May 2019

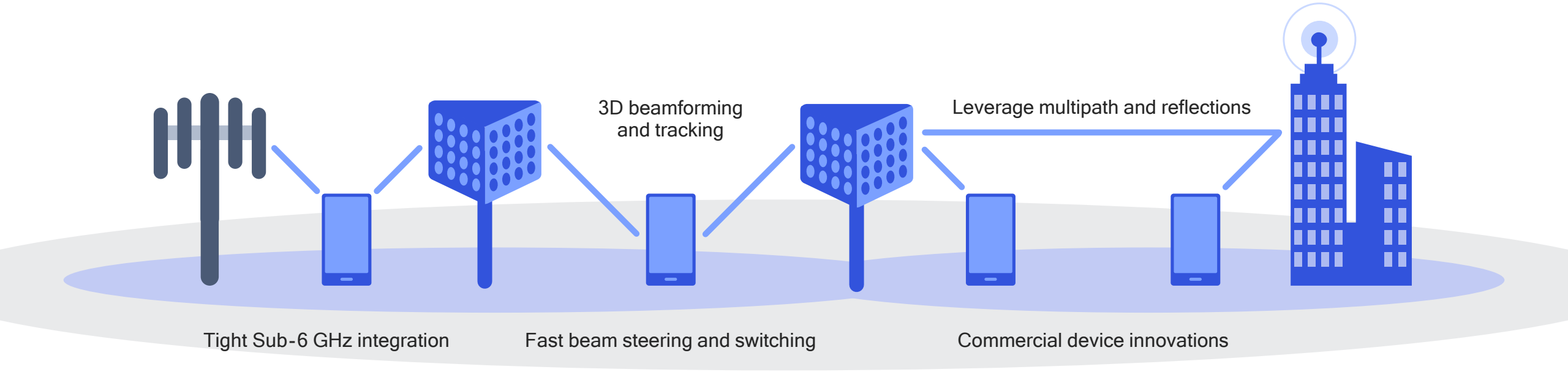
@qualcomm_tech

Location

Qualcomm

Breaking the wireless barriers to mobilize 5G NR mmWave

Breaking the wireless barriers to mobilize 5G NR mmWave



Overcoming “impossible challenges” through system-level innovations

Wide-area coverage, non-line-of-sight, seamless mobility, and smartphone formfactor

Leading commercialization with smartphone launches in 1H 2019

Early R&D, prototypes, standards, simulations, ecosystem IoDTs, field trials, modem / RFFE products

Driving 5G NR evolution for new use cases and enhanced performance

New indoor and venue deployment opportunities and flexibility with integrated access / backhaul

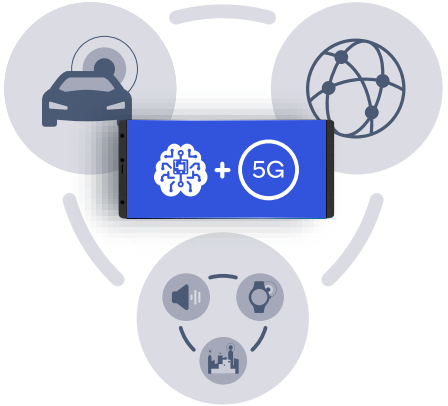
Leading mobile innovation for over 30 years

Digitized mobile communications

Analog
to digital

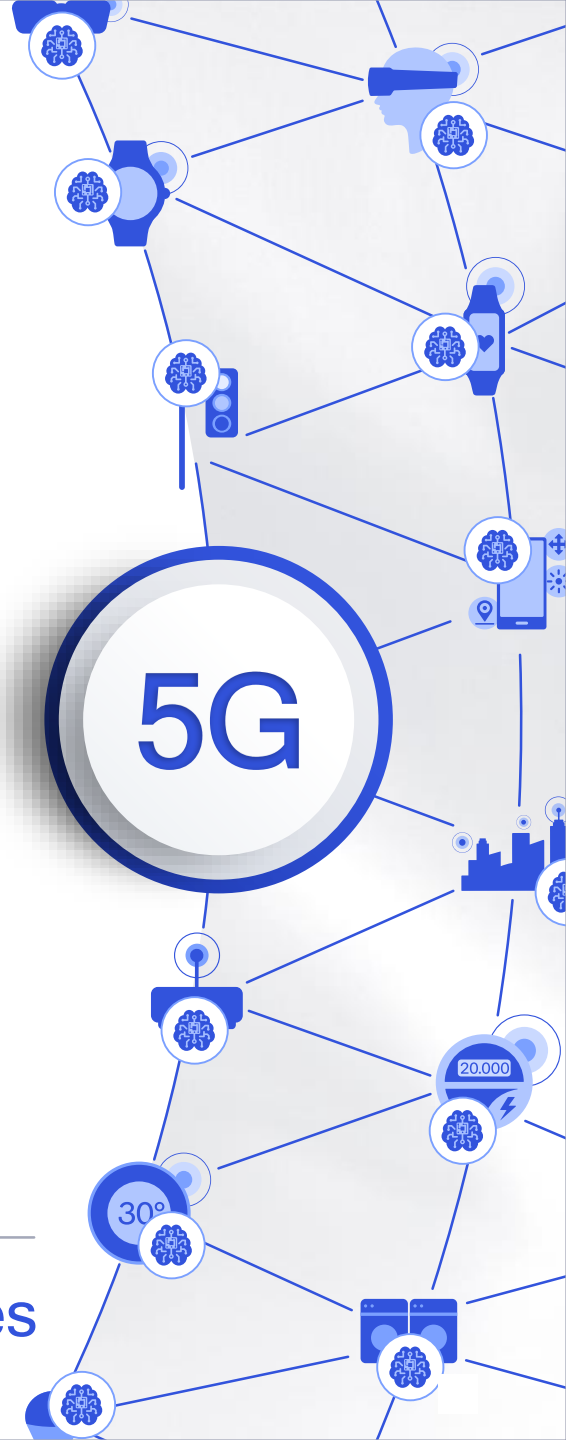
Redefined computing

Desktop to
smartphones



Transforming industries

Connecting virtually everything
at the wireless edge



Transforming how the world connects, computes and communicates


A unifying connectivity fabric for future innovations
Like electricity, you will just expect it everywhere
5G
Multi-gigabit speed
Scalable to extreme simplicity
Ultra-low latency
Virtually unlimited capacity
Extreme reliability
On-device intelligence

5G will address the insatiable demand for mobile broadband

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

~136B Gigabytes

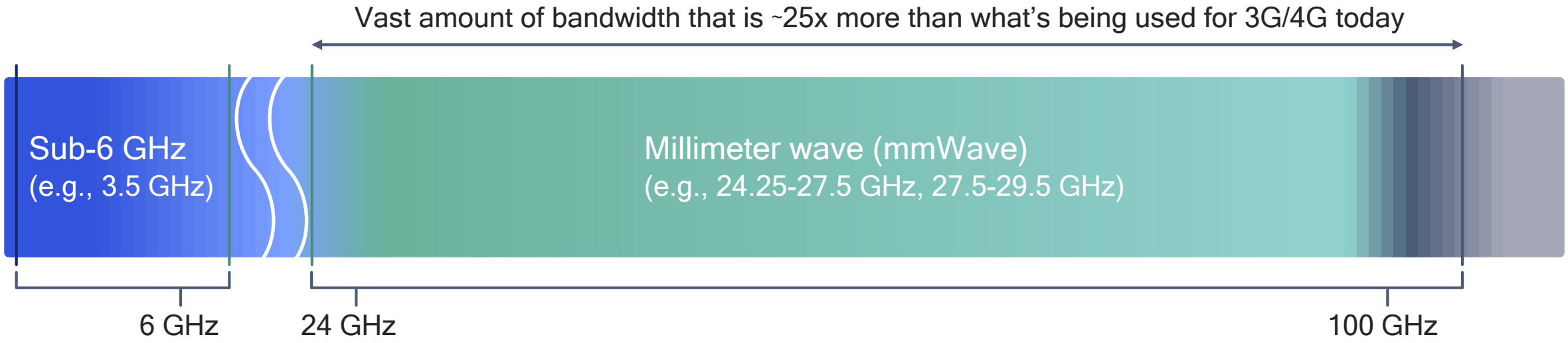
Monthly global mobile data traffic in 2024

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 November 2018

New frontier of mobile broadband – mobilizing mmWave



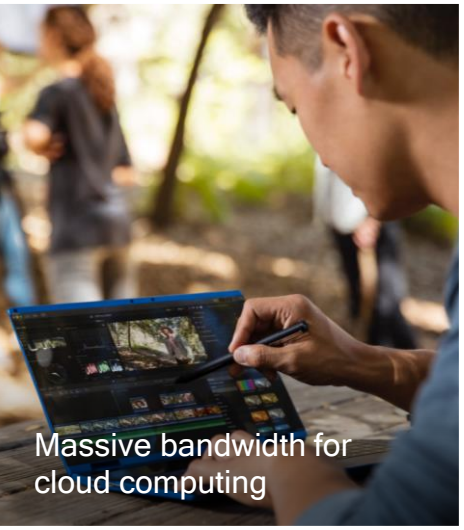
Multi-Gbps data rates
With large bandwidths (100s of MHz)

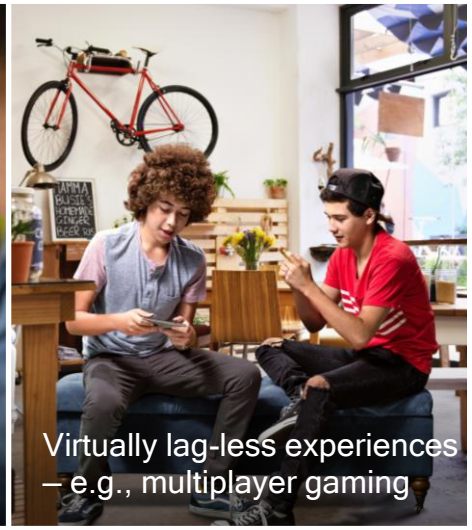
Much more capacity
With dense spatial reuse

Lower latency
Bringing new opportunities


Rich media and entertainment for outdoor – augmenting lower bands


More indoor capacity as outdoor mmWave offloads outdoor lower bands


Massive bandwidth for cloud computing


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


Dense indoor & outdoor connectivity for venues


New indoor opportunities – e.g., connected enterprises


Fiber-like broadband to the home – fixed mmWave


Beyond smartphones – e.g., smart manufacturing

5G

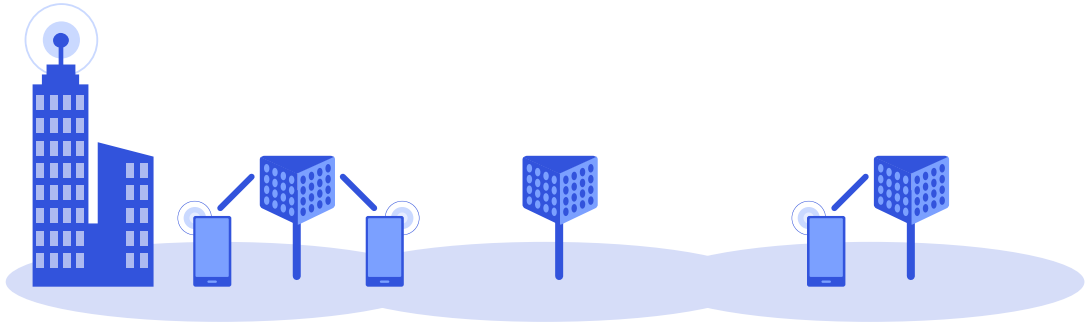
5G NR mmWave will support new and enhanced mobile experiences

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

5G NR mmWave is bringing new waves of opportunities

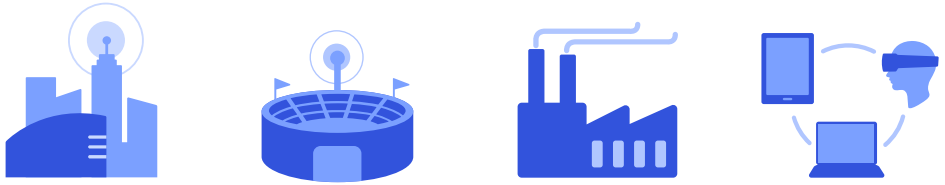
For outdoor deployments…

- 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,…

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.

Qualcomm founders

CORPORATE OBJECTIVE

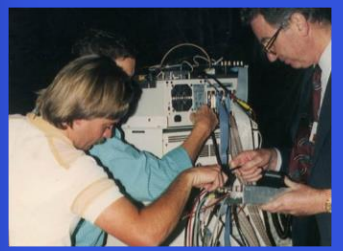
From the onset of our industrial careers, we have been dedicated to the "elegant solution"--the solution that provided the most cost effective, reliable answer to today's communication problems. As more sophisticated communication systems become feasible, particularly due to the advent of the microprocessor, it becomes especially important to use sound principles of information theory and computer science to analyze system performance and simulate system operation wherever feasible, to ensure that the resulting system as implemented performs its assigned tasks in a cost effective and efficient manner. Now more than ever before, the existing tools of our trade--microprocessors and VLSI, along with the emerging technology of artificial intelligence and expert systems--offer exciting new approaches to elegance and innovation in synthesizing practical solutions to real-world problems.

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.

We have a proven record of accomplishment in the digital communication, software engineering and signal processing fields. We have put together an experienced team that has produced not only theoretical innovation, but real, working, quality products and systems to start QUALCOMM. This group of people has, for the most part, worked together for the last 15 years and is dedicated to building QUALCOMM into what its name implies--The Quality Communication Company of our time.

