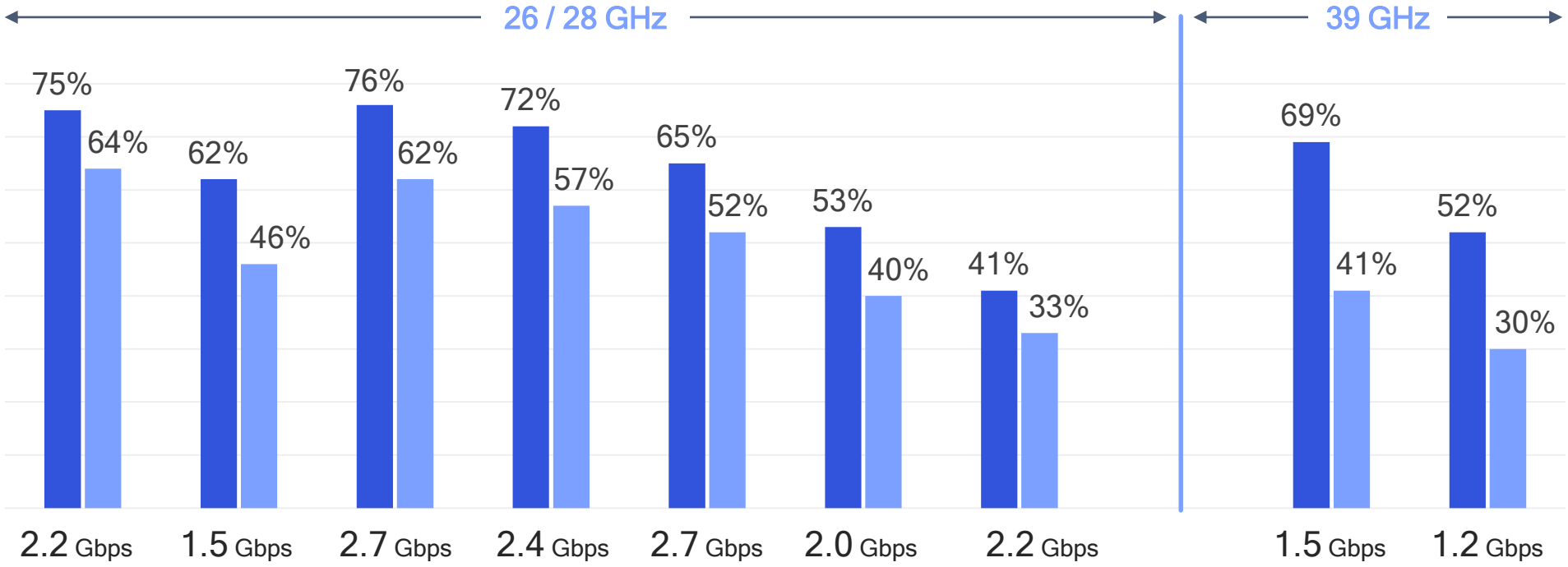
For a wide range of mobile devices:

Downlink

Uplink

Coverage %

Co-siting with LTE



Median Downlink Burst Rate (Gbps)

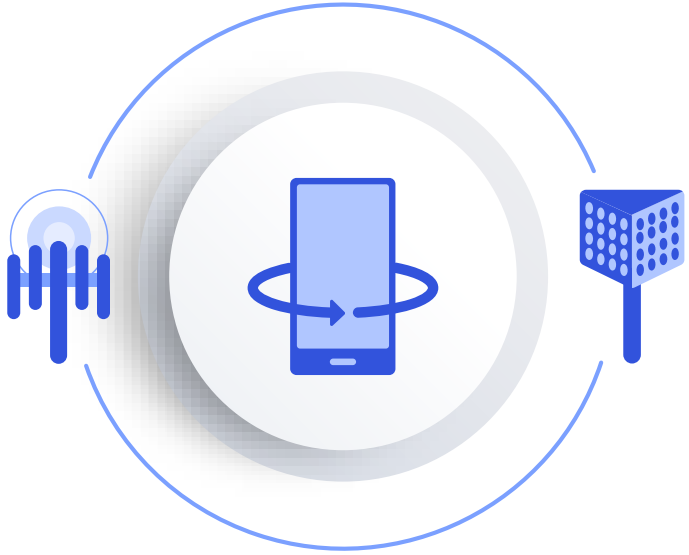
Site density (per km^2)		US City 1	US City 2	Korean City 1	Hong Kong	Japan City 1	Russia City 1	Europe City 1	US City 1	US City 2
	Total	48	36	41	39	28	26	28	48	36
	Macro	0	8	33	39	28	26	7	0	8
	Small	48	28	8	0	0	0	21	48	28

Simulations assumptions: Based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and city/area specific models; minimum 0.4 bps/Hz and 0.2 bps/Hz for downlink data and control, out-to-out coverage only; Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD

