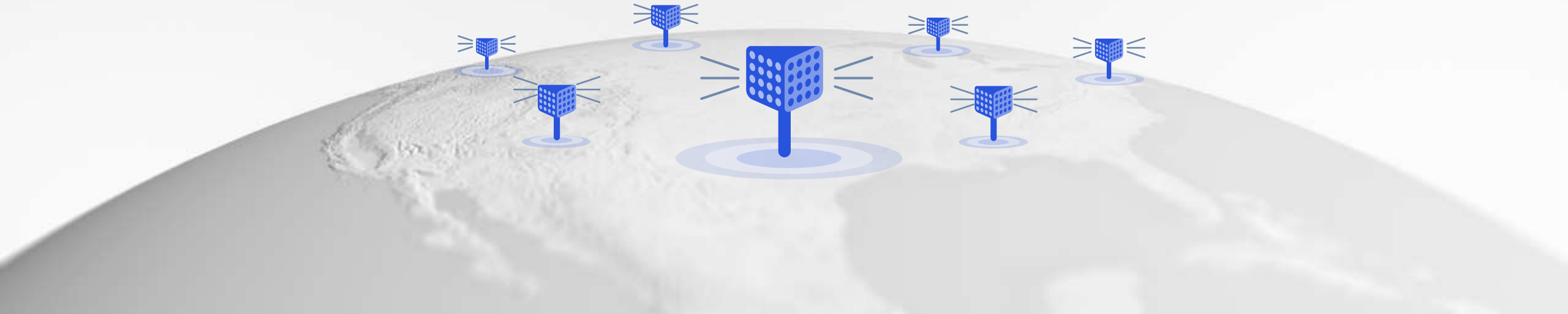
Qualcomm October 2021 @QCOMResearch

5G mmwave

What's in the future of 5G millimeter wave?



New frontier of mobile broadband — mobilizing mmWave for vast bandwidth

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

Solving system-level problems is in our DNA

Qualcomm's mission statement

"Qualcomm's objective is to apply our experience to systems problems that arise in the design, analysis, implementation and testing of digital communication processing systems and networks to bring reliable, functionally effective, user-friendly products to the marketplace."

Dr. Irwin Mark Jacobs
Dr. Andrew J. Viterbi
July 1, 1985

1989: CDMA
We proved the skeptics wrong

Many argued that CDMA was too complex to deploy.
Others said it just wouldn't work.

We overcame the “impossible” mobile mmWave challenge

Challenges

Limited coverage and too costly
Limited to just a few hundred feet, thus requiring many small cells.

Works only line-of-sight (LOS)
Blockage from hand, body, walls, foliage, rain severely limits signal propagation.

Only viable for fixed use
Only commercially proven for wireless backhauls and satellites.

Immature RFIC technology
Power hungry due to wider bandwidth with thermal challenges in small formfactor.

Solutions

Significant coverage with co-siting
Analog beamforming w/ narrow beam to overcome path loss. Achieving significant coverage when reusing existing sites.

Operating in LOS and Non-LOS
Pioneered advanced beamforming, beam tracking leveraging path diversity and reflections.

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

Commercialized smartphone
Launched modem, RF, and antenna products to meet formfactor, thermal constraints and regulatory compliance.

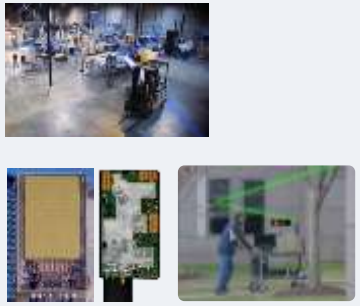
A SYSTEM APPROACH TO INNOVATION

from vision to commercialization

1

Industry-leading R&D

Breaking technology boundary to bring new capabilities and efficiencies for new devices, services, deployments



2

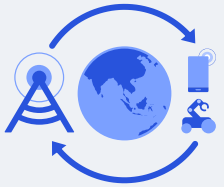
Prototyping while driving standards

Validating new designs by building real systems – networks and devices, driving standards with learning

3

Advanced system simulations

Using real models to accurately predict system performance in a wide range of scenarios



4

Broad industry collaboration and trials

Working closely with the ecosystem to prototype new solutions, fully utilizing our global experience

5

Cutting-edge system solutions

Delivering not just device chipsets but system solutions, such as small cells, device and data management

MANY MILESTONES

mobilizing 5G NR mmWave

1990+

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

Oct. 2016

Introduced world's first announced 5G modem-RF, Snapdragon® X50, mmWave and sub-6 GHz

Mar. 2017

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

Sep. 2017

Showcased 5G NR mmWave coverage simulations announced prototype mmWave UE

Dec. 2017

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

May 2018

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

Sep. 2018

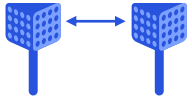
Announced first 3GPP-compliant 5G NR mmWave OTA call with a mobile form factor device

Feb. 2019

Announced our second generation multimode 5G modem-RF, Snapdragon X55

1H19 onwards

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



Jul. 2020

Completed second 5G standard – Release 16, bringing enhanced mmWave performance and efficiency

Jun. 2021

Showcased our latest 5G mmWave innovations (e.g., smart repeaters, mmWave for IIoT) using our test network and system simulations

5G NR field trials with MNOs and infra vendors

Continued mobile mmWave evolution

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

Sep. 2017

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

Oct. 2017

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

MWC 2018

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

Jul. 2018

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

Oct. 2018

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

MWC 2019

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

Feb. 2020

Announced our third generation 5G modem-RF, Snapdragon X60, and evolved our mmWave test network

