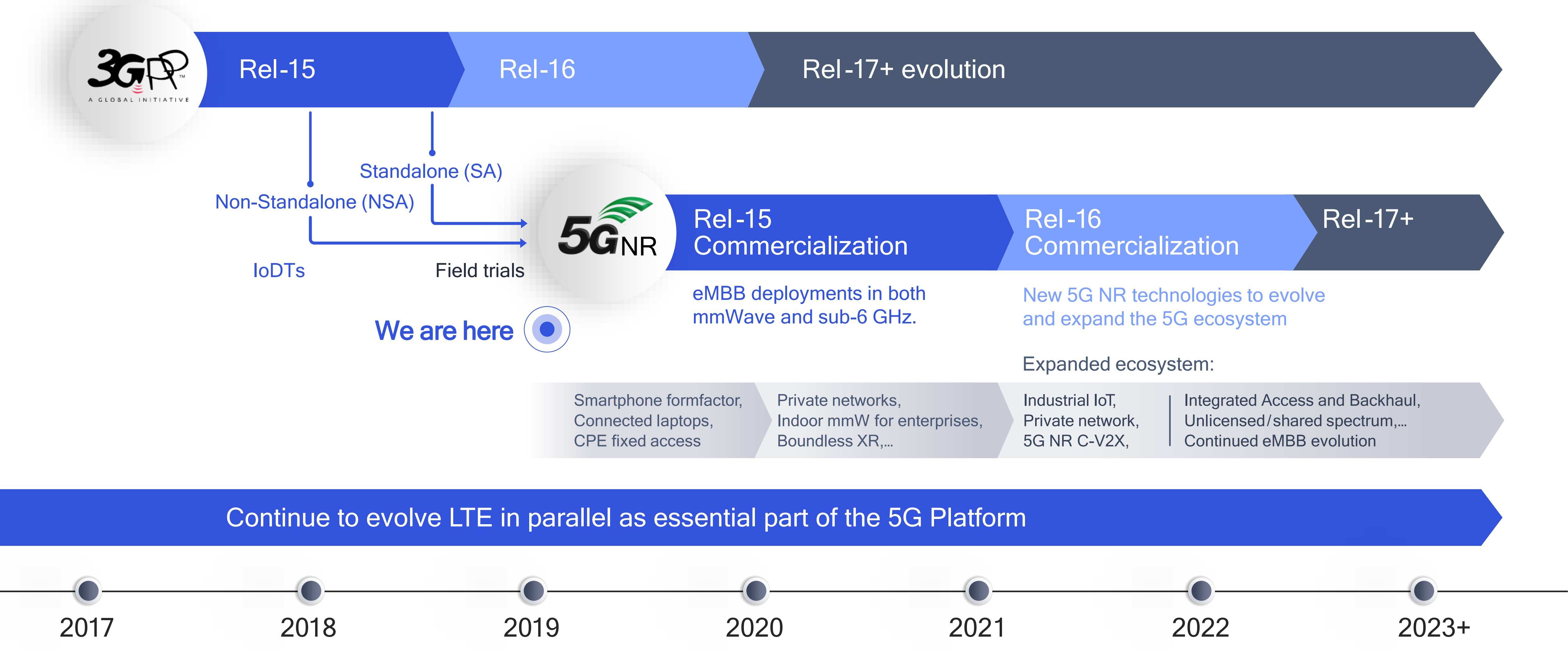
January 2019 @qualcomm_tech

Qualcomm

Breaking the wireless barriers to mobilize 5G NR mmWave


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

Driving the 5G roadmap and ecosystem expansion



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

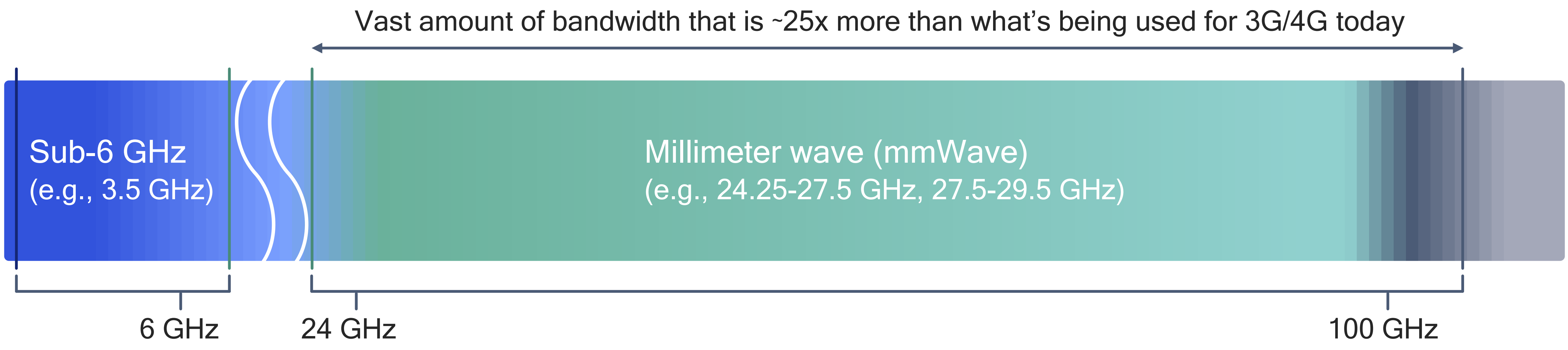
In 2024, ~75% of mobile data traffic from multi-media creation & consumption