Significant 5G NR mmWave outdoor coverage via co-siting

Simulations based on over-the-air testing and channel measurements

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

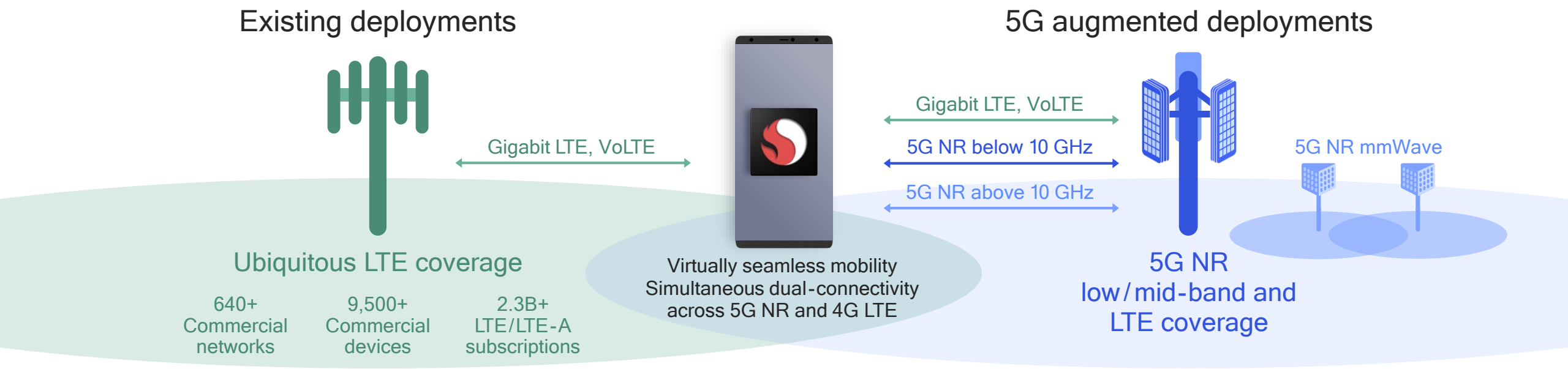
E.g., Licensed and unlicensed with 5G NR Licensed Assisted Access (LAA) – approved Rel-15 Study Item

Building on solid LTE CA and Dual Connectivity foundation

LTE Rel-10+	5G NR Rel-15+
Supplemental DL	LTE/5G NR NSA
FDD/TDD CA	Supplemental UL
LAA CA	Supplemental DL
Dual Connectivity	FDD/TDD CA
	NR LAA CA
	Dual Connectivity

Dual connectivity to fully utilize LTE investments

Gigabit LTE provides the coverage foundation for 5G eMBB



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

Enabling gigabit experiences virtually everywhere

Providing VoLTE leveraging LTE's ubiquitous coverage

Supplementing 5G NR mid-band and mmWave

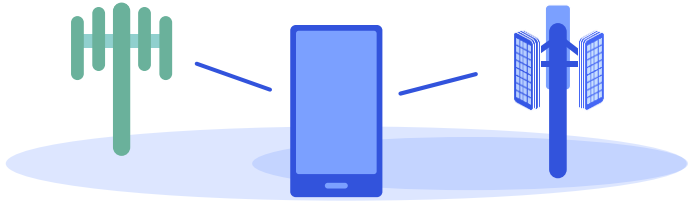
5G NR FDD/TDD CA to support mid-band deployments

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

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)

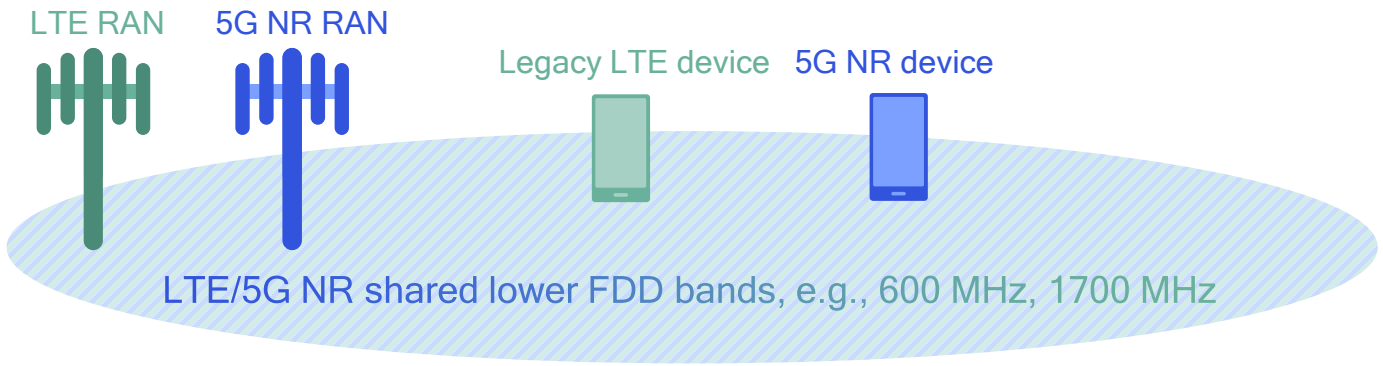
NR low-band can carry NR uplink control and data for edge cell users