Dr. Irwin Mark Jacobs

Dr. Andrew J. Viterbi



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

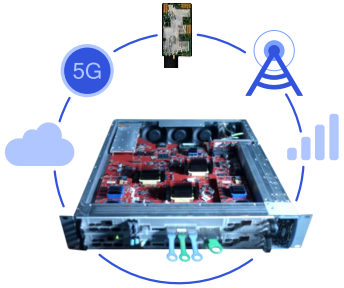
mmWave is intrinsically more power hungry due to wider bandwidth with thermal challenges in small formfactor

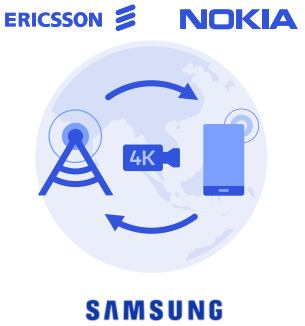
Commercializing smartphone

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

A system approach to the mobile mmWave challenge





1

Cutting-edge R&D

Overcoming numerous challenges to make mmWave viable for mobile use cases

2

Prototyping while driving standards

Validating mobile 5G NR mmWave technologies, feedback loop to standards

3

Advanced network and system simulations

Accurately predicting mmWave coverage, capacity, performance using real network models

4

Broad interoperability testing and trials

Fully utilizing prototype systems and our leading global network experience

5

Cutting-edge modem and RFFE solutions

Announced the Qualcomm Snapdragon X50 5G modem family & QTM052 antenna module

Many milestones to mobilize 5G NR mmWave

1990+

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

October 2016

Introduced world's first announced 5G modem, the Qualcomm® Snapdragon™ X50, mmWave and Sub 6 GHz

March 2017

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

September 2017

Showcased 5G NR mmWave coverage simulations announced prototype mmWave UE

December 2017

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

July 2018

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

October 2018

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

1H19

Commercial 5G NR mmWave networks and devices

5G NR field trials with MNOs and infra vendors

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

September 2017

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

October 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

ERICSSON
NOKIA
SAMSUNG

September 2018

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

MWC 2019

Stay tuned for groundbreaking mmWave demos

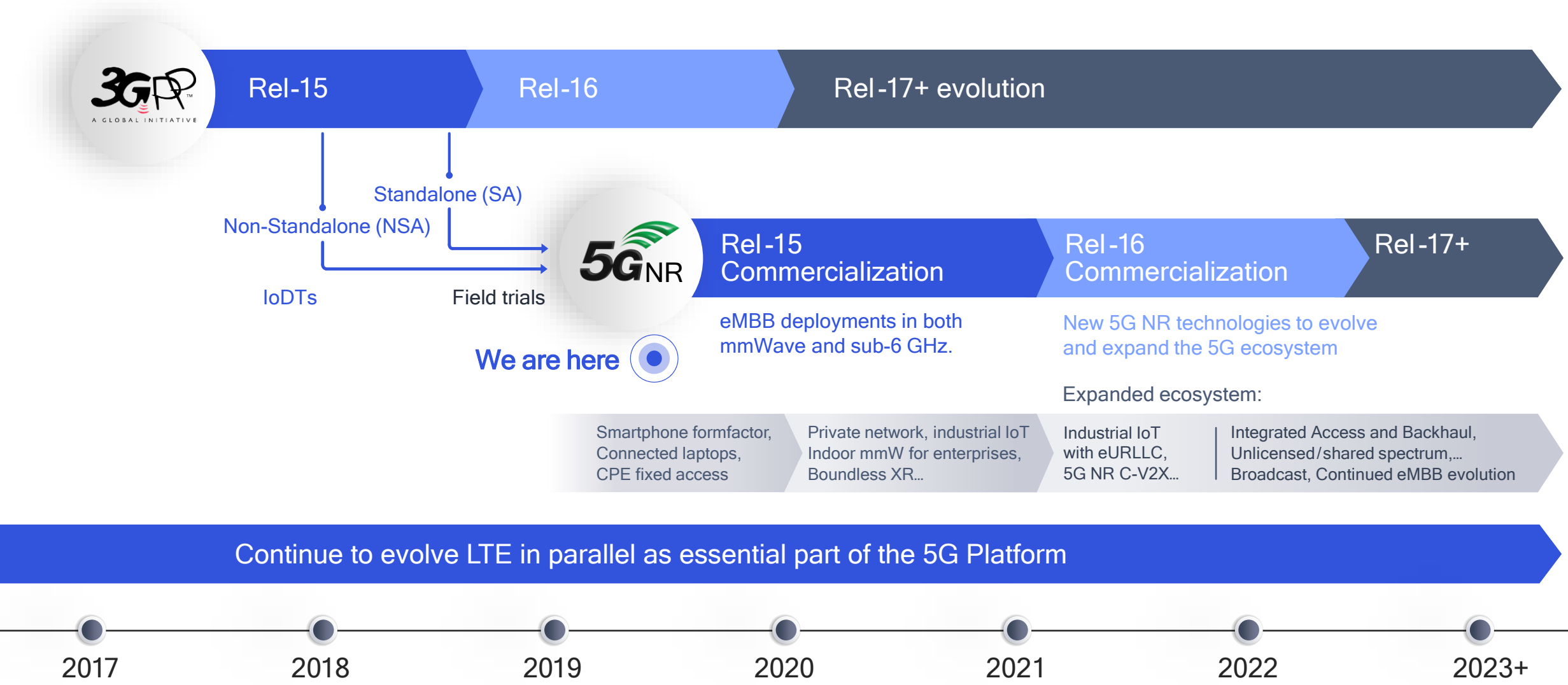
MOBILE WORLD CONGRESS

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

Breaking the wireless barriers to mobilize 5G NR mmWave

Standardized in 3GPP Rel-15

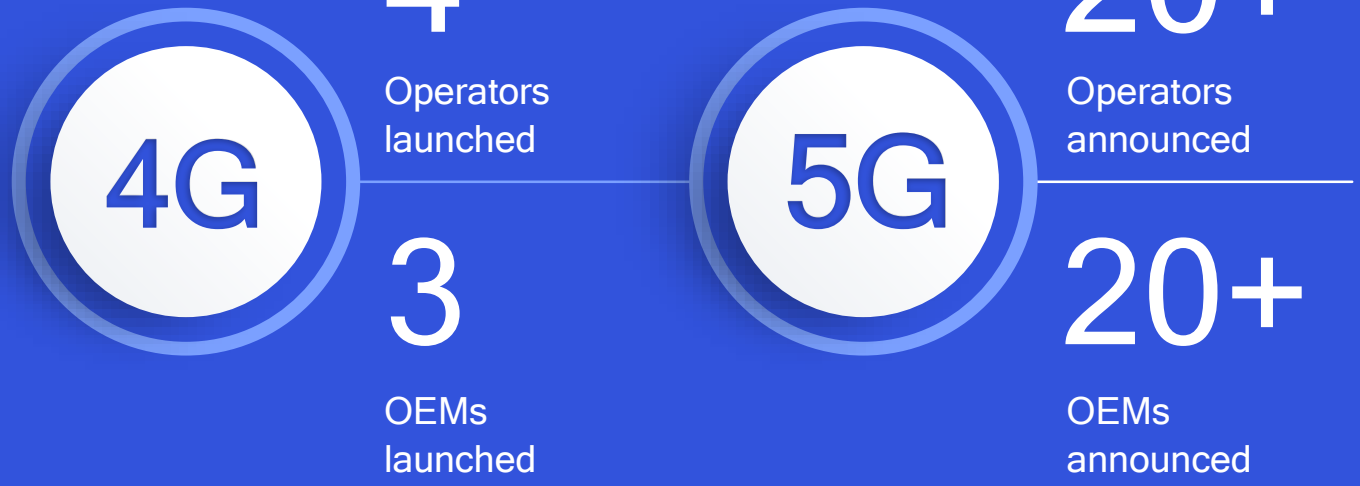
Driving the 5G roadmap and ecosystem expansion



2019 is the year of 5G

Deployments happening in regions across the globe

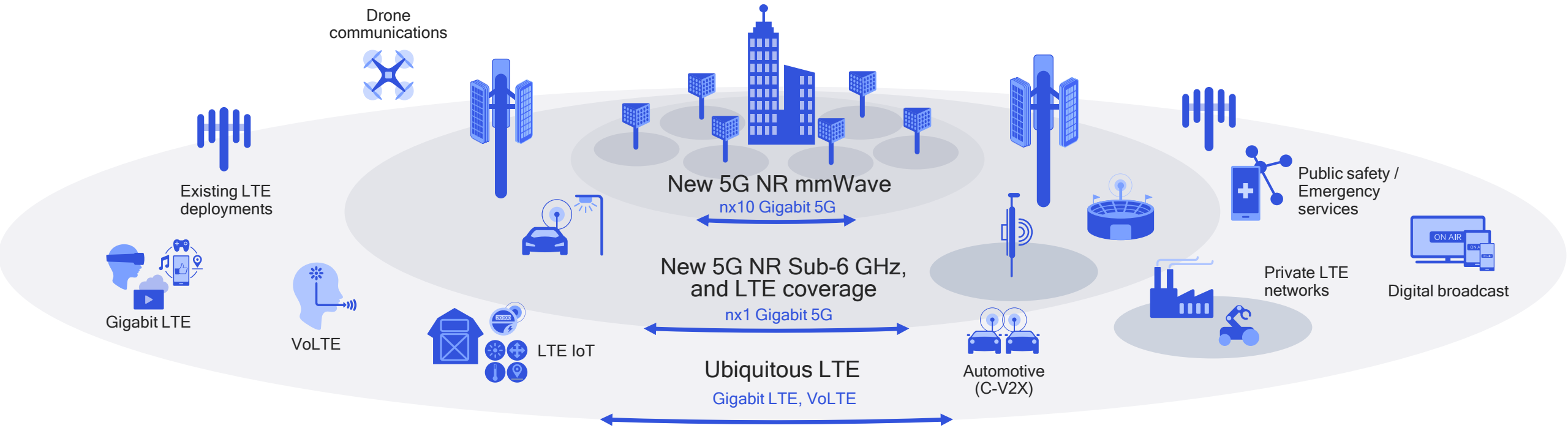
5G rollout happening much faster than 4G



Source: IHS Report Jan ’19, Qualcomm Technologies data

Year 1 announcements underscore tremendous momentum with 5G

LTE is essential to the 5G NR mmWave experience



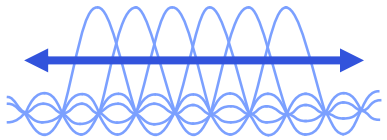
LTE provides ubiquitous coverage and services that complement 5G NR

Tight integration of mmWave with 5G NR sub-6 GHz, dual connectivity with LTE

Leverage investments by co-siting mmWave with LTE, including more LAA small cells

Our technology inventions drove Release 15 specifications

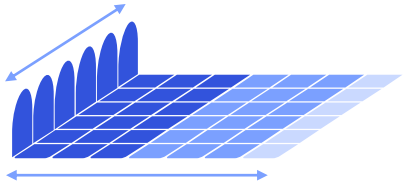
Scalable OFDM-based air interface



Scalable OFDM numerology

Address diverse services, spectrum, deployments

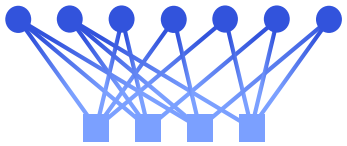
Flexible slot-based framework



Self-contained slot structure

Low latency, URLLC, forward compatibility

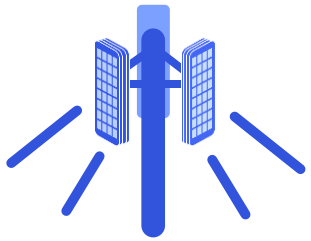
Advanced channel coding



Multi-Edge LDPC and CRC-Aided Polar

Support large data blocks, reliable control channel

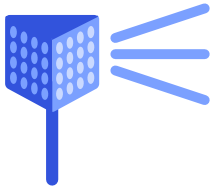
Massive MIMO



Reciprocity-based MU-MIMO

Large # of antennas to increase coverage/capacity

Mobile mmWave



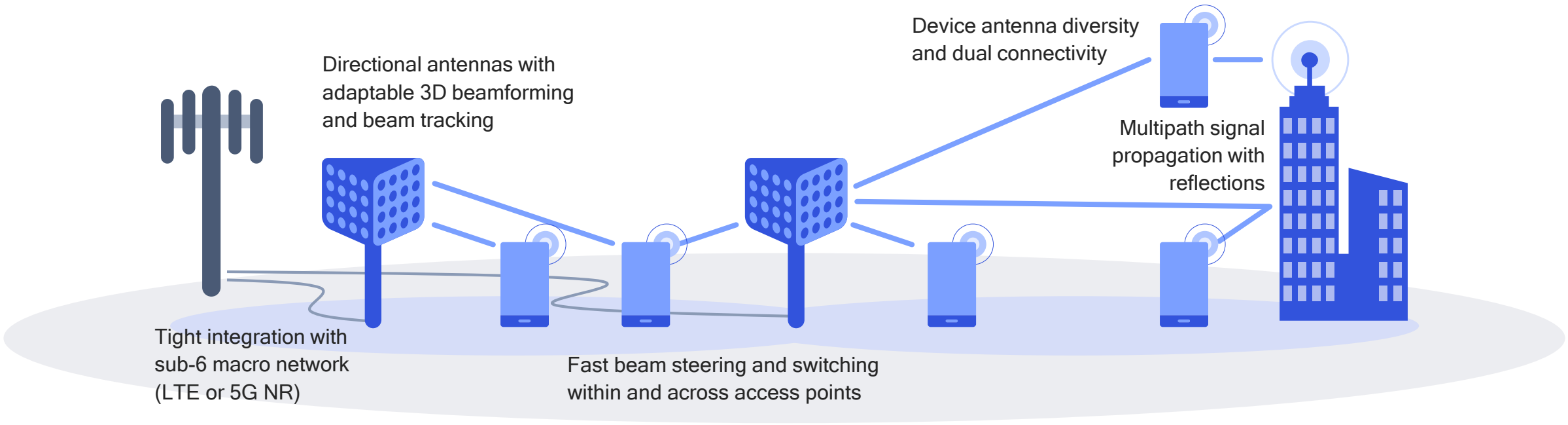
Beamforming and beam-tracking

For extreme capacity and throughput

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

Mobilizing mmWave with 5G NR technologies

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



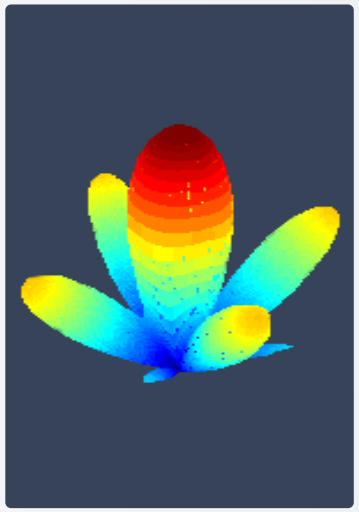
Delivering robust NLOS connectivity

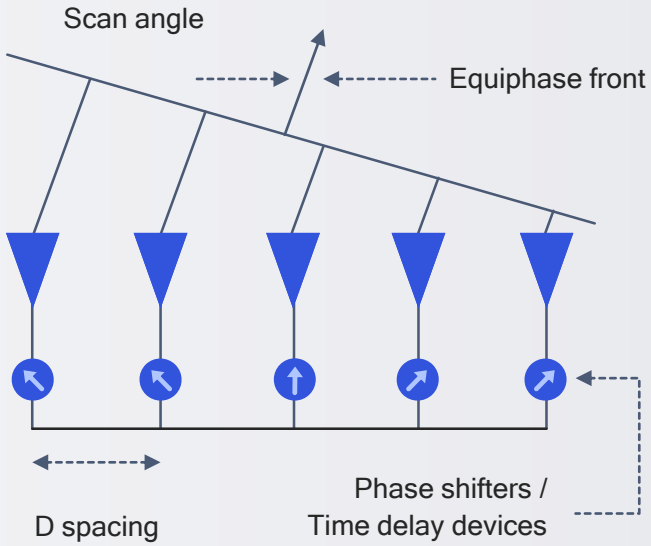
Supporting seamless mobility

Complementing macro area coverage

Addressing mobility challenges with multi-beam techniques

Improves coverage, robustness, and non-line of sight operations

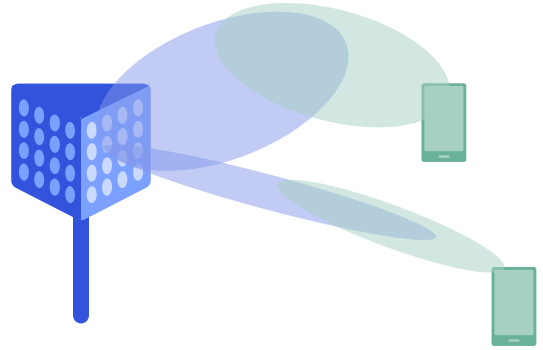




High-gain directional antenna arrays

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

Required in both base station (~128 to 256+ elements) and mobile device (~4 to 32 elements) for 3D beamforming