5G

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



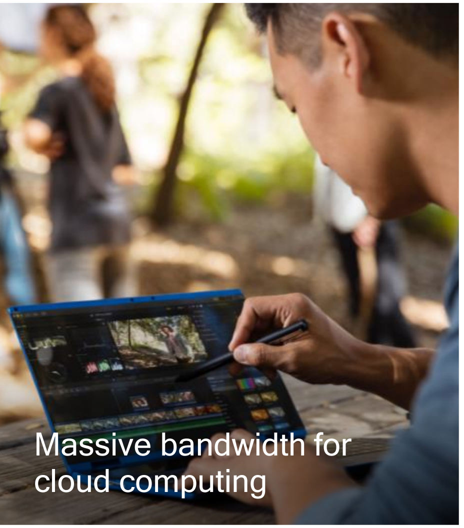
Multi-Gbps data rates
With large bandwidths (100s of MHz)

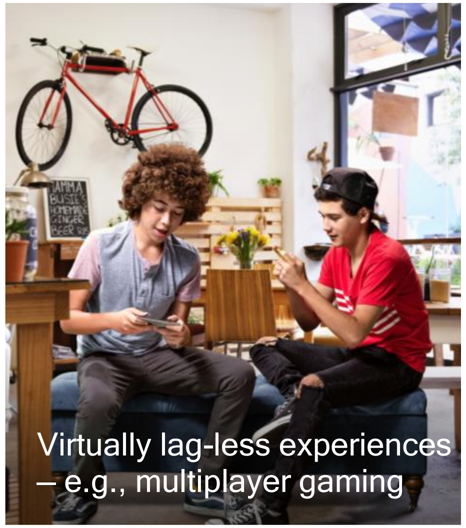
Much more capacity
With dense spatial reuse

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 NR mmWave will support new and enhanced mobile experiences

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

Many milestones to mobilize 5G NR mmWave

1990+
Many years of foundational technology research on mmWave, MIMO, advanced RF

MWC 2016
Demonstrated Non-line of sight (NLOS) mmWave mobility with beam steering, first at 5G analyst day in October 2015

October 2016
Introduced world's first announced 5G modem, the Qualcomm® Snapdragon™ X50, mmWave and Sub 6 GHz

MWC 2017
Demonstrated NLOS van mobility with beam steering & switching across access points

March 2017
A GLOBAL INITIATIVE

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

September 2017
Launched world's first mmWave smartphone, Asus ZenFone, supporting 802.11ad 60 GHz

September 2017


Showcased 5G NR mmWave coverage simulations announced prototype mmWave UE

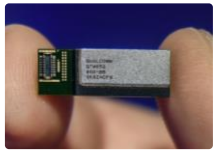
October 2017
Demonstrated world's first 5G mmWave connection based on Snapdragon X50; announced smartphone reference design

December 2017
ERICSSON

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

MWC 2018
Completed interoperability testing with multiple infrastructure vendors, showcased 5G network capacity simulations

ERICSSON
NOKIA
SAMSUNG

July 2018


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

September 2018
Announced first 3GPP-compliant 5G NR mmWave OTA Call with a mobile form factor device

October 2018


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

5G NR field trials with MNOs and infra vendors

MWC 2019
Stay tuned for groundbreaking mmWave demos

GSMA MOBILE WORLD CONGRESS

1H19
Commercial 5G NR mmWave networks and devices

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

Global mmWave spectrum status

	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 expected by March 2019

Italy

5G spectrum auction completed in Sept. 2018 with right of use starting January 1st, 2019