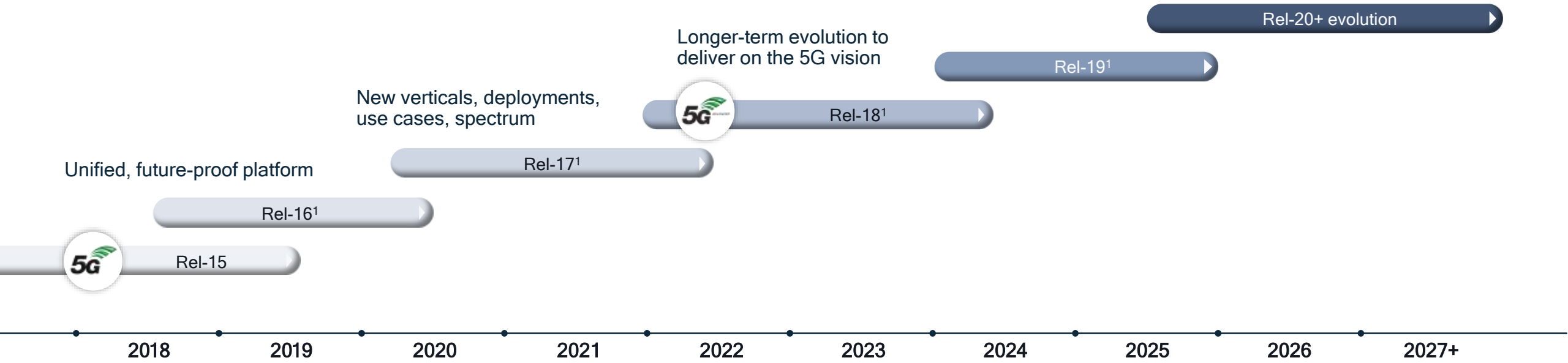
Feb. 2021

Announced our fourth generation 5G modem-RF, Snapdragon X65

Advancing 5G to fulfill its full promise

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

Driving the 5G technology evolution in the new decade



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

Advancing 5G for the new decade

Release 15

Established 5G NR technology foundation

- eMBB – enhanced mobile broadband services
- 5G core network and enhanced E2E security
- Sub-6 GHz with massive MIMO
- Advanced channel coding
- Scalable OFDM-based air interface
- Mobile mmWave
- Flexible framework
- LTE integration

Release 16

Expanding to new use cases and industries

- 5G broadcast[1]
- In-band eMTC/NB-IoT and 5G Core[2]
- Mission-critical services with eURLLC (e.g., 5G NR IIoT)
- Positioning across use cases
- eMBB evolution - improved power, mobility, more[3]
- 5G NR Cellular V2X
- Better coverage with IAB, uplink MIMO
- 5G NR in unlicensed spectrum
- IAB integrated access/ backhaul
- Private Networks, SON, satellites[4]

Release 17

Continued expansion and enhancements

- Enhanced DL/UL MIMO, multiple transmission points[5]
- NR-Light Reduced Capability (RedCap) for low-complexity IoT
- More capable, flexible IAB
- Unlicensed spectrum across all use-cases
- New spectrum above 52.6 GHz
- Centimeter accuracy IIoT with mmWave
- Expand sidelink for V2X reliability, P2V, IoT relay
- Enhancements to 5G NR Industrial IoT
- Non-terrestrial network (i.e., satellites)
- Rel-15 deployment learning, eMBB improvements, XR, drones, others[6]

5G Advanced

Release 18+

Potential projects (nominal work expected to start in 2022)

- Further eMBB enhancements
- Full-duplex MIMO
- Extended reality
- Smart repeaters for coverage expansion
- Automotive and NR V2X enhancements
- Non-terrestrial access enhancements
- 5G NR-Light expansion for IoT
- AI/ML data-driven designs
- Broadcast enhancements
- Sidelink in unlicensed spectrum

1. Enhancing Rel-14 LTE enTV to meet 5G requirements; 2. eMTC/NB-IOT in-band 5G NR and connected to 5G core; 3. MIMO, power consumption, mobility, MR DC/CA, interference management and more; 4. non-public networks (private networks), NR SON/MDT and more; 5. further improvements to capacity, coverage, mobility, power consumption, spectral efficiency; 6. mixed-mode multicast, small data transmission, multi-SIM, multimedia