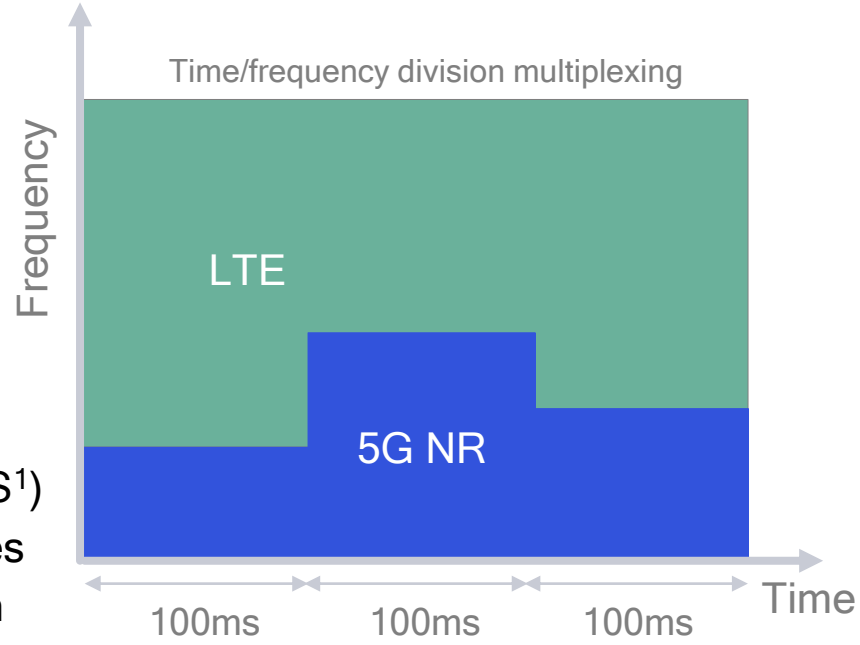
e.g. <1 GHz | NR TDD, e.g. 3.5 GHz

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

Dynamic Spectrum Sharing (DSS) in 3GPP Release 15

For supporting 5G NR in lower FDD bands for NSA and SA deployments





- LTE controlled sharing – 5G NR to avoid resources used by LTE (e.g., LTE CRS[1])
- No impact to legacy LTE devices – DSS support only required for 5G NR devices
- System efficiency depends on LTE/5G NR traffic volume and device penetration

1 Cell Specific Reference Signal

Supports 5G NR in LTE bands today with “soft refarming”

