Millimeter wave is the missing piece of the 5G puzzle
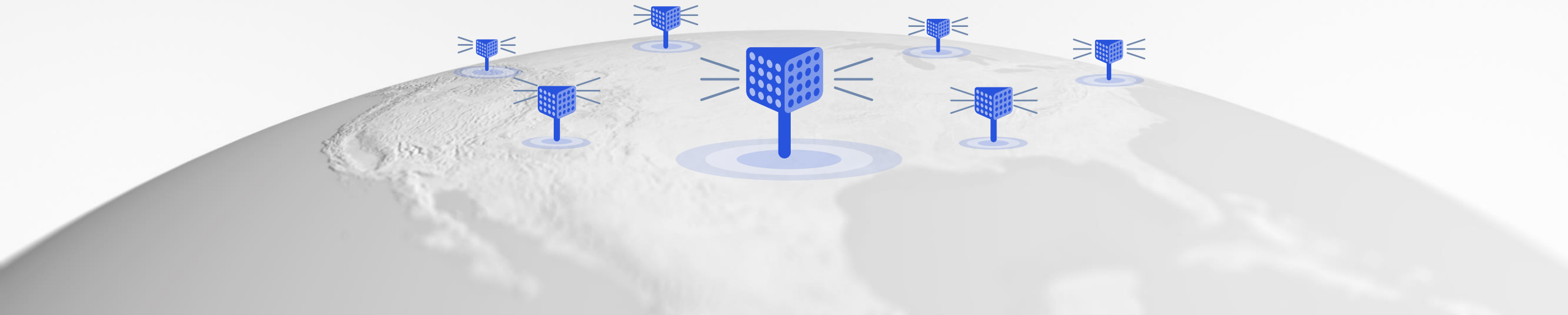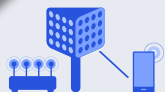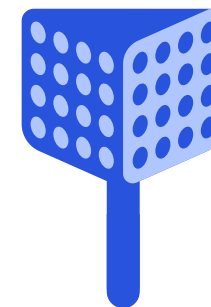
And the key enabler for the 5G future

Millimeter wave (mmWave)
is the key enabler for the 5G future

Mobilizing mmWave
To deliver unparalleled 5G system capacity and customer experience

Deploying mmWave
To achieve great return-on-investment and set up for the 5G future

Evolving mmWave
To support new use cases and enhanced performance

New frontier of mobile broadband — mobilizing mmWave for vast bandwidth

~25x more bandwidth than what's being used for 3G/4G

6 GHz   24 GHz   ~100 GHz

Sub-6 GHz
(e.g., 3.5 GHz)

Millimeter wave (mmWave)
(e.g., 26 GHz, 28 GHz, 39 GHz, 60 GHz)

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

Much more capacity
With dense spatial reuse

Lower latency
Bringing new opportunities

Rich media and entertainment for outdoor – augmenting lower bands

More indoor capacity as outdoor mmWave offloads outdoor lower bands

Beyond smartphones – e.g., smart manufacturing

Fiber-like broadband to the home – fixed mmWave

Massive bandwidth for cloud computing

Virtually lag-less experiences – e.g., multiplayer gaming

Dense indoor and outdoor connectivity for venues

New indoor opportunities –e.g., connected enterprises

5G mmWave

Supporting 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

5G
accelerating globally

1B+
5G connections by 2023 –
2 years faster than 4G

275+
Additional operators
investing in 5G

3.8B+
5G smartphones to ship
between 2020 and 2024

175+
Operators with 5G
commercially deployed

750M+
5G smartphones
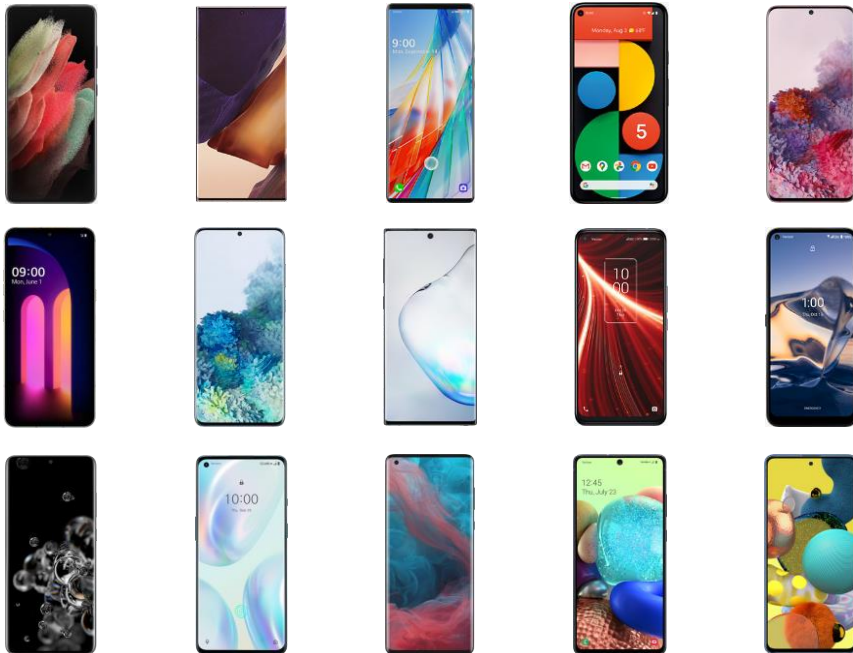to ship in 2022

1000+
5G designs launched
or in development

5G mmWave

120+ 5G mmWave devices, virtually all powered by Snapdragon® platform

Qualcomm Technologies continues to pave the way for 5G commercialization

5G smartphones

PCs

Modules

Hotspots

CPEs

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

* Source: GSA, Jun. '21. Includes pre-commercial and commercial devices. Complemented with Qualcomm Technologies' data when chipset information was not available from GSA.
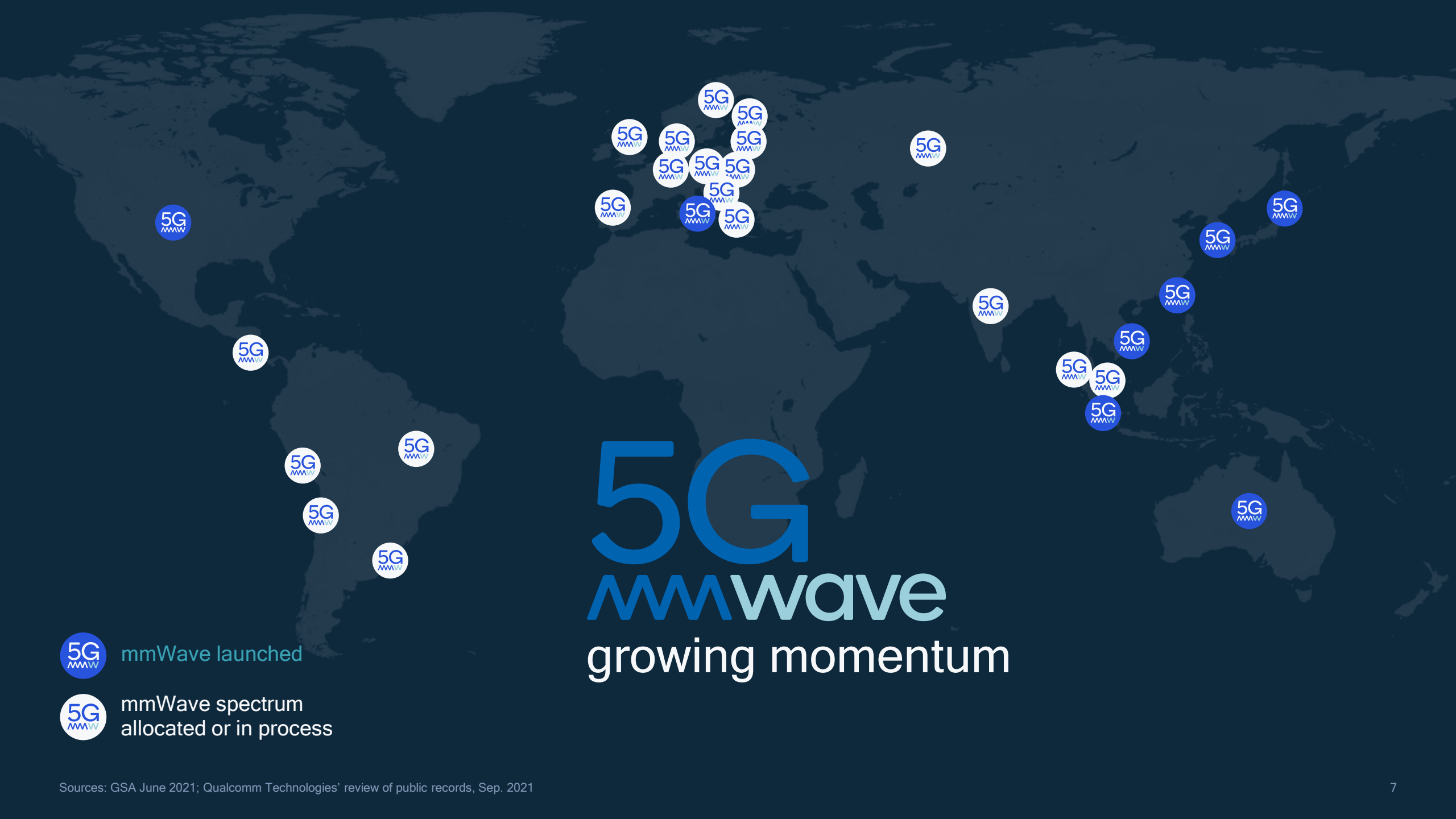
5G mmWave

growing momentum

5G mmWave launched

5G mmWave spectrum allocated or in process

40+

Global mobile industry leaders commit to support 5G mmWave

United States
AT&T
Casa Systems
Motorola
UScellular

Latin America
Telecom Argentina
WEG

Europe
Deutsche Telekom
Elisa
Ericsson
Fastweb
HMD Global
Nokia
Orange
Telia Finland
TIM
Vodafone