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

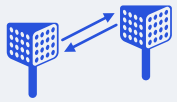
Dual connectivity optimization

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

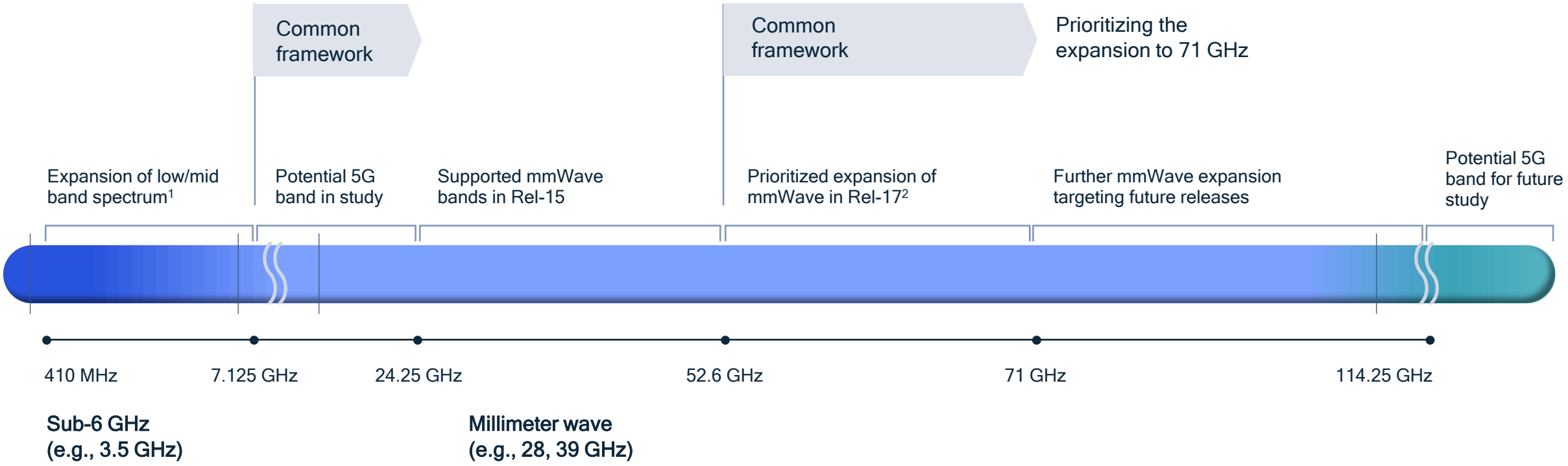
New use cases beyond eMBB

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

Enhanced positioning

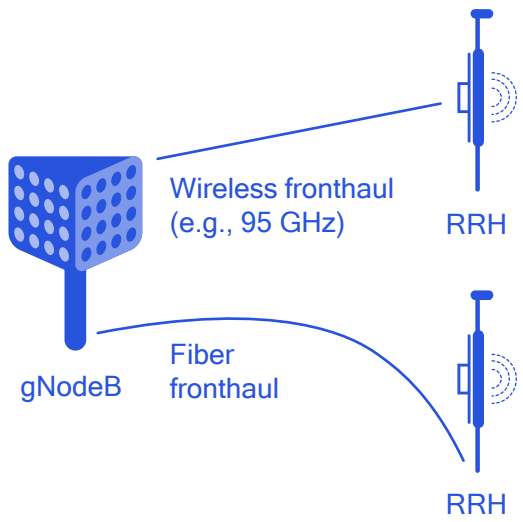
Enhancing capability for a wide range of use cases – cm-level accuracy, lower latency, higher capacity

Expanding mmWave spectrum with the common framework



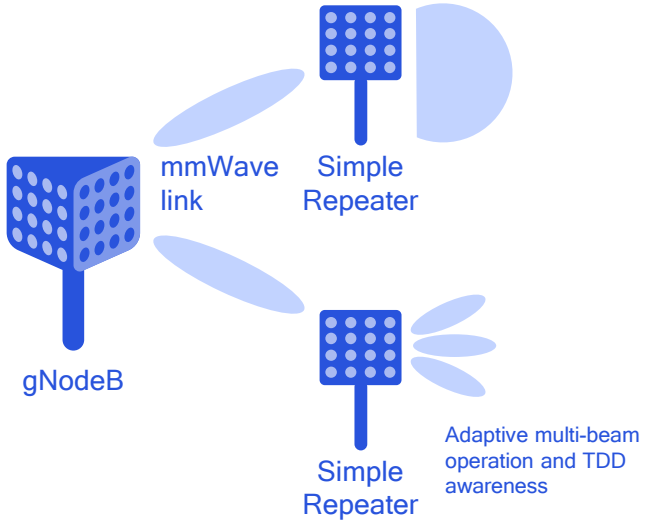
1. Rel-15 supported 450 MHz to 6 GHz; 2 To support global unlicensed 60 GHz bands, SCS scaling from 24.25-52.6 GHz band with same characteristics (e.g., waveforms)

Distributing antennas to improve robustness and coverage



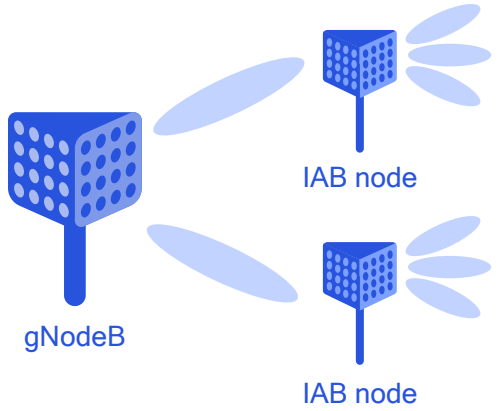
mmWave gNodeB

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



mmWave repeaters

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



mmWave integrated access and backhaul (IAB)