Efficient use of spectrum with low sharing overhead

DSS & carrier aggregation are key enablers for SA migration

Accelerated 5G to 2019 with non-standalone mode

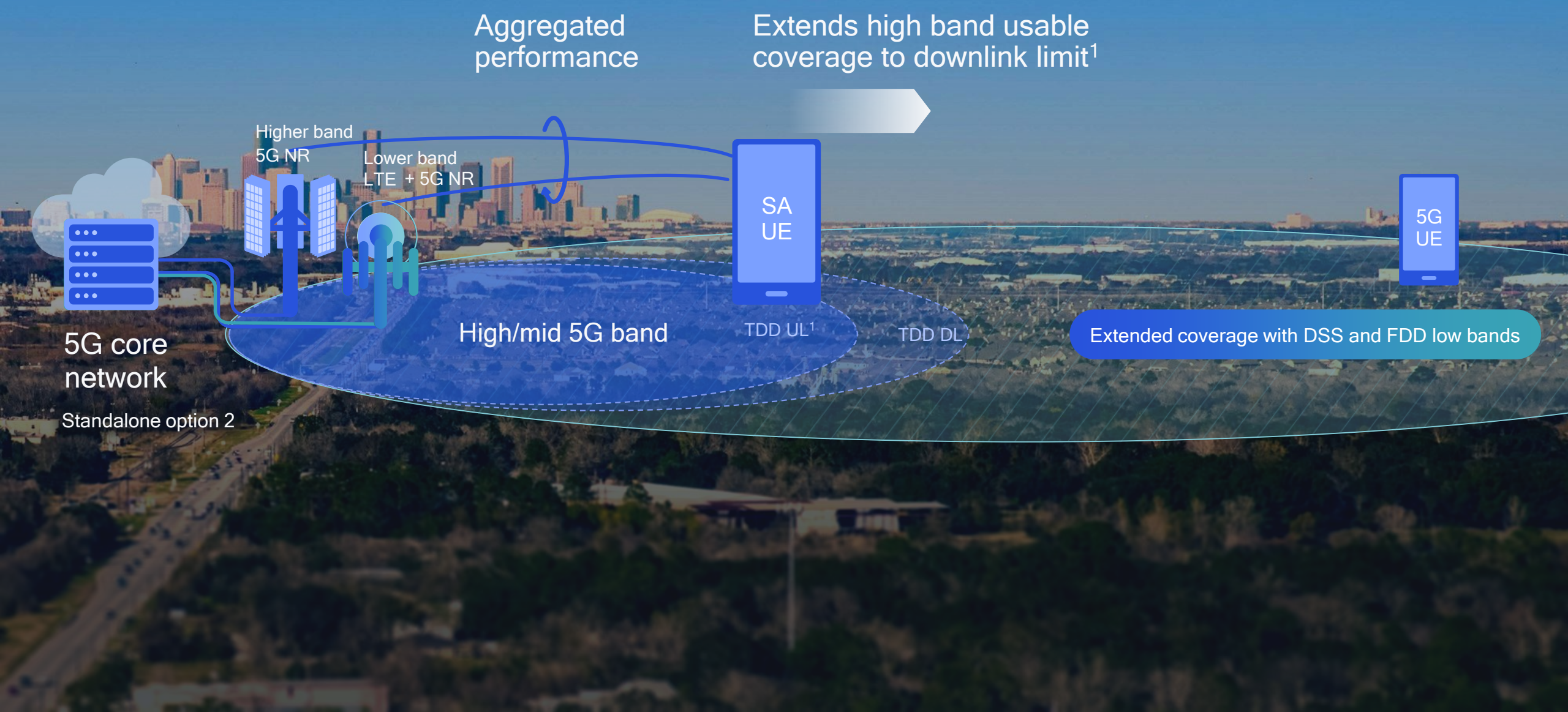
Expand coverage with lower bands

Expand 5G coverage

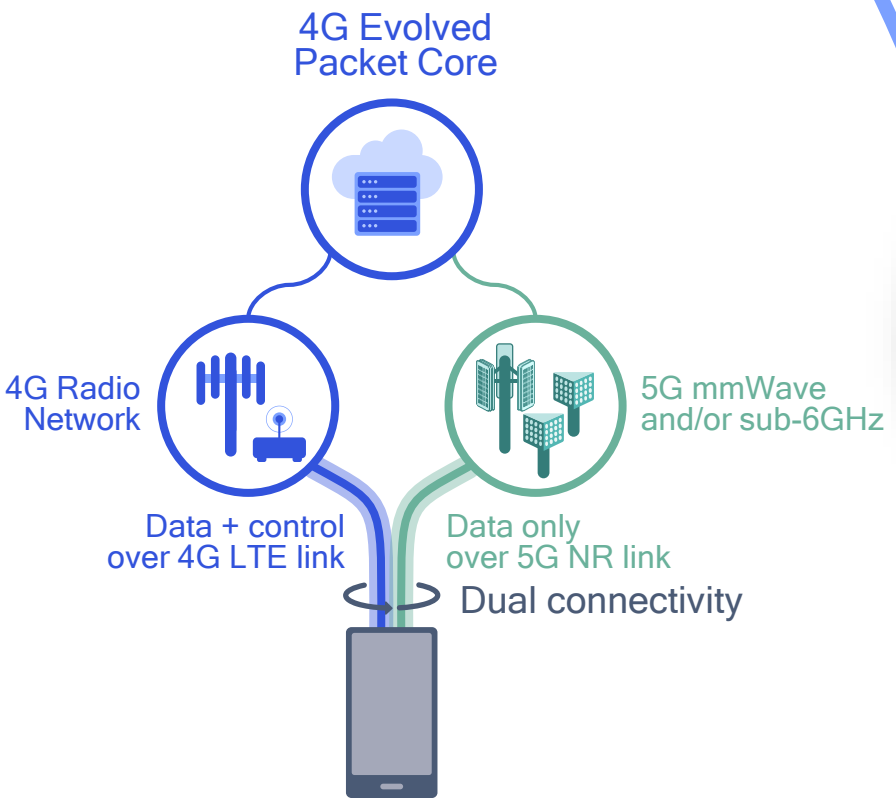
- Dynamic Spectrum Sharing (DSS)
- 5G FDD in low bands

Direct migration to standalone core network with DSS

Increase 5G performance with carrier aggregation



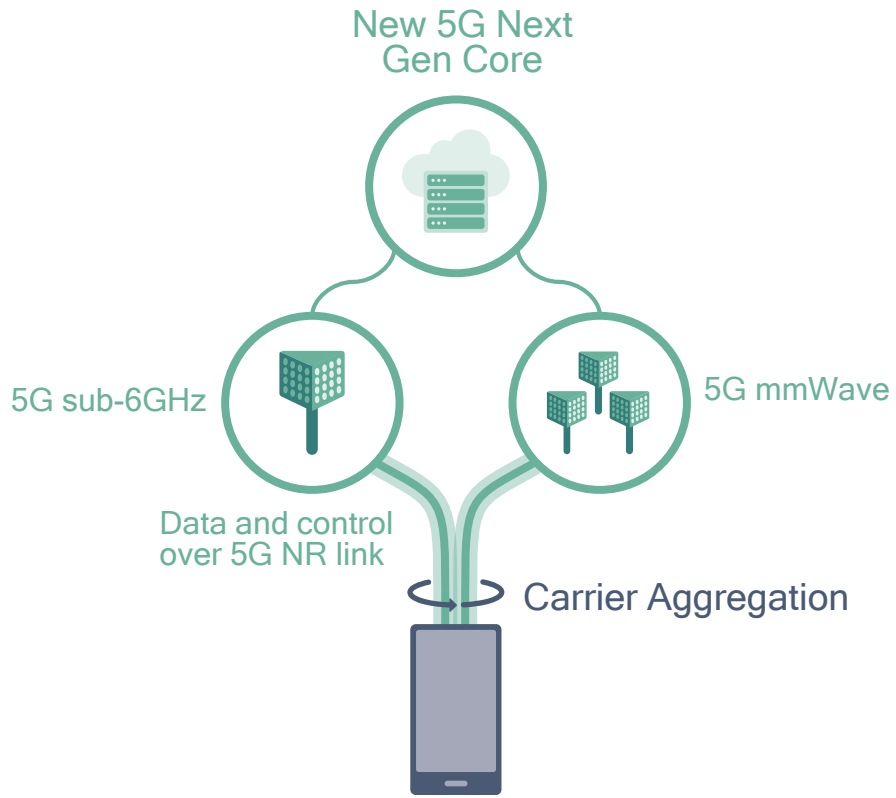
Non-Standalone (NSA) stepping stone to new core