India
Airtel
Jio

Japan
KDDI
Kyocera
NTT DOCOMO
Rakuten Mobile
SoftBank

Korea
ETRI
Informark
Innowireless
Partron
Samsung Networks

Australia
NBN
Optus
Telstra

Mainland China
China Unicom
Honor
Oppo
TCL
vivo
Xiaomi
ZTE
Fibocom
Gongjing
MeiG
Quectel
Sunsea

Rest of Asia Pacific
Chunghwa Telecom
Singtel
True Corporation

5G MMwave

Bringing new waves of opportunities

Creating value for the mobile ecosystem

Operators
Service providers
Venue owners
Infra vendors
Device OEMs

For outdoor deployments…

Significantly elevate today's mobile experiences – initially focusing on smartphones

Deployments predominantly driven by mobile operators – initially focusing on dense urban

For indoor deployments…

Complementing existing wireless services provided by Wi-Fi–also expanding to new device types
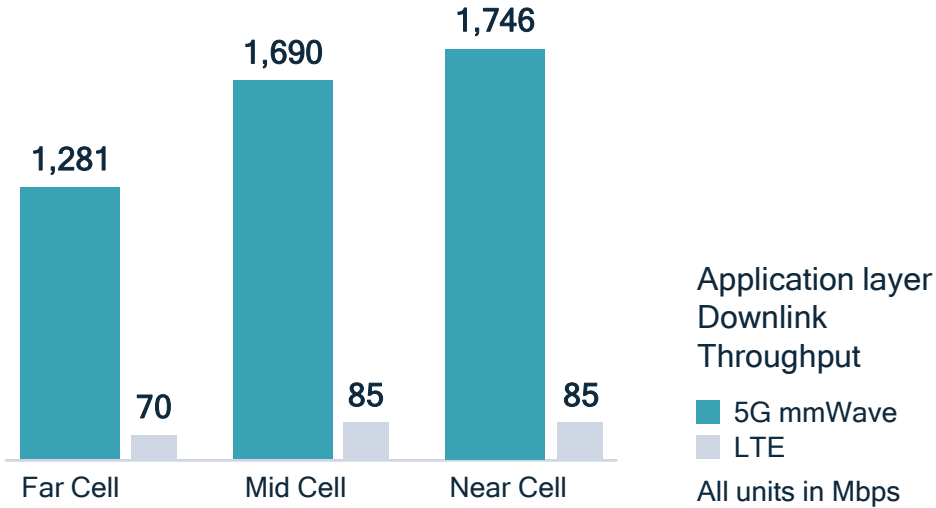
Bringing superior speeds and virtually unlimited capacity for enhanced experiences

Conducting 5G mmWave performance field tests

Tests in commercial network show 1 Gbps+ downlink sustained throughput in all scenarios

Imagery ©2020 Maxar Technologies, Sanborn, U.S. Geological Survey. Map data ©2020 Google

Near cell — 33 meters
195 meters — Mid cell
294 meters — Far cell

5G mmWave gNodeB

Application layer Downlink Throughput

■ 5G mmWave
■ LTE

All units in Mbps

	Far Cell	Mid Cell	Near Cell
5G mmWave	1,281	1,690	1,746
LTE	70	85	85

Image capture: Aug 2019 ©2020 Google

50 meters LOS

Throughput achieved*
1,821 Mbps downlink
96.9 Mbps uplink

Image capture: Jul 2019 ©2020

386 meters LOS

Throughput achieved*
1,780 Mbps downlink
73.1 Mbps uplink

*Measured using Ookla SpeedTest

5G mmWave performance
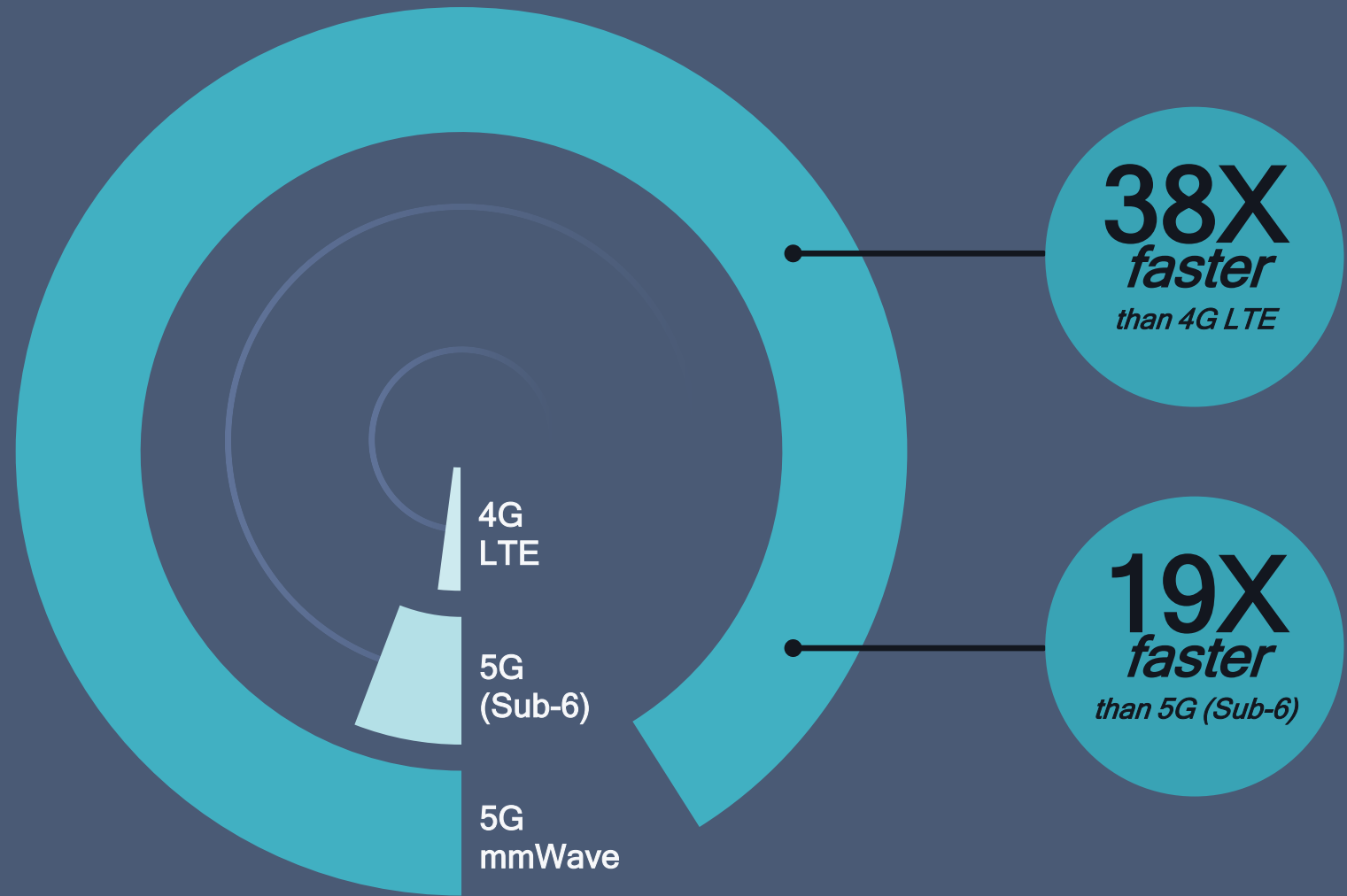
4G
LTE

5G
(Sub-6)

5G
mmWave

38X
faster
than 4G LTE

19X
faster
than 5G (Sub-6)

