November 2020
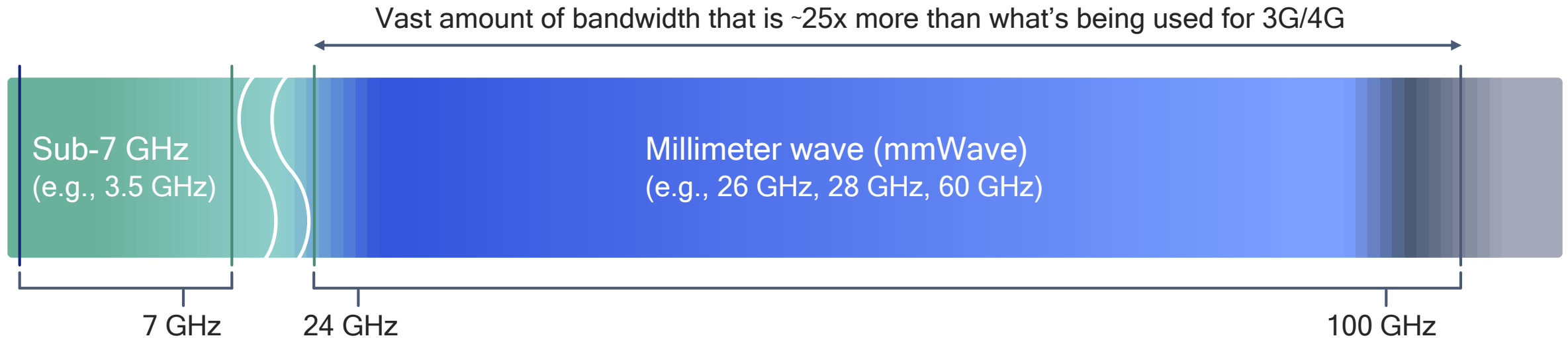
@qualcomm_tech

Qualcoww

Deploying 5G NR mmWave to unleash the full 5G potential

New frontier of mobile broadband – mobilizing mmWave

Vast amount of bandwidth that is ~25x more than what's being used for 3G/4G

Sub-7 GHz
(e.g., 3.5 GHz)

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

7 GHz   24 GHz   100 GHz

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

Much more capacity
With dense spatial reuse

Lower latency
Bringing new opportunities

Global mmWave spectrum targets

	24-28GHz	37-40GHz	64-71GHz	>95GHz
🇺🇸	24.25-24.45GHz 24.75-25.25GHz 27.5-28.35GHz	37-37.6GHz 37.6-40GHz 47.2-48.2GHz	57-64GHz 64-71GHz	>95GHz
🇨🇦	26.5-27.5GHz 27.5-28.35GHz	37-37.6GHz 37.6-40GHz	57-64GHz 64-71GHz	
🇪🇺	24.5-27.5GHz		57-66GHz	
🇬🇧	26GHz		57-66GHz	
🇩🇪	26GHz		57-66GHz	
🇫🇷	26GHz		57-66GHz	
🇮🇹	26.5-27.5GHz		57-66GHz	
🇨🇳	24.75-27.5GHz	40.5-43.5GHz		
🇰🇷	25.7-26.5GHz 26.5-28.9.5GHz 28.9-29.5GHz	37GHz	57-66GHz	
🇯🇵	26.6-27GHz 27-29.5GHz	39-43.5GHz	57-66GHz	
🇹🇼	27.9-29.5GHz			
🇮🇳	24.25-27.5GHz 27.5-29.5GHz	37-43.5GHz		
🇦🇺	24.25-29.5GHz	39GHz	57-66GHz	

5G NR mmWave spectrum highlights

Ready for deployment in 2020 & beyond

🇺🇸 **U.S.** — Completed three mmWave auctions so far, including 24, 28, 37, 39, and 47 GHz

🇰🇷 **South Korea** — 28 GHz auction completed in Jun. 2018; each operator assigned 800 MHz; plan to secure additional spectrum in 2021

🇯🇵 **Japan** — Assigned 28 GHz mmWave spectrum in Apr. 2019; technical rules for additional spectrum (e.g., 26.6-27 GHz and 39.5-43.5 GHz planned for 2021

🇹🇼 **Taiwan** — Auction completed in Feb. 2020 with a total of 1.6 GHz in 28 GHz band awarded to 4 operators

🇮🇹 **Italy** — 5G spectrum auction completed in Sep. 2018 with right of use starting January 1st, 2019

🇷🇺 **Russia** — 26 GHz auction completed in Q4 2018 to enable 2019+ commercial deployments
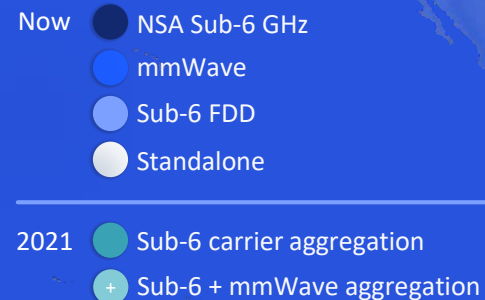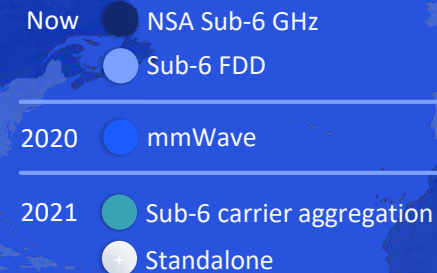
🇩🇪 **Germany** — 26 GHz spectrum award planned for Q4 2020

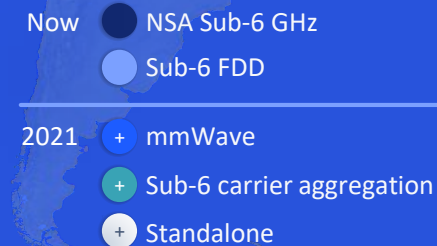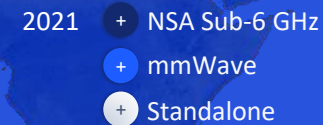Finland, UK have also made mmWave spectrum available

5G Rollout Outlook

China

Now	●	NSA Sub-6 GHz
2020	●	Sub-6 FDD
	○	Standalone
2021	●	Sub-6 carrier aggregation
	⊕	mmWave

Japan

Now	●	NSA Sub-6 GHz
	●	mmWave
2020	●	Sub-6 FDD
	●	Sub-6 carrier aggregation
2021	○	Standalone
	⊕	Sub-6 + mmWave aggregation

Europe

Now	●	NSA Sub-6 GHz
	●	Sub-6 FDD
2020	●	mmWave
2021	●	Sub-6 carrier aggregation
	⊕	Standalone

USA

Now	●	NSA Sub-6 GHz
	●	mmWave
	●	Sub-6 FDD
	○	Standalone
2021	●	Sub-6 carrier aggregation
	⊕	Sub-6 + mmWave aggregation

Korea

Now	●	NSA Sub-6 GHz
2020	●	mmWave
	○	Standalone
2021	⊕	Sub-6 FDD
	⊕	Sub-6 carrier aggregation
	⊕	Sub-6 + mmWave aggregation

India

2021	⊕	NSA Sub-6 GHz
	⊕	mmWave
	⊕	Standalone

LatAm

Now	●	NSA Sub-6 GHz
	●	Sub-6 FDD
2021	⊕	mmWave
	●	Sub-6 carrier aggregation
	⊕	Standalone

SEA

Now	●	NSA Sub-6 GHz
2020	⊕	mmWave
2021	○	Standalone

Australia

Now	●	NSA Sub-6 GHz
2020	●	Sub-6 FDD
2021	●	mmWave
	●	Sub-6 carrier aggregation
	⊕	Standalone

"+" implies the year indicated and beyond

5G mmWave commercial devices powered by Snapdragon

5G smartphones

PCs

Modules

Hotspots

CPEs

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

5

5G NR mmWave is bringing new waves of opportunities

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
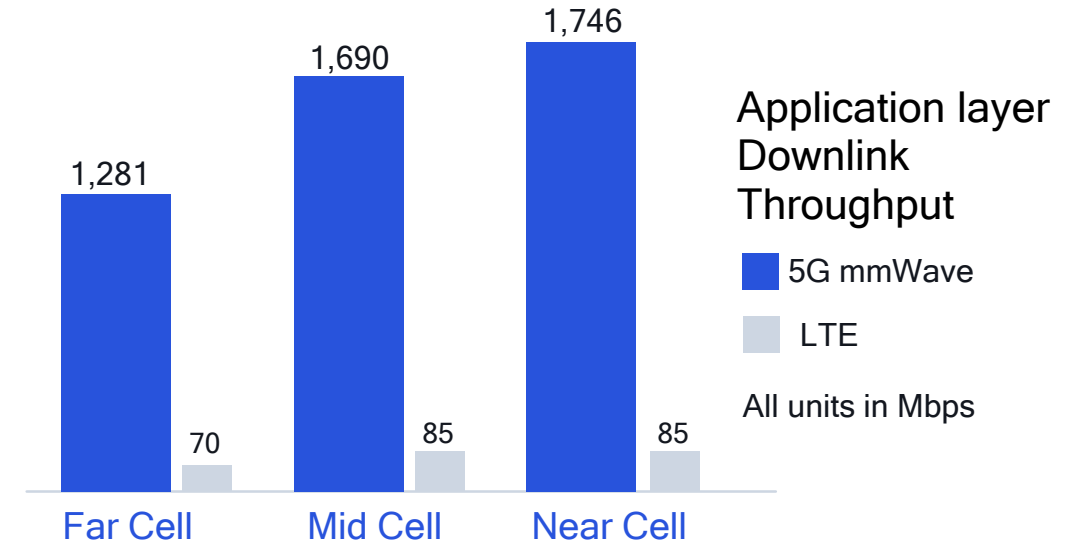
Creating value for the mobile ecosystem
Operators, service providers, venue owners, infra vendors, device OEMs,…