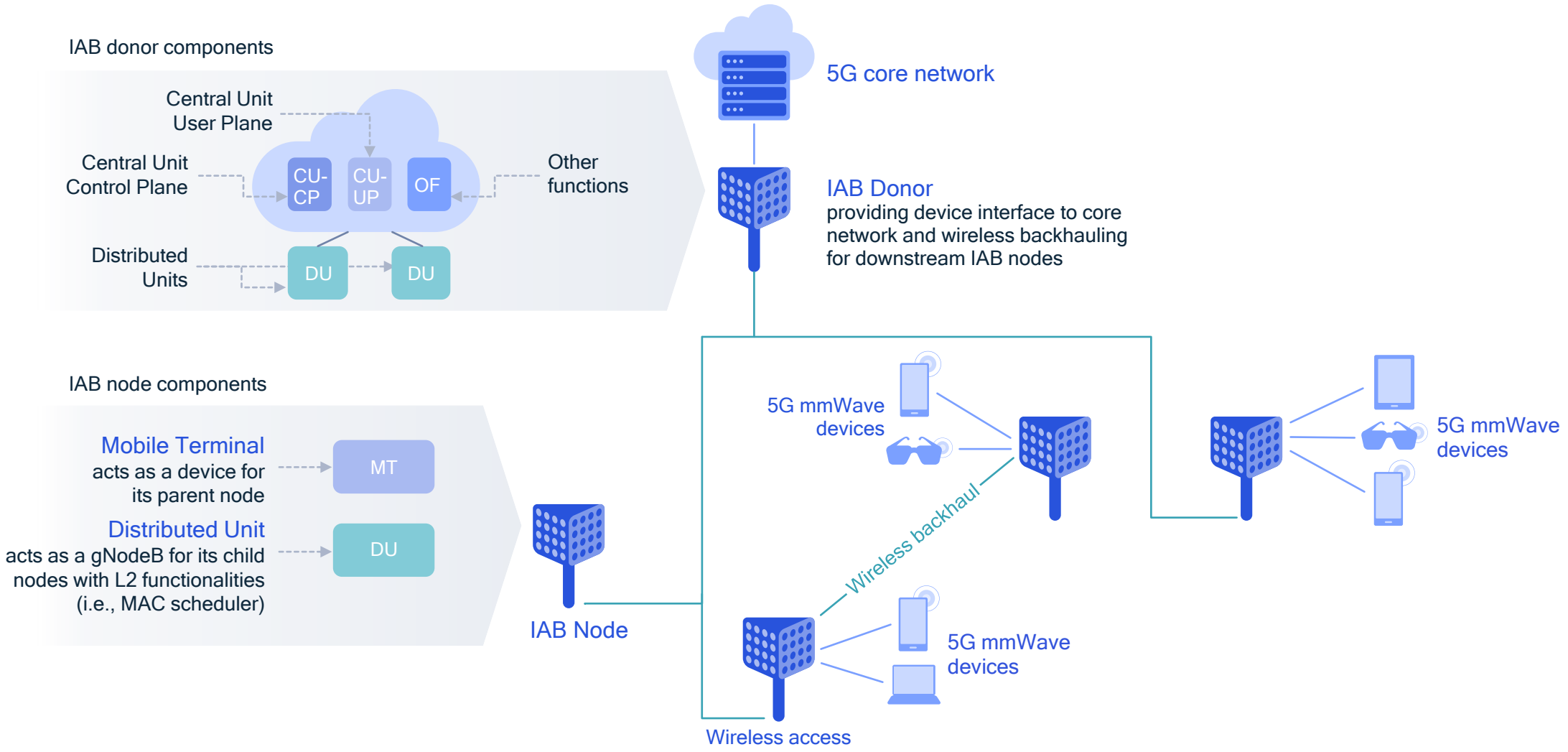
Rel-16 IAB improves coverage and capacity, further enhancements in Rel-17+

Beam overlap with improved angular diversity

Flexible spatial reuse from single mmWave cell

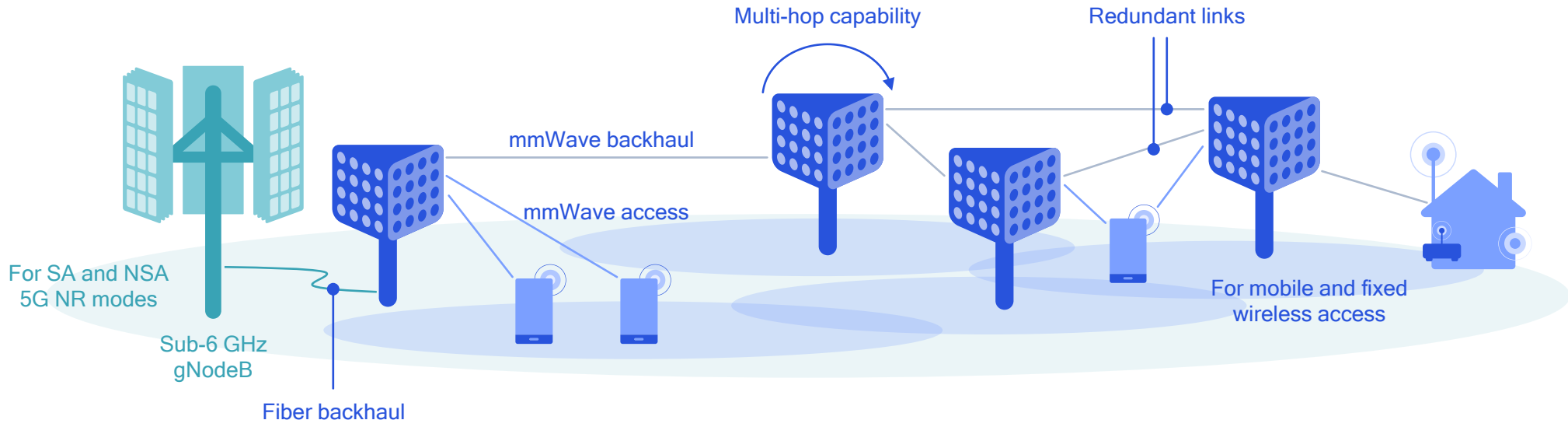
Range extension and coverage around blockages

Disaggregated architecture for integrated access and backhaul



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

Improves coverage and capacity, while limiting backhaul cost



Traditional fiber backhaul can be expensive for mmWave cell sites

mmWave access inherently requires small cell deployment

Running fiber to each cell site may not be feasible and can be cost prohibitive

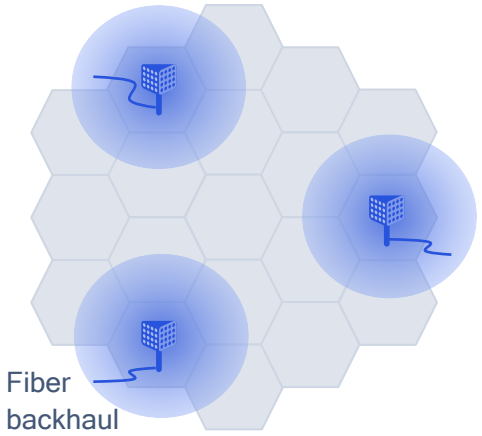
mmWave backhaul can have longer range compared to access

mmWave access and backhaul can flexibly share common resources

1 Integrated Access and Backhaul

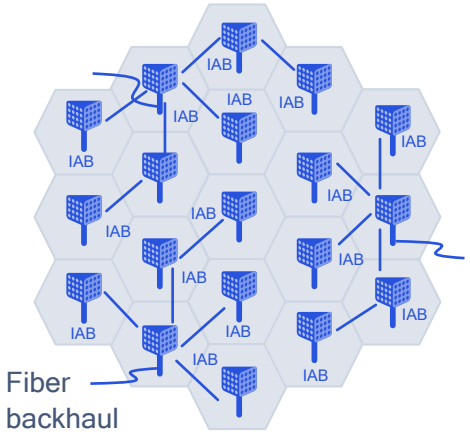
Supporting a flexible network deployment strategy