Deploying mmWave

to prepare for the 5G future
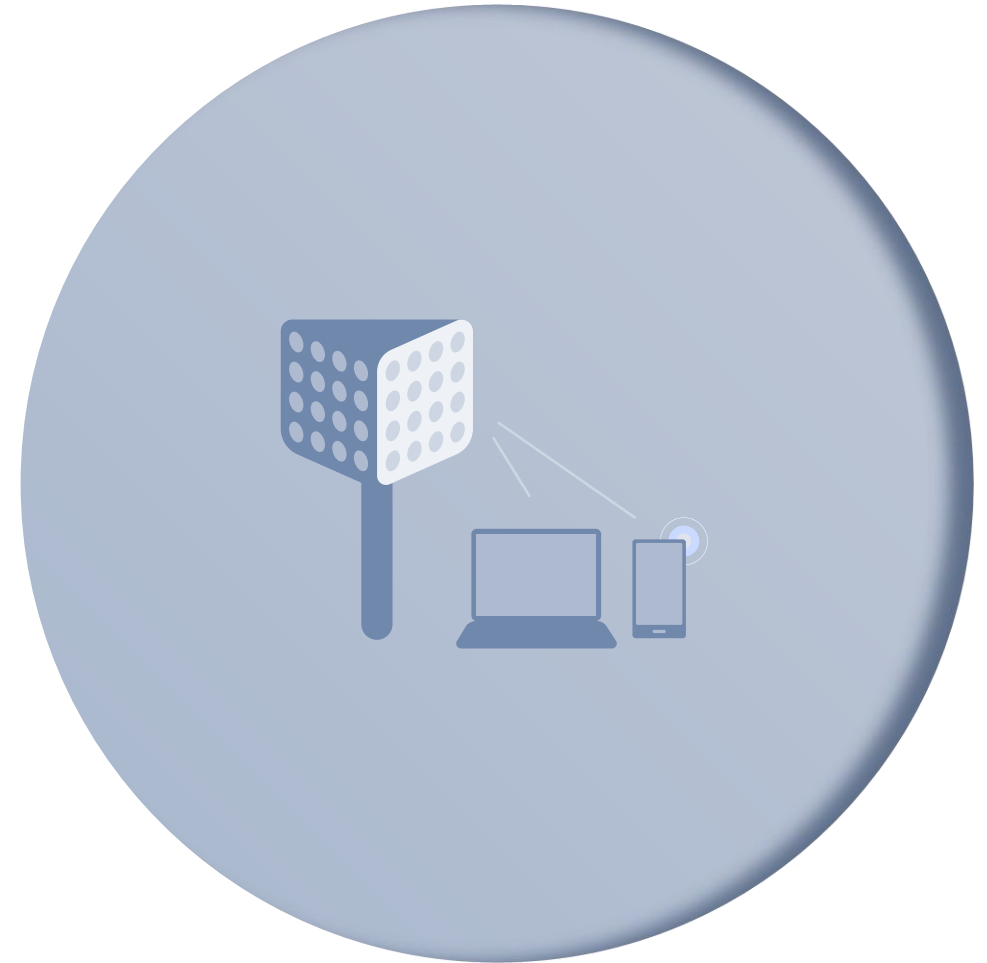
Smartphones in dense urban deployment

Key factors

Population density

Demand growth

5G installed base

Market share

mmWave bandwidth

Net present value (NPV) of total cost of ownership (TCO) for a 3.5 GHz plus mmWave 5G network

Base 100: 3.5 GHz-only TCO

	3.5 GHz-only TCO	Greater China	Europe
5%		87%	100%
10%		78%	96%
25%	100%	72%	65%

Connected users   5%   10%   25%
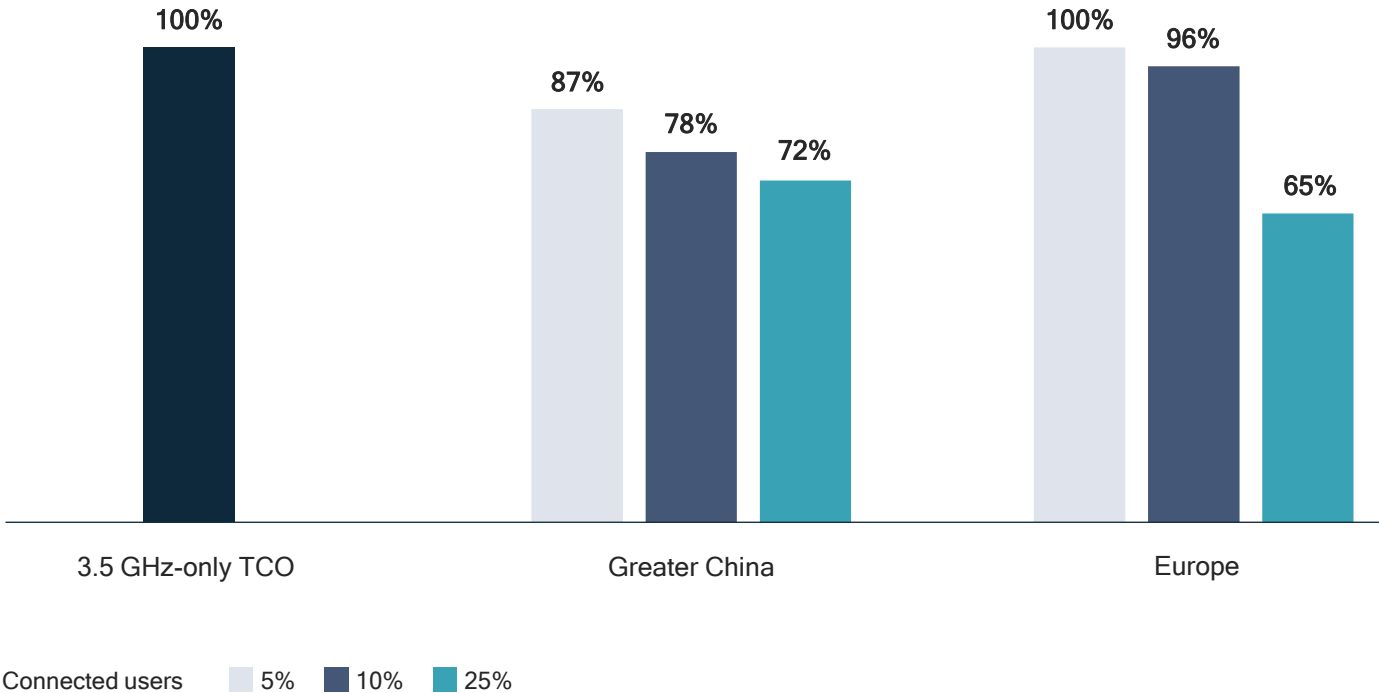
5G mmWave

Superb monetization and ROI

From cost-effective deployment to monetization and new, incremental business potential, 5G mmWave can help drive growth and realize significant return on investment

mmWave scenarios' relative value proposition

⬆ **8%**
Incremental annual revenue

⬆ **20%**
Average ROI[1]

258M+ USD
New opportunity per year with FWA and laptops

75% Savings
Cost/GB Savings for mmWave in hotspots compared to mid-band

94M+ USD
Monetization potential per year of `incremental traffic

<4 Years
Payback period[2] assuming marginal revenues

mmWave + Sub-6 GHz = Extreme capacity, multi-Gigabit 5G where it matters
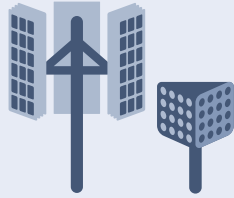
mmWave + Fixed Wireless Access = Fiber through the air for 5G-connected homes and more

5G mmwave

DEPLOYING MMWAVE TO

Complete the 5G puzzle

mmWave + Open RAN = Easily scalable, flexible, high-performance 5G

mmWave + Sub-6 GHz + Standalone = Critical infrastructure for industry 4.0 and more

Efficiently deploy 5G mmWave
for a wide range of use cases

Fixed wireless access
Urban cities, suburban towns, rural villages

Indoor enterprises
Offices, auditoriums, manufacturing

Transportation hubs
Airports, train terminals, subway stations

Industrial IoT
Factories, warehouses, logistic hubs

Indoor / outdoor venues
Conventions, concerts, stadiums

Multi-Gigabit speeds with virtually unlimited capacity

Beyond smartphones, laptops, tablets, extended reality, …

Leveraging existing Wi-Fi or cellular by co-siting

Flexible and efficient deployment with disaggregated RAN (e.g., O-RAN)

Testing 5G mobile mmWave for indoor enterprises

Using commercial equipment

Achieving significant coverage at 28 GHz[1]

- Single sector provides solid coverage in the lobby, atrium, and part of the auditorium

- Significant NLOS coverage behind the gNodeB, including the 2nd and 3rd floor

Extreme capacity for enterprise use cases

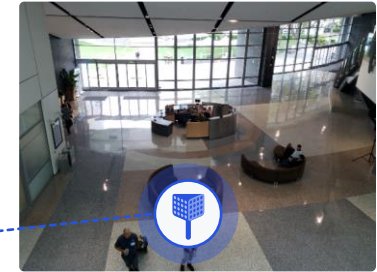- Downlink median burst rate[2] of 3.1 Gbps

Achieving Gigabit speeds even in NLOS

1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Using 400 MHz DL bandwidth

View from gNodeB

28 GHz gNodeB
1-sector; ~20ft. height
400 MHz bandwidth

Legend	
> -60.00	(0.0%)
> -70.00	(0.0%)
> -80.00	(10.0%)
> -90.00	(52.7%)
> -100.00	(63.4%)
> -110.00	(67.5%)
> -115.00	(69.8%)
> -120.00	(100.0%)
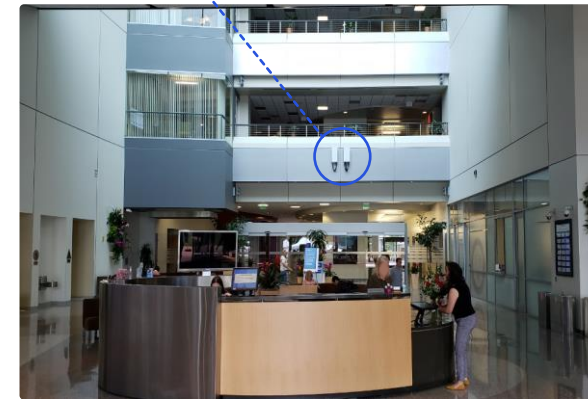
View from building entrance
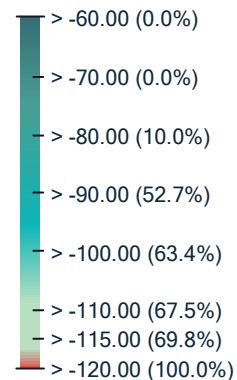
Field testing 5G mmWave in a railway station