Conducting 5G mmWave performance field tests

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

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

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

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

50 meters LOS

Image capture: Aug 2019   © 2020 Google

Throughput achieved*
1,821 Mbps downlink
96.9 Mbps uplink

386 meters LOS
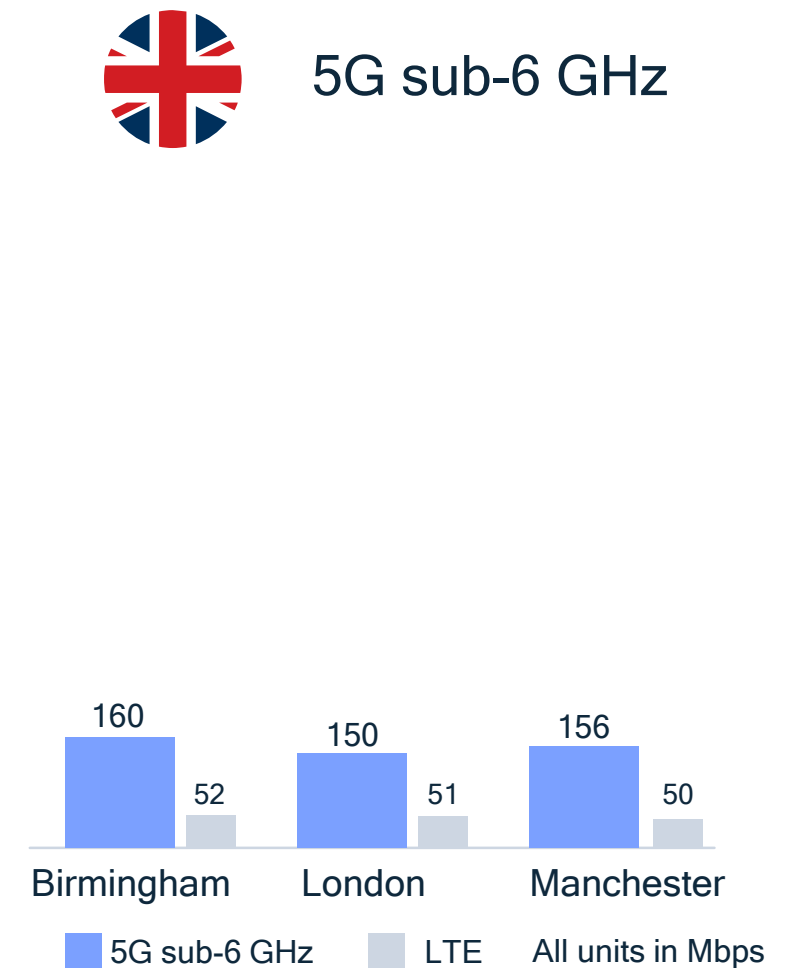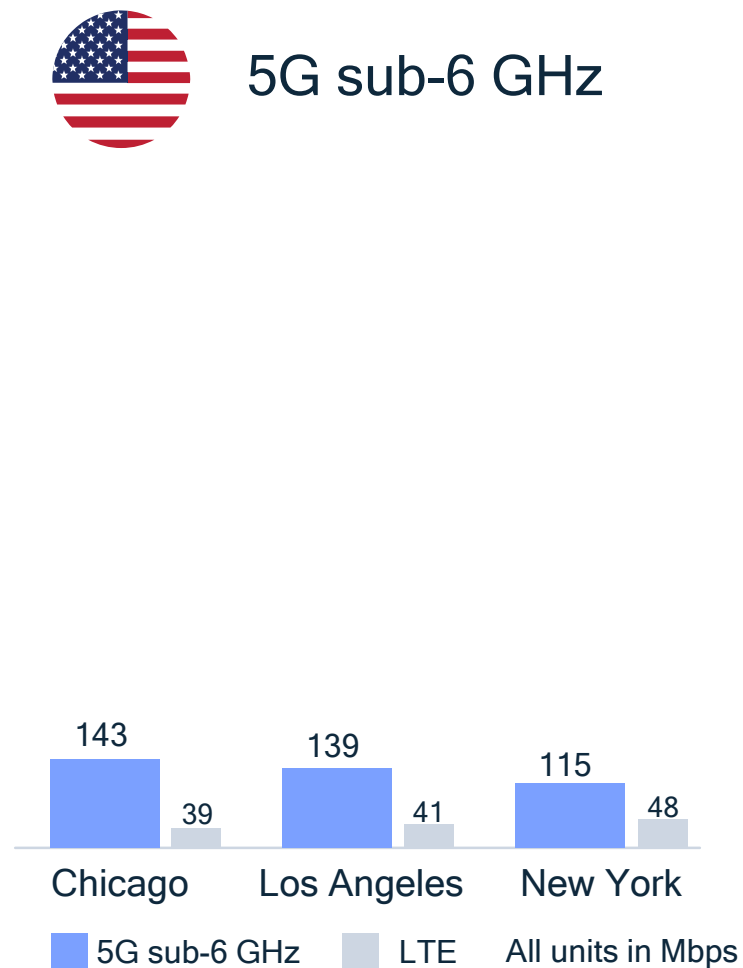
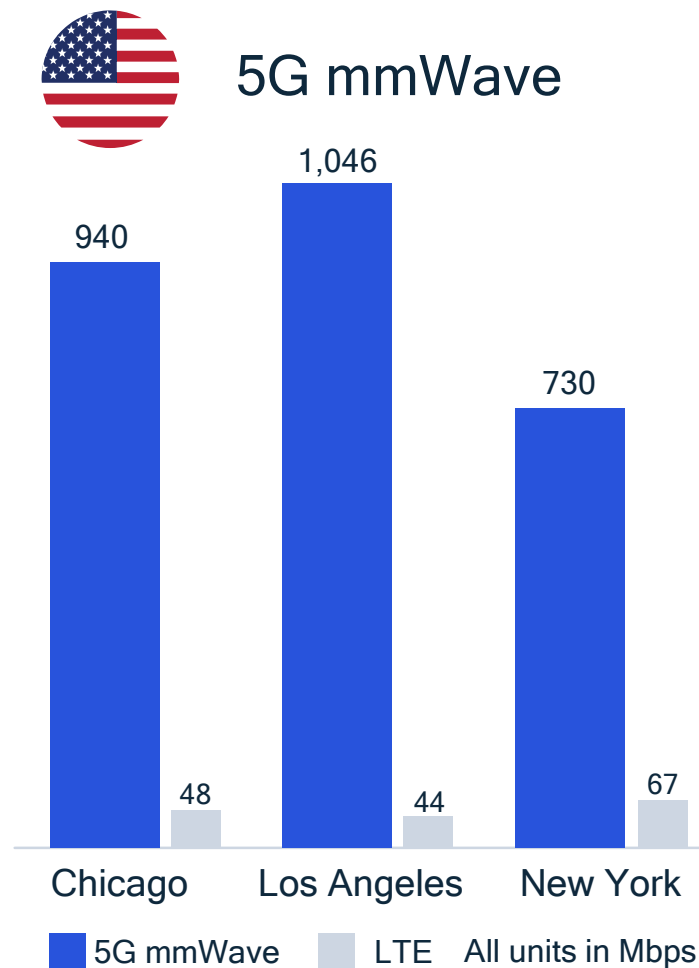Image capture: Jul 2019   © 2020 Google

Throughput achieved*
1,780 Mbps downlink
73.1 Mbps uplink

*Measured using Ookla SpeedTest

5G mmWave delivers unparalleled user experience ⏱ SPEEDTEST®

3 Gbps in peak download speed and significant gains in average throughput observed by 5G mmWave users

5G mmWave

- Chicago: 940 / 48
- Los Angeles: 1,046 / 44
- New York: 730 / 67

■ 5G mmWave ■ LTE All units in Mbps

5G sub-6 GHz

- Chicago: 143 / 39
- Los Angeles: 139 / 41
- New York: 115 / 48

■ 5G sub-6 GHz ■ LTE All units in Mbps

5G sub-6 GHz

- Birmingham: 160 / 52
- London: 150 / 51
- Manchester: 156 / 50

■ 5G sub-6 GHz ■ LTE All units in Mbps

Based on analysis by Ookla® of Speedtest Intelligence® data average download monthly 5G results from defined cities for Q4 2019 - Q3 2020. Ookla trademarks used under license and reprinted with permission.

Indoor enterprises
Offices, auditoriums, manufacturing

Indoor/outdoor venues
Conventions, concerts, stadiums

Transportation hubs
Airports, train terminals, subway stations

Fixed wireless access
Urban cities, suburban towns, rural villages

Industrial IoT
Factories, warehouses, logistic hubs

Expanding mmWave indoors, private networks, homes, IIoT

Multi-Gigabit speeds with virtually unlimited capacity

Beyond smartphones, laptops, tablets, extended reality, ...

Leveraging existing Wi-Fi or cellular by co-siting

Testing 5G NR 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
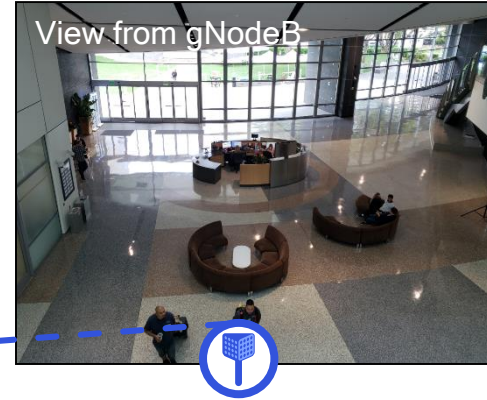- Significant NLOS coverage behind the gNodeB, including the 2nd and 3rd floor

Extreme capacity for enterprise use cases

- Downlink median burst rate[2] of 3.1 Gbps
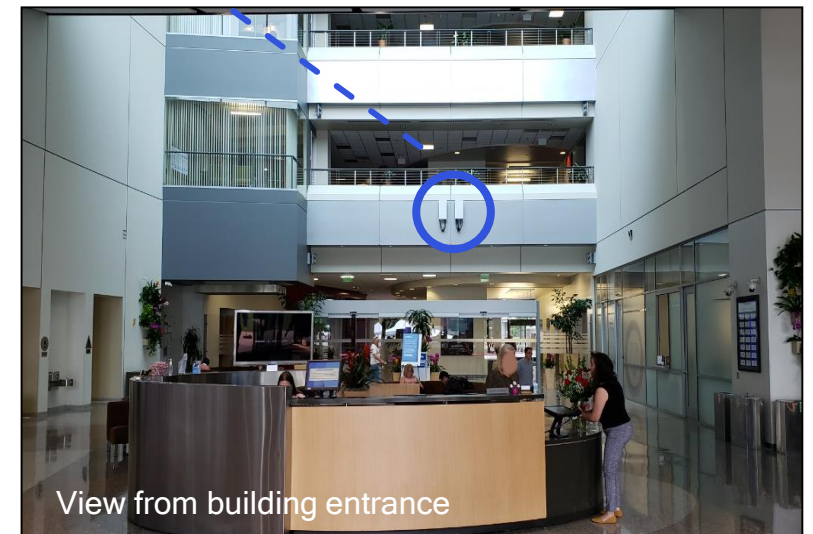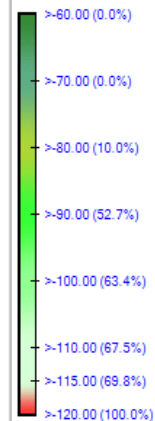

Achieving Gigabit speeds even in NLOS

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

Path loss (dB)