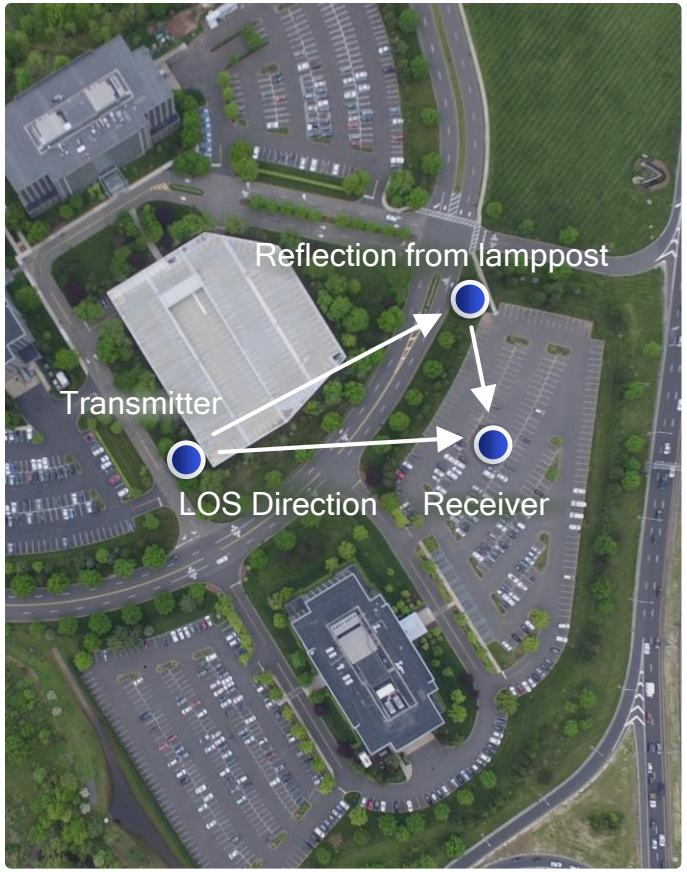


Beam switching — Switches between candidate beams to adapt to changing environment

Beam steering — Changes direction of uplink beams to match the that of incoming beams from gNodeB

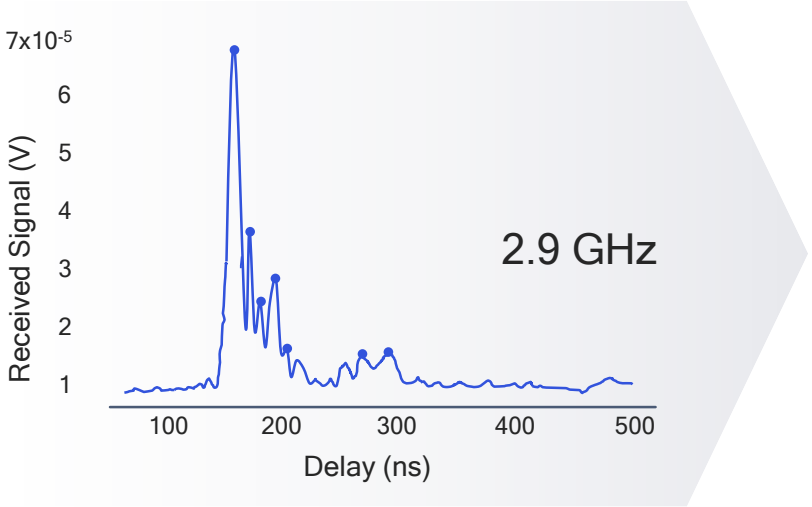
Beam tracking — Distinguishes between beams arriving from gNodeB

Smart, closed-loop algorithms determine most promising signal paths with fast switching within and across access points

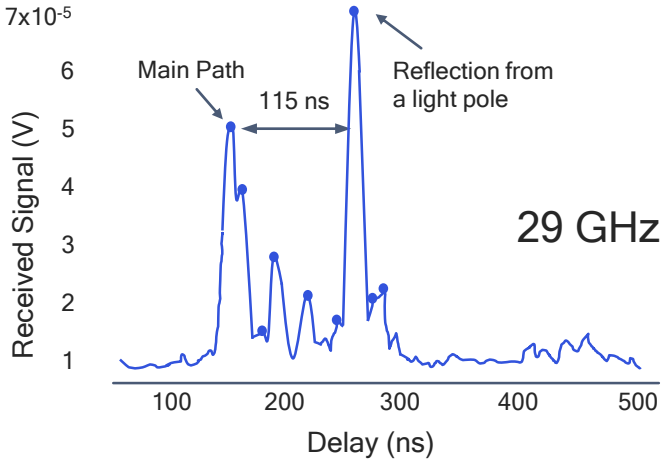


Channel response from omni-directional antennas
(Example measurement)

Operating at sub-6 GHz



Operating above 24 GHz



- Alternative paths in mmWave can have very large receive signal
- Small objects affect mmWave propagation more than sub-6 GHz (e.g., tree branches)

Showcasing reflections provide alternative paths when LOS is blocked – based on our outdoor channel measurements

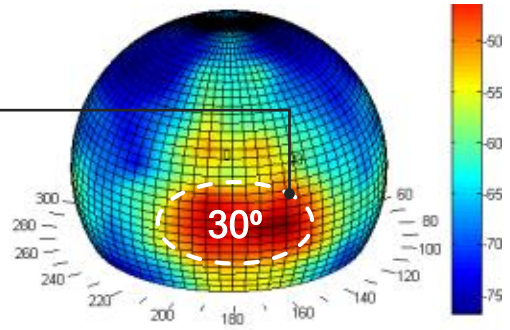
Leveraging path diversity to overcome blockage

Based on our spherical scan measurements

Indoor office

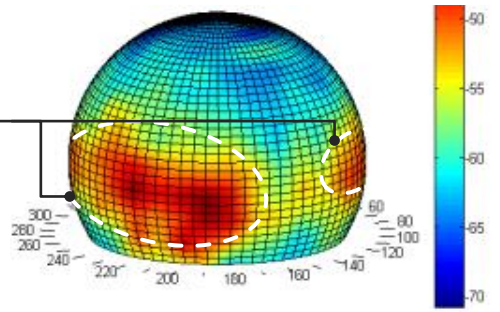
Diversity in elevation

Numerous resolvable paths in elevation



Diversity in Azimuth

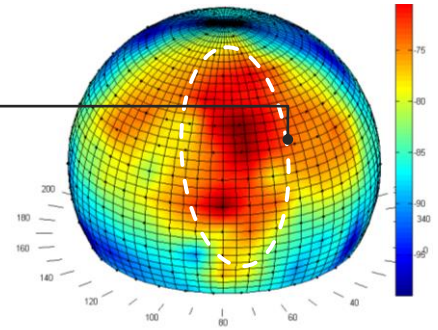
Significant path diversity in azimuth – Ability to withstand blockage events



Outdoor

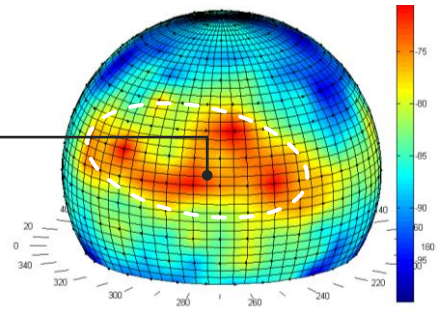
Diversity in elevation

Reflections from tall buildings result in wide elevation spread



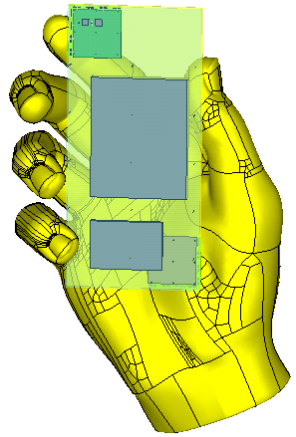
Diversity in Azimuth

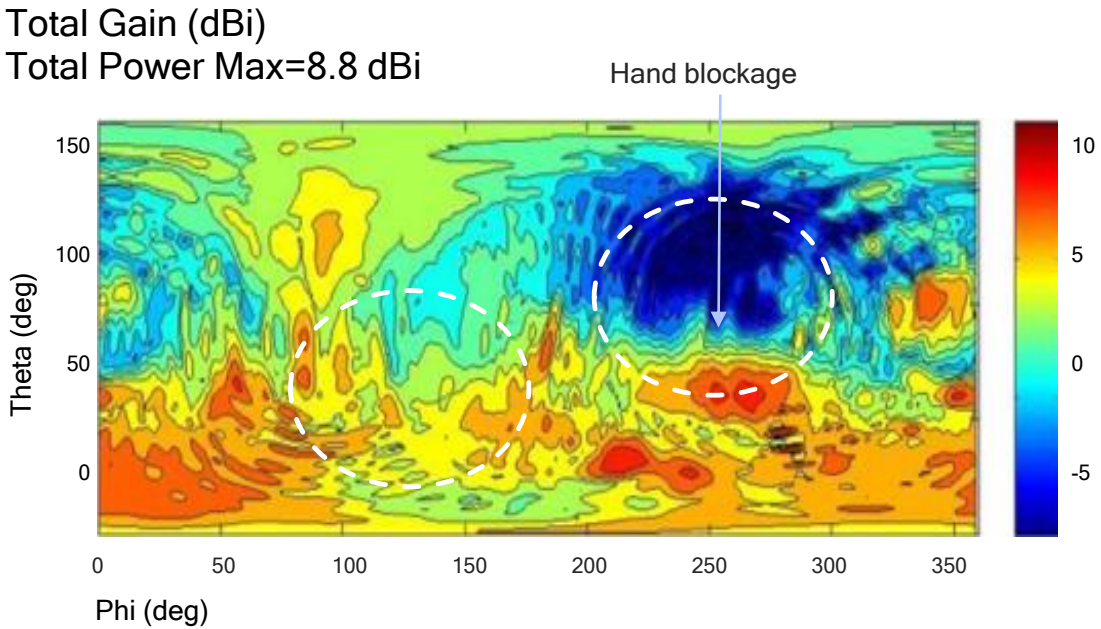
Foliage obstructed diffracted path – energy spread across wide azimuth



Improving reliability utilizing device antenna diversity

Provides nearly spherical coverage in free space





Qualcomm Research Simulations

Mitigates hand-blocking and reduces impact of random user orientation

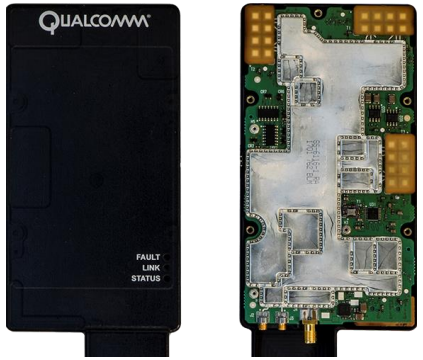
Results drove commercial products – Qualcomm® QTM052 5G NR mmWave antenna module

Leveraging best-in-class 5G NR mobile prototype systems

To verify concepts, feed into standards, track standards, early interoperability

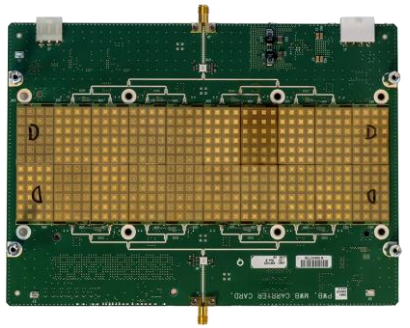
5G NR Baseband

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

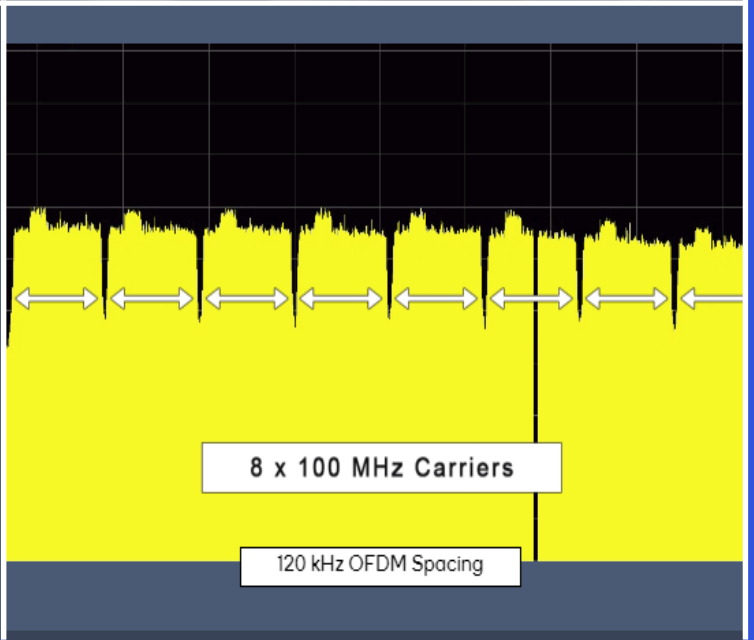
Enable early system-level testing and demonstrations

Announced world's first announced 5G NR mmWave prototype – September 2017

Achieved world's first 5G NR mmWave mobile data connection – December 2017

Completed multiple 5G NR mmWave interoperability testing – February 2018

Downlink
Application Layer (Layer 2)



ERICSSON Qualcomm December 2017

Global mobile industry leaders achieve world's 1st multi-band 5G NR interoperability

In collaboration with AT&T, NTT DOCOMO, Orange, SK Telecom, Sprint, Telstra, T-Mobile US, Verizon, and Vodafone

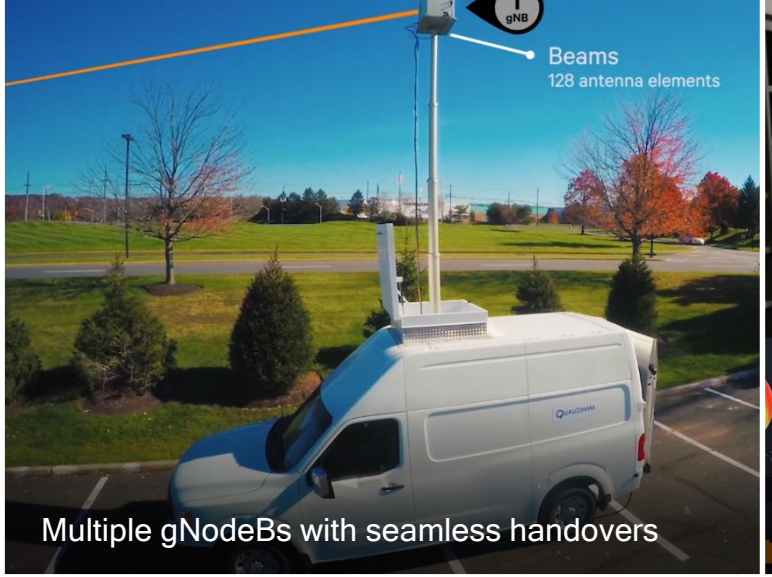
Compliant with the 3GPP 5G NR standard

- 5G NR scalable OFDM air interface
- 5G NR low latency slot-based framework
- 5G NR advanced channel coding
- 8x100 MHz bandwidth, operating at 28 GHz
  100 MHz bandwidth; operating at 3.5 GHz