Deploying in 28 GHz (n257) with NSA option 3x using 2.1 GHz (B1) LTE anchor

mmWave gNodeB

mmWave gNodeB

L1 DL Throughput

Legend: CC7, CC6, CC5, CC4, CC3, CC2, CC1, CC0

Time [mm:ss]: 04:01 04:31 05:01 05:31 06:01 06:31 07:01 07:31 08:01 08:31 09:01 09:31 10:01
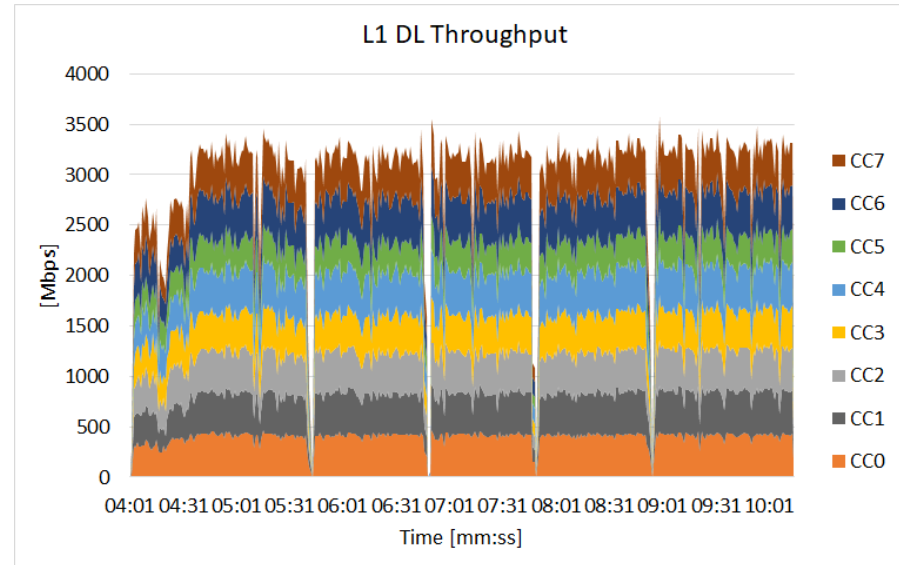
[Mbps]

3.6 Gbps

Peak downlink throughput with 800 MHz BW (8x CA)

L1 UL Throughput

Legend: CC1, CC0

Time [mm:ss]: 02:58 03:28 03:58 04:28 04:58 05:28 05:58 06:28 06:58 07:28 07:58 08:28

[Mpbs]
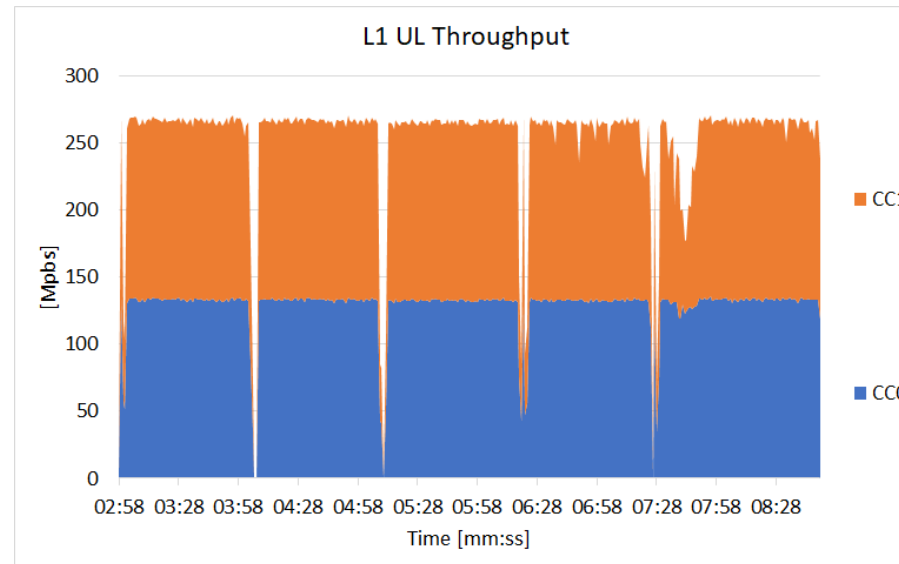
271 Mbps

Peak downlink throughput with 200 MHz BW (2x CA)

5G mmWave antenna locations

On the overhang of upper level

On extensions of speaker poles

On lighting structures

100%
5G coverage on all 3 levels[1]

79
5G mmWave sectors[2]

59/45
5G/4G sectors in parking lot
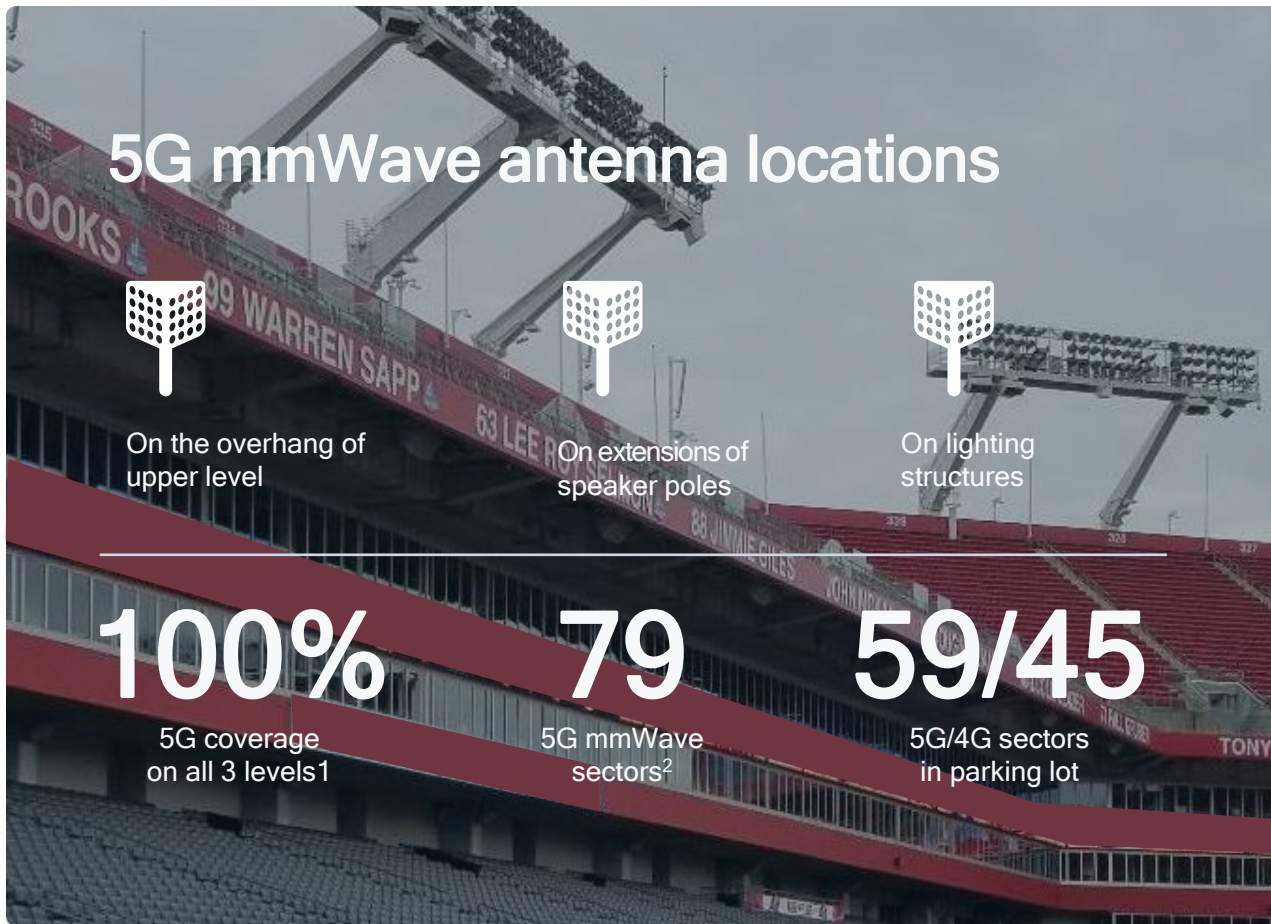
5G vs. 4G downlink throughput

5G mmWave delivers >3 Gbps peak speed in several sectors

- 18x / 1x — Level I
- 20x / 1x — Level II
- 19x / 1x — Level III

■ 5G mmWave (600 MHz) ■ LTE (35 MHz)
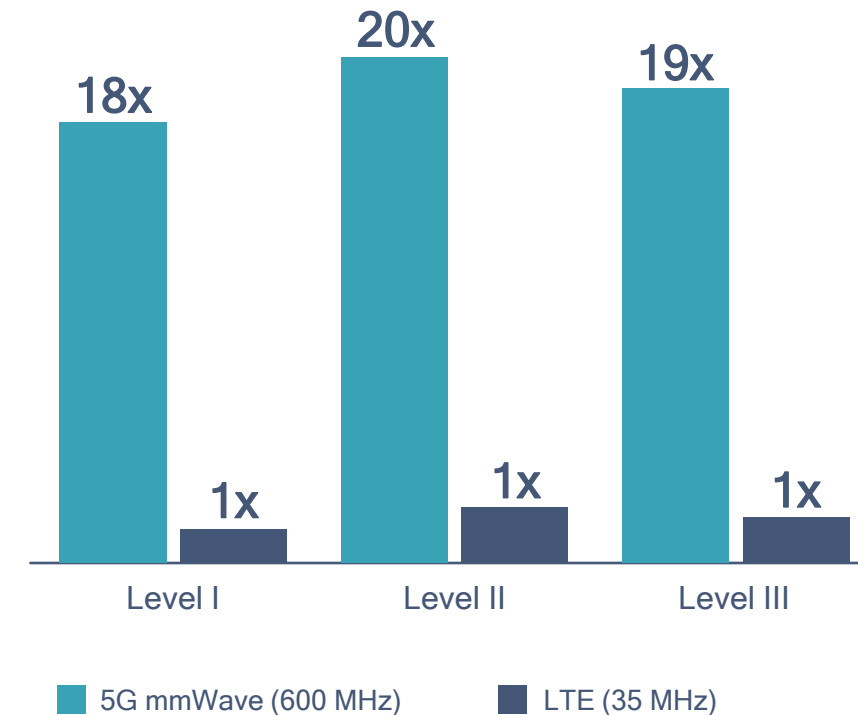
Bringing massive capacity and new experiences to stadiums