>-60.00 (0.0%)
>-70.00 (0.0%)
>-80.00 (10.0%)
>-90.00 (52.7%)
>-100.00 (63.4%)
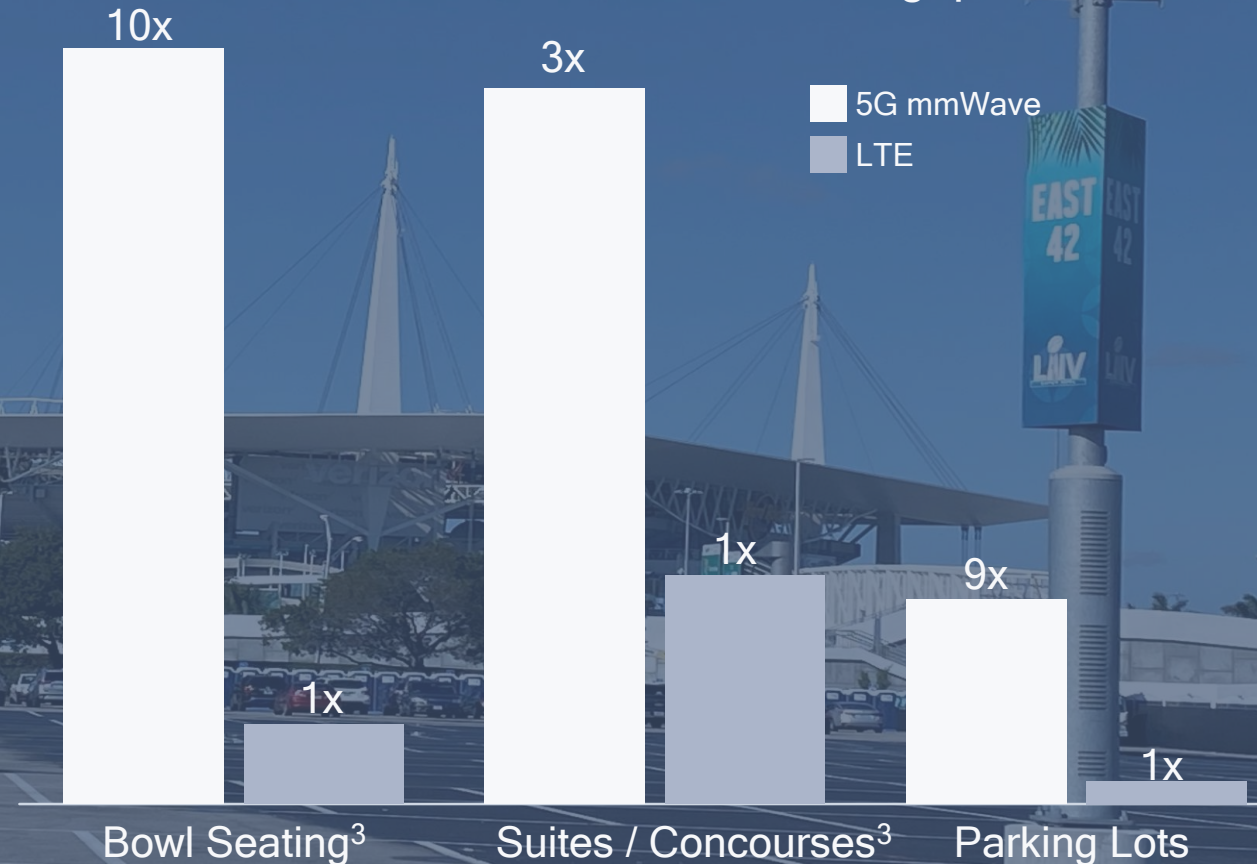>-110.00 (67.5%)
>-115.00 (69.8%)
>-120.00 (100.0%)

View from building entrance

Bringing massive capacity and new experiences to stadiums

28 GHz band with 4x100 MHz CA – NSA with multiple LTE anchors[1]

98% — 5G coverage in bowl seating from 8 sectors 28 GHz with 100x4 MHz BW

**121** — Bowl sectors 100 sectors in AWS/PCS 21 sectors in 700 MHz band

45 / 62 — 5G / 4G Sectors in parking lot

5G vs. 4G Downlink Throughput[2]

- 5G mmWave
- LTE

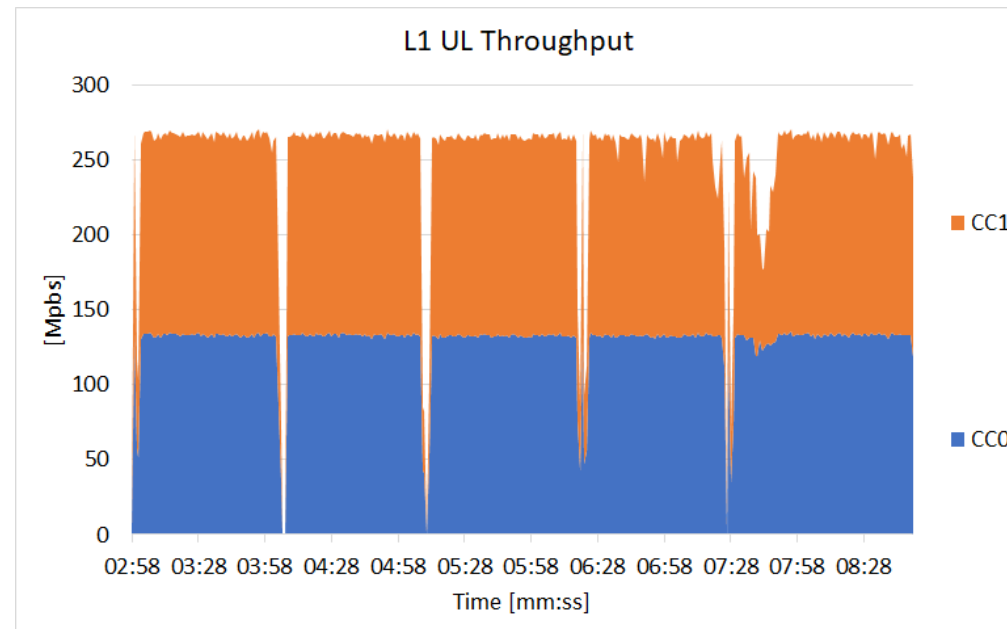|	Bowl Seating[3]	Suites / Concourses[3]	Parking Lots
5G mmWave	10x	3x	9x
LTE	1x	1x	1x

Field testing 5G mmWave in a railway station

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

L1 DL Throughput

Legend: CC7, CC6, CC5, CC4, CC3, CC2, CC1, CC0
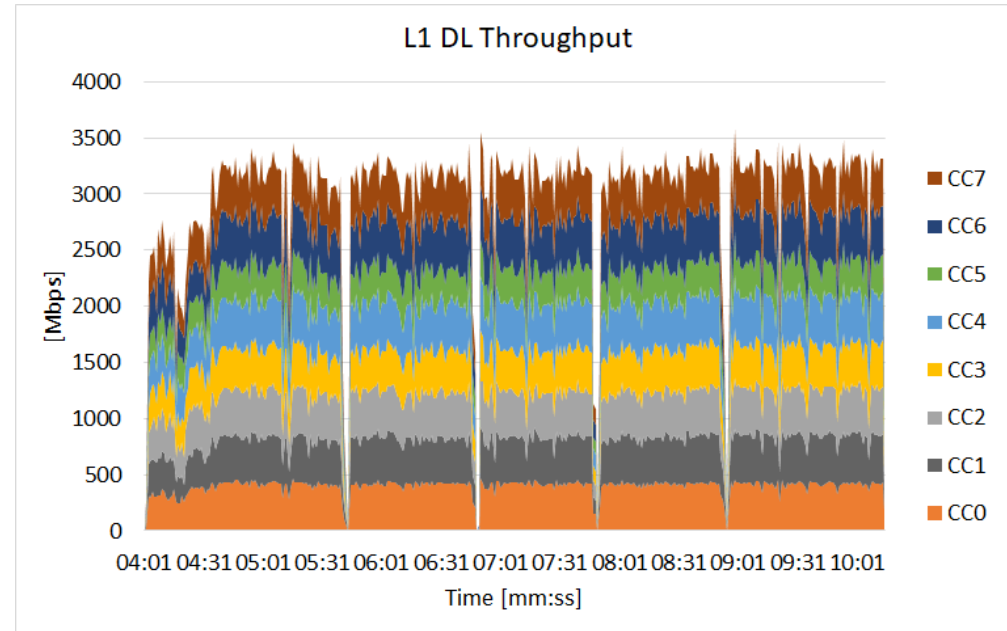
3.6 Gbps
Peak downlink throughput with 800 MHz BW (8x CA)

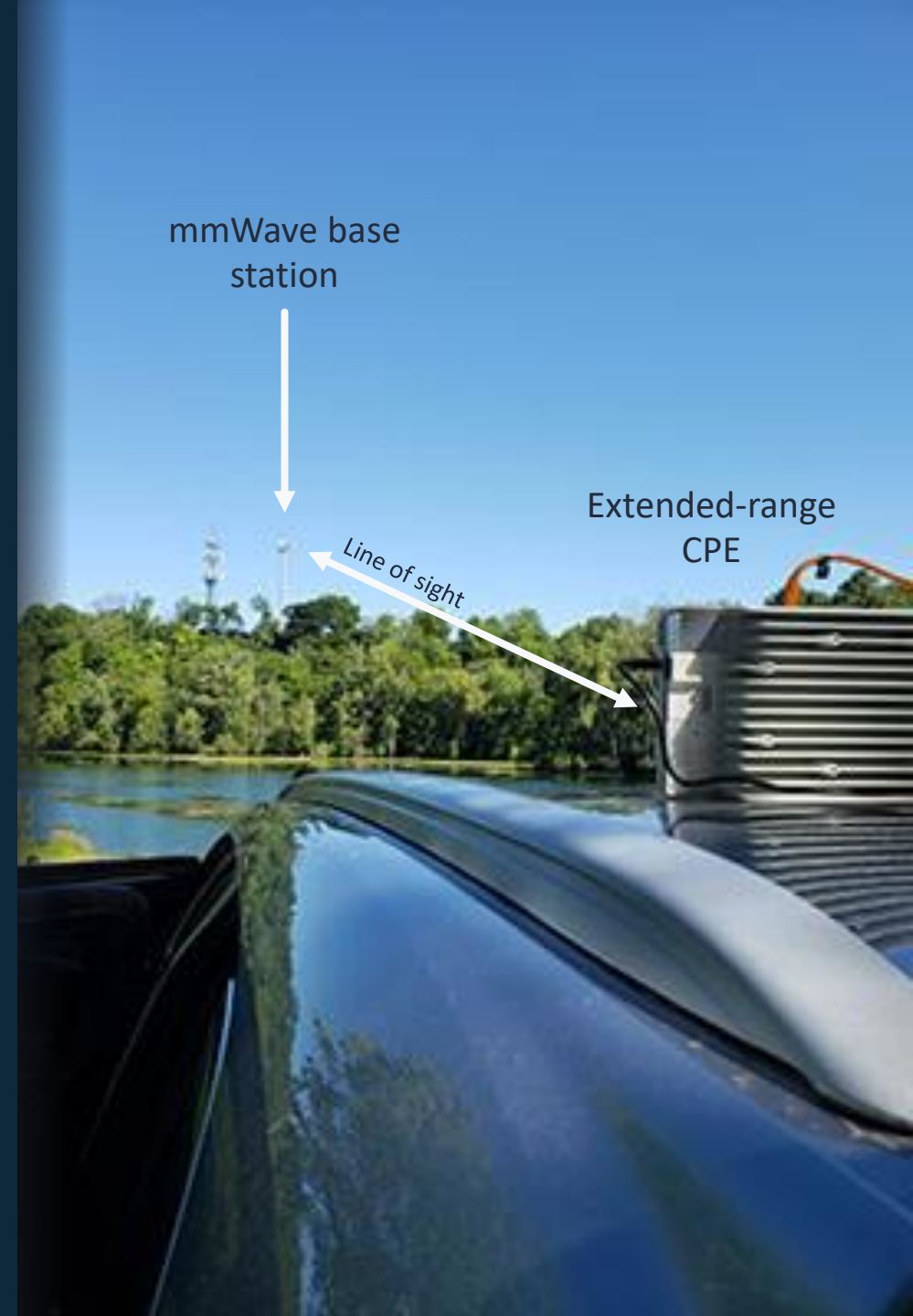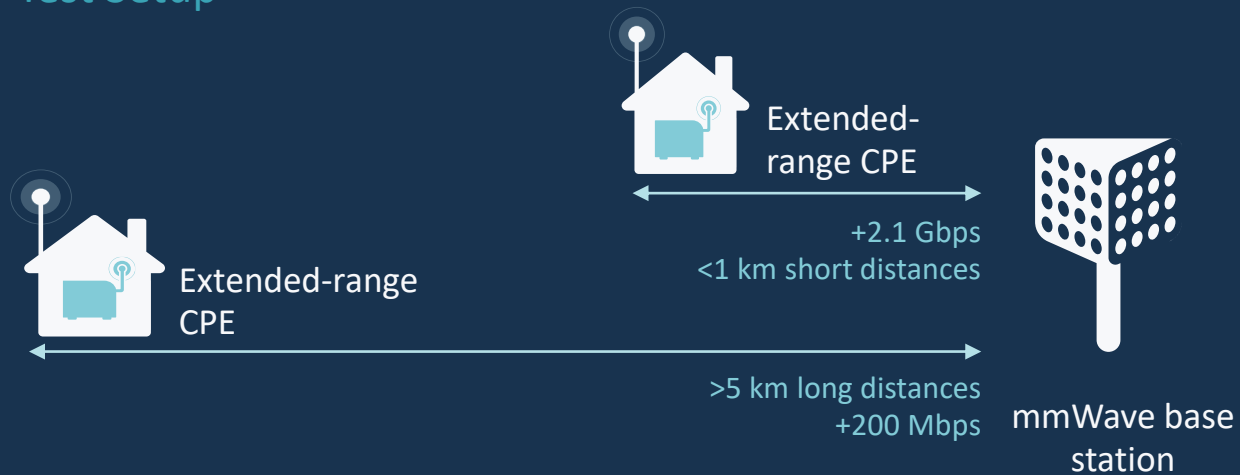## L1 UL Throughput