Initial commercial deployment expected in 2019

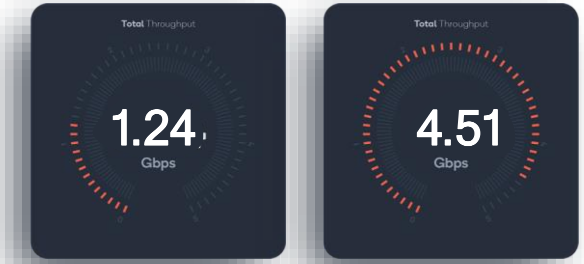
Russia

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

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

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

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

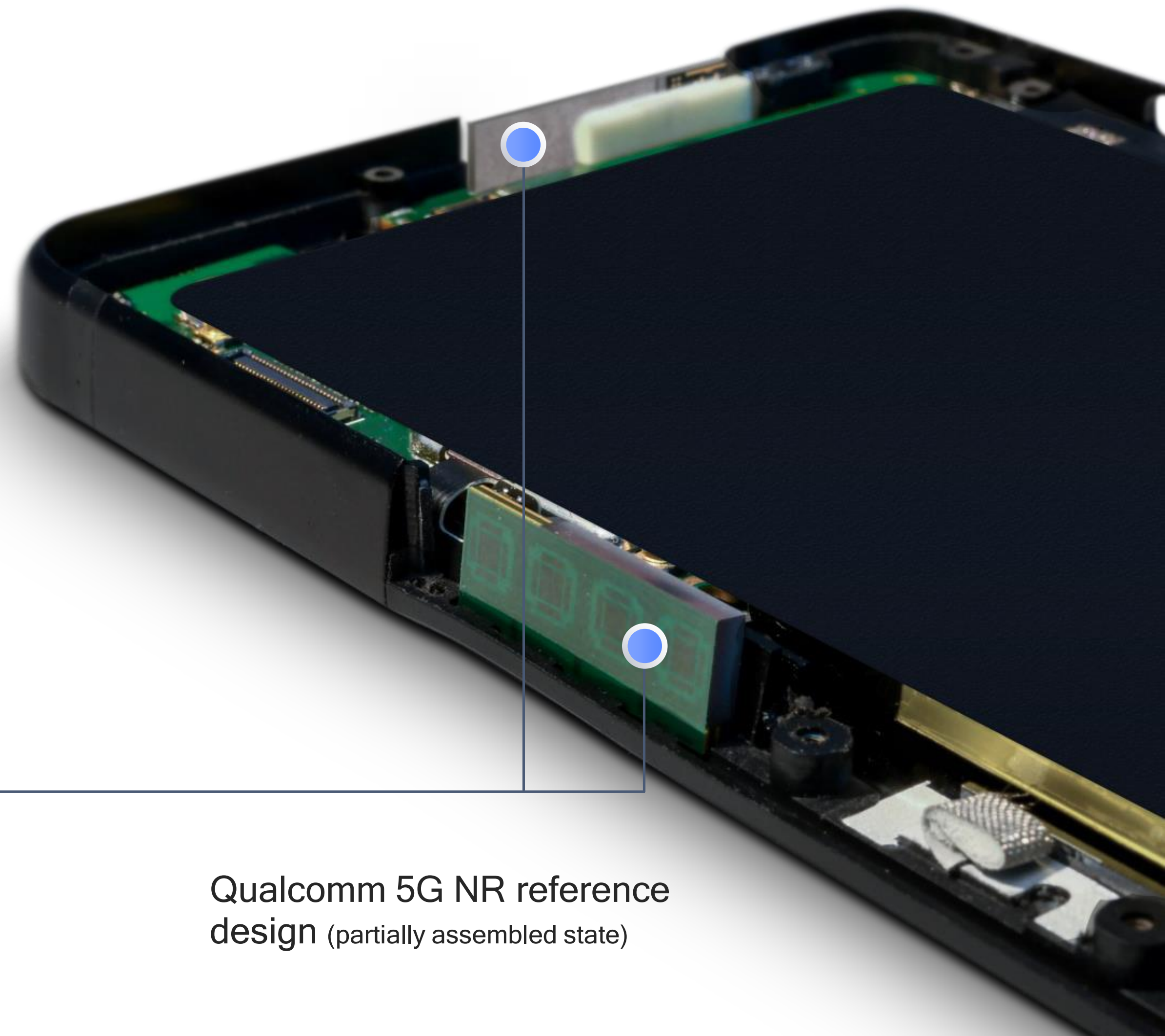
Vodafone Group

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)

Qualcomm QTM052 is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.
Qualcomm 5G NR Reference Design is a program of Qualcomm Technologies, Inc. and/or its subsidiaries.

Breaking the wireless barriers to mobilize 5G NR mmWave

Standardized in 3GPP Rel-15

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

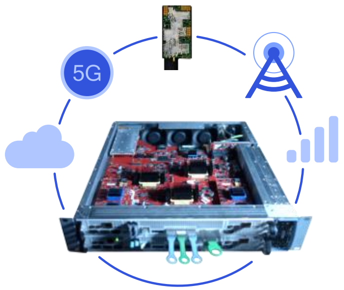
mmWave is intrinsically more power hungry due to wider bandwidth with thermal challenges in small formfactor

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

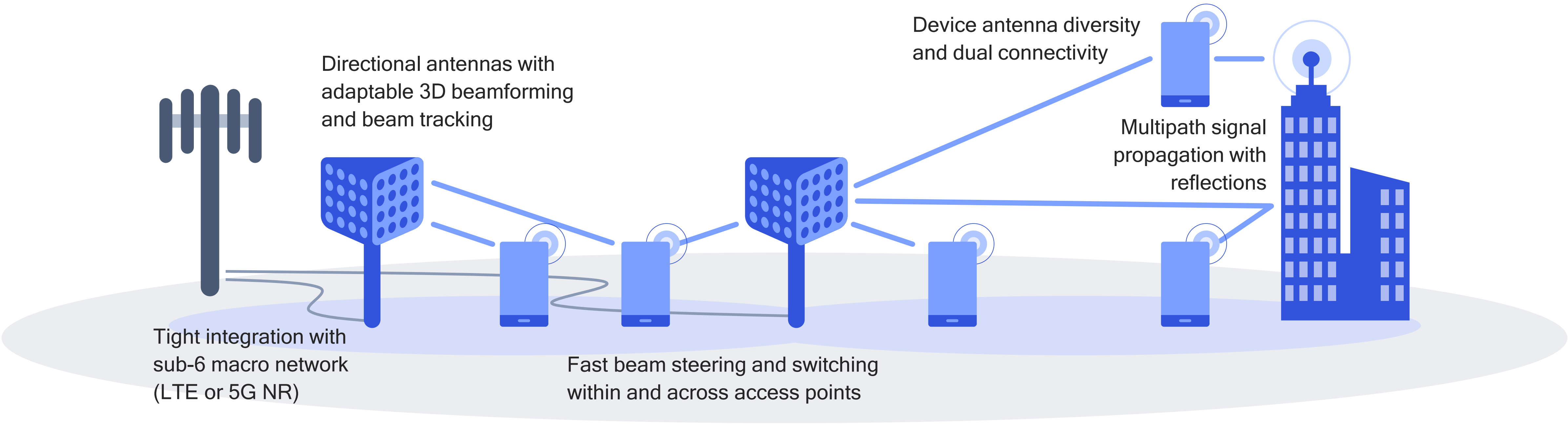
Fully utilizing prototype systems and our leading global network experience