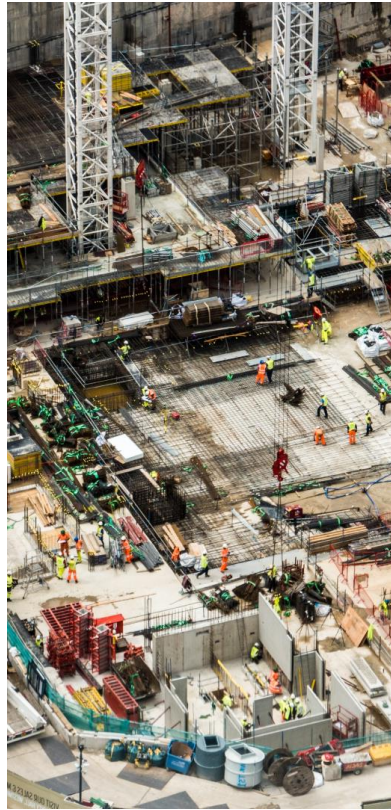# Fixed wireless access use cases

Compelling solution offering broadband services to houses, small businesses, and enterprises.

Remote operation

Monitor and respond

Agile industry

Temporary and moveable

Synchronous collaboration

Power and speed
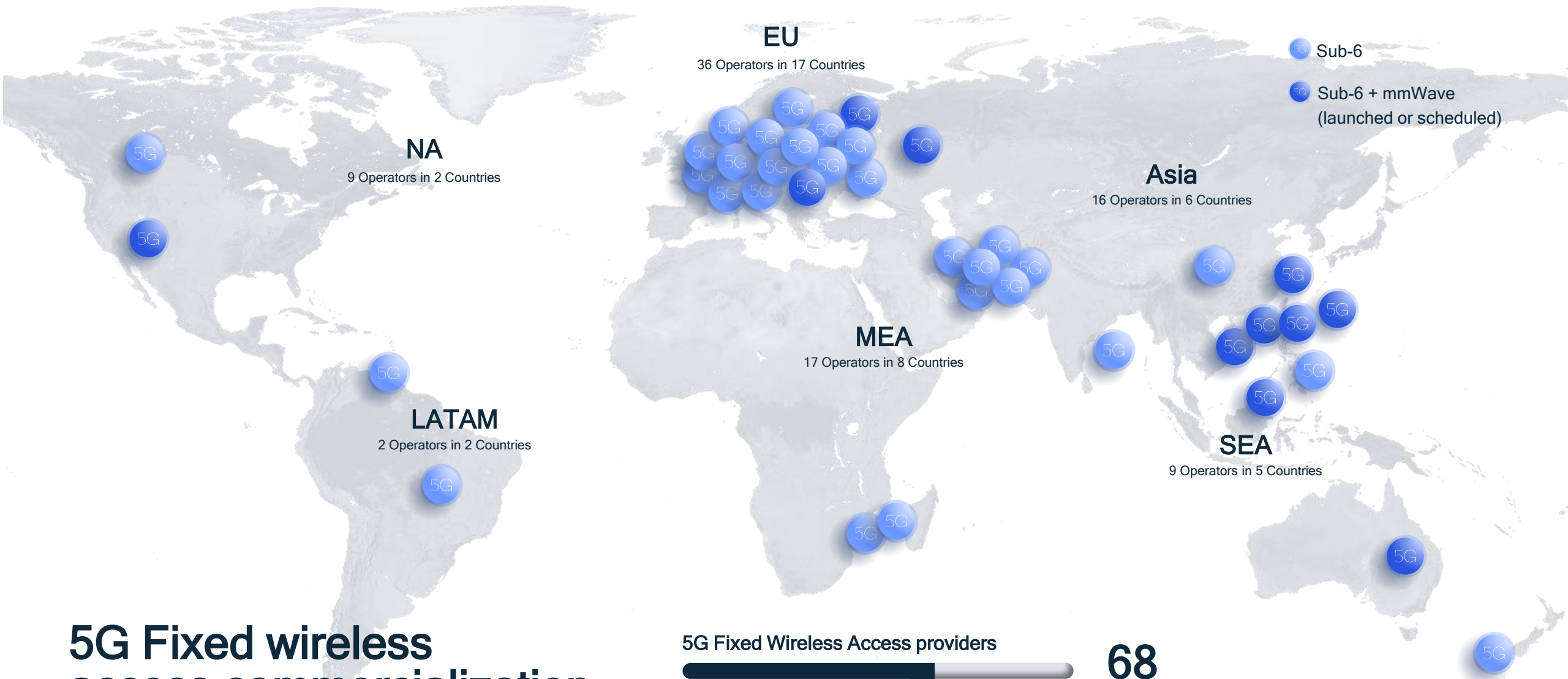
5G Fixed wireless access commercialization

moving into the mainstream

NA — 9 Operators in 2 Countries

EU — 36 Operators in 17 Countries

Asia — 16 Operators in 6 Countries

MEA — 17 Operators in 8 Countries

LATAM — 2 Operators in 2 Countries

SEA — 9 Operators in 5 Countries

Sub-6

Sub-6 + mmWave (launched or scheduled)

5G Fixed Wireless Access providers — **68**

Countries — **32**

Qualcomm® Fixed Wireless Access Platform drives 5G FWA adoption

U.S.A.

5G

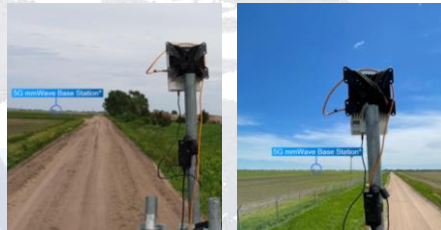Configuration:

Rural | 400 MHz | n261 | 46dBm

Sept 2020

Qualcomm,
U.S. Cellular, Ericsson

+5 km, 100 Mbps

Sept 2020

Movil America,
Qualcomm, Ericsson

~3 km , +650 Mbps

Dec 2020

Fastweb, Qualcomm

Launched 5G Fixed
Wireless Access Commercial

+6 km , 1 Gbps

Jan 2021

Nbn, Ericsson,
Qualcomm,
Casa Systems

+7 km ,~1 Gbps

May 2021

U.S. Cellular, Qualcomm, Ericsson,
Inseego

+7 km , ~1 Gbps

Jun 2021

U.S. Cellular, Qualcomm, Nokia

**~10 km
~1 Gbps**

5G for Industry 4.0

Enhanced mobile broadband

Head mounted display

Massive IoT

Computer vision

Sensors

5G

Handheld terminal

Ultra-reliable low-latency

Industrial robot

Automated guided vehicle (AGV)

Wireless edge analytics

Boost 5G networks for
Industry 4.0 with the power of mmWave

5G mmWave

5G Standalone

5G Sub-6 GHz
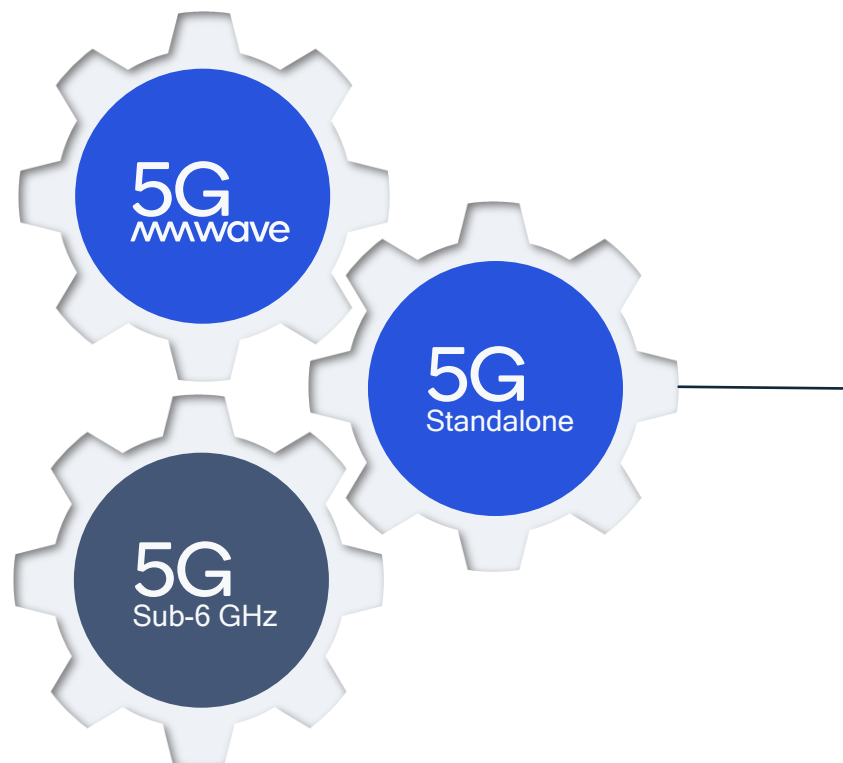
Ultra-high capacity

Ultra-reliability with CoMP, dual connectivity, and network slicing

Seamless mobility

Low latency and edge compute

Secure private networks

Time sensitive networking (TSN)