Legend: CC1, CC0

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

Rural America: Extended-Range mmWave delivers significant coverage improvement

Field trial collaboration with U.S. Cellular operator and Ericsson

Test Setup

Extended-range CPE

Extended-range CPE

+2.1 Gbps
<1 km short distances

>5 km long distances
+200 Mbps

mmWave base station

mmWave base station

Extended-range CPE

Line of sight

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

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
> -70
> -80
> -90
> -100
> -110
> -115
> -120

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]

Qualcomm Webinar Series Part 1: Deploying mmWave to unleash the full 5G potential

mmWave 5G: high-band economics

Definitive data and analysis for the mobile industry

3 Global Offices
Delhi Barcelona London

Serves over 800 organisations

40,000 users worldwide

Extensive Datasets
Over 30 million data points, updated daily.

Topical and Timely Research
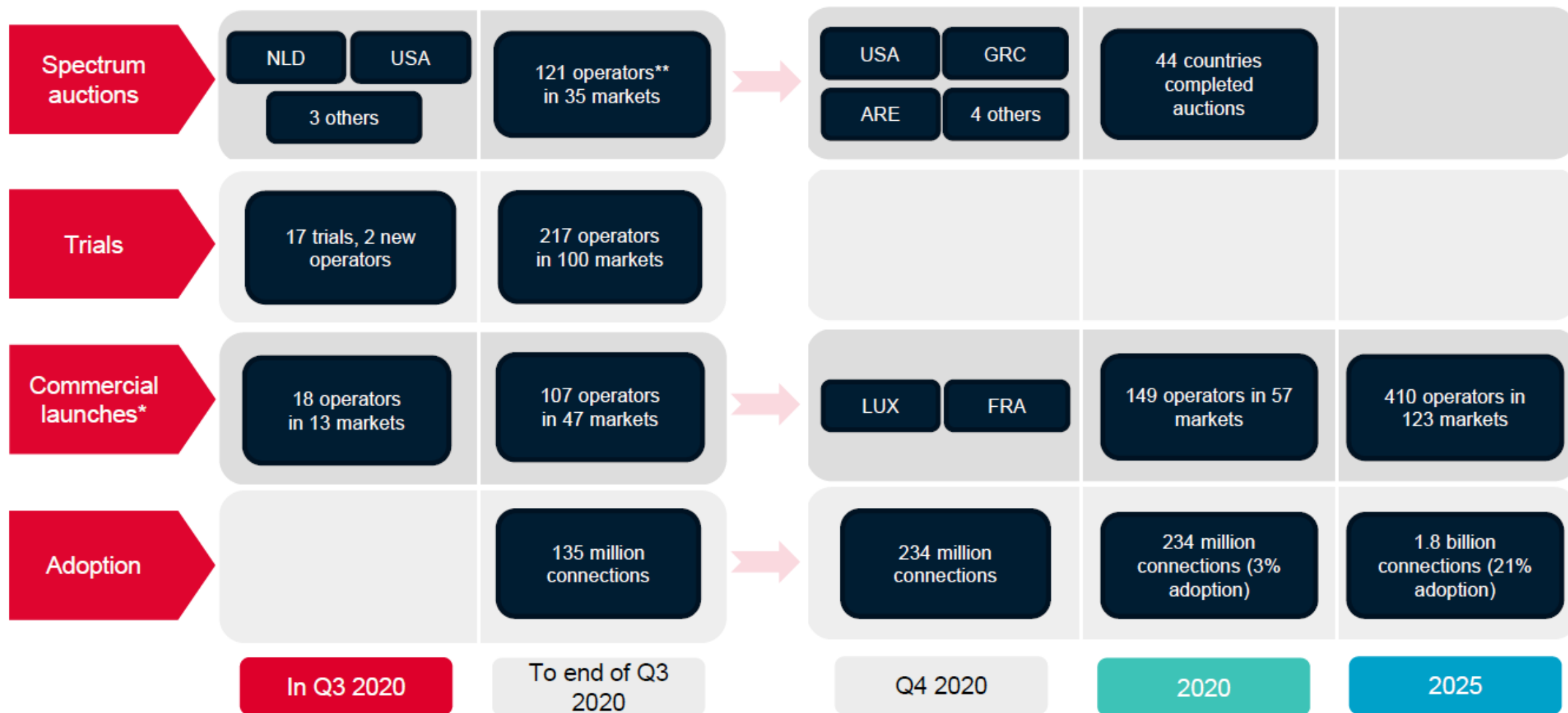Over 100 reports and exclusive analyses published annually.

Pinpoint Accuracy
Five-year forecasts consistently accurate within +/- 2.5 % of reported data, updated quarterly.

Industry Trusted
Serving businesses across the mobile ecosystem and many other vertical industries.
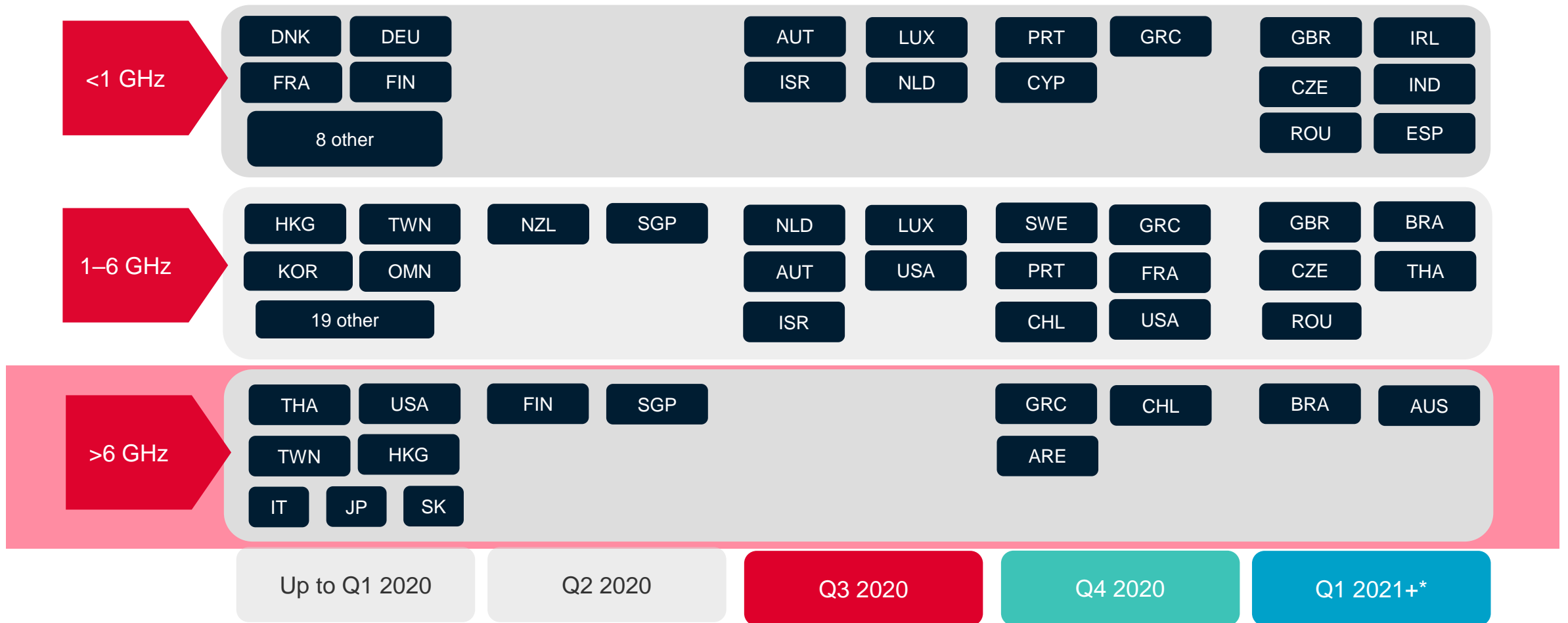
5G services now a reality

GSMA Intelligence

	In Q3 2020	To end of Q3 2020	Q4 2020	2020	2025
Spectrum auctions	NLD, USA, 3 others	121 operators** in 35 markets	USA, GRC, ARE, 4 others	44 countries completed auctions	
Trials	17 trials, 2 new operators	217 operators in 100 markets			
Commercial launches*	18 operators in 13 markets	107 operators in 47 markets	LUX, FRA	149 operators in 57 markets	410 operators in 123 markets
Adoption		135 million connections	234 million connections	234 million connections (3% adoption)	1.8 billion connections (21% adoption)

*Launches of commercial mobile and FWA 5G services
**Excludes regional US and Canada operators

For updates, see gsmaintelligence.com

5G spectrum and mmWave

GSMA™ Intelligence

<1 GHz
| DNK | DEU |
| FRA | FIN |
| 8 other |

| AUT | LUX | PRT | GRC |
| ISR | NLD | CYP |

GBR	IRL
CZE	IND
ROU	ESP

1–6 GHz
| HKG | TWN |
| KOR | OMN |
| 19 other |

| NZL | SGP |

NLD	LUX	SWE	GRC
AUT	USA	PRT	FRA
ISR		CHL	USA

| GBR | BRA |
| CZE | THA |
| ROU |

>6 GHz
THA	USA
TWN	HKG
IT	JP	SK

| FIN | SGP |

| GRC | CHL |
| ARE |

| BRA | AUS |

| Up to Q1 2020 | Q2 2020 | **Q3 2020** | **Q4 2020** | **Q1 2021+*** |

*Q1 2021+ data not exhaustive; preference by date

The pros and cons of mmWave

GSMA Intelligence

The CONS

- Short range
- Susceptible to interference
- Indoor penetration difficulties
- New deployment strategies required