Fast-to-launch | VoLTE & CS voice

5G NR

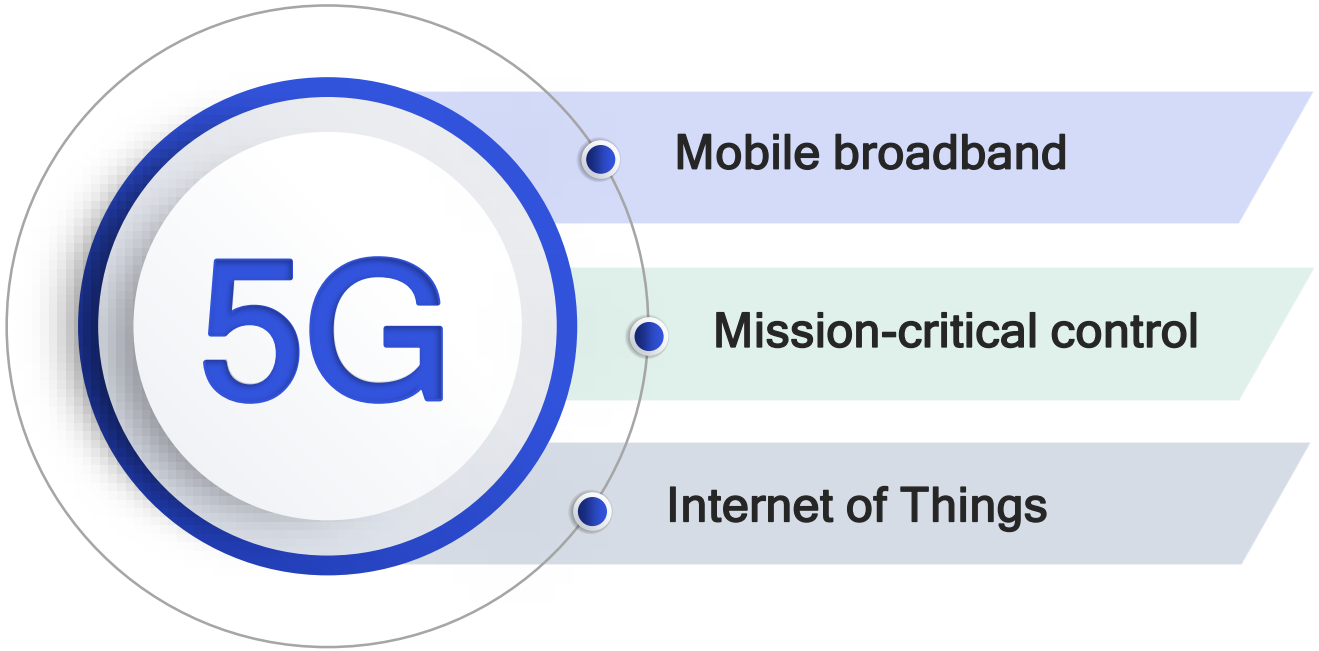
Standalone (SA) for new core benefits



NFV and SDN | VoNR & fallback to VoLTE

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

NFV: Network Functions Virtualization; SDN: Software Defined Networking

Better cost/energy efficiency | Optimized performance | Flexible biz models and deployments | Dynamic creation of services