Public network fallback

Precise positioning

Broad range of devices for diverse applications

CoMP: Coordinated multi-point

Critical applications

AR / VR

Interactive collaboration

Mobile robots

Operations and security services

Real-time control for industrial IoT

Factory automation with wireless Ethernet and TSN

Mission-critical industrial applications

Industrial handhelds

Immersive training

HD video surveillance

Precise indoor locationing

Guided execution

Automation & motion control

Mobile robots (e.g., AGV)

Mobile workstations

5G Smart Manufacturing

~4.8T

In global economic value by 2035

* The 5G Economy in a Post-COVID-19 Era – an independent study from IHS Markit, commissioned by Qualcomm Technologies, Inc.

5G mmWave brings benefits to a broad set of industrial use cases

Inherently ultra-low latency

Fiber-like data speeds

Massive capacity

Indoor / outdoor isolation

Simple deployment

Deploying 5G mmWave in industrial settings (e.g., factories, warehouses) can deliver new classes of service and performance

**Automated
Guided Vehicles (AGVs)**

UHD video captured with edge AI processing for issues identification and surveillance

Low-latency and ultra-reliable control

**Boundless
Extended Reality (XR)**

Next-generation human-machine interface

Remote guided maintenance / repair

Immersive hands-on training

**Always-connected
Laptops and Devices**

Instant access to cloud compute / storage

Immersive virtual telepresence

Real-time collaboration

Collaborating with ecosystem leaders to deploy 5G mmWave smart factory

Initial use cases:

Automatic inspection of product lines via automated guided vehicle (AGV) and overhead transmission (OHT)
— 20 Mbps DL, 120 Mbps UL

Remote augmented reality for equipment troubleshooting, maintenance, and repair
— 25 Mbps DL, 25 Mbps UL

Immersive virtual/augmented reality for visitors of Green Technology Education Center
— 25 Mbps DL, 2.5 Mbps UL

1 With DL and UL bandwidth of 400 MHz and 200 MHz, respectively
Source: https://ase.aseglobal.com/en/press_room/content/5g_smart_factory_en

Factory manufacturing floor (~34,159 sq. ft.); 12 ft. ceiling height

~160 ft.

~213 ft.

Pillar
Wall / Room
Ceiling obs.
Equipment
AGV route
OHT route

Path loss (dB)
> -60.00
> -70.00
> -80.00
> -90.00
> -100.00
> -110.00
> -115.00
> -120.00

5G NR NSA network operating in 28 GHz band, achieving median throughput greater than **1.5 Gbps** in DL and **120 Mbps** in UL[1]

5G mmWave can support diverse use cases infactories of the future
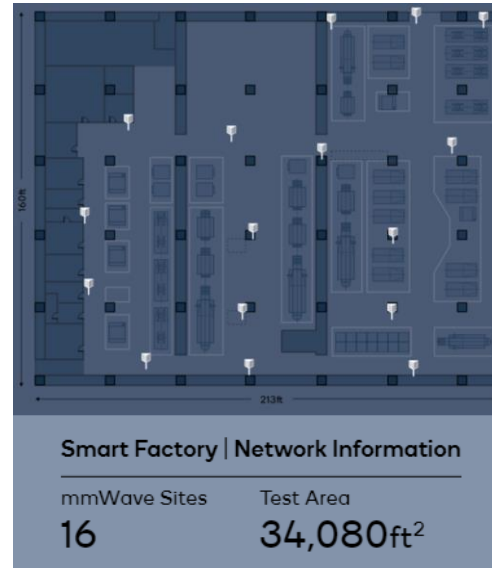
Enhanced mobile broadband
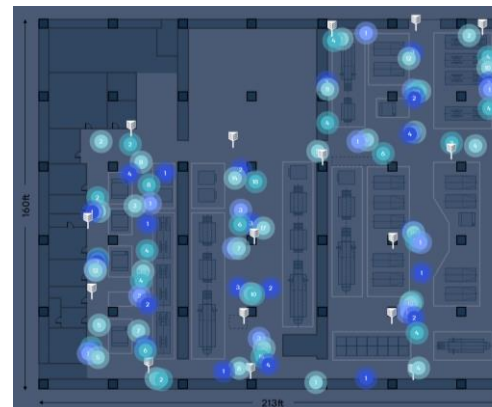- Smartphone and laptops
- Boundless XR

Mission-critical services
- Industrial automation (e.g., robots)

Massive IoT
- Camera sensors

Smart Factory | Network Information

mmWave Sites	Test Area
16	34,080ft²

Proof-of-concept end-to-end system simulations

Simulated Devices

Smartphones and Laptops

Average DL Throughput
805.5 Mbps

Extended Reality

Average DL Throughput	Successful Packets	Average Latency
212.2 Mbps	≥ 99 %	0.8 ms
> 100 Mbps required		< 10 ms required

Industrial Automation

Traffic Profile	Successful Packets	Average Latency
48.0 bytes / ms	≥ 99.9999 %	0.5 ms
		< 1 ms required

Camera Sensors

Average UL Throughput
281.5 Mbps

Evolving the 5G network

Traditional RAN
Combined baseband processing unit + Radio unit

Internet

Core hub

Backhaul

BBU
Radio
Cell site

BBU
Radio
Cell site
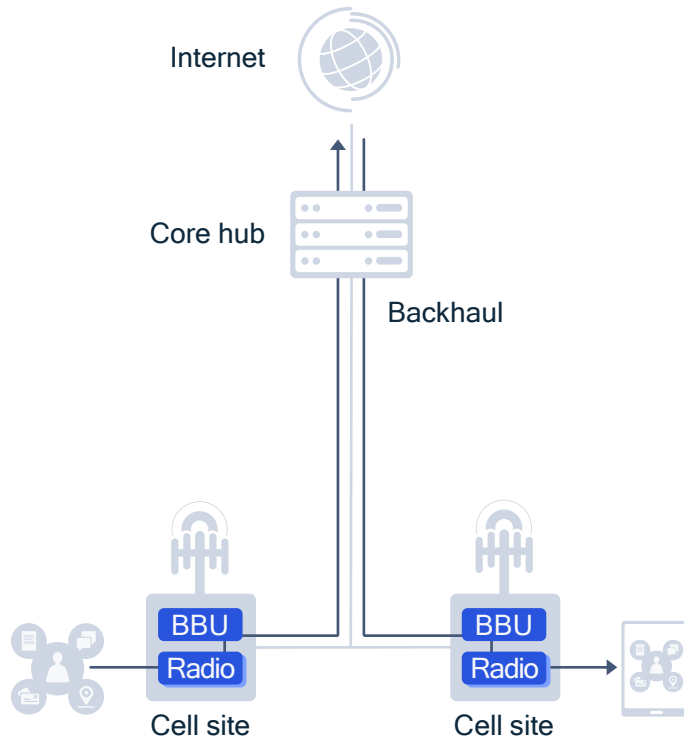
Centralized RAN (C-RAN)
Centralized baseband processing unit

Internet

Core hub

Backhaul

C-RAN hubs   BBU

Fronthaul

Radio
Cell site

Radio
Cell site
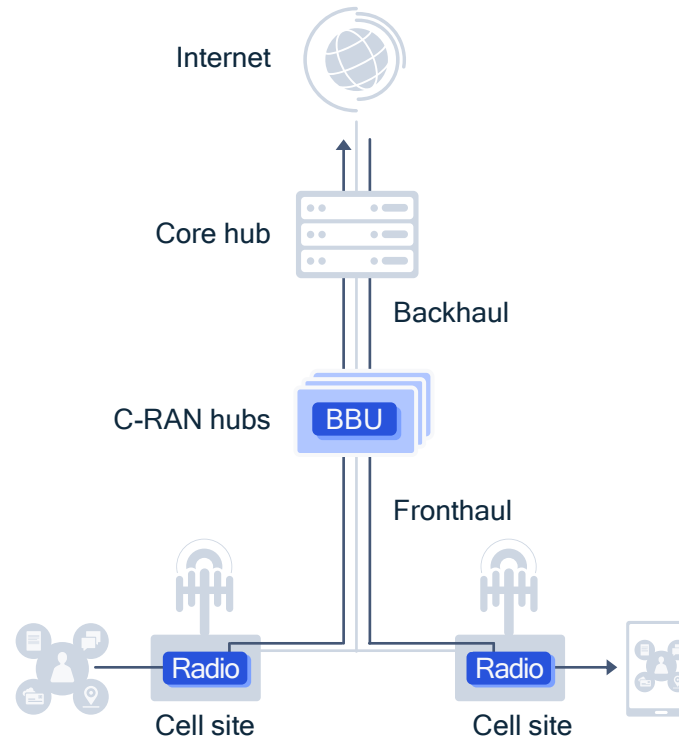
Virtual RAN (vRAN) + MEC
Virtualized baseband processing unit with disaggregation