The PROS

- Mobile data traffic growing rapidly
- High-speeds and low-latency a must for 5G
- More spectral bandwidth and contiguous spectrum than any other band
- **Market ready?**
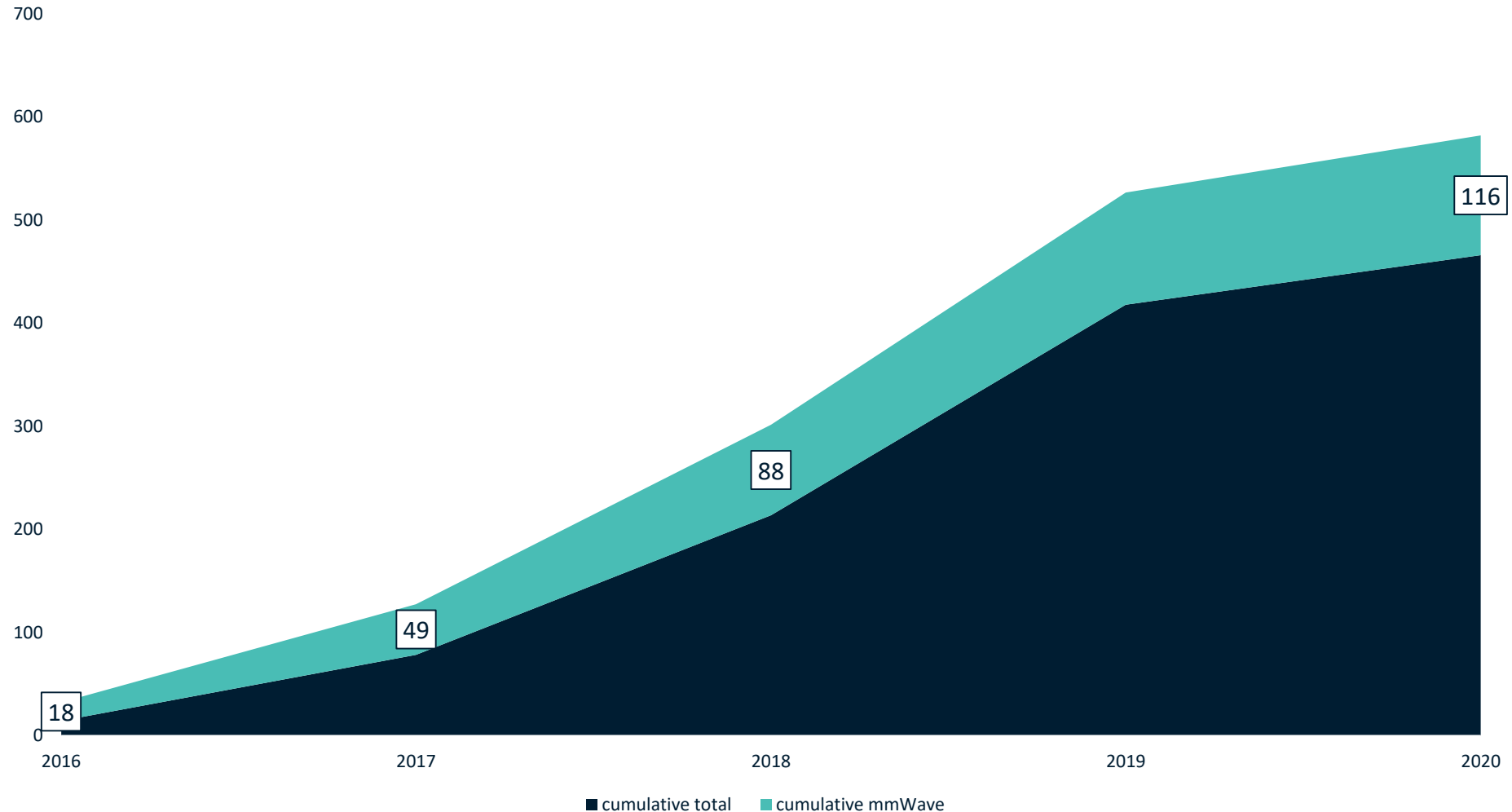
Devices / equipment scaling

Consumer devices

2019: Smartphones 5, FWA CPEs 5
2020: Smartphones 10+, FWA CPEs 35+
2021: Smartphones 100+, FWA CPEs 50+

■ Smartphones ■ FWA CPEs
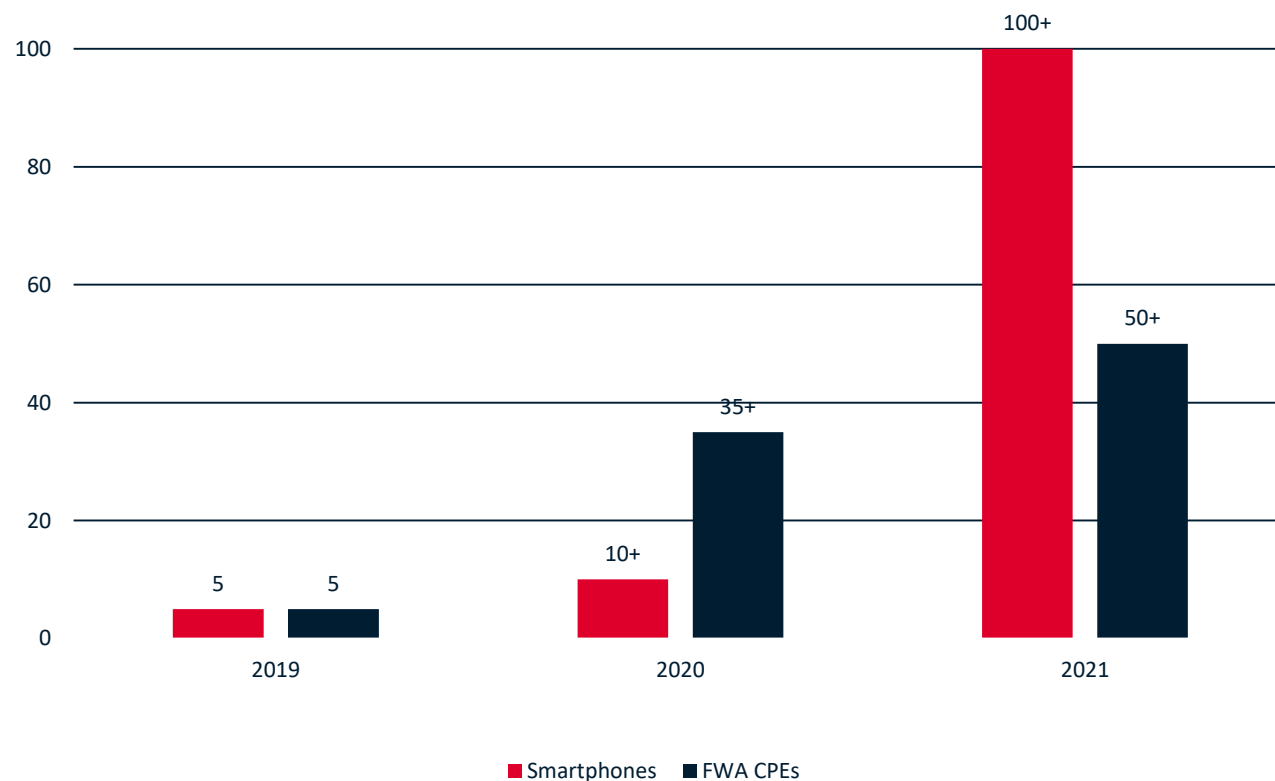
Network equipment

- all major network equipment vendors are now offering mmWave solutions
- Three main product categories available at the end of 2020:
  - High-capacity macro sites
  - Micro, lamp or pole sites
  - Indoor 5G small cell solutions
- cost gap between sub-6 GHz and mmWave solutions steadily decreasing

Scenario: Dense Urban

Cost-effective?

- Two deployment strategies: 3.5 GHz-only vs 3.5 GHz + mmWave

- Period 2020 to 2025

- Scenario constructed using population density and satellite data on major cities in Greater China and Europe

- In **dense urban Greater China,** mmWave cost effective in the densest parts of cities as soon as spectrum is available

- In **dense urban Europe**, mmWave 5G cost effective from 2024 in the densest parts of urban areas if traffic demand is high

Cost index (100 = 3.5 GHz-only TCO)

3.5GHz-only TCO

PRELIMINARY RESULTS

Greater China   Europe

Connected users   ■ 5%   ■ 10%   ■ 25%

Scenario: 5G FWA

Cost-effective?
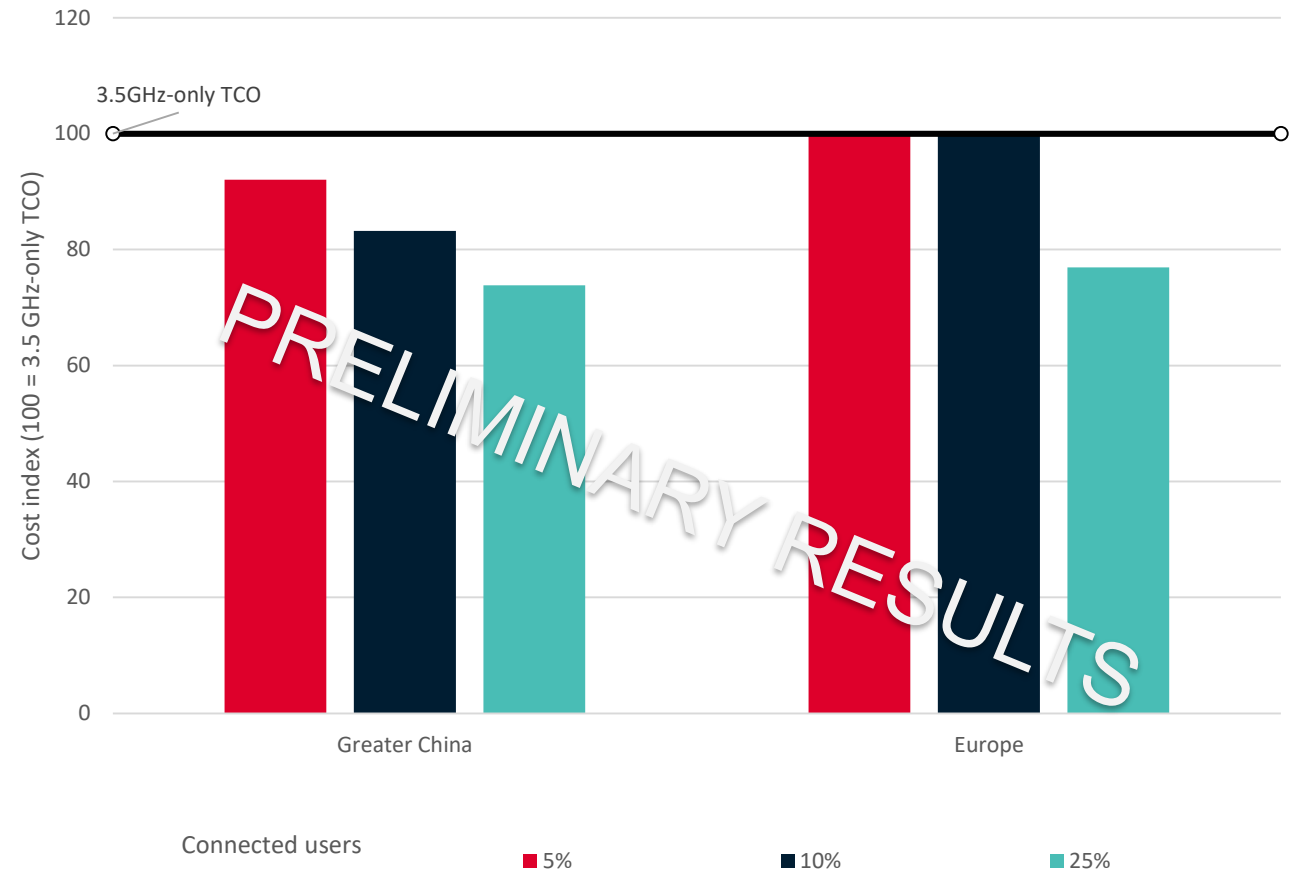
- Two deployment strategies : 3.5 GHz FWA vs mmWave FWA