5 Cutting-edge modem and RFFE solutions

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

Mobilizing mmWave with 5G NR technologies

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



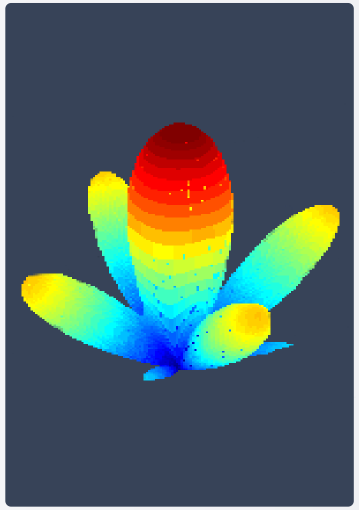
Delivering robust NLOS connectivity

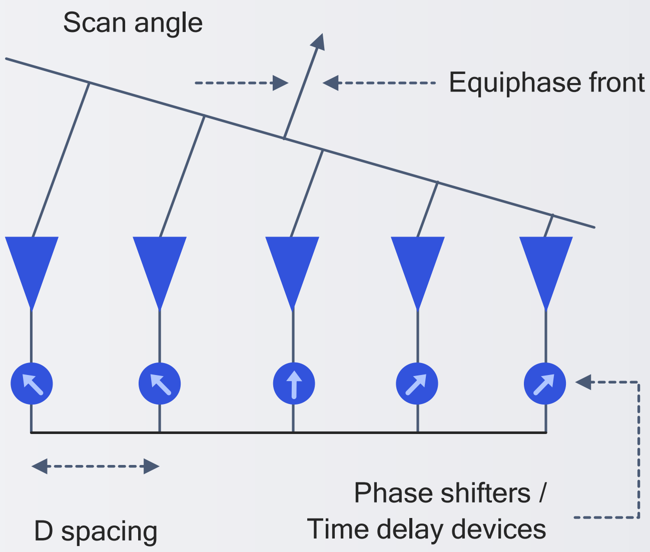
Supporting seamless mobility

Complementing macro area coverage

Addressing mobility challenges with multi-beam techniques

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

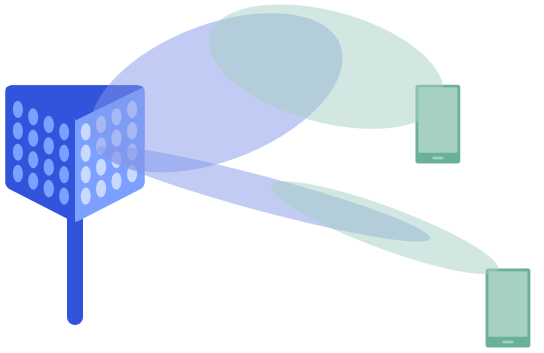




High-gain directional antenna arrays

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

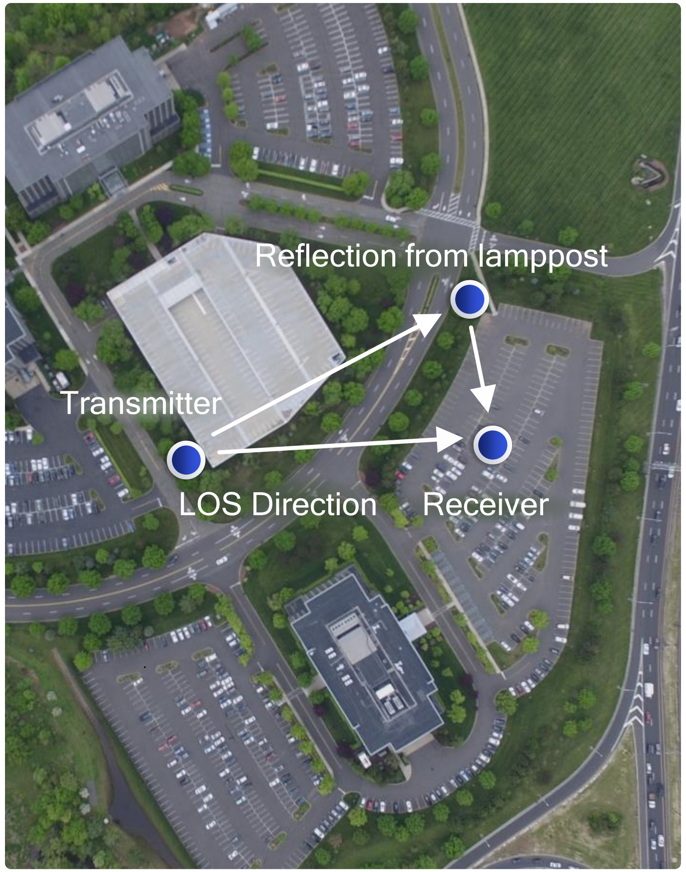


Beam switching Switches between candidate beams to adapt to changing environment