Internet

Core hub

Backhaul

Edge data centers

MEC
vCore
vCU

Open RAN interfaces

Midhaul

DU

RU
Cell site

Fronthaul

RU
Cell site
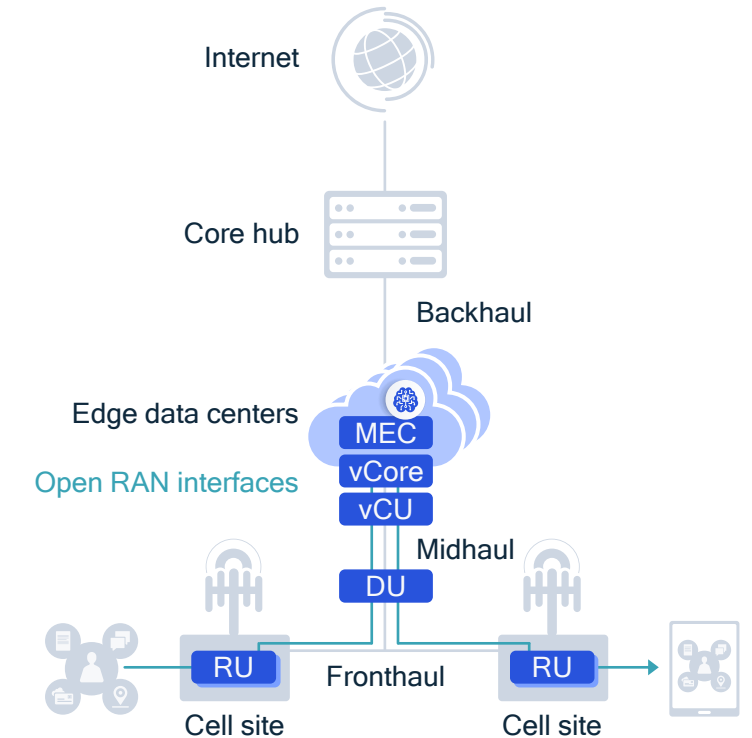
For better coordination, scalable capacity, faster deployments, lower latency, and new use cases

5G Infrastructure Trends

vRAN, O-RAN, COTS

Traditional RAN

Core

BBU
- L3
- L2 NRT
- L2 RT
- L1 High

RU
- L1 Low
- RFIC
- RFFE

C-RAN

Core

CU
- L3
- L2 NRT

DU
- L2 RT
- L1 High

RU
- L1 Low
- RFIC
- RFFE

vRAN 2.0

Core

CU
- L3
- L2 NRT

vDU
- L2 RT
- L1 High

RU
- L1 Low
- RFIC
- RFFE

■ Dedicated hardware   ■ Virtualized- running on GPP
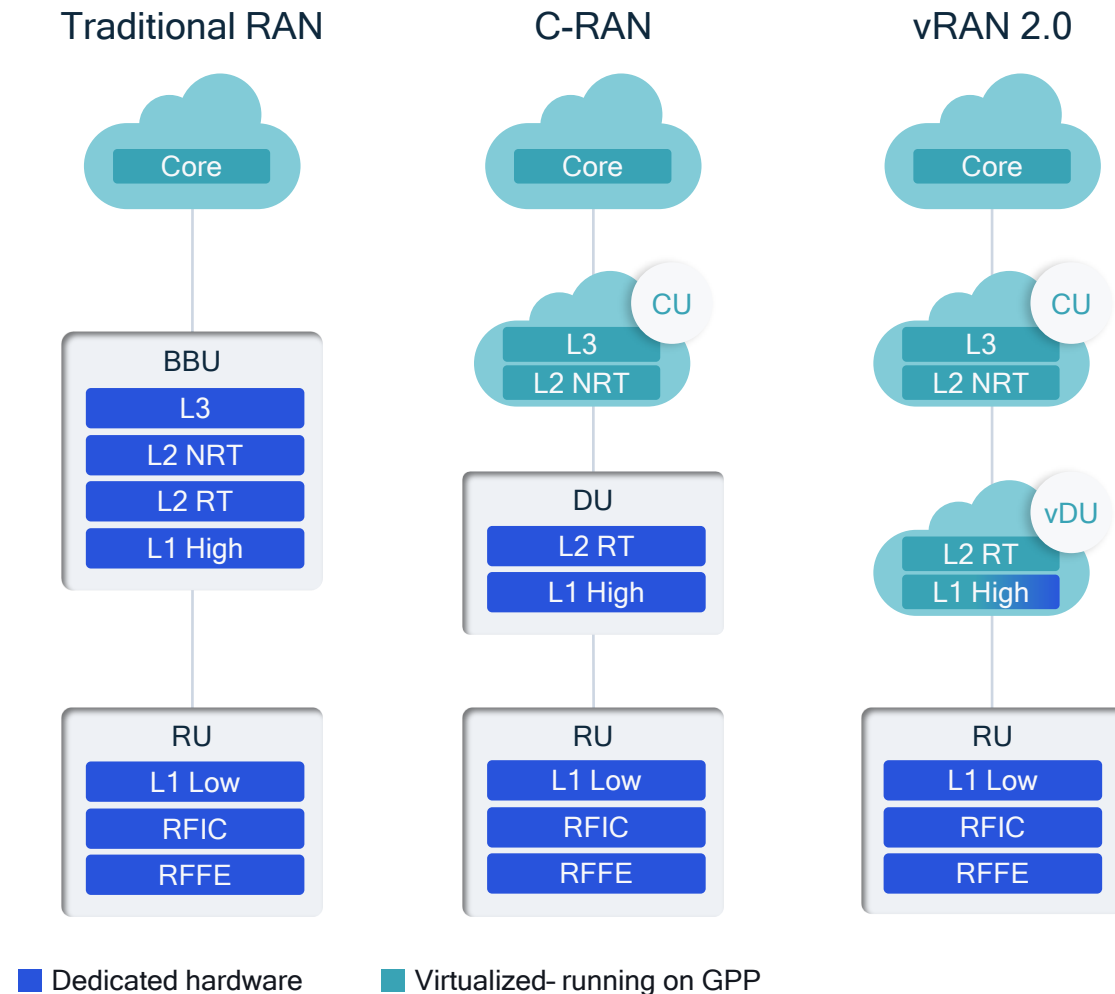
O-RAN
Open interfaces between network elements (Core, Protocols, BB, RF)

vRAN
RAN virtualization with GPP

COTS
General Purpose Processors (GPP)

High Performance Products
Low-latency high-throughput operations

Dedicated hardware accelerators
- Full RU implementation
- L1 accelerators for vDU

Our Goal
Enable high performance vRAN products using open interfaces

Support different deployment scenarios

Higher utilization of scalable resources

Efficiently deploy new services

Real Estate Savings

Build RAN cost-effectively

Place processing and analytics where it is needed

Simplify orchestration

Resource pooling allows trunking gains and better cost and energy effectiveness

Rapidly scale virtual resources for additional capacity

Support lower end-to-end latency

Components can evolve and be upgraded separately

Tailor dimensioning and features to suit the use case with 5G private networks

Reduce cell-site footprint by relocating disaggregated functions to data centers

Broaden the ecosystem for competition

Vendor diversity spurs innovation

Deploy networks faster

with vRAN and disaggregation

Build flexible, higher-performance 5G networks with O-RAN and mmWave

Edge cloud

RIC

O-CU

F1 interface

O-DU

CUS interface

O-DU

O-RU

O-RU

Cell site

Cell site
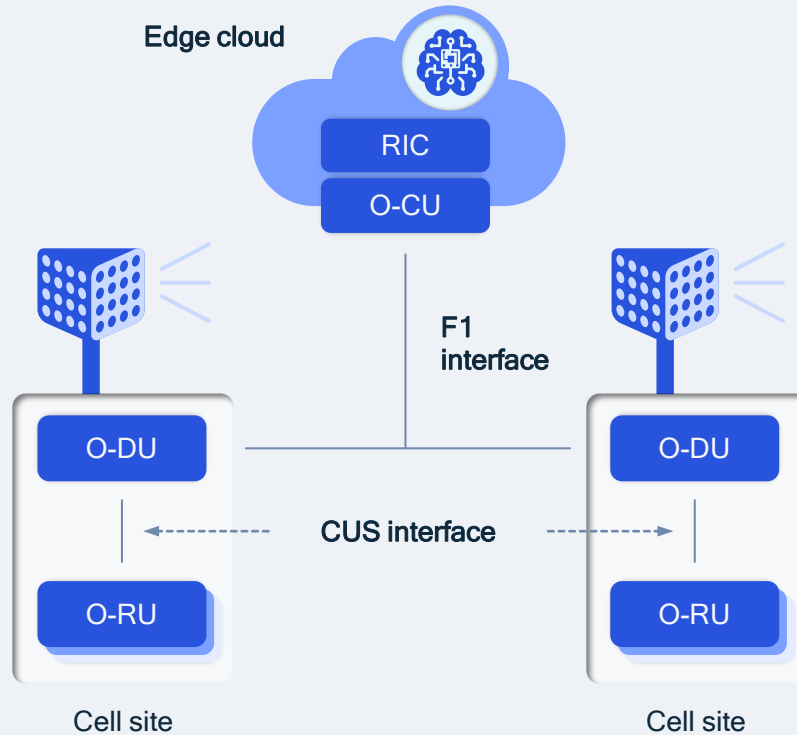
Intelligent and flexible 5G mmWave deployments with O-RAN elements and interfaces