- Scenario constructed using population density data and satellite data on urban areas in Greater China, sub-urban areas in Europe and rural towns in the US

- mmWave FWA deployments in **urban China, sub-urban Europe** and **rural towns in the US** can be cost-effective

- 5G mmWave FWA makes sense when it can capture a significant percentage of the residential broadband market demand (chart shows results when adoption reaches 50% by 2025) or if traffic demand is relatively high

Scenario: Indoor

- Two deployment strategies compared: 3.5 GHz-only vs 3.5 GHz and mmWave

- Scenario constructed using a hypothetical office building where indoor coverage is poor; only a small share of traffic on 5G (just 15% of downlink traffic and 5% of uplink traffic) can be offloaded to outdoor sites

- A mmWave **indoor office** 5G network could be cost effective and generate cost savings between 5% and 20%

- Significant share of data traffic needs to be supported by indoor 5G services

PRELIMINARY RESULTS

Cost index (100 = 3.5 GHz-only TCO)

10%   30%

■ With standard communications equipment

■ With advanced communications equipment
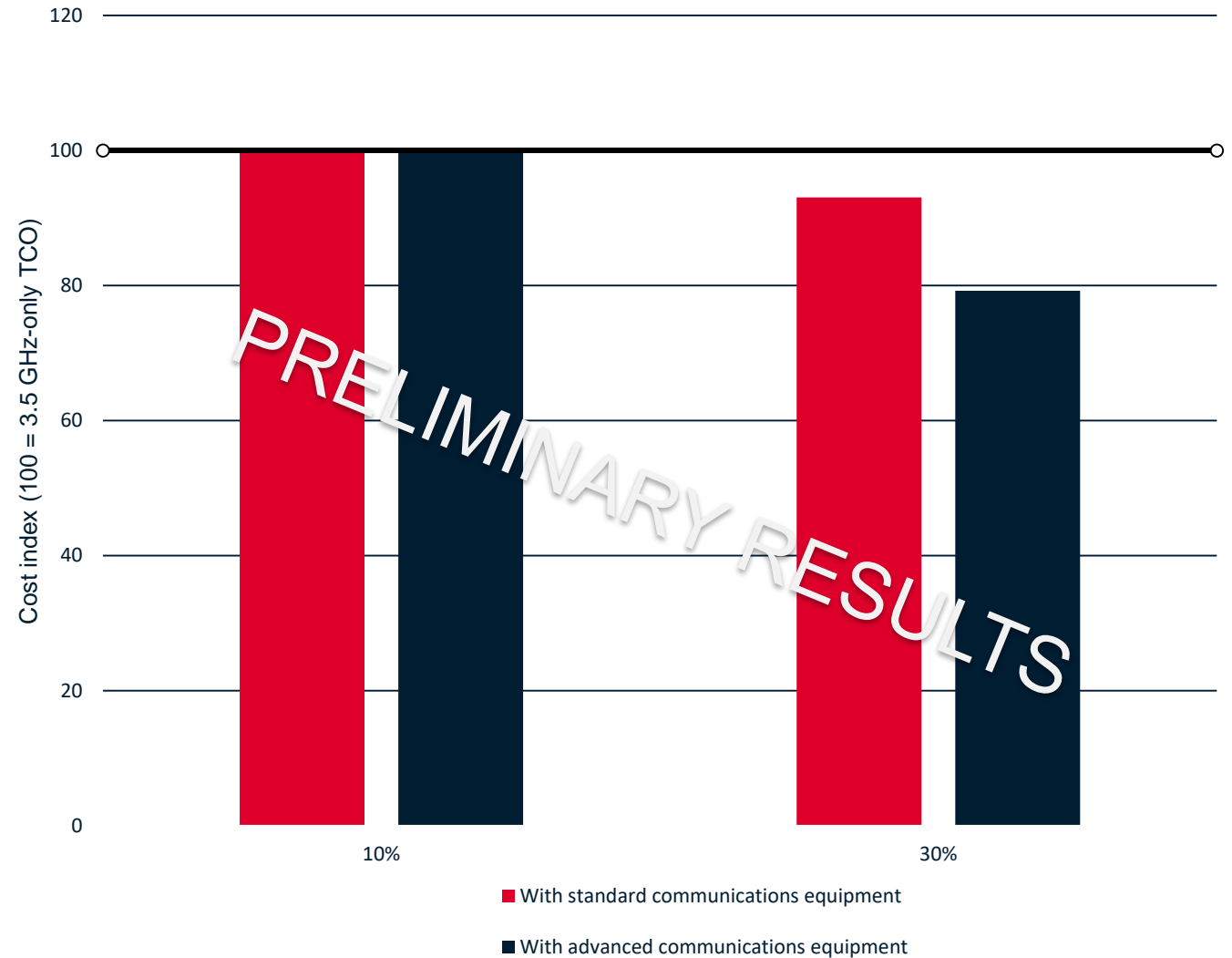
mmWave out to 2030: importance will continue to grow

Recommendations
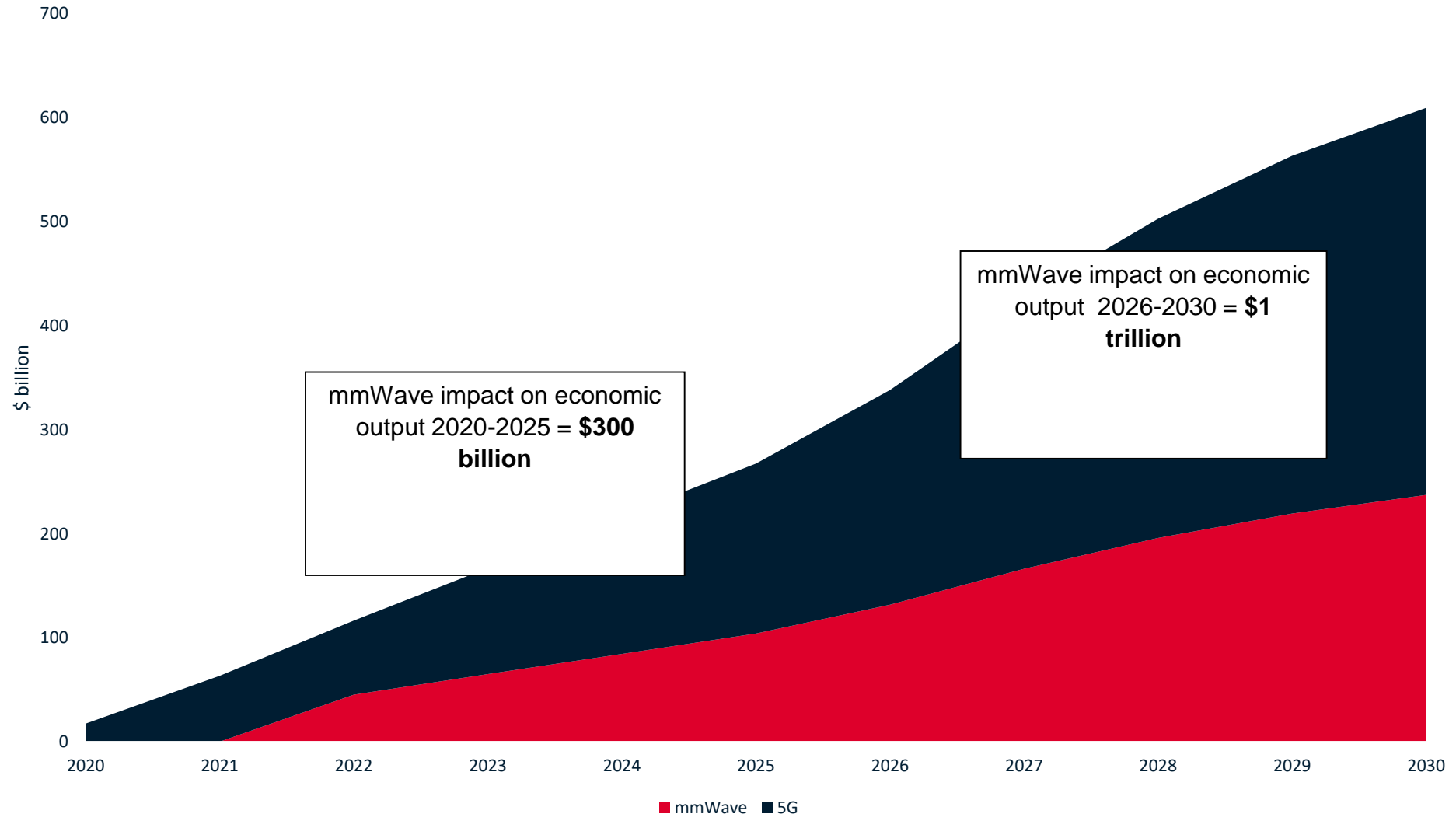
1. **Operators** – do not underestimate the role of mmWave in the short run

2. **Governments** – make clear plans for the assignment of mmWave bands

3. **Vendors** – scale is key: a wider choice of consumer devices and equipment will reduce costs and facilitate adoption

THANKS!