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

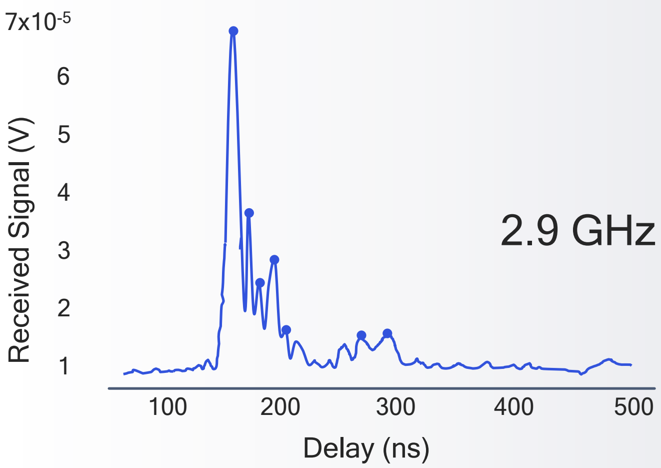
Beam tracking Distinguishes between beams arriving from gNodeB

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

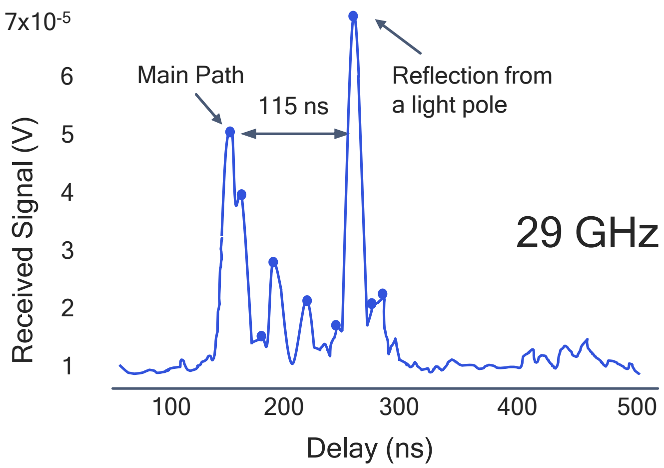


Channel response from omni-directional antennas
(Example measurement)

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

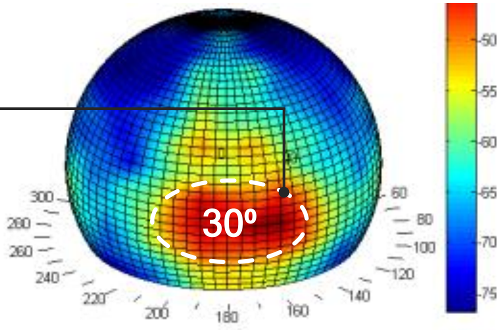
Leveraging path diversity to overcome blockage

Based on our spherical scan measurements

Indoor office

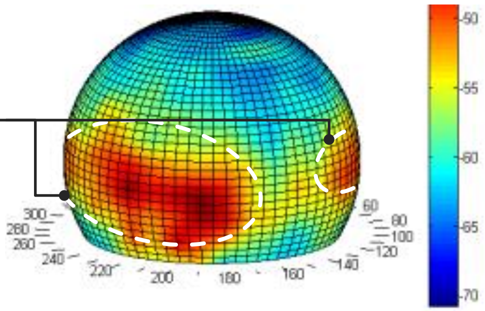
Diversity in elevation

Numerous resolvable paths in elevation



Diversity in Azimuth

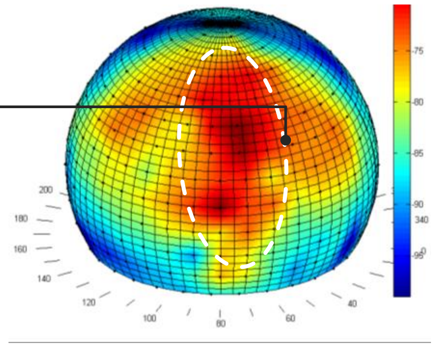
Significant path diversity in azimuth – Ability to withstand blockage events