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



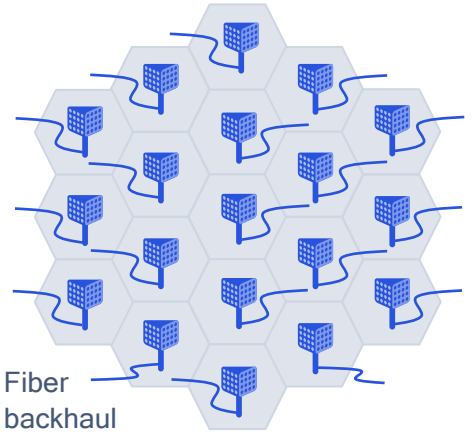
Early 5G NR mmWave deployments based on Rel-15

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

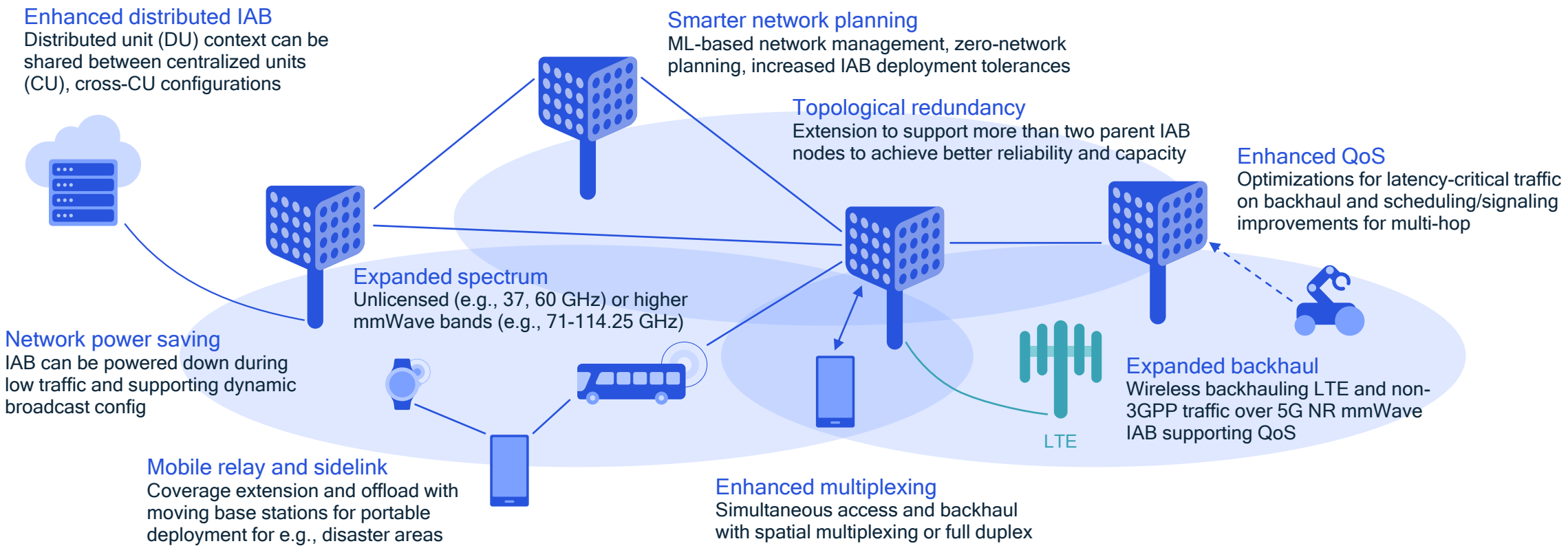


Supporting rapid traffic growth with additional fibers

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

Evolving IAB for broader, more efficient deployment

Rel-17+ brings better capabilities, more flexible deployments, and new use cases



Qualcomm

Spring 2020

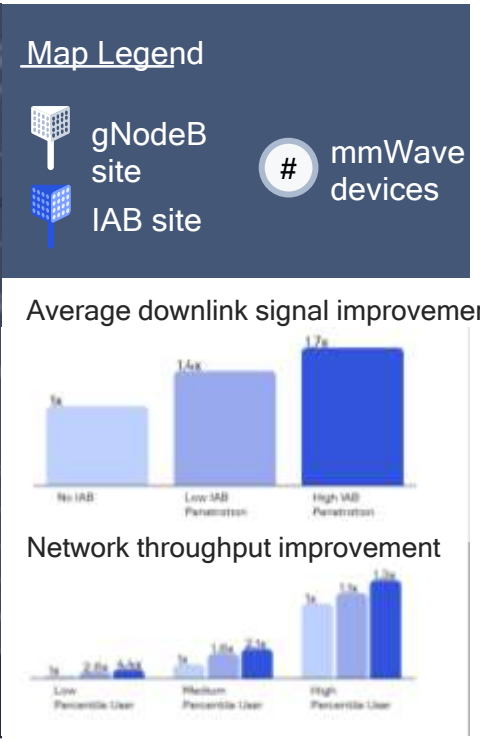
Deploying IAB to expand mmWave coverage

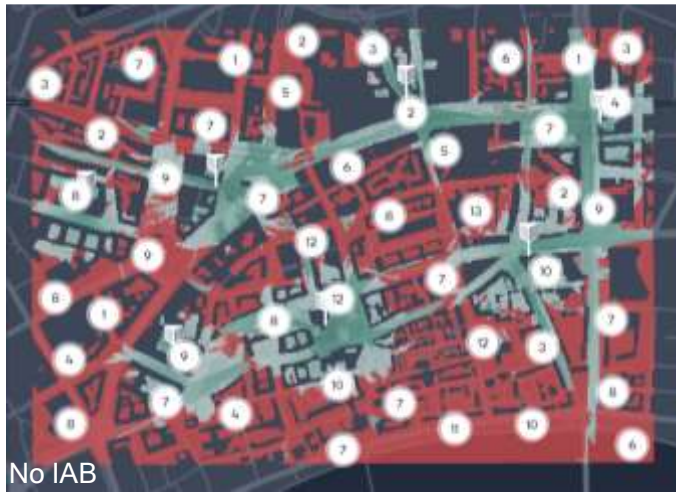
End-to-end system simulations using 5G NR mmWave at 28 GHz

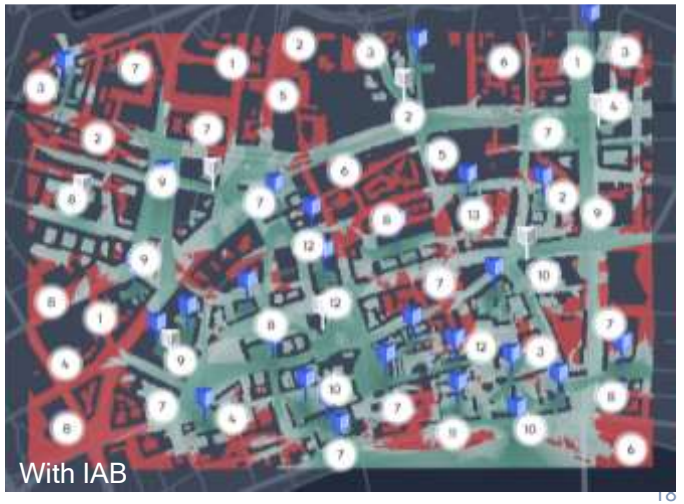
Frankfurt, Germany

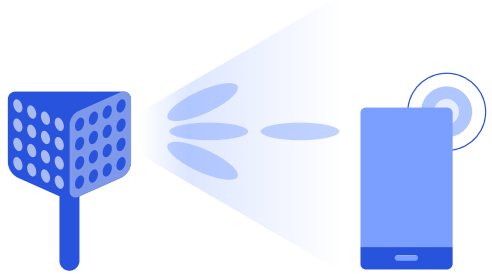
Total simulation area:	~1 km^2
Total number of gNodeBs:	7
Total number of IAB nodes:	28
Total number of devices:	300

[Link to full demonstration video]









Improved reliability

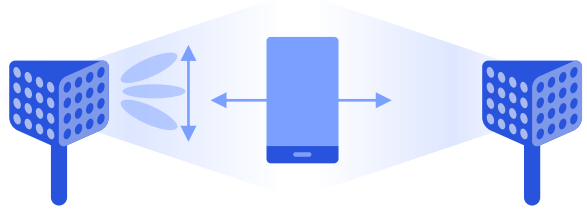
Supporting multi-beam repetitions

More robust beam failure recovery schemes1 for both UL and DL

Higher performance

Multiple antenna panels support to improve throughput and diversity

UL/DL beam selection decoupled for optimal performance in both directions2



Better mobility / coverage

More efficient beam management to support higher intra- and L1/L2 inter-cell mobility
(e.g., expanded beam selection)

Further enhancing mmWave beam management in Rel-16+

1 Including proactive beam set switching, SCell beam failure recovery, and UL beam failure recovery; 2 Via device-based beam management that also helps to adhere to MPE - Maximum Permissible Exposure; for example, when a finger is on top of a patch antenna, the MPE is significantly lower than otherwise (+34dBm vs. +8dBm)

Qualcomm

Spring 2020

Showcasing network benefits of Multi-TRP

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

Frankfurt, Germany

Total simulation area:	~1 km²
Total number of gNodeBs:	113
Total number of devices:	300