Pau Castells

Head of Economic Analysis,
GSMA Intelligence

Evolving mmWave in 3GPP Rel-16+
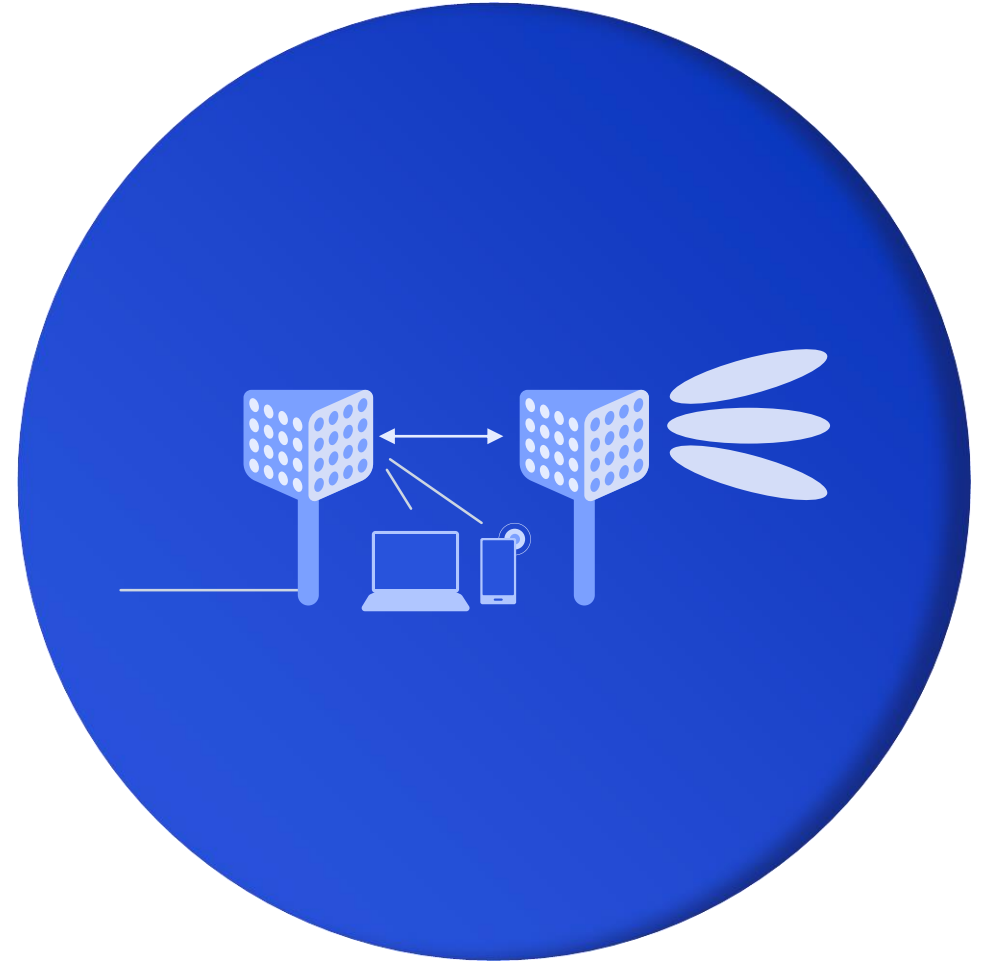
Driving the 5G technology evolution

Continue expansion to new verticals, deployments, use cases, spectrum

Rel-18+ evolution

Delivering on the 5G vision

Rel-17[1]

Unified, future-proof platform

Rel-16[1]

Rel-15

3GPP — A GLOBAL INITIATIVE

5G NR

LTE essential part of the 5G platform

Rel-15 commercialization

Commercialization of Rel-16, 17, and future releases

| 2018 | 2019 | 2020 | 2021 | 2022 | 2023+ |
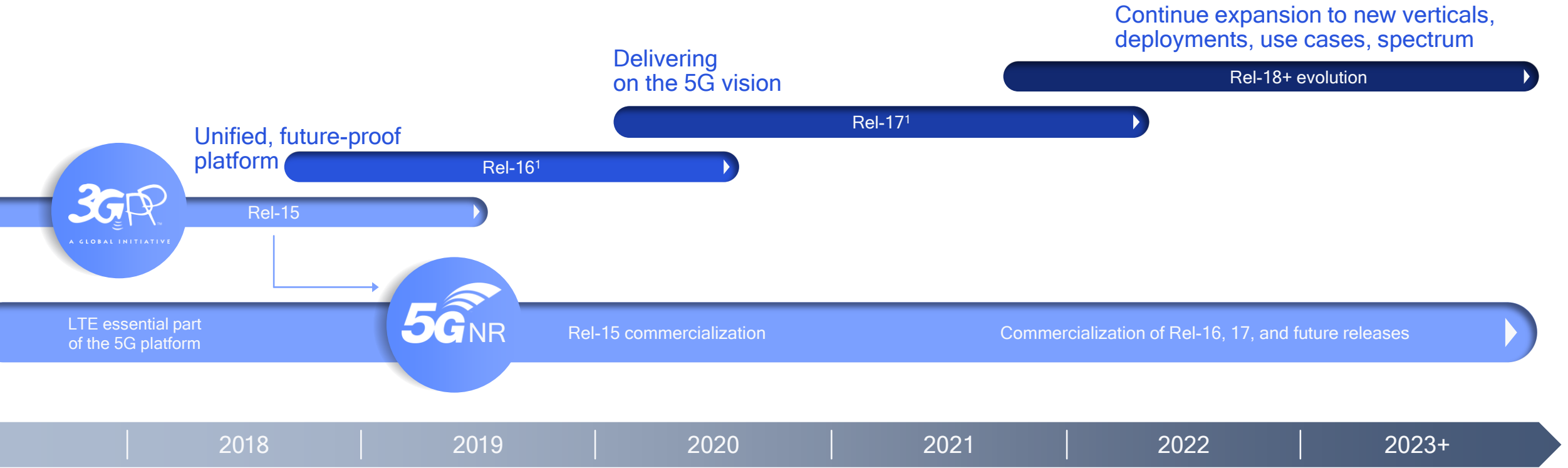
Rel-15 eMBB focus
- 5G NR foundation
- Smartphones, FWA, PC
- Expanding to venues, enterprises

Rel-16 industry expansion
- eURLLC and TSN for IIoT
- NR in unlicensed (NR-U)
- Positioning
- 5G V2X sidelink multicast
- In-band eMTC/NB-IoT

Rel-17+ long-term expansion
- Lower complexity NR-Light
- Boundless extended reality (XR)
- Higher precision positioning and more…

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

Distributing antennas to improve robustness and coverage

mmWave gNodeB

Wireless fronthaul (e.g., 95 GHz)

RRH

Fiber fronthaul

gNodeB

RRH
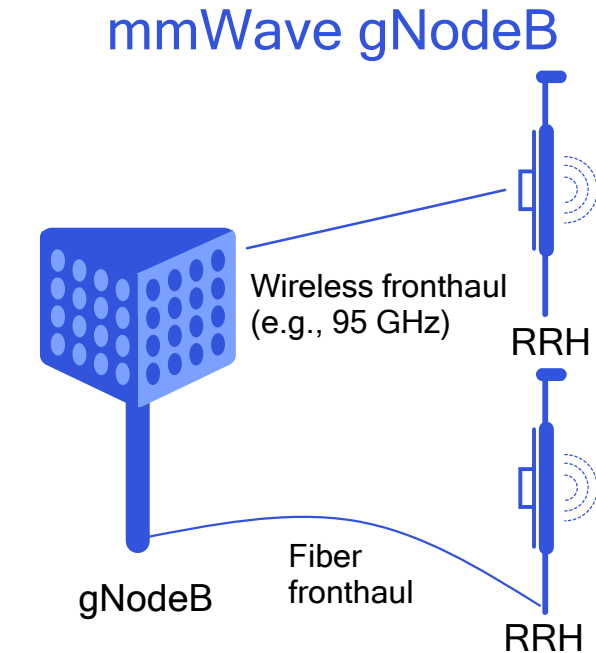
5G NR mmWave gNodeB and remote radio heads (RRHs)

mmWave repeaters

mmWave link

Simple Repeater

gNodeB

Adaptive multi-beam operation and TDD awareness

Smart Repeater

Extending coverage with simple repeaters, smart repeaters in Rel-17+

mmWave integrated access and backhaul (IAB)

IAB node

gNodeB

IAB node

Rel-16 IAB improves coverage and capacity, further enhancements in Rel-17+

Beam overlap with improved angular diversity

Flexible spatial reuse from single mmWave cell

Range extension and coverage around blockages

5G NR mmWave IAB[1] for cost-efficient dense deployments

Improves coverage and capacity, while limiting backhaul cost

Sub-6 GHz gNodeB

Multi-hop capability

Redundant links

mmWave backhaul

mmWave access

For SA and NSA 5G NR modes

Fiber backhaul

For mobile and fixed wireless access
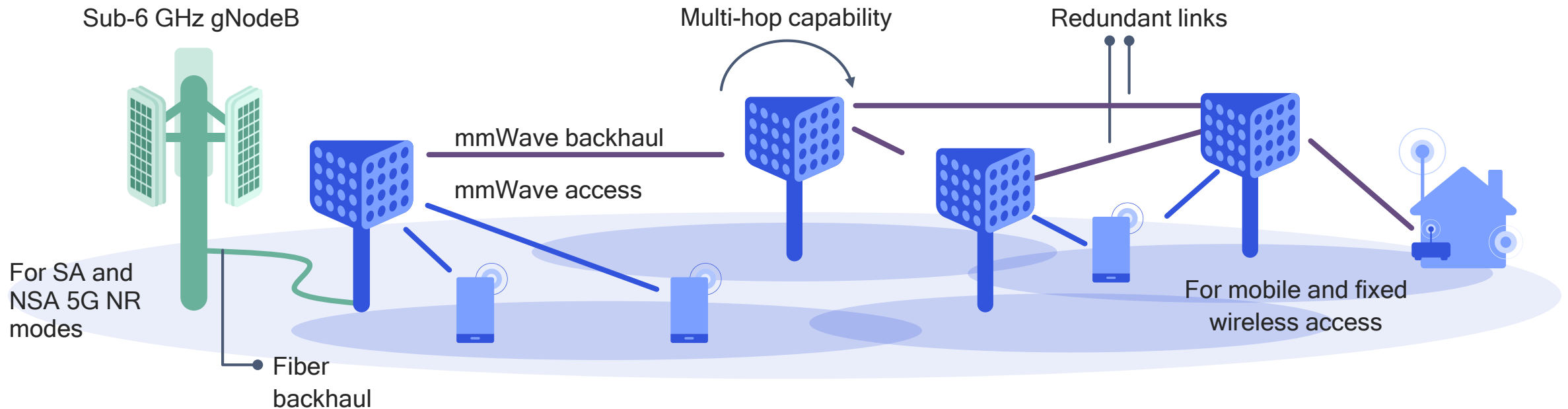
1 Integrated Access and Backhaul

Traditional fiber backhaul can be expensive for mmWave cell sites

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

Supporting a flexible network deployment strategy

IAB can enable rapid and cost-efficient 5G NR mmWave network buildout

Fiber backhaul

Fiber backhaul

Fiber backhaul
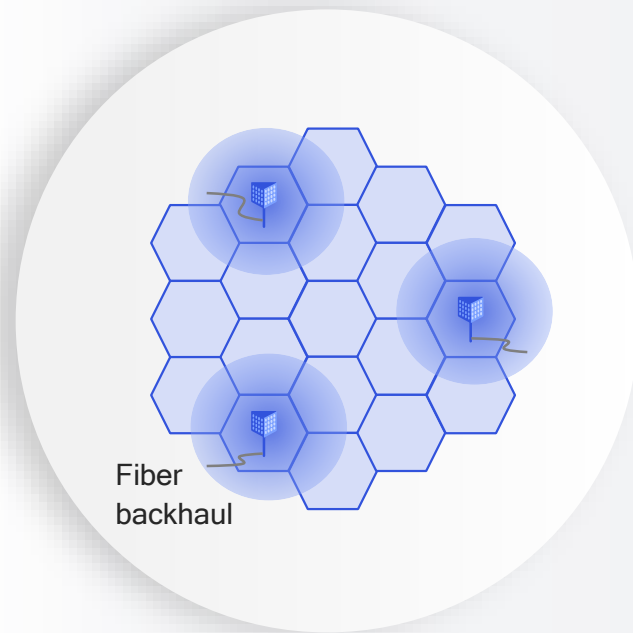
Early 5G NR mmWave deployments based on Rel-15