Outdoor

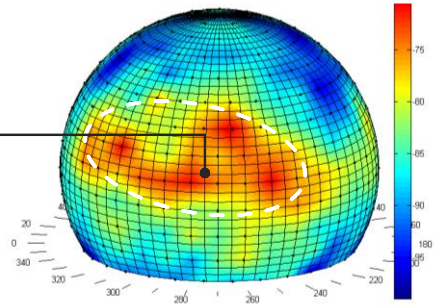
Diversity in elevation

Reflections from tall buildings result in wide elevation spread



Diversity in Azimuth

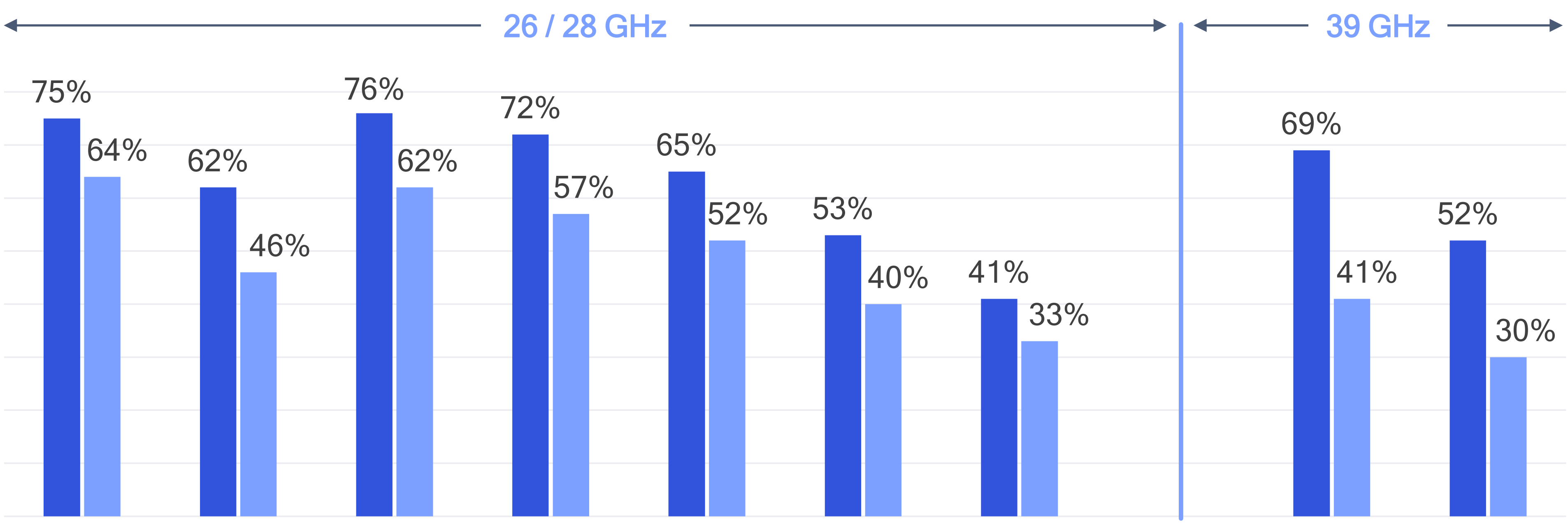
Foliage obstructed diffracted path – energy spread across wide azimuth