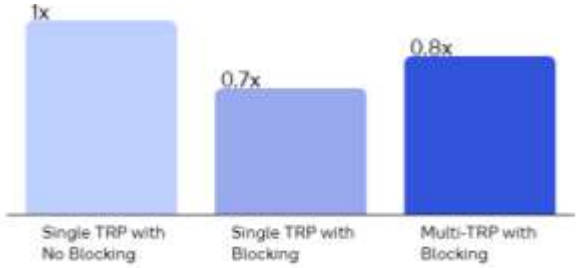
Link to full demonstration video

Map Legend

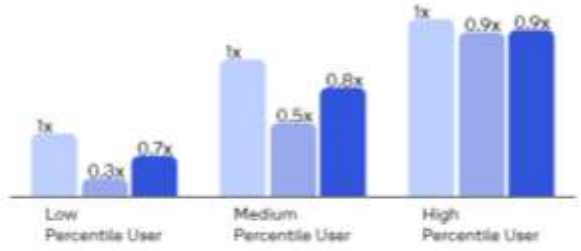
gNodeB site

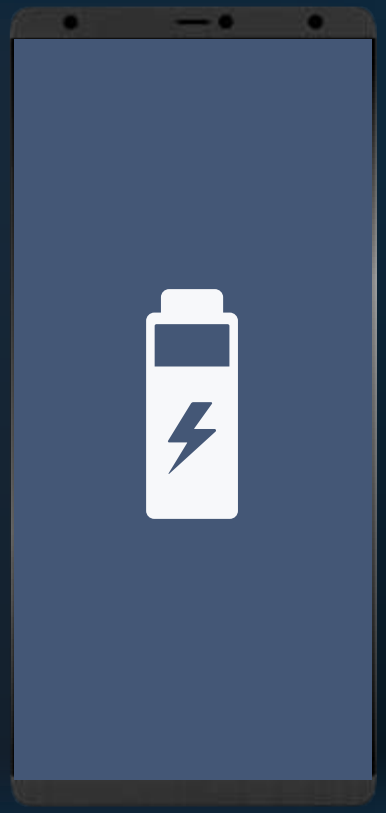
\# Multi-TRP devices

Network throughput improvement



Average device downlink signal improvement



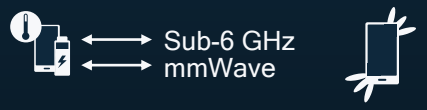


Further improving power efficiencies for 5G NR mmWave

Focusing on connected mode power saving – 3GPP Rel-16+

Device assisted power savings

Device provides additional information (e.g., battery level and temperature) for network to select carrier or power mode[1]



Multi-panel beam management

Antenna information is provided by the device to enable more power-efficient beam sweeping/switching

Efficient carrier aggregation operation

Reduce number of blind decoding to optimize power consumption

Integrated WUR[2] with beam management in C-DRX[3]

Beamformed wakeup signal improves beam pairing success and extends sleep[4]

More efficient control channel

Reduce processing overhead with control channel (PDCCH) skipping

Enhanced low-power modes

Improve device power consumption in idle and inactive modes

1 For example, using lower rank/CA during power-saving mode; 2 Wakeup Receiver; 3 Connected discontinued receive;
4 Power saving ranges from 10% to 80% over baseline C-DRX depending on the Ton and Tcycle configurations;

Qualcomm

Spring 2020

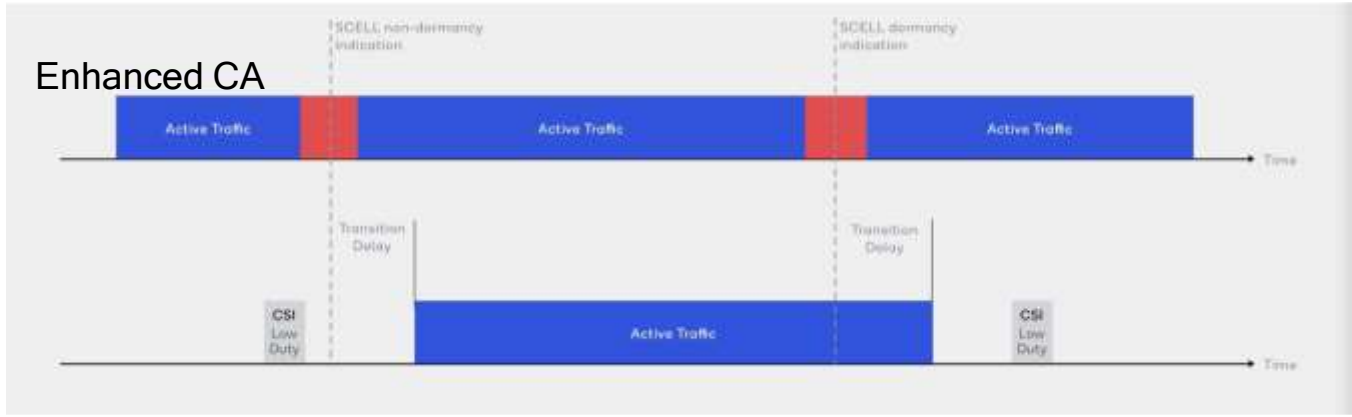
Simulating device power saving features

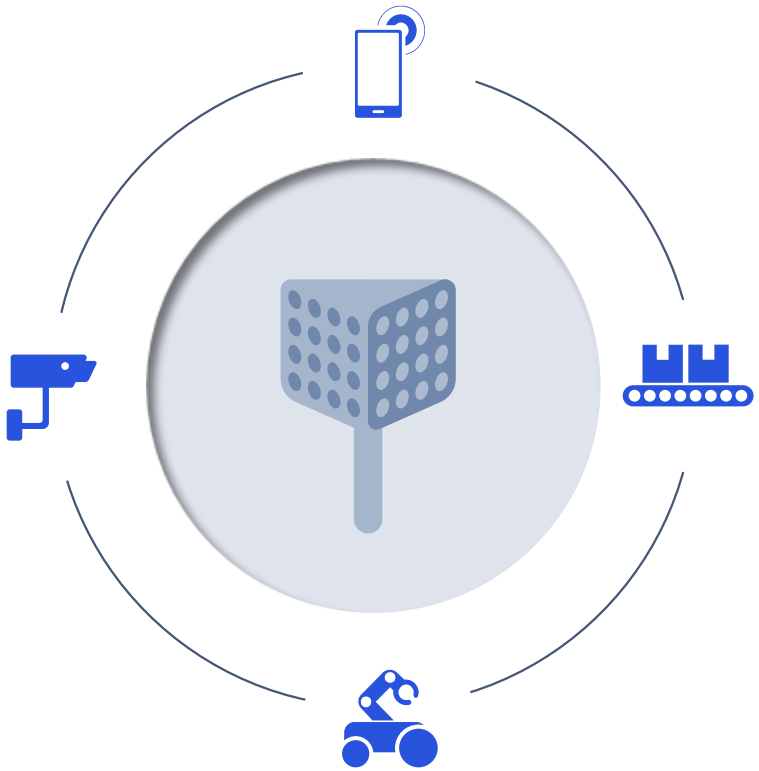
With R15 C-DRX baseline, R16 Wakeup Signal and Enhanced CA

Frankfurt, Germany

Total simulation area:	~1 km²
Total number of gNodeBs:	96
Total number of devices:	1500