Making 5G NR a commercial reality

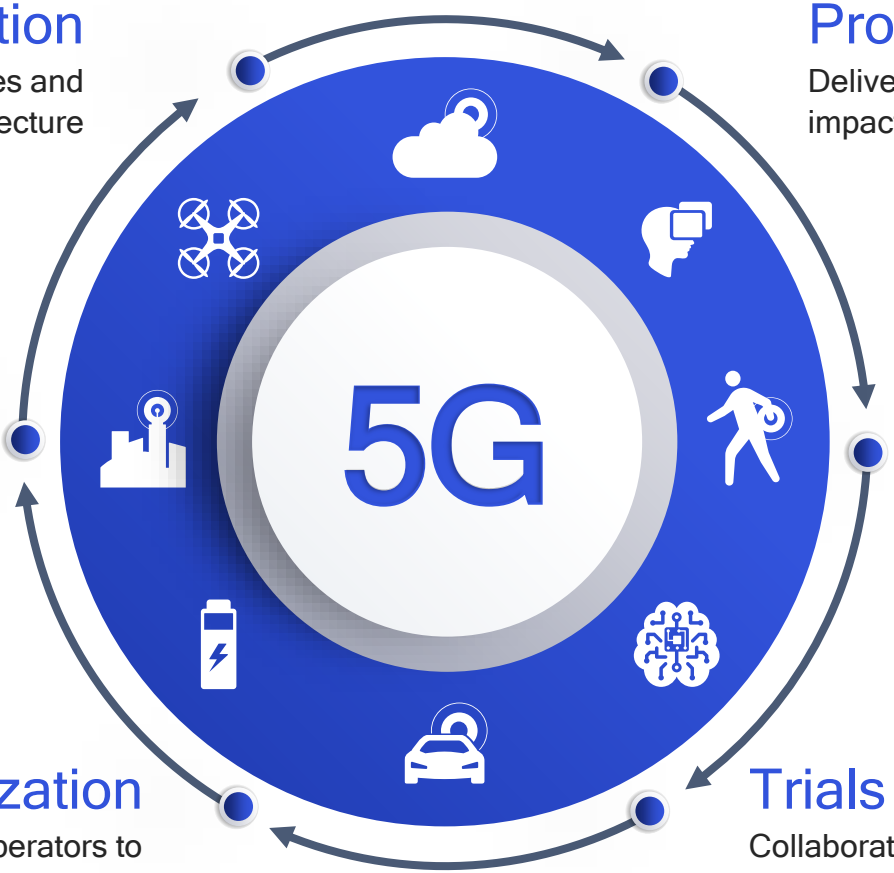
Qualcomm, leading the world to 5G

Our system-level inventions fuel the mobile industry

*Cumulative expenditures to date since 1985. Taking significant risks to start early with an end-to-end design

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

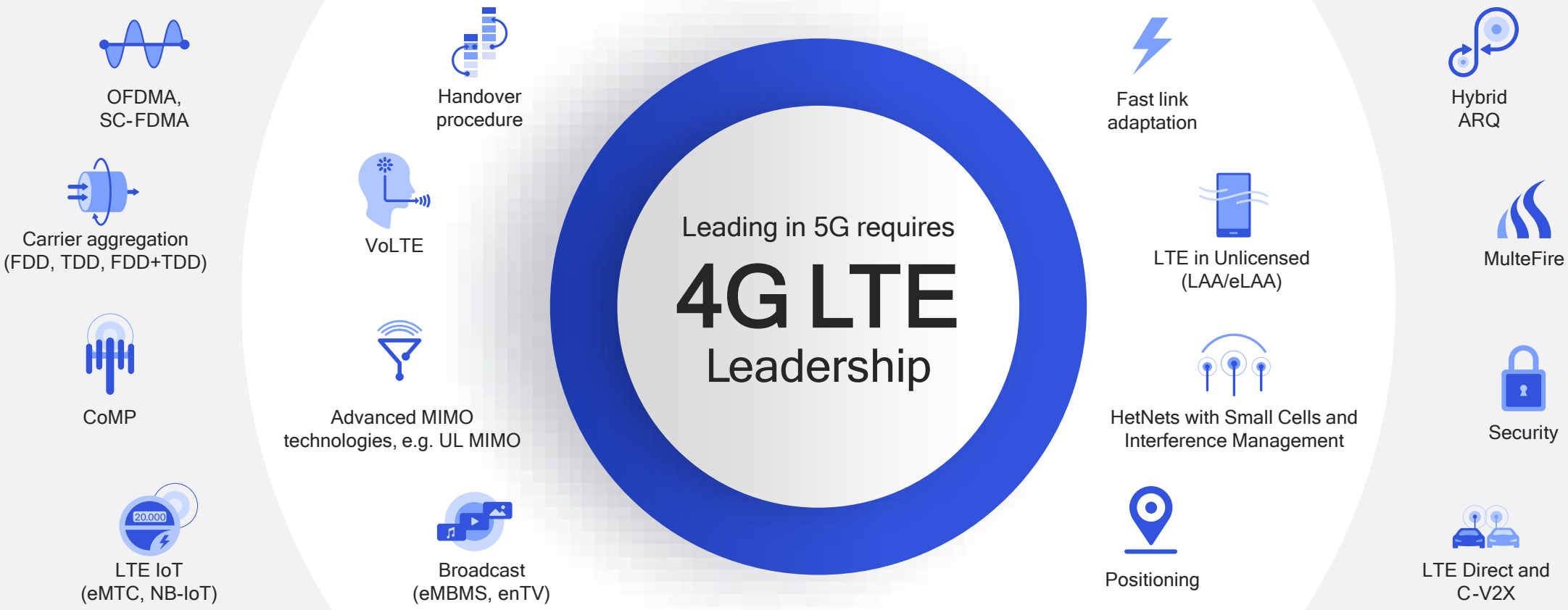
Engage with global network operators to deploy new features with standards-compliant infrastructure and devices