Watch video

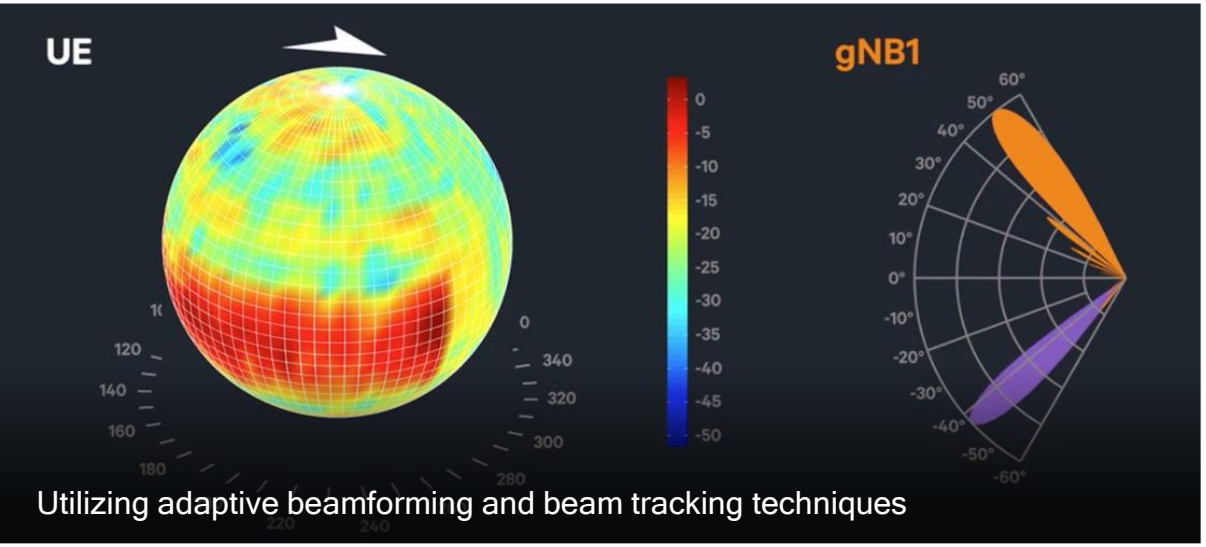
www.qualcomm.com/videos/5g-nr-mmwave-interoperability-testing

Handheld and in-vehicle UEs with hand-blocking



Multiple gNodeBs with seamless handovers

Indoor mobility with wall penetration and dynamic blocking

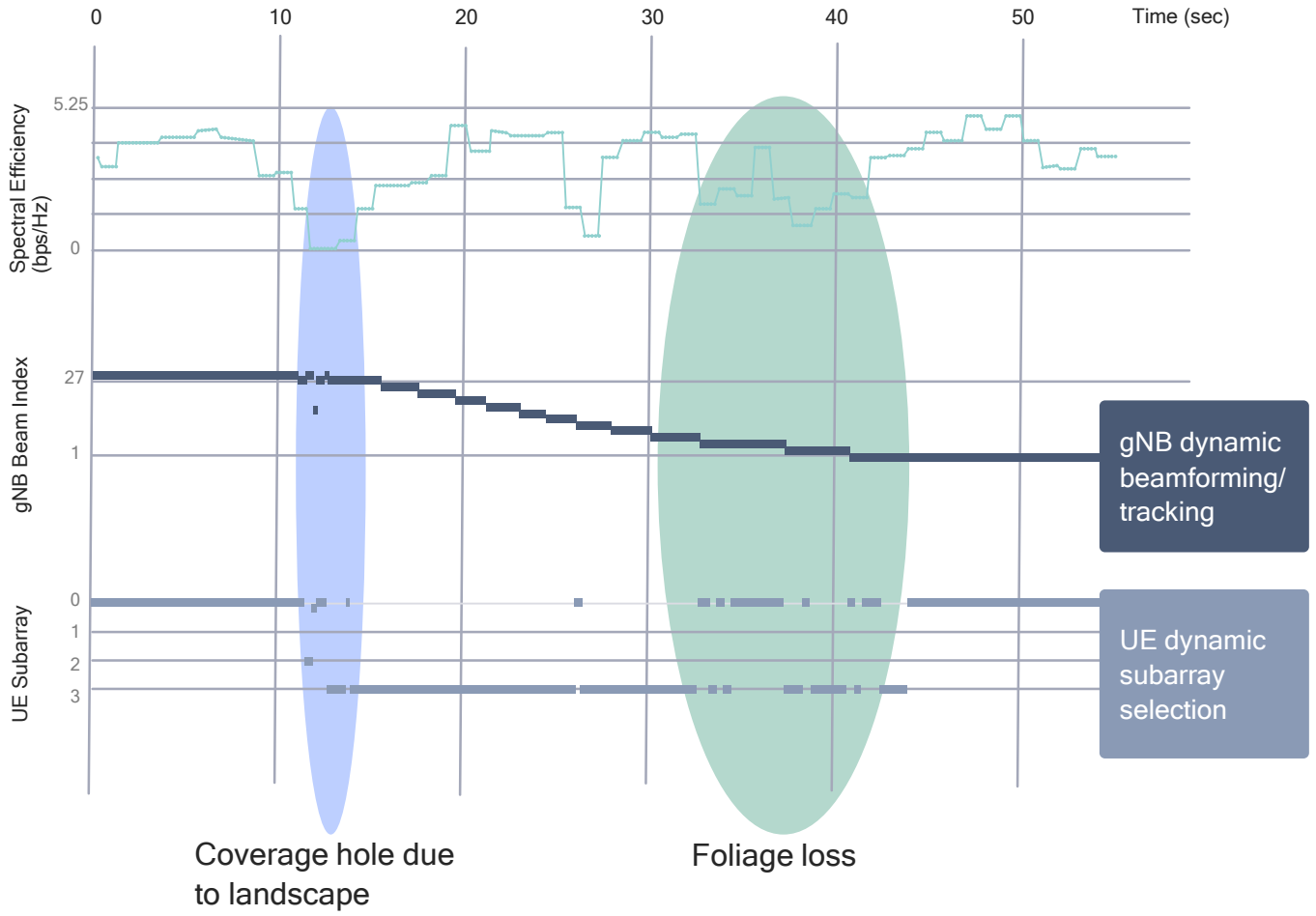


Utilizing adaptive beamforming and beam tracking techniques

Outdoor vehicular mobility with handovers

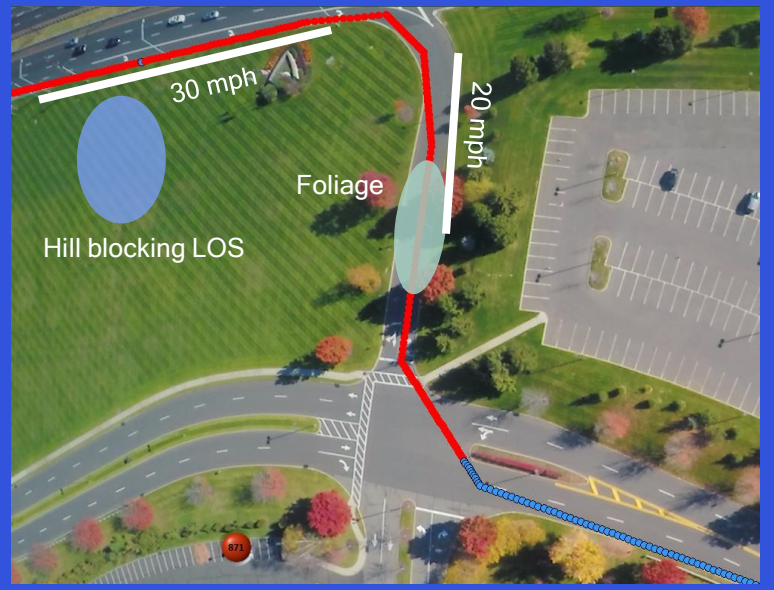
Showcasing robust mobile communication in real-world OTA testing using Qualcomm Research 5G mmWave prototype

Outdoor OTA example test results



Demonstrating sustained mobile communications outdoors, with NLOS and device mobility

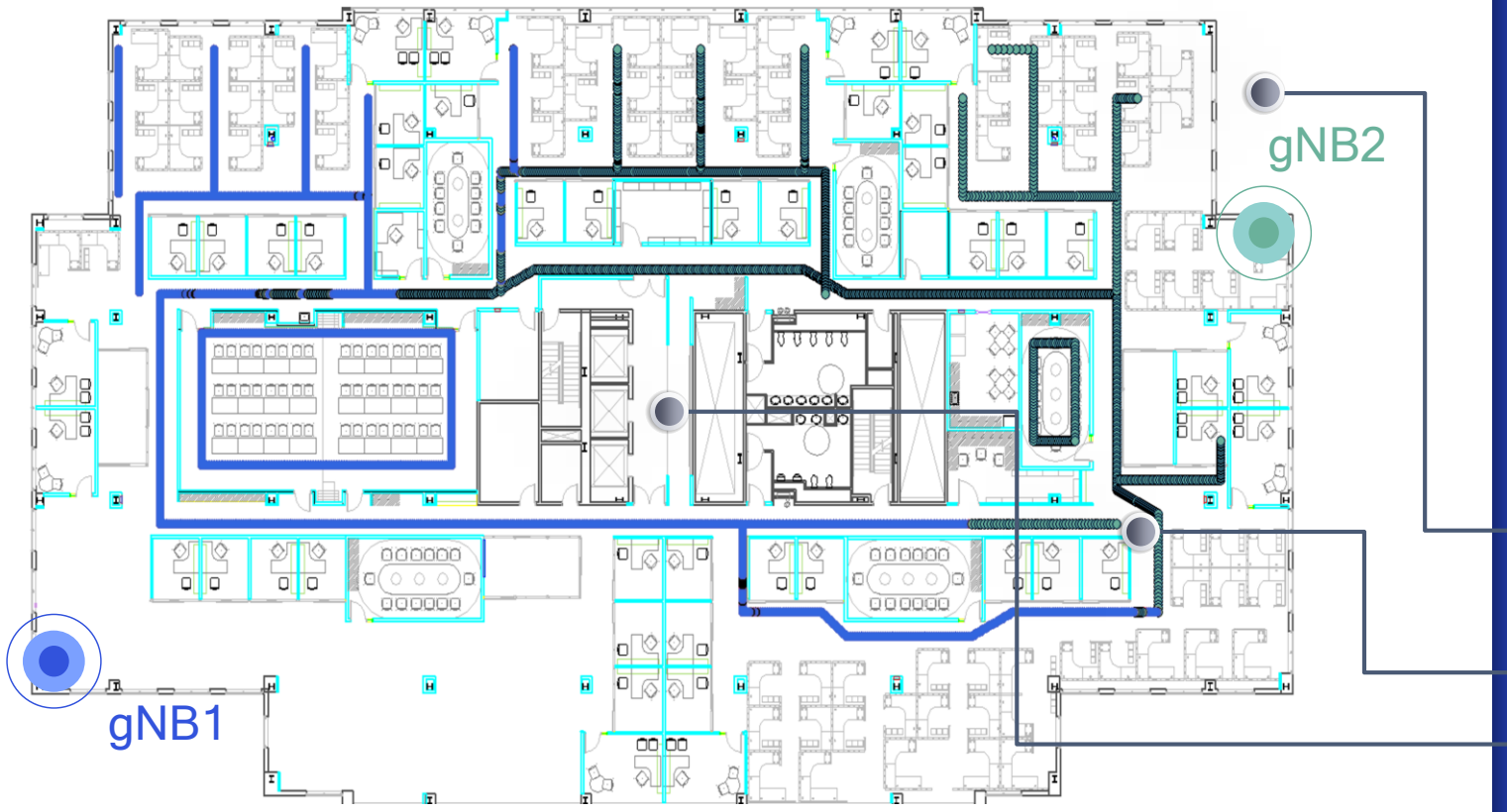
Qualcomm Research over-the-air outdoor testbed



Source: Qualcomm Technologies Inc.

Indoor Office OTA example test results

with dimensions of 75m x 40m with seamless handovers between two gNodeBs



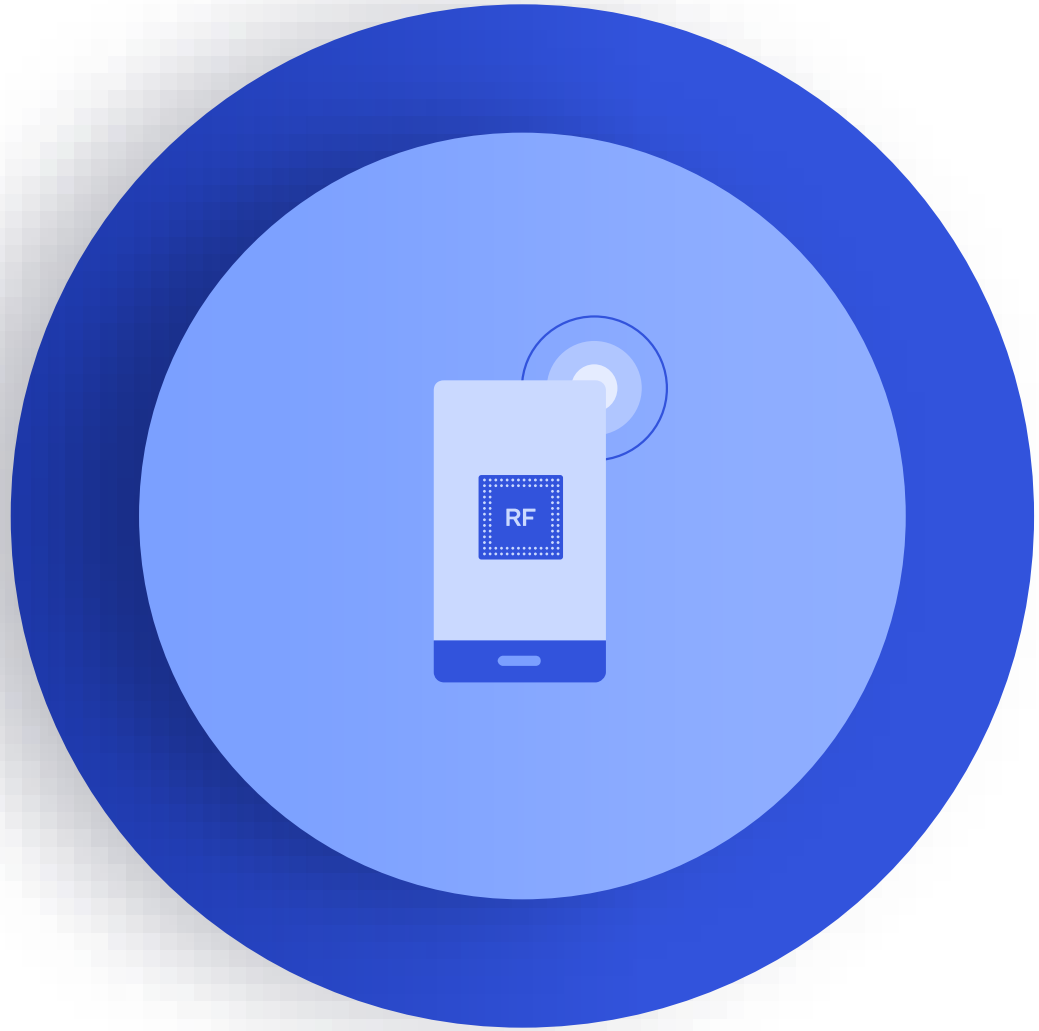
● Connectivity to gNB1 ● Connectivity to gNB2 *Min 1 bps/Hz

Demonstrating sustained mobile communications indoors, with wall penetration and hand/body-blocking

- Two gNBs provides adequate coverage for large, walled indoor office
- Cell-boundaries not well-defined – function of the environment
- Coverage holes, e.g. area near elevators, can be addressed with more gNBs

Source: Qualcomm Technologies Inc.