[Link to full demonstration video]





Release 17+ Enhancements

Improving reliability, capability, and performance

Further enhancing 5G mmWave design for industrial IoT

Reliability enhancements

Multi-beam operation

More candidate beams (e.g., beam sweeping for DL control, UL control and data), device-based fast beam update

Latency enhancements

Beam failure recovery

Quicker beam failure detection and recovery procedure activation based on device feedback

Beam management

Overhead reduction with pre-determined beam switching (predictable device movements in IIoT environment)

Enhanced device feedback

Refined HARQ (hybrid automatic repeat request) feedback and enhanced CSF (channel state feedback)

Scaling down 5G mmWave

for new IoT applications

5G mmWave

Highest performance
Rel-15+

Surveillance cameras

Lower-tier mobile devices

Industrial sensors

High-end wearables

5G NR-Light mmWave

Lower complexity and power
Rel-17+

Lower device complexity

Reduced bandwidths (e.g., 50/100 MHz)

Fewer antennas

Half duplex

Relaxed device processing capability and time

Power savings

Control overhead reduction

Enhanced power saving modes

Limited mobility and handovers

Coverage optimization

Repetition and bundling

Lower order modulation

Sidelink or relays

Increased network efficiency

Reduced signaling overhead

Asymmetric traffic optimization

Better resource management

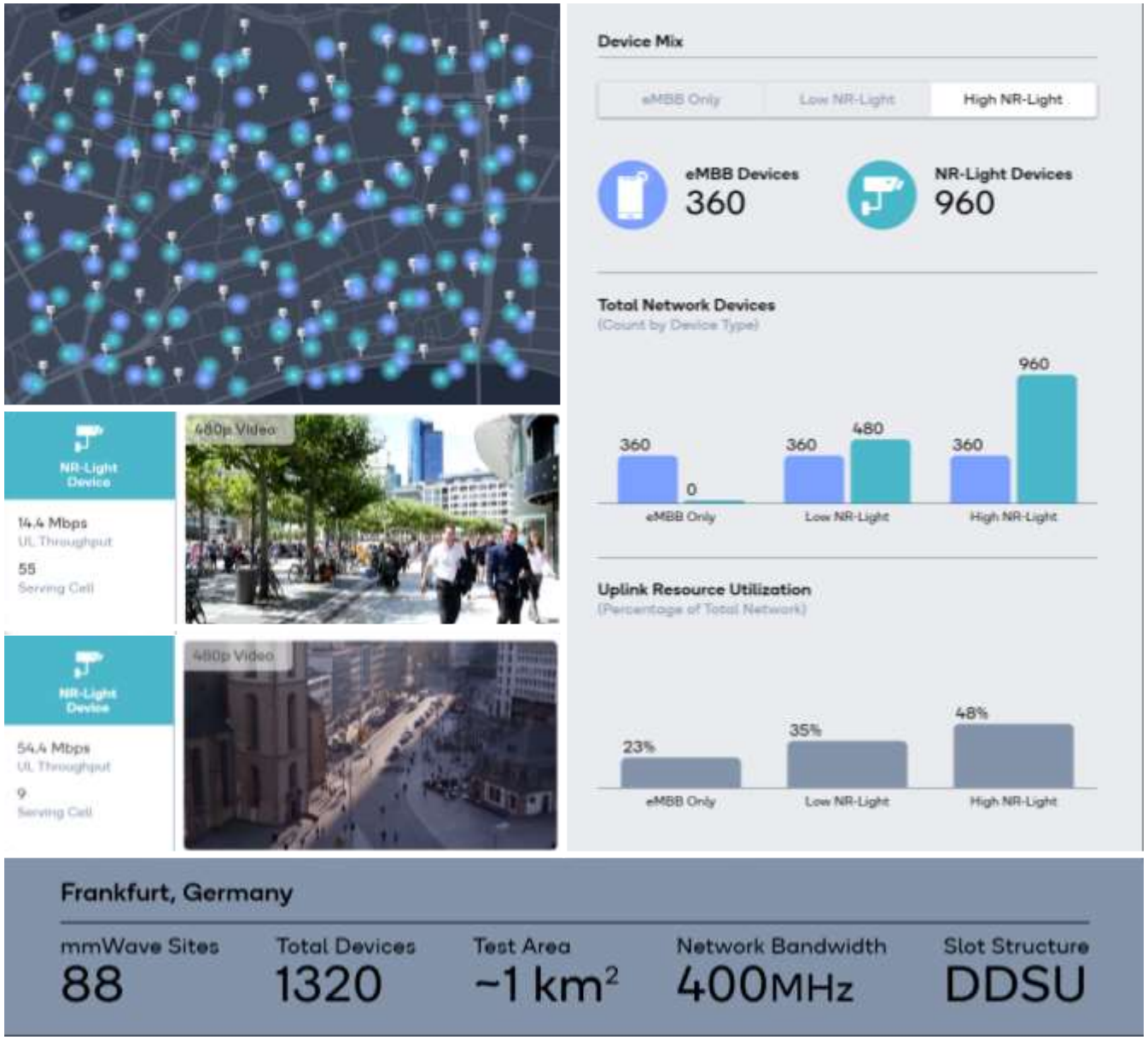
Service coexistence

Qualcomm

MWCB 2021

Scaling 5G mmWave to more efficiently support lower complexity devices

5G NR-Light operating in mmWave frequencies support lower bandwidth devices (e.g., 50 MHz) for more efficient 5G IoT deployments



Qualcomm MWCB 2021

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

5G

Continued evolution

Rel-15
eMBB focus

Rel-16 and 17 expanding to new industries

5G ADVANCED

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

6G

Next technology leap for new capabilities and efficiencies

Historically 10 years between generations

Strong 5G momentum sets stage for global expansion

Qualcomm

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