Trials

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

We have led the evolution and expansion of LTE

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

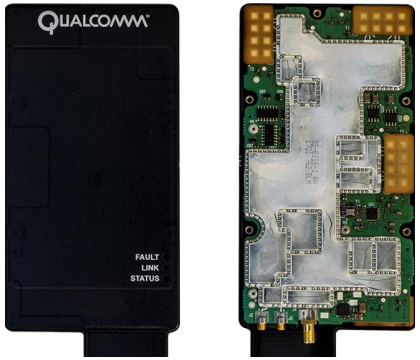


Cutting-edge 5G NR mobile prototype systems

Sub-6 GHz and mmWave

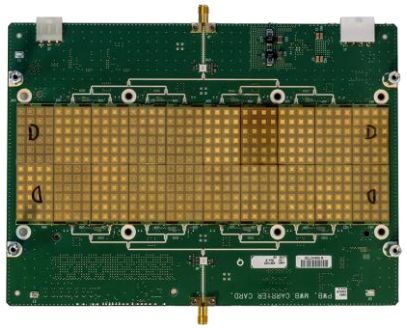
5G NR Baseband

Flexibly designed to track and drive 3GPP standardization in Rel-15+



5G NR UE

RFFE in mobile form-factors to mimic real-world performance



5G NR gNodeB

Enable early system-level testing and demonstrations

- World's first announced 5G NR prototype – June 2016
- World's first 5G NR data connection – February 2017
- World's first interoperable 5G NR system – November 2017

World's first 5G NR milestones led by Qualcomm

MWC 2016

Demonstrated Non-line of sight (NLOS) mmWave mobility with beam steering, first at 5G analyst day in October 2015

MWC 2017

Demonstrated NLOS van mobility with beam steering & switching across access points

November 2017

ZTE中兴

World's first interoperable 5G NR sub-6 GHz data connection

December 2017

ERICSSON

World's first interoperable 5G NR mmWave data connection

February 2018

NOKIA

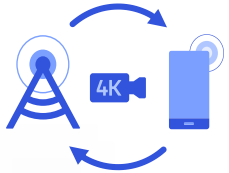
Successful multi-band 5G NR interoperability testing

MWC 2018

GSMA MOBILE WORLD CONGRESS

Interoperable 5G NR sub-6 GHz & mmWave connections with 5 vendors

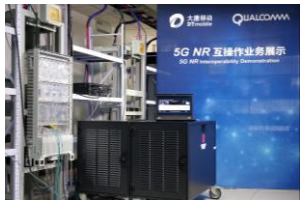
SAMSUNG HUAWEI



June 2018

大唐移动 DTmobile

5G NR interoperability testing preparing for the Chinese mass market



2H-2018

Rel-15 5G NR trials based on Snapdragon X50 modem chipset and QTM052 antenna modules

Qualcomm snapdragon X50 5G modem

1H19

Commercial 5G NR networks and devices

Driving the 5G ecosystem towards 2019 launches in collaboration with 40+ global mobile network operators and 40+ device manufacturers

Commercializing mmWave

in a smartphone form factor

mmWave (60 GHz) viability in handset form factor

11ad in Asus Zenfone 4 Pro

Qualcomm® 5G NR mmWave prototype

Qualcomm® 5G NR mobile test device

5G NR mmWave Qualcomm® Reference Design

Qualcomm® Snapdragon™

X50

5G Modem family

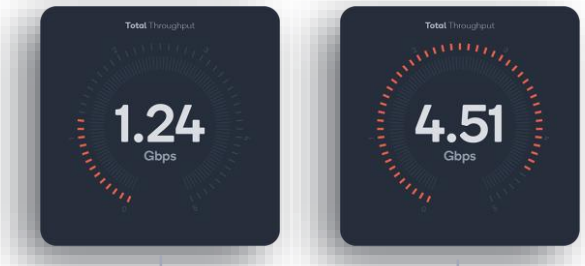
World's first announced
5G NR multimode modems

- 5G NR standards compliant
- Sub-6 + mmWave
- Premium-tier smartphones in 2019

Multi-Gigabit over mmWave on working Snapdragon X50 silicon

5G NR Interoperability and field trials using form factor mobile test device

Providing Qualcomm Reference Design to accelerate commercial devices



First 5G NR mmWave over-the-air data call, with Ericsson

First 5G NR Sub 6 GHz over-the-air data call, with Ericsson

Qualcomm snapdragon X50 5G modem-RF system

Oct 2017

Feb 2018

2H 2018

Sep 2018

Oct 2018

1H 2019

Qualcomm snapdragon X50 5G modem-RF system

World's first 5G NR modem-RF system

- 5G NR standards compliant
- Sub-6 + mmWave
- Premium-tier smartphones in 2019

Milestones achieved in 2019

Feb 2019
Built an end-to-end 5G NR massive MIMO over-the-air test network

Feb 2019
Introduced industry's first mobile platform with integrated 5G

May 2019
Qualcomm and Lenovo unveil world's first 5G PC

July 2019
Introduced end-to-end over-the-air 5G mmWave test network in Europe

Sept 2019
Successful 5G data connection in standalone mode

Feb 2019
Demonstrated 5G NR mmWave technologies on over-the-air test networks supporting NSA mode at 28 GHz

Feb 2019
Unveiled world's most advanced commercial multimode 5G modem

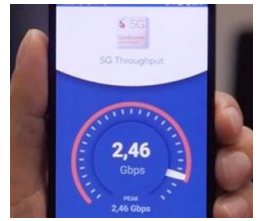
Qualcomm snapdragon X55 5G modem-RF system