Solving RF complexities in 5G NR mmWave smartphones



mmWave RF complexities in designing 5G handsets

Implementing 5G mmWave in smartphone form factors presents difficult but solvable challenges

Link budget
Achieve target radiated power with high bandwidths at mmWave frequencies

Stringent size constraints
Achieve high antenna efficiency and multi-band support in challenging smartphone form factors

Power consumption
Support multi-Gigabit throughputs with high power efficiency

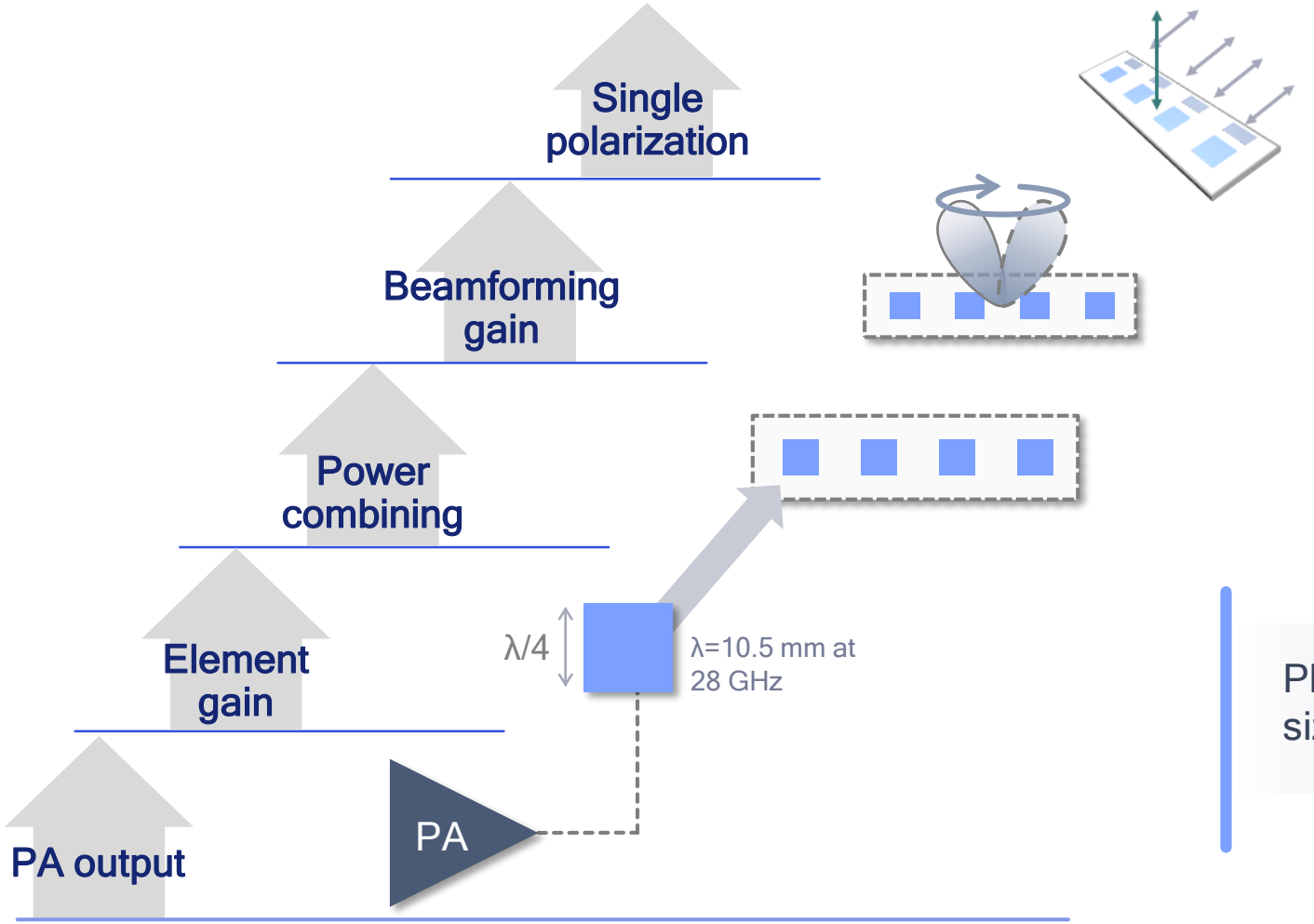
Thermal performance
Support high transmit power while maintaining thermal stability and avoiding localized hot spots

Mobility
Maintain reliable mmWave connectivity in a changing, mobile environment

Regulatory compliance
Optimize transmit power and throughput while meeting regulatory requirements

Achieving required transmit power for mobile mmWave

Required transmit power (EIRP[1])



Beamforming and directional architectures allow more gain

# of antennas in array determines max EIRP

Physics dictates antenna size and spacing

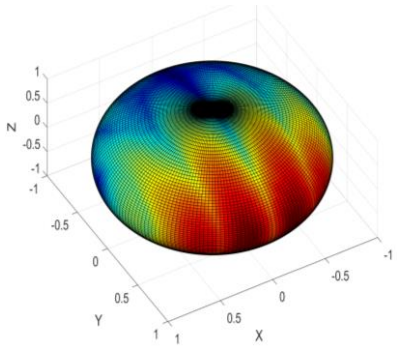
1 EIRP = Equivalent Isotropic Radiated Power. Represents peak directional power transmitted from the antenna array relative to an isotropic transmission

UE antenna module design for coverage

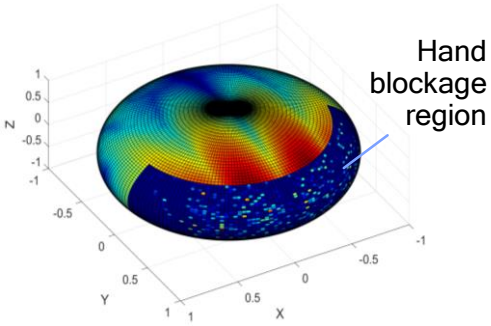
Design objectives

- Uniform performance independent of UE orientation
- Mitigate impact of hand/body blockage

Single antenna module

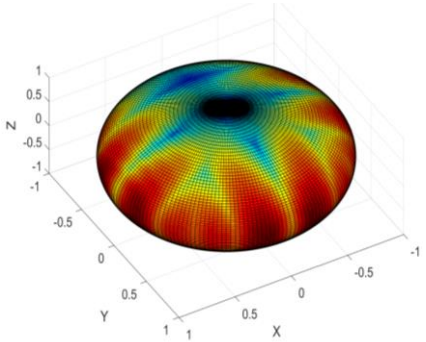


36% spherical coverage



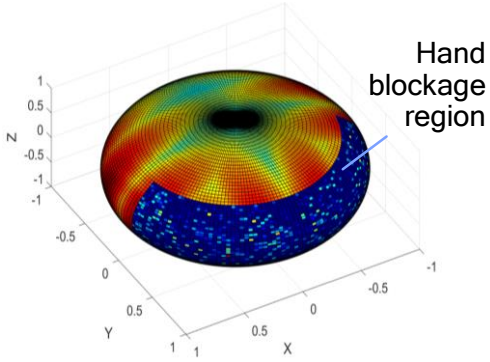
18% spherical coverage

Three antenna modules



78% spherical coverage

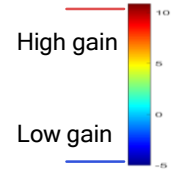
Hand blockage



60% spherical coverage

Better spherical coverage in hand-blockage scenarios with 3 modules

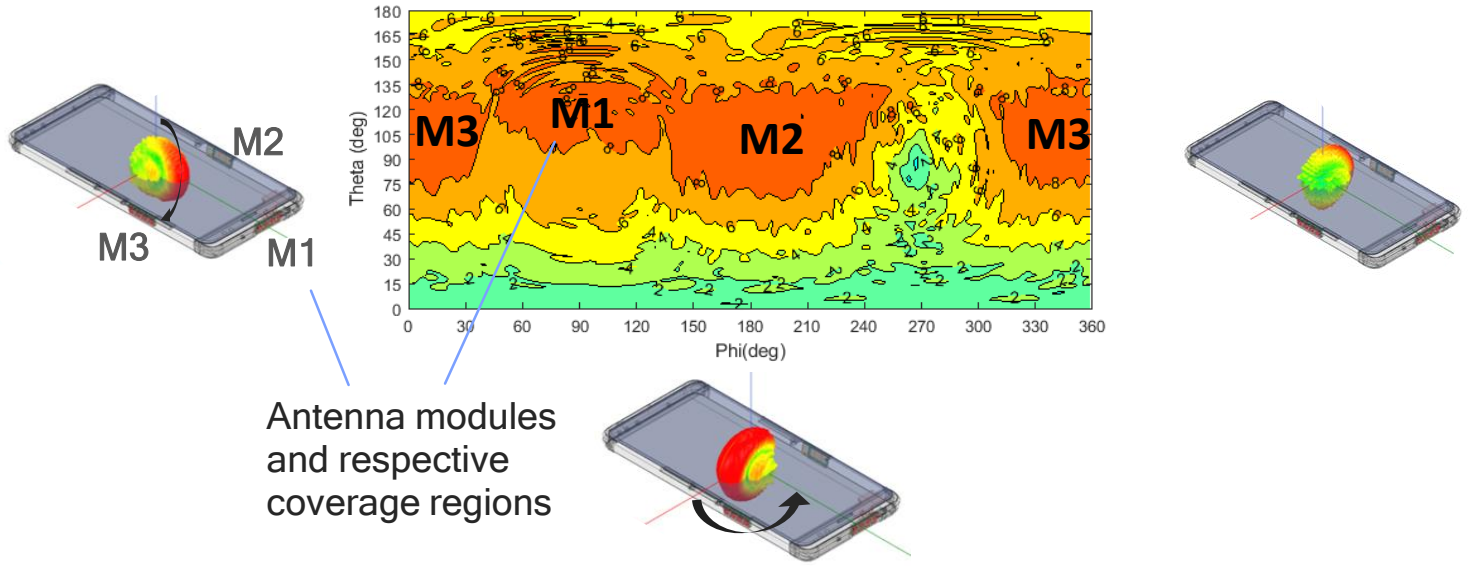
Multiple antenna modules provide nearly spherical coverage for both polarizations

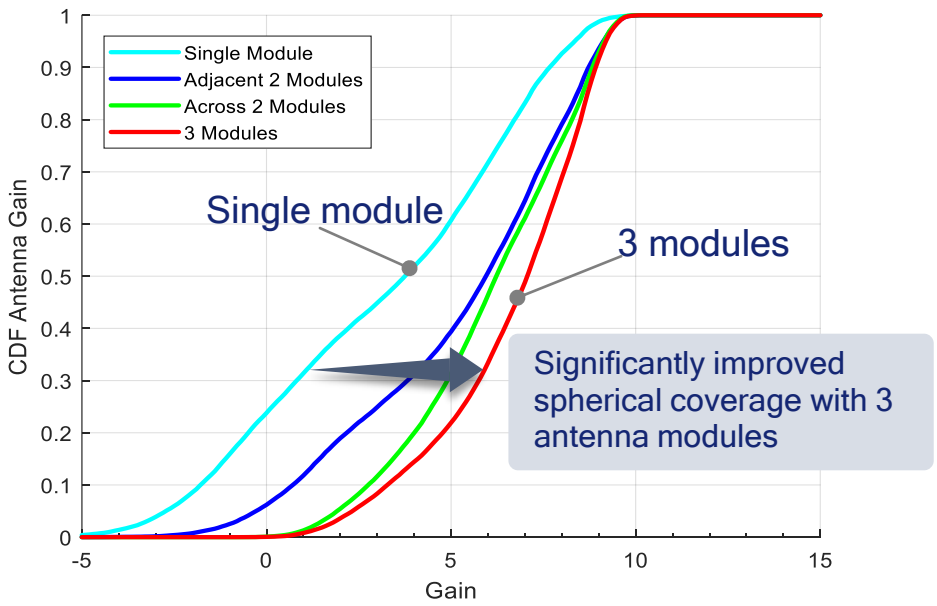


Source: Qualcomm Technologies, Inc.

UE antenna module design for coverage

Three-antenna configuration provides more robust spherical coverage than single antenna

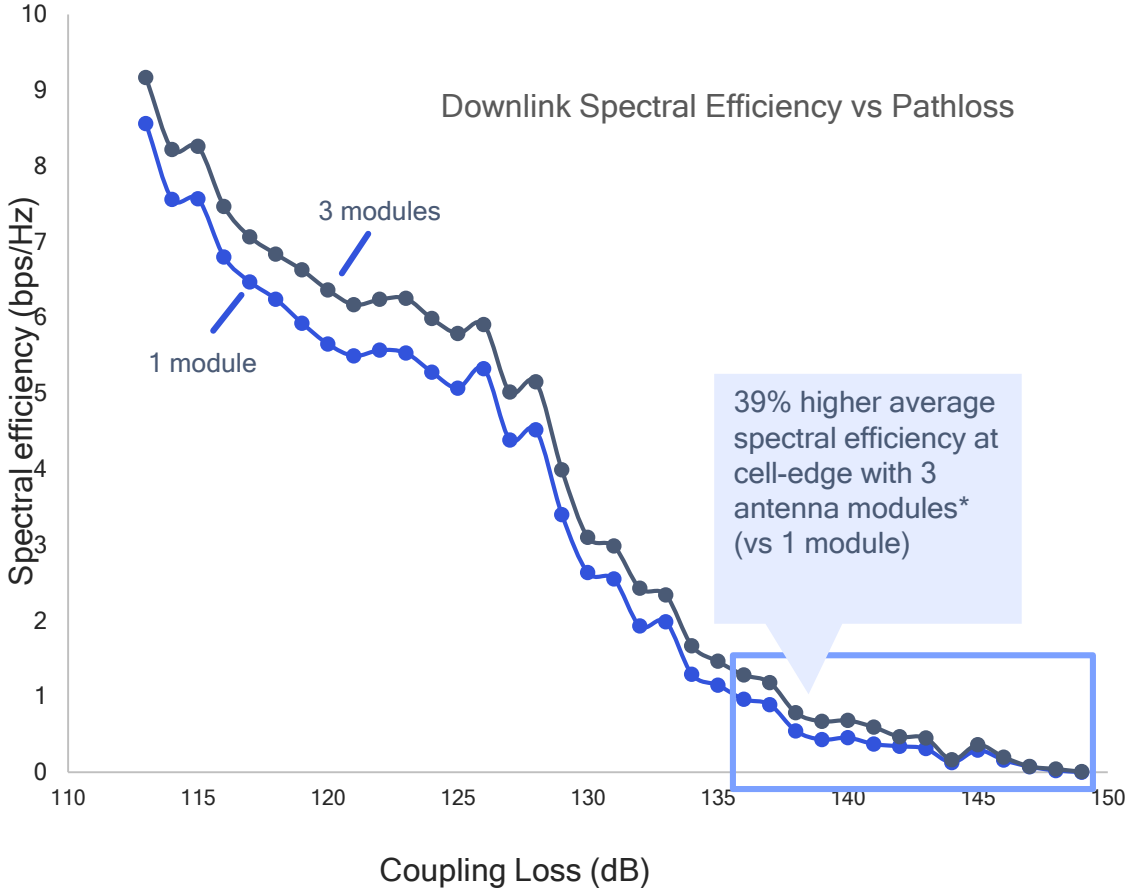




Source: Qualcomm Technologies, Inc.