Starting to connect new 5G NR mmWave base stations using limited/existing fiber links
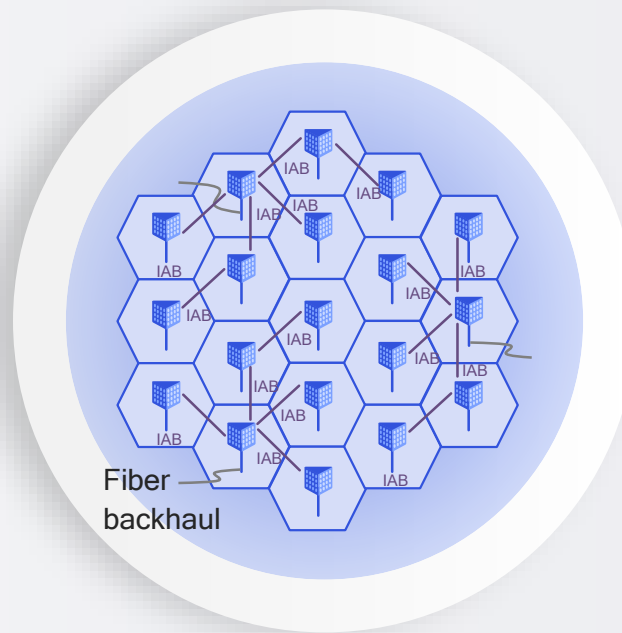
Widening 5G NR mmWave coverage using IAB

Incrementally deploying additional base stations with IAB still using limited/existing fiber links
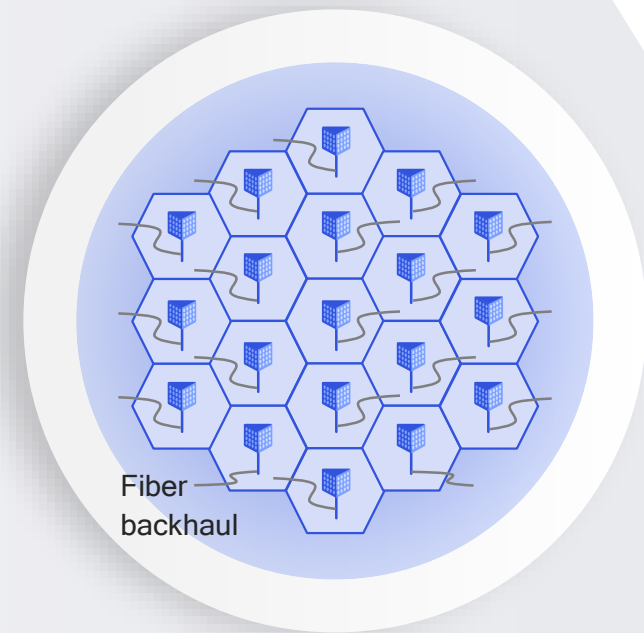
Supporting rapid traffic growth with additional fibers

Deploying new fiber links for selected IAB nodes as capacity demands increase

Qualcomm — February 2020

Deploying IAB to expand mmWave coverage

End-to-end system simulations using 5G NR mmWave at 28 GHz

Frankfurt, Germany

Total simulation area:	~1 km²
Total number of gNodeBs:	7
Total number of IAB nodes:	28
Total number of devices:	300

Link to full demonstration video

Map Legend

- gNodeB site
- IAB site
- # mmWave devices

Average downlink signal improvement

1x — No IAB
1.4x — Low IAB Penetration
1.7x — High IAB Penetration
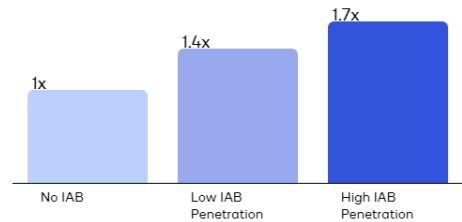
Network throughput improvement

Low Percentile User: 1x, 2.8x, 4.4x
Medium Percentile User: 1x, 1.8x, 2.1x
High Percentile User: 1x, 1.1x, 1.3x

mmWave coverage simulation results

No IAB

With IAB
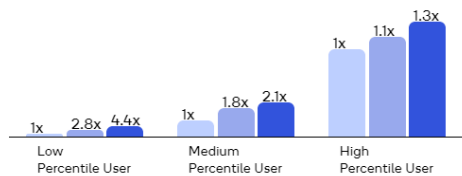
Breaking the technology boundary with 5G mobile mmWave evolution

Advanced 5G mmWave OTA test network

- 3GPP-compliant 5G mmWave network operating at 28 GHz capable of 800 MHz bandwidth
- Robustness with crowd blocking and high-speed mobility (i.e., device travelling on a drone)
- Boundless virtual reality (VR) experiences using 5G, edge cloud and on-device processing

5G mobile mmWave technology evolution

- System simulations of new features in Rel-16+
    - Integrated access and backhaul
    - Multiple transmission and reception point
    - Advanced device power saving features
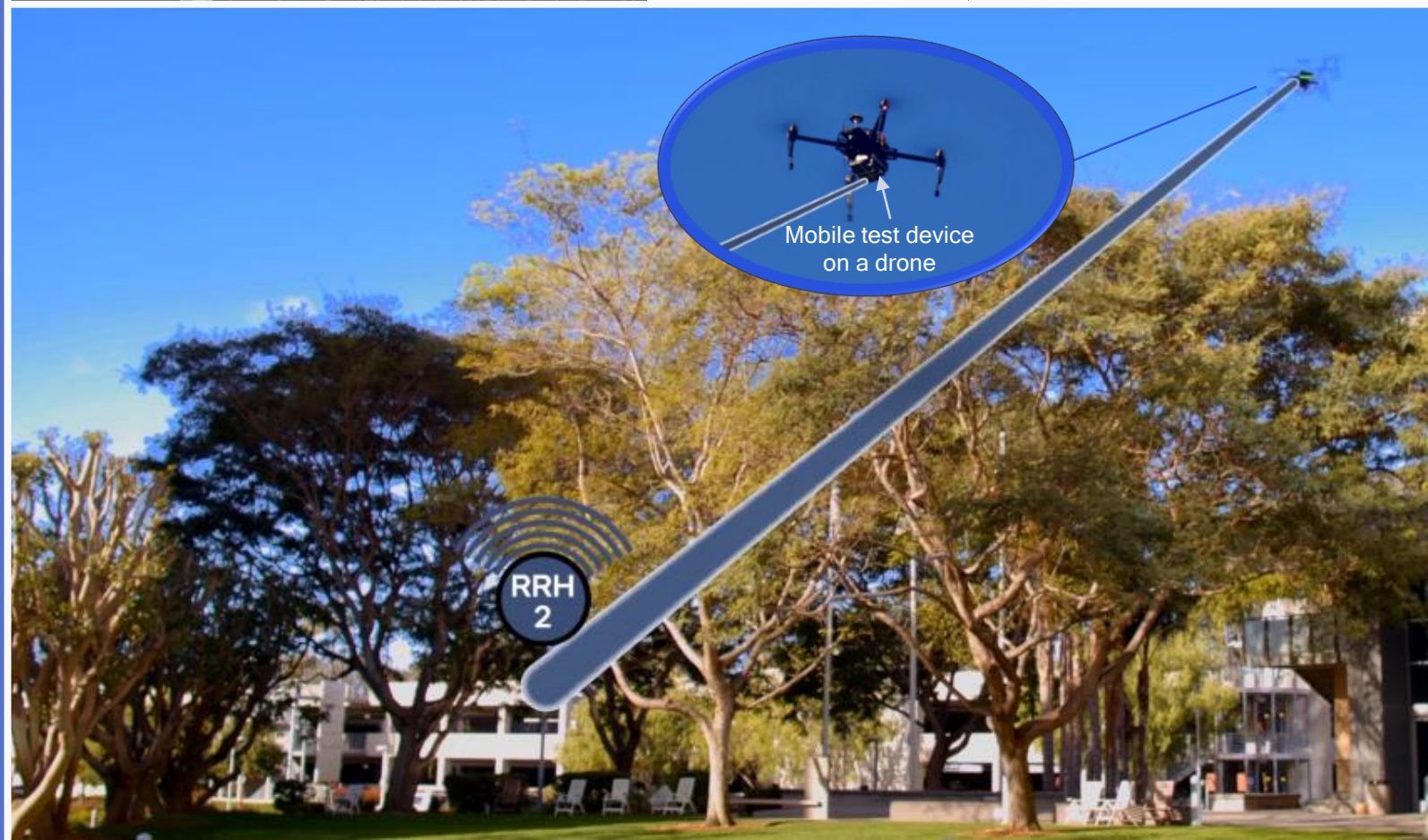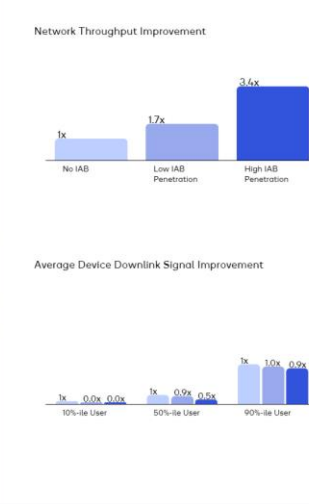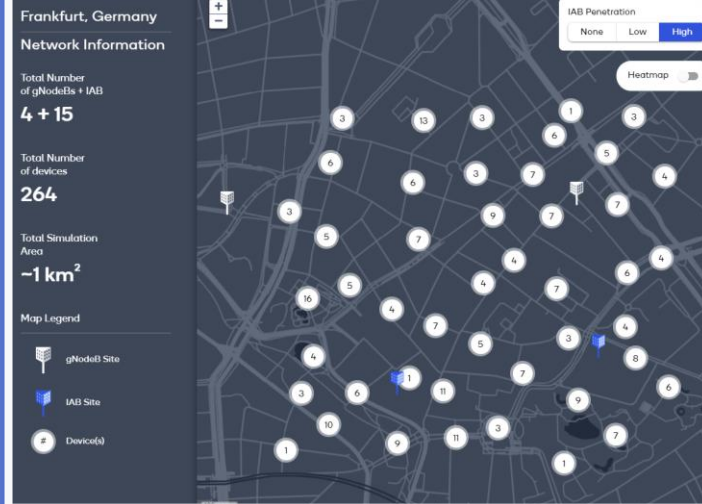
5G NR enhancements for mmWave

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
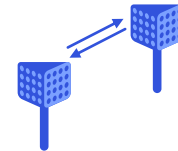
Improved IAB for distributed deployment
Introducing full duplex operations and mobile relays for improved capability, coverage, and QoS
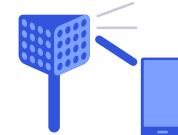
Optimized coverage & beam management
Reducing overhead, enhancing performance (e.g., beam selection), improving coverage
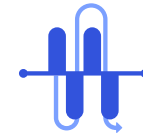
Expanded spectrum support
Supporting licensed and unlicensed spectrum in frequencies ranging from 52.6 GHz to 71 GHz

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

Questions?

Qualcomm

Thank you

Follow us on: f 🐦 in 📷

For more information, visit us at:

www.qualcomm.com & www.qualcomm.com/blog