Accelerate 5G mmWave deployments

Broaden the ecosystem for vendor diversity
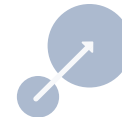Spur competitive innovation

Advance capabilities and performance with the O-RAN Radio Intelligent Controller (RIC)

Improve mmWave connectivity with RAN intelligence
Train machine learning models at scale

Build denser networks

Disaggregate to reduce cell-site footprint
Access more locations with a smaller footprint

Efficiently scale new bandwidth-intensive services

Evolve and upgrade components separately
Rapidly scale virtual resources

Evolving mmWave in 3GPP Rel-16+
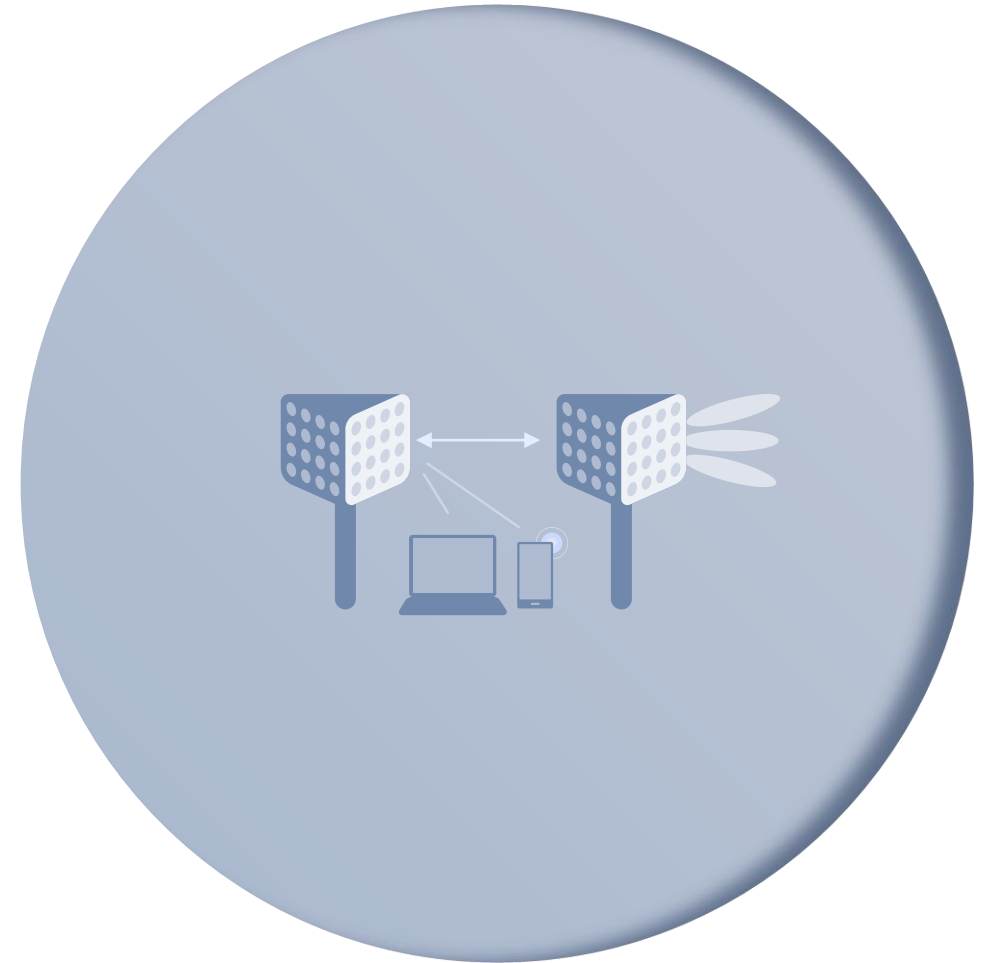
Advancing 5G to fulfill its full promise

Enhanced mobile experiences, new capabilities, and expansion to diverse verticals

Industry 4.0

5G

Wide-area 5G

Mobile mmWave

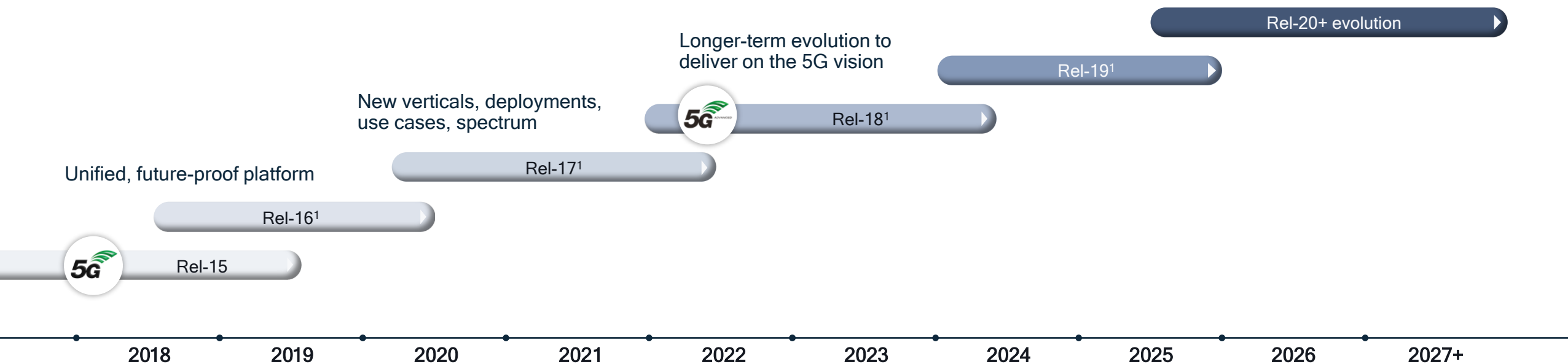Boundless XR

5G V2X Sidelink

Green networks

Driving the 5G technology evolution in the new decade

Rel-20+ evolution

Longer-term evolution to
deliver on the 5G vision

Rel-19[1]

New verticals, deployments,
use cases, spectrum

5G Rel-18[1]

Rel-17[1]

Unified, future-proof platform

Rel-16[1]

5G Rel-15

| 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027+ |

Rel-15 eMBB focus

- 5G NR foundation
- Smartphones, FWA, PC
- Expanding to venues, enterprises

Rel-16 industry expansion

- eURLLC and TSN for IIoT
- NR in unlicensed
- 5G V2X sidelink multicast
- In-band eMTC/NB-IoT
- Positioning

Rel-17 continued expansion

- Lower complexity NR-Light
- Higher precision positioning
- Improved IIoT, V2X, IAB, and more…

Rel-18+ 5G-Advanced

- Next set of 5G releases (i.e., 18, 19, 20, …)
- Potential projects in discussions
- Rel-18 expected to start in 2022

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

5G NR enhancements for mmWave

Completed Release 16 Projects

Integrated access and backhaul (IAB)
Enabling flexible deployment of small cells reusing spectrum and equipment for access and backhaul

Enhanced beam management
Improving latency, robustness and performance with full beam refinement and multi-antenna-panel beam support

Power saving features
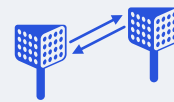Maximizing device sleep duration to improve power consumption as well as allowing faster link feedback

Dual connectivity optimization
Reducing device initial access latency and improving coverage when connected to multiple nodes

Positioning
Meeting initial accuracy requirements of 3m (indoor) to 10m (outdoors) for 80% of time

Release 17+ Projects

Improved IAB for distributed deployment
Introducing full duplex operations and mobile relays for improved capability, coverage, and QoS
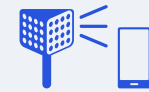
Optimized coverage and beam management
Reducing overhead, enhancing performance (e.g., beam selection), improving coverage

Expanded spectrum support
Supporting licensed and unlicensed spectrum in frequencies ranging from 52.6 GHz to 71 GHz

New use cases beyond eMBB
Expanding mmWave support for sidelink, URLLC, and industrial IoT use cases (e.g., NR-Light)

Enhanced positioning
Enhancing capability for a wide range of use cases – cm-level accuracy, lower latency, higher capacity

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Delivering 5G mobile mmWave enhancements and new use cases

Smart 5G mmWave Repeaters

Improved coverage and service multiplexing with repeaters in LOS, NLOS, out-to-in scenarios using our 5G mmWave OTA test network

ML Enhanced mmWave Beam Prediction

Machine learning can further improve 5G mmWave robustness and efficiency, reducing overhead in our 5G mmWave OTA test network

Network Topology Optimization

Simplifying network planning with an ML-based approach, exploring performance/cost tradeoffs with different mmWave topology options

5G mmWave NR-Light IoT

Scaling 5G down for lower-complexity IoT, showing how mmWave NR-Light devices can make efficient use of 5G network resources

5G mmWave in Smart Factory

Simulating 5G mmWave to meet the diverse requirements in the factory of the future, ranging from high-performance to low-complexity

▶ 5G mmWave OTA prototypes
5G mmWave technology evolution

Innovating to pave the path to 6G

A unified connectivity
fabric for this decade

Next technology leap
for new capabilities
and efficiencies

Continued evolution

5G

Rel-15
eMBB focus

Rel-16 and 17 expanding
to new industries

5G ADVANCED

Rel-18, 19. 20 and beyond
Continued 5G proliferation

6G

**Strong 5G momentum sets
stage for global expansion**

Historically 10 years
between generations

Qualcomm

Thank you

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