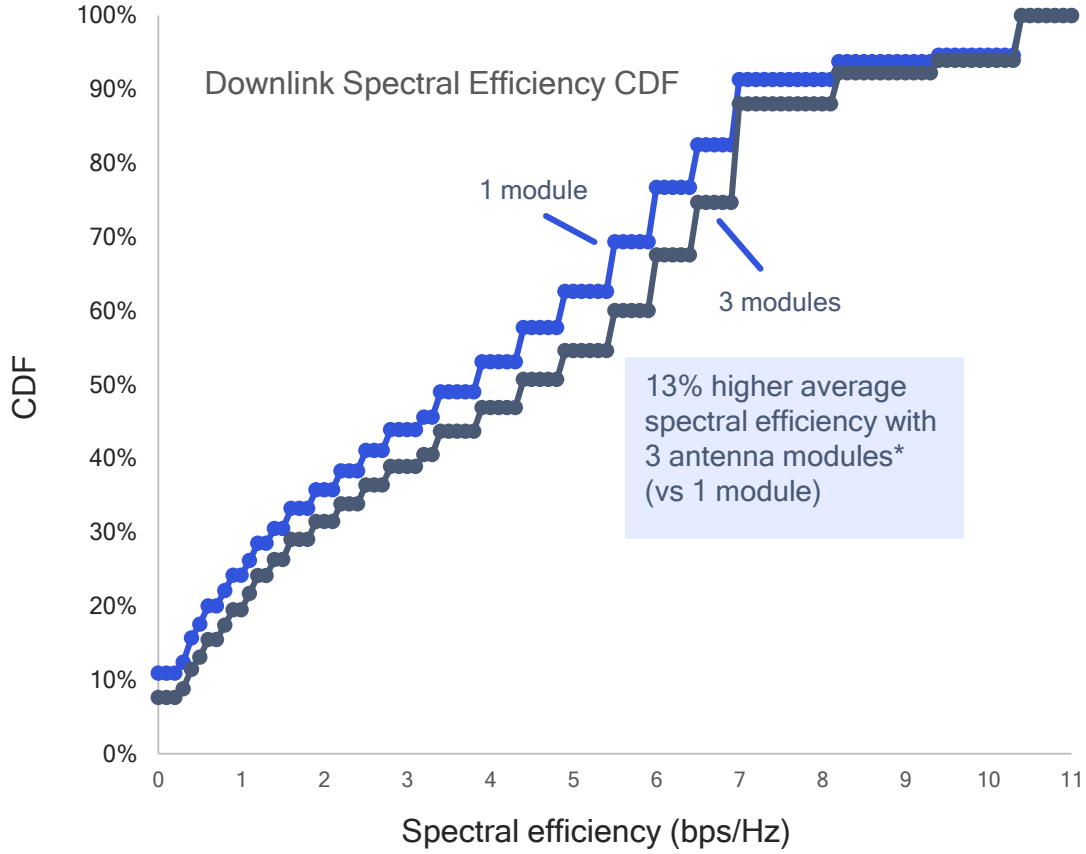
Number of antenna modules impact user experience and network performance

Downlink cell-edge user experience



* Average spectral efficiency - 0.75 bps/Hz vs 0.54 bps/Hz for 3 modules and 1 module, respectively

Downlink system capacity



* Average spectral efficiency - 4.3 bps/Hz vs 3.8 bps/Hz for 3 modules and 1 module, respectively

Cell-edge defined as 135dB or higher coupling loss
Source: Qualcomm Technologies, Inc.

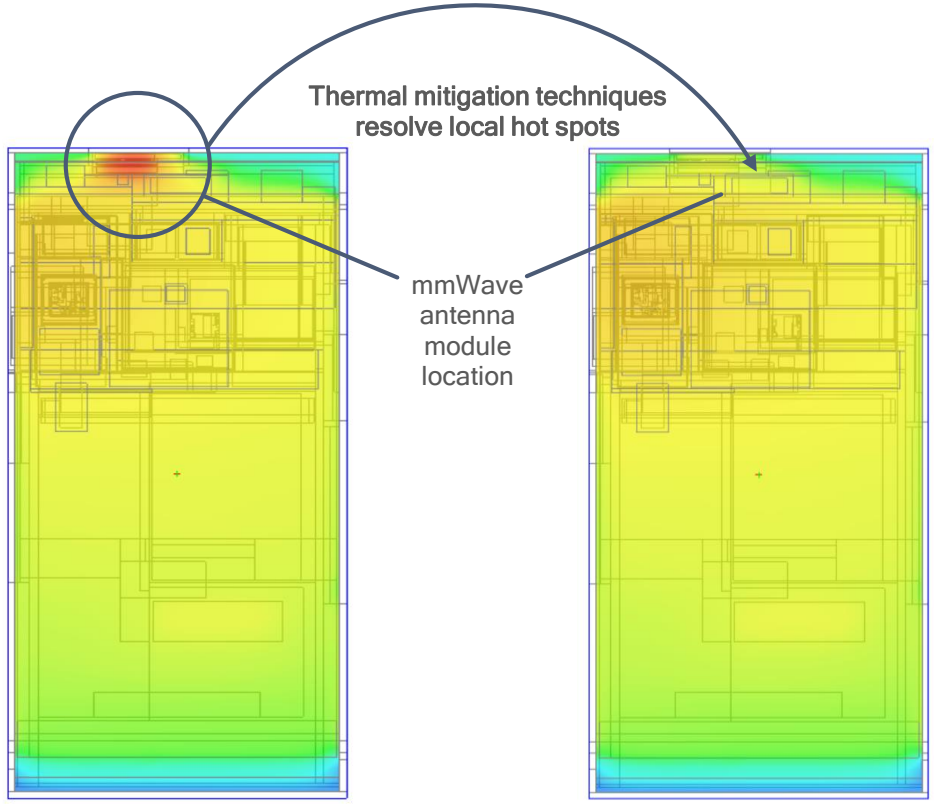
Addressing mmWave thermal design challenges

Stringent thermal constraints

- 4 Watt thermal power envelope limit
- Mitigate local hot spots for uniform surface temperature
- mmWave small fraction of power consumption, but concentrated and close to phone surface

Thermal management

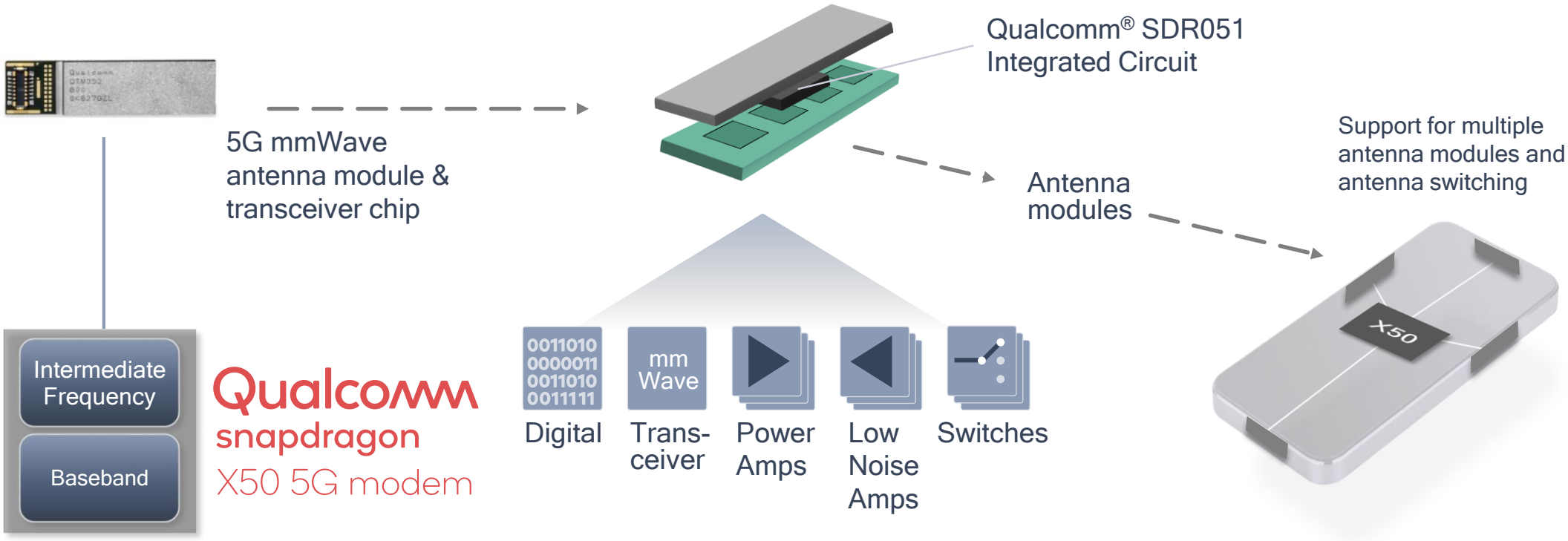
- Optimal positioning of antenna modules within device
- Use of appropriate materials for mounting, heat conduction and thermal spreading
- Advanced packaging technology for thermal performance



5G Qualcomm Reference Design example

Source: Qualcomm Technologies, Inc.
Qualcomm 5G Reference Design is a program of Qualcomm Technologies, Inc. and/or its subsidiaries.

Modem-to-antenna 5G mmWave solution



Snapdragon X50 5G mmWave architecture

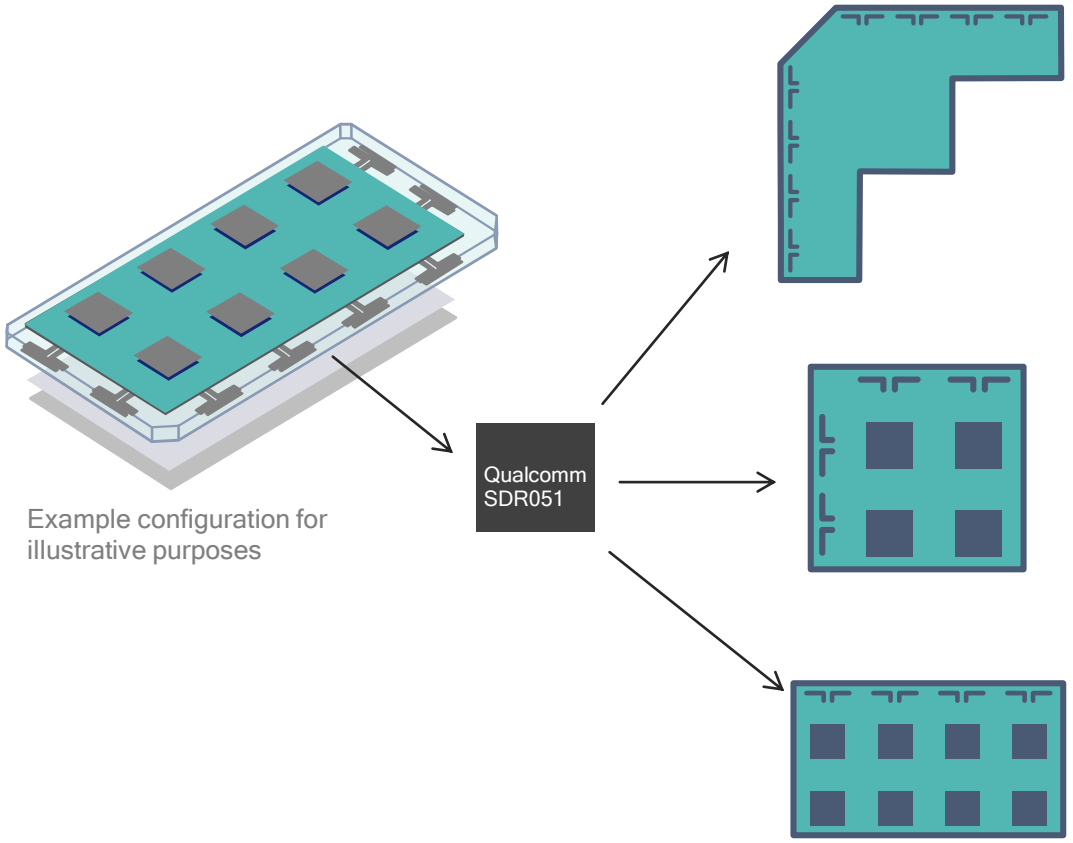
Integrated antenna array and RFFE for performance and ease-of-use

Architecture allows flexible placements and multiple modules

Flexible RFIC architecture allows optimizing antenna topology for mmWave handset design

One RFIC architecture to support several possible antenna designs

- Advanced Tx/Rx antenna switching
- Sub-array polarization and switching
- Low power consumption
- Low noise figure LNAs, high efficiency power amplifiers
- Up to 800 MHz RF bandwidth



Example configuration for illustrative purposes

Several antenna topologies and architectures evaluated to arrive at Qualcomm QTM052 configurations

Leading the 5G NR mmWave commercialization

Enabling smartphones in 2019

World’s first 5G NR milestones led by Qualcomm

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

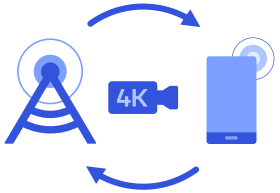
Successful multi-band (sub-6 + mmWave) 5G NR interoperability testing

MWC 2018

GSMA MOBILE WORLD CONGRESS

Interoperable 5G NR sub-6 GHz (5 vendors) & mmWave (3 vendors) connections

SAMSUNG HUAWEI



June 2018

大唐移动 DTmobile

5G NR sub-6 GHz interoperability testing preparing for the Chinese mass market

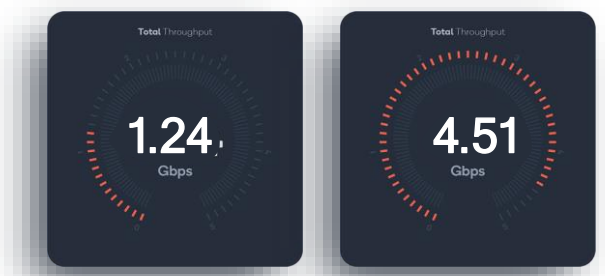
2H-2018

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

Qualcomm snapdragon X50 5G modem

Driving the 5G ecosystem towards 2019 launches in collaboration with 18+ global mobile network operators and 20+ device manufacturers