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

Downlink
Uplink
Coverage %

Co-siting with LTE



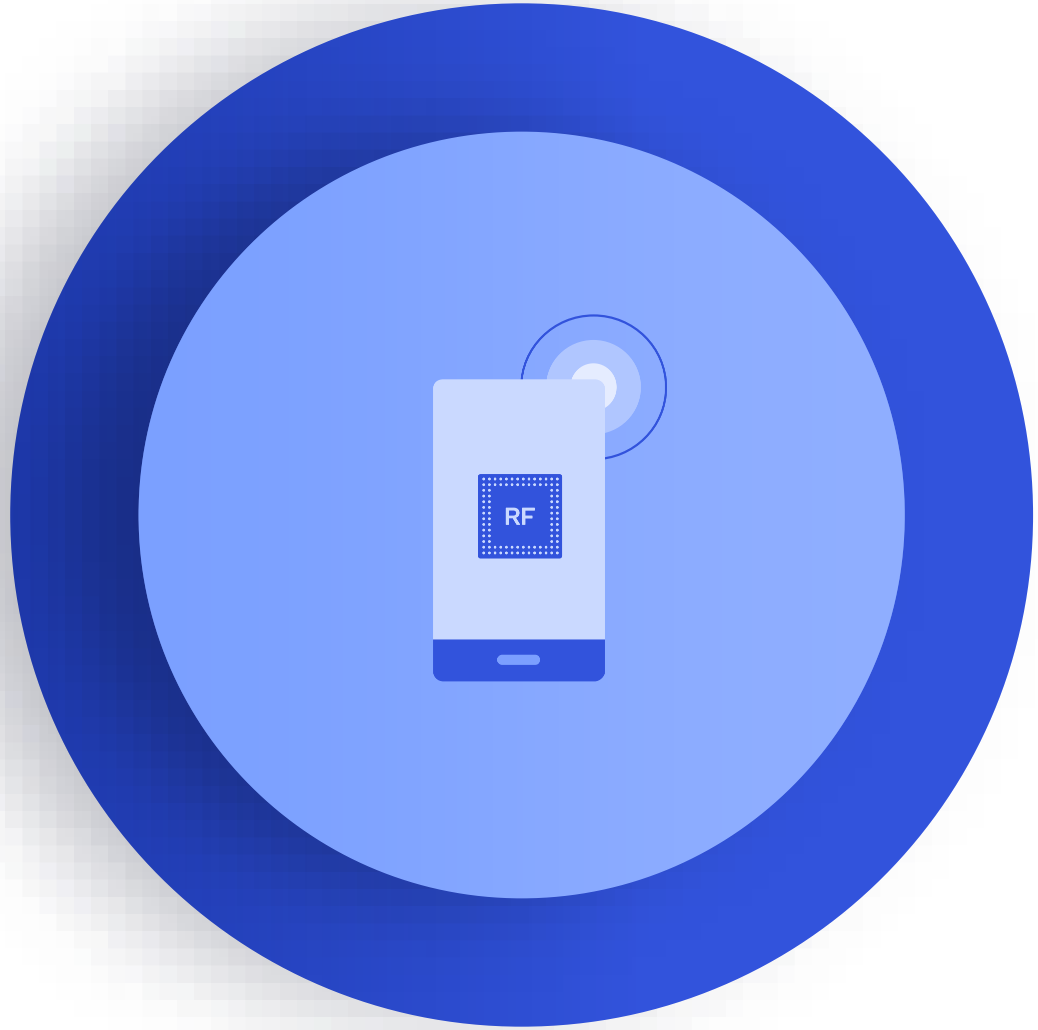
		US City 1	US City 2	Korean City 1	Hong Kong	Japan City 1	Russia City 1	Europe City 1	US City 1	US City 2
Median Downlink Burst Rate (Gbps)		2.2 Gbps	1.5 Gbps	2.7 Gbps	2.4 Gbps	2.7 Gbps	2.0 Gbps	2.2 Gbps	1.5 Gbps	1.2 Gbps
Site density (per km^2)	Total	48	36	41	39	28	26	28	48	36
	Macro	0	8	33	39	28	26	7	0	8
	Small	48	28	8	0	0	0	21	48	28

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

Significant 5G NR mmWave outdoor coverage via co-siting

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

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

Power consumption
Support multi-Gigabit throughputs with high power efficiency

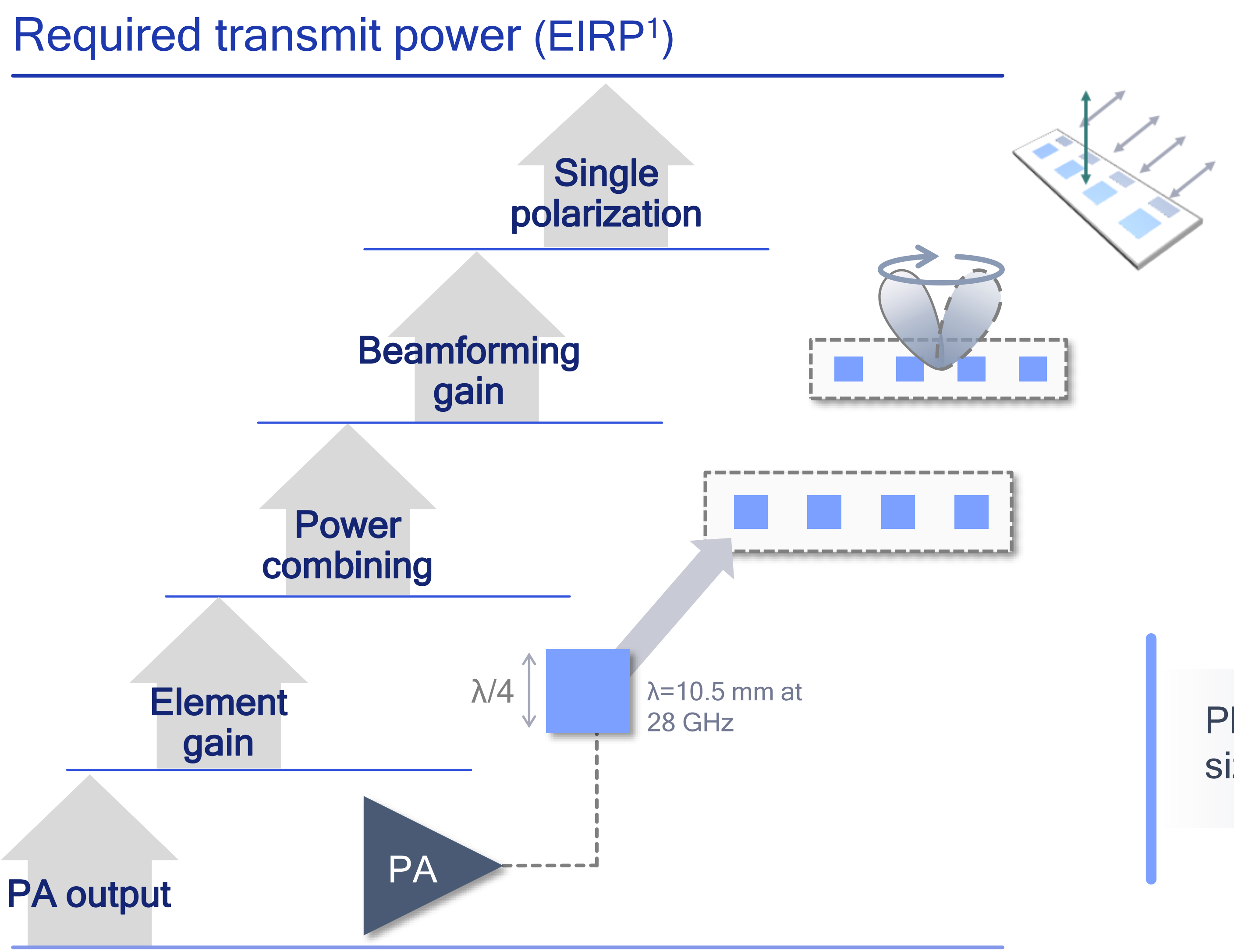
Mobility
Maintain reliable mmWave connectivity in a changing, mobile environment