April 2019
Qualcomm and Swisscom bring 5G to Europe with the first-announced commercial services

Askey
LG
OPPO
WNC

July 2019
World's first low-band 5G data session on a commercial 5G modem

Aug 2019
Enabled Europe's first 5G mmWave network in Moscow



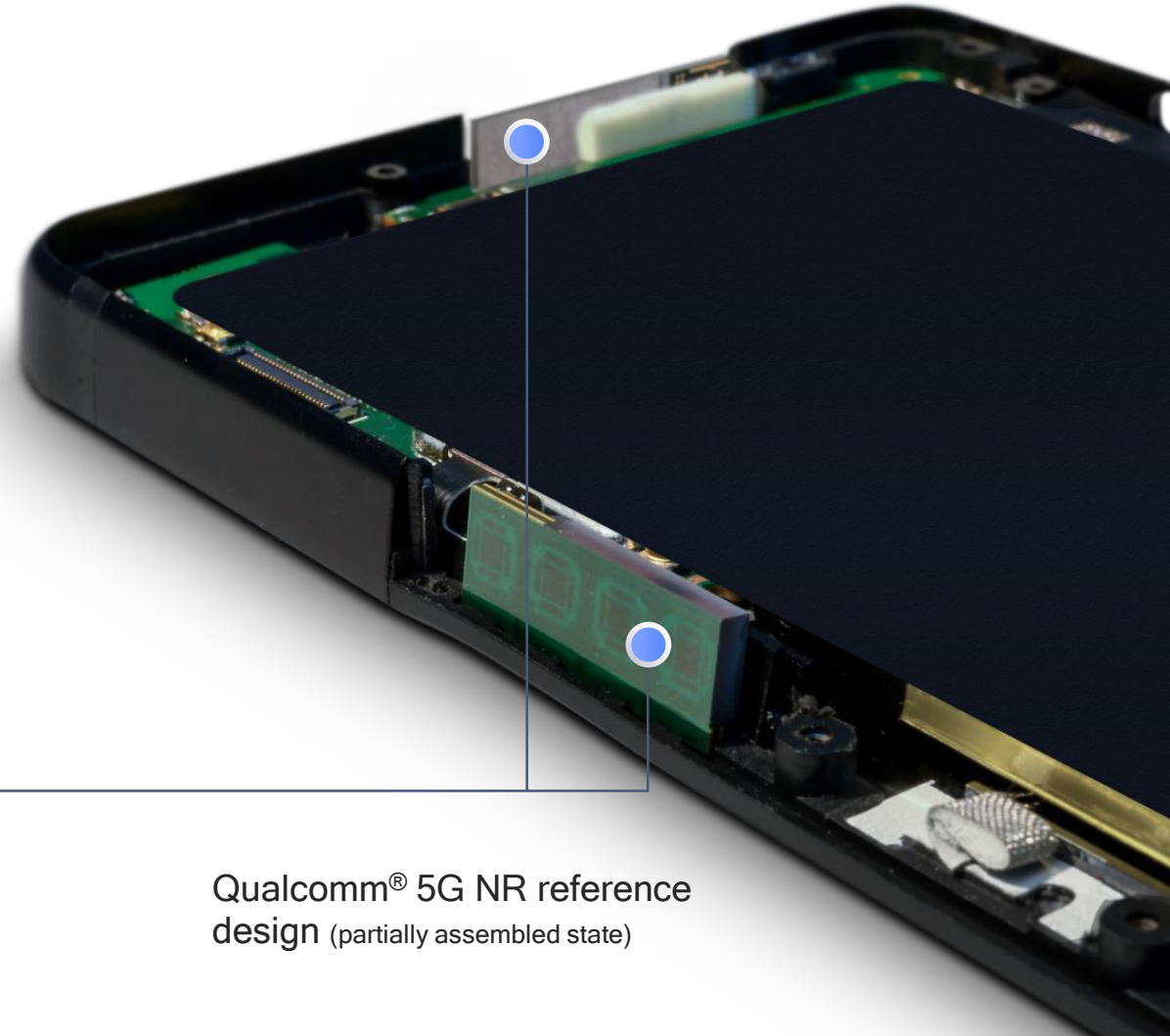
Global operators and OEMs using Qualcomm® Snapdragon™ X50 5G NR modem family for mobile 5G NR trials and devices

Qualcomm® QTM052 5G mmWave antenna module

Rapid miniaturization of mmWave modules to bring 5G smartphones to the World in 2019

July 2018

October 2018



Qualcomm® 5G NR reference design (partially assembled state)

Driving 5G NR evolution and expansion

3GPP Release-16 and beyond

Driving the 5G expansion

Our technology inventions drove the 5G foundation

Rel.15
eMBB expansion

Laptops

Automotive

Fixed wireless access

New device classes like tethered XR

Smartphones

Private networks

5G massive IoT

5G broadcast

mmWave evolution, indoor, enterprises

Sub-6 GHz evolution, new use case

Industrial IoT with eURLLC

5G NR C-V2X, smart transportation

Future verticals, services, devices

Shared / unlicensed spectrum

New device classes like boundless XR

Rel.16-17

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

Questions?

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

http://www.slideshare.net/qualcommwirelessevolution

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