Multi-Gigabit over **mmWave** on working **Snapdragon X50 silicon**



October 2017

February 2018

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

2H 2018

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

September 2018

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

October 2018

Providing **Qualcomm® Reference Design** to accelerate commercial devices

Qualcomm snapdragon X50 5G modem

More than 30 commercial 5G **mobile devices** scheduled to launch in 2019

1H 2019

Qualcomm snapdragon X50 5G modem family

World's first announced 5G NR modems

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

ERICSSON Qualcomm

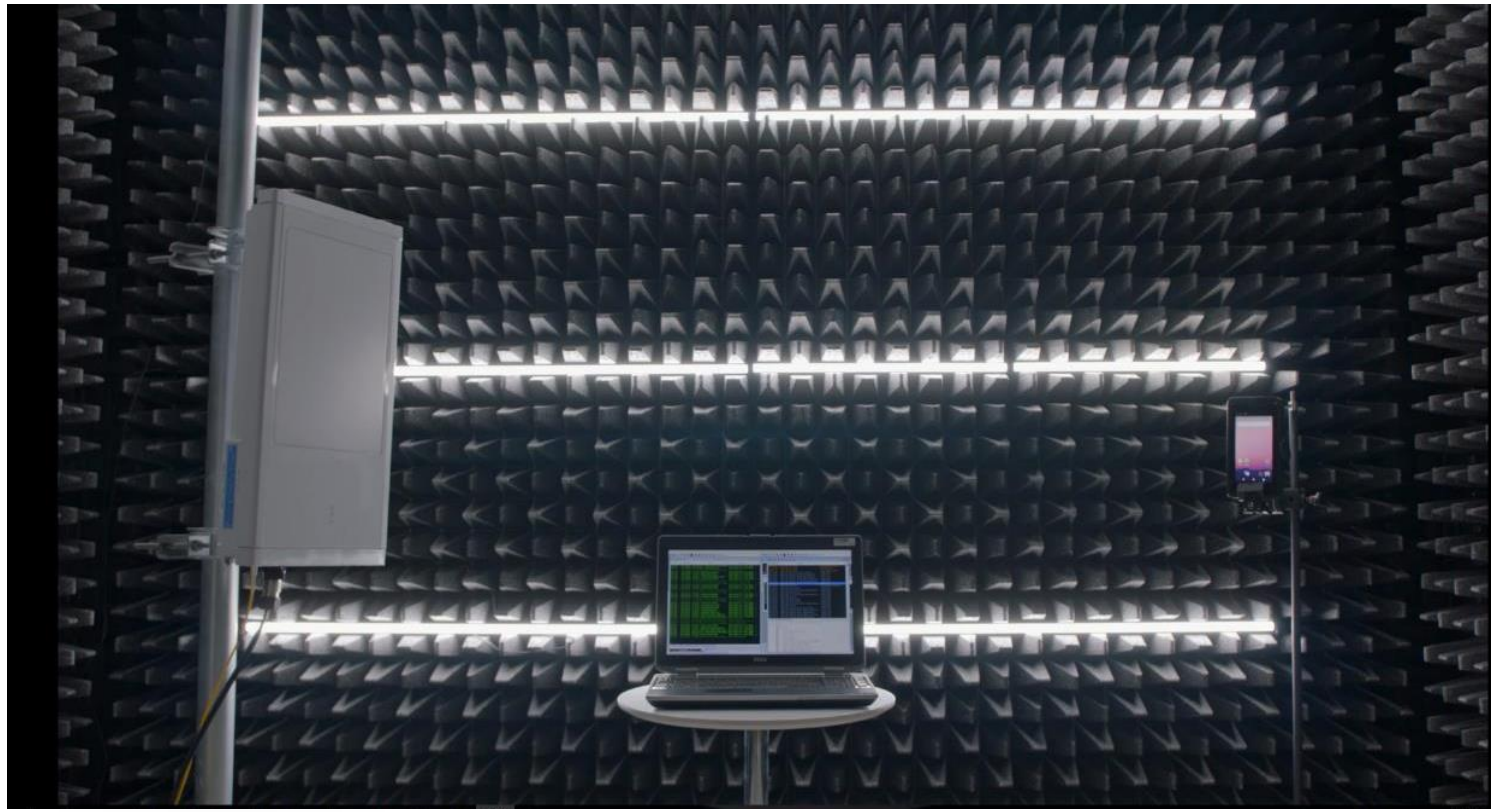
First 5G NR mmWave and sub-6 GHz over-the-air data call in a mobile form factor

Compliant with 3GPP 5G NR Rel-15 standard

Operating in NSA (non-standalone) mode

Using 3.5, 28 and 39 GHz 5G bands

Accelerating commercial deployments in 2019



Qualcomm Technologies' mobile test device with integrated Qualcomm® Snapdragon™ X50 5G modem and RF subsystem

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

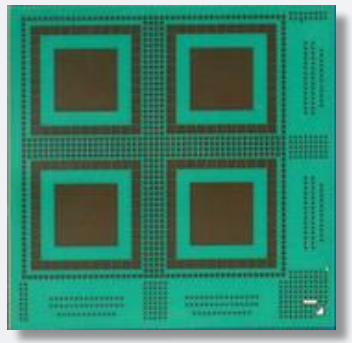
5G NR mmWave Qualcomm® Reference Design

Qualcomm

QTM052 mmWave antenna module family

Qualcomm Technologies continues to push the envelope on 5G mmWave smartphone design

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



2017

July 2018

25% smaller

October 2018

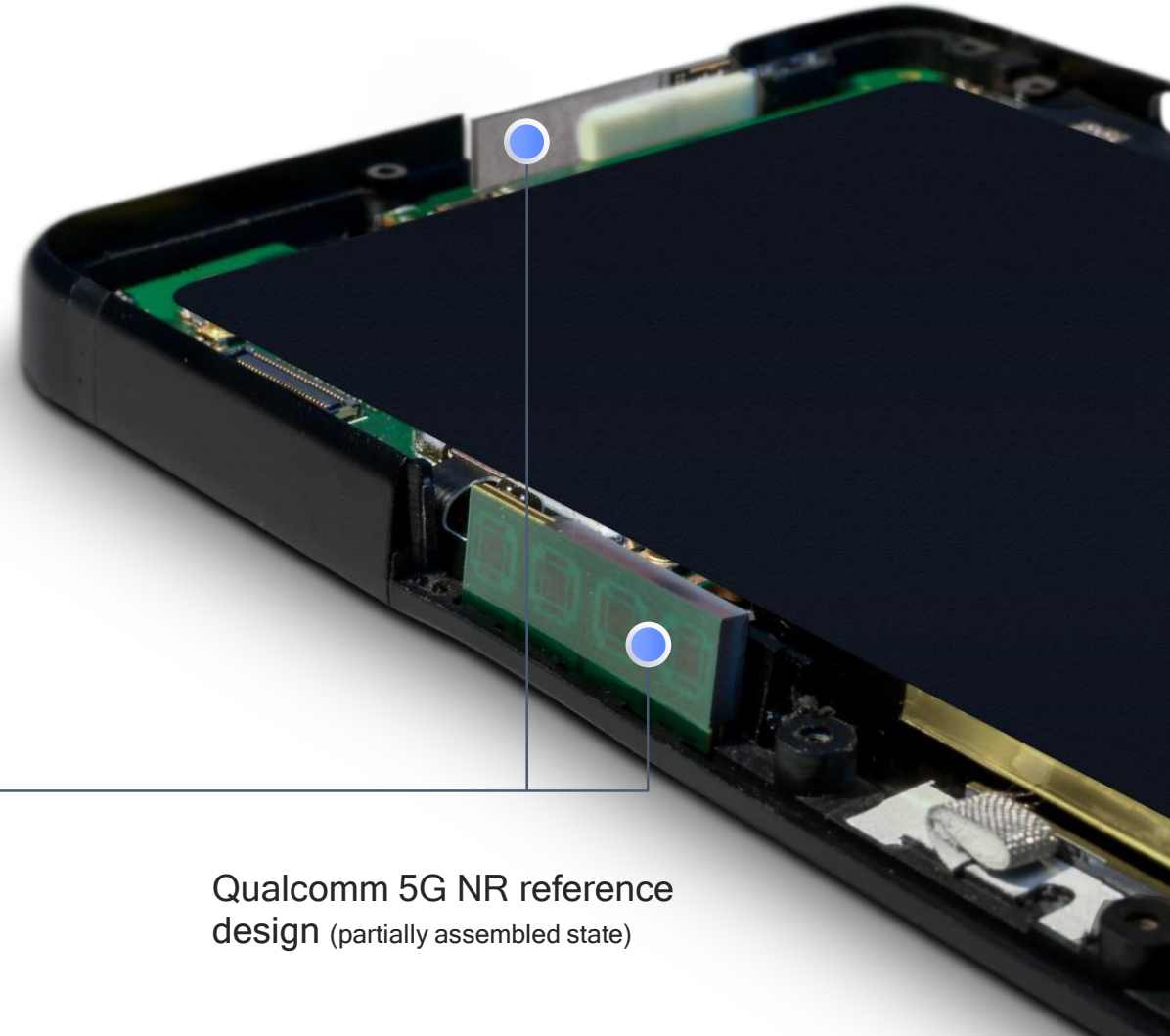
The latest, smallest addition to the QTM052 mmWave antenna module family

Qualcomm® QTM052 5G mmWave antenna module

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

July 2018

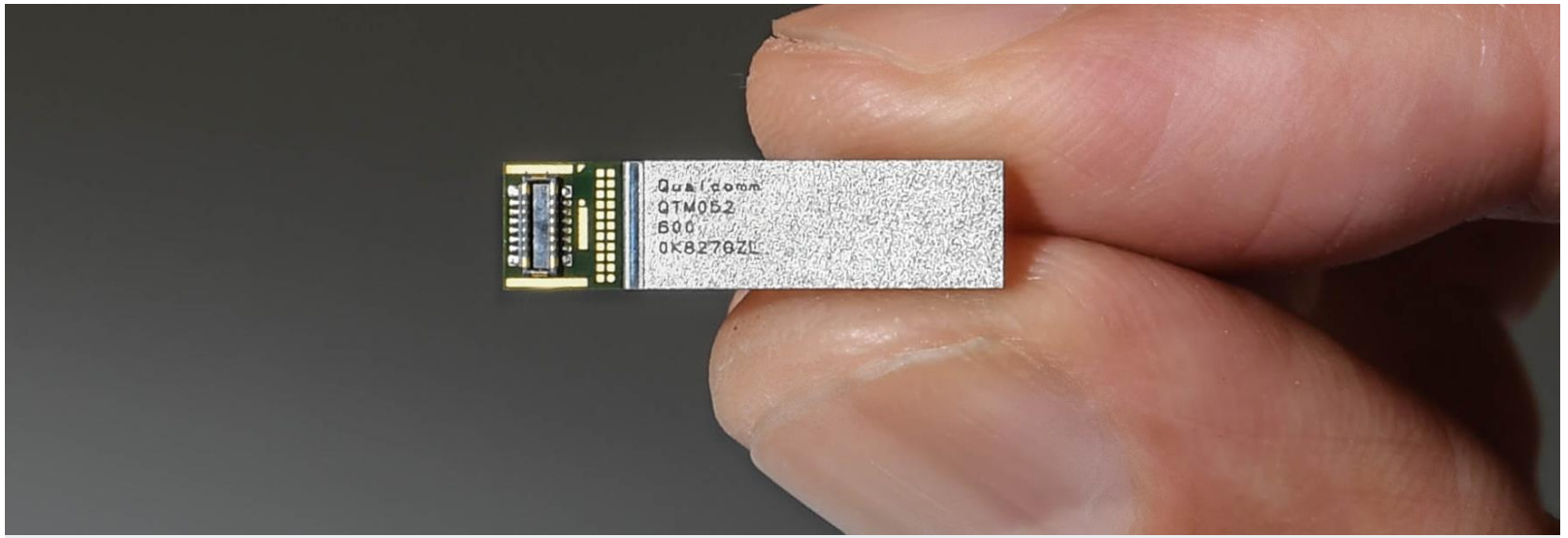
October 2018



Qualcomm 5G NR reference design (partially assembled state)

QTM052 mmWave antenna modules

Pairs with Snapdragon X50 5G modem to deliver modem-to-antenna capabilities across spectrum bands



Smartphone form factor

Suitable for compact smartphone industrial designs with four mmWave modules

Fully-integrated mmWave RF

Including transceiver, PMIC, RF front-end components, and a phased antenna array

Supported mmWave bands

Support for up to 800 MHz of bandwidth in n257, n260, and n261 5G NR mmWave bands[1]

Advanced mobility features

Supporting beamforming, beam steering, and beam tracking for bi-directional mmWave communications

1 3GPP band definition are n257 (26.5-29.5 GHz); n260 (37-40 GHz); n261 (27.5-28.35 GHz)

Global mmWave spectrum targets

	24-28GHz	37-40GHz	64-71GHz
	24.25-24.45GHz 24.75-25.25GHz 27.5-28.35GHz	37-37.6GHz 37.6-40GHz 47.2-48.2GHz	64-71GHz
	26.5-27.5GHz 27.5-28.35GHz	37-37.6GHz 37.6-40GHz	64-71GHz
	24.5-27.5GHz		
	26GHz		
	26GHz		
	26GHz		
	26.5-27.5GHz		
	24.5-27.5GHz	37.5-42.5GHz	
	26.5-29.5GHz		
	27-29.5GHz		
	24.25-27.5GHz	39GHz	

5G NR mmWave spectrum highlights

Regions targeting 2019 deployments

U.S.

- Allocated 12.55 GHz of mmWave spectrum so far
- Auction started in Nov18 for 28 GHz with 24 GHz following; 37/39/47 GHz auction expected in 2H19

South Korea

- 28 GHz auction completed in Jun. 2018; each operator (SKT, KT, LG U+) secured 800 MHz
- Expected additional 3 GHz bandwidth in 2019+

Japan

- Official 5G mmWave band in 28 GHz spectrum with maximum 2 GHz bandwidth
- Assignment completed in April 2019

Italy

- 5G spectrum auction completed in Sept. 2018 with right of use starting January 1st, 2019
- Initial commercial deployment expected in 2019

Russia

- 26 GHz auction completed in Q4 2018 to enable 2019 commercial deployments

Germany

- Regulator published draft proposed allocation procedure and condition of use for 26 GHz

Qualcomm
FSM100xx
10nm

Qualcomm® FSM100xx

Industry's First 5G NR Solution for Small Cells and Remote Radio Heads

Full 5G spectrum support
Global sub-6GHz and mmWave bands

Enterprise-grade
Supporting small form factor and PoE (Power over Ethernet)

Flexible architecture
Adaptable for Cloud RAN or distributed deployment models

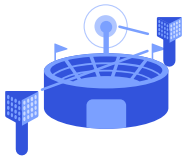
Mobile expertise
Leveraging 10nm mobile tech for optimum power & performance

Driving the 5G NR mmWave evolution

5G NR Release 16+

Evolving 5G NR mmWave beyond 3GPP Rel-15

Bringing new capabilities, efficiencies, spectrums, and deployment opportunities



Integrated access and backhaul (IAB)

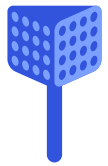
Enabling flexible deployment of 5G NR mmWave small cells reusing spectrum and equipment for access and backhaul

Expanded spectrum support

Supporting bands above 52.6 GHz and unlicensed spectrum for both license-assisted and standalone operations[1]

Wideband positioning

Providing accurate device positioning (down to 0.5m) complementing LTE positioning and for new use cases[2]



Enhanced beam management

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

Dual connectivity optimization

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

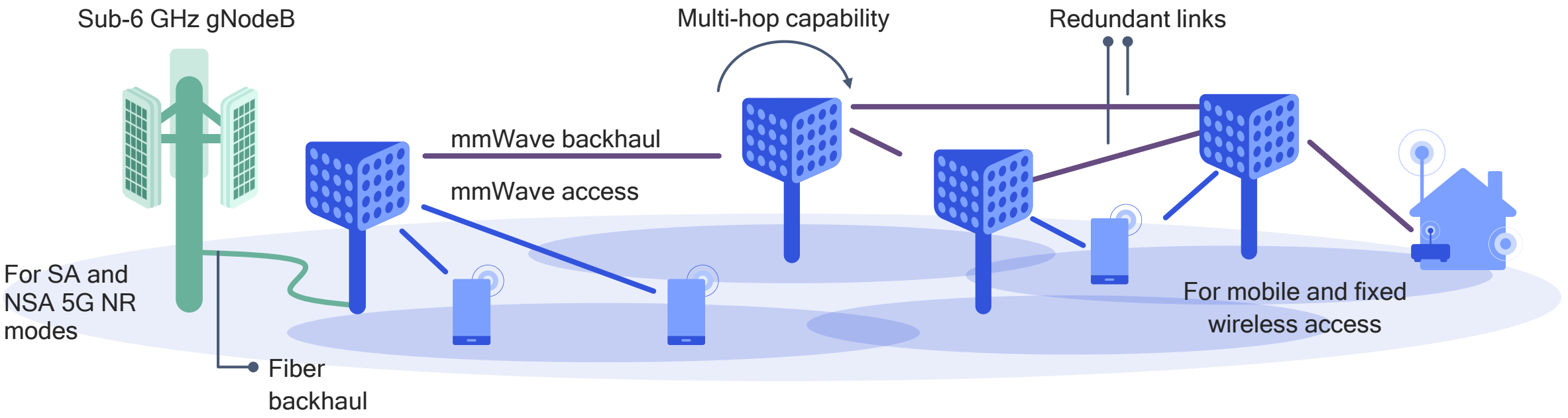
Power saving features

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

1 mmWave operating in unlicensed expected in Rel-17, including 57-71 GHz band; 2 Such as automotive and industrial IoT; 3 C-DRX - Connected Discontinued Receive