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

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

Regulatory compliance
Optimize transmit power and throughput while meeting regulatory requirements

Achieving required transmit power for mobile mmWave



Beamforming and directional architectures allow more gain

# of antennas in array determines max EIRP

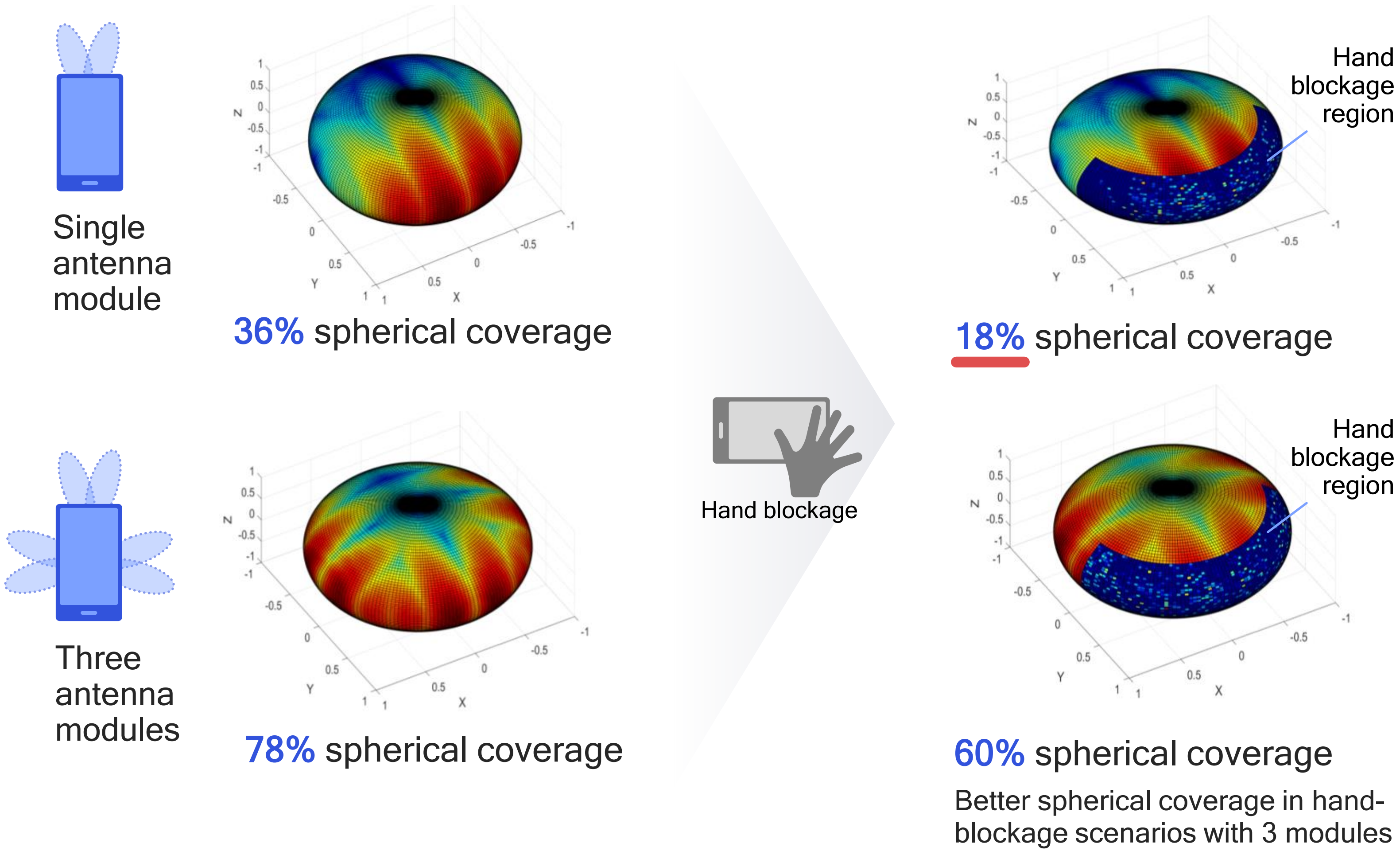
Physics dictates antenna size and spacing

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