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

Improves coverage and capacity, while limiting backhaul cost



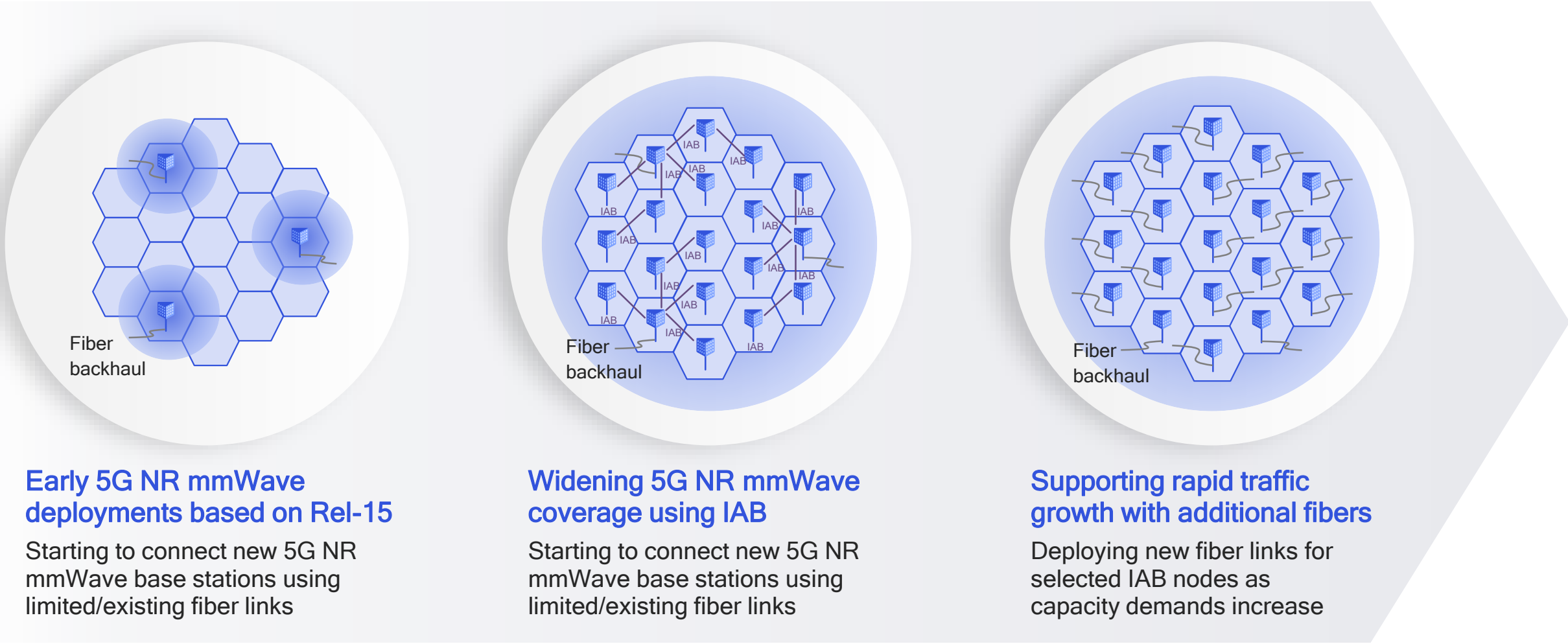
1 Integrated Access and Backhaul

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



Early 5G NR mmWave deployments based on Rel-15

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

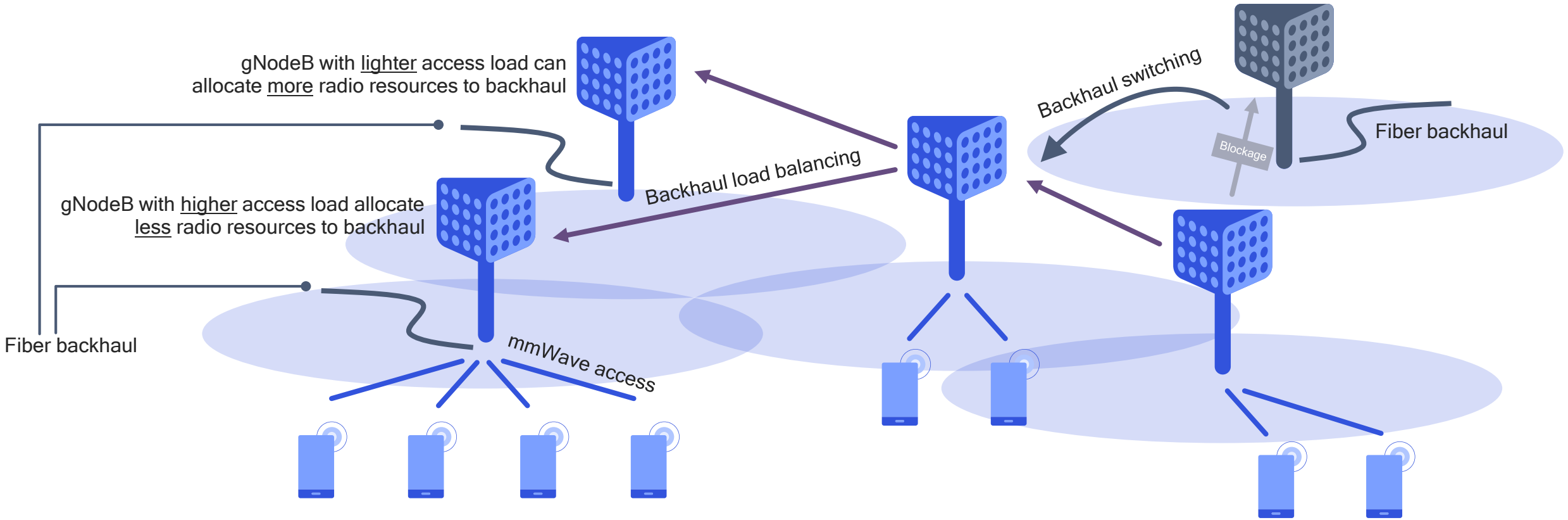
Widening 5G NR mmWave coverage using IAB

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

Supporting rapid traffic growth with additional fibers

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

Dynamic topology adaptation for better efficiency/reliability



Fully flexible resource allocation between access and backhaul

Different access-backhaul partitioning allowed at different gNodeBs

Dynamic backhaul switching mitigates blockage/interference

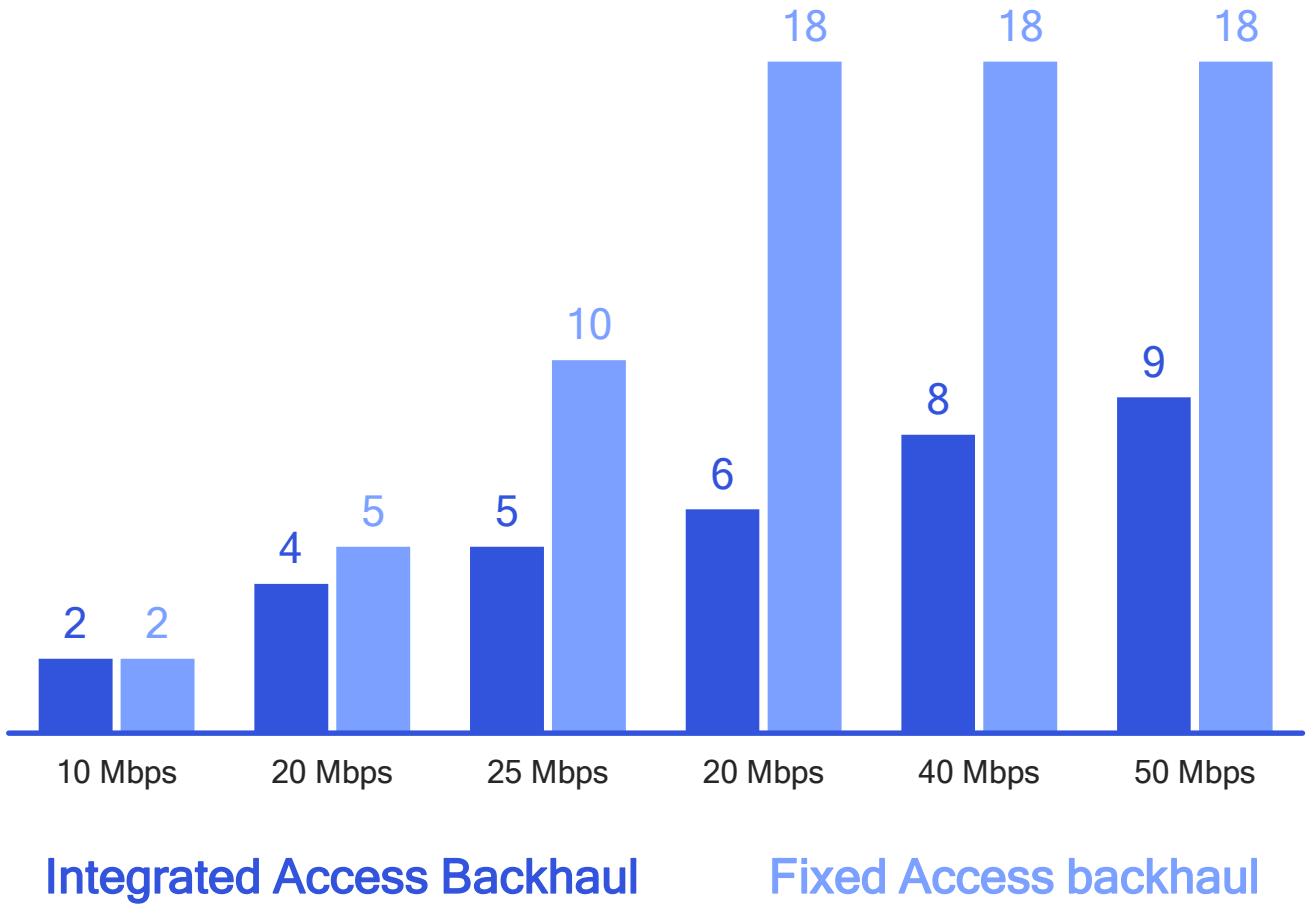
5G NR Integrated Access & Backhaul

Supports more flexible deployments and reduces network cost

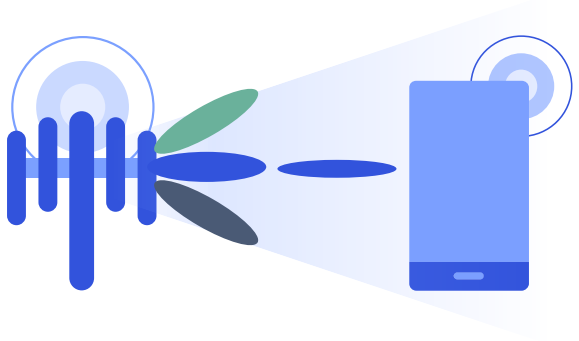
Fewer fiber drop points needed compared to fixed backhaul for a given traffic demand

Dynamically adjusts to changes in fiber drop locations and numbers

Number of fiber drops needed

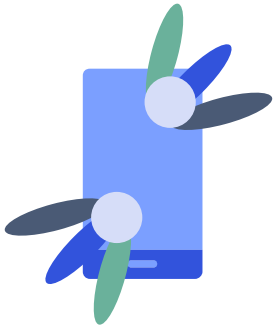


*Assumptions: 28 GHz band, 1GHz b/w, 18 base-stations; 200m ISD; 600 devices, uniform distribution; results obtained without any constraint on the number of hops



Improved reliability

- Supporting multi-beam repetitions
- More robust beam failure recovery schemes[1] 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 directions[2]

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)

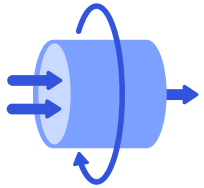
Further enhancing mmWave beam management

Further improving power efficiencies for 5G NR mmWave

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

Device assisted power savings

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



Efficient carrier aggregation operation

Reduce number of blind decoding to optimize power consumption

Multi-panel beam management

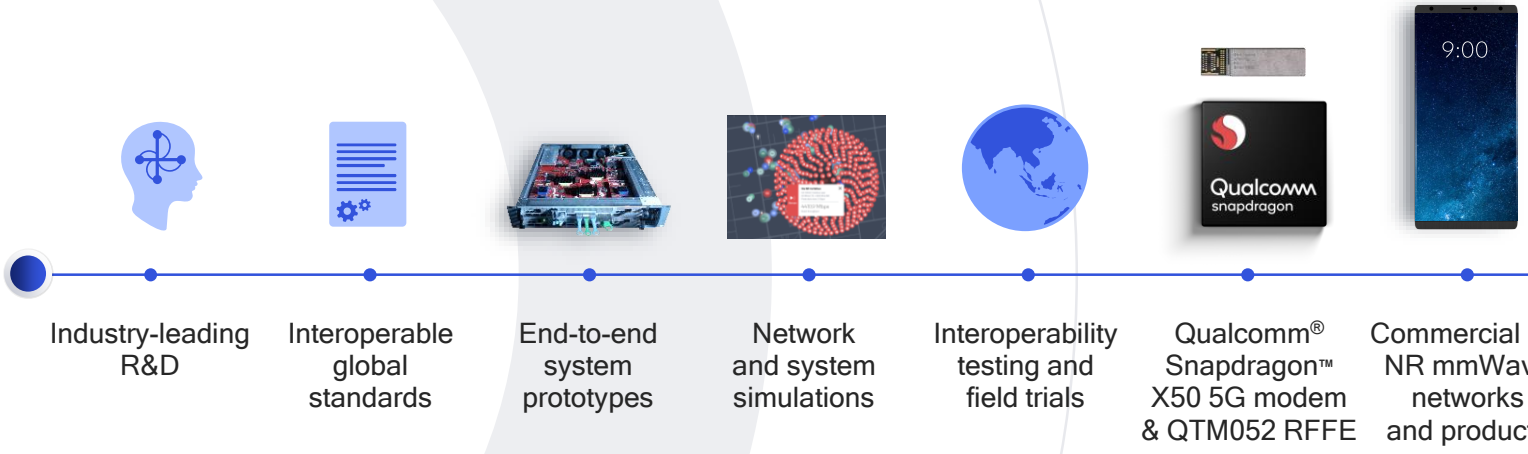
Antenna panels information is provided by the device to enable more power-efficient beam sweeping/switching

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

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

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;

Making 5G NR mmWave a commercial reality in 2019



Industry-leading R&D

Interoperable global standards

End-to-end system prototypes

Network and system simulations

Interoperability testing and field trials

Qualcomm® Snapdragon™ X50 5G modem & QTM052 RFFE

Commercial 5G NR mmWave networks and products

Qualcomm

Thank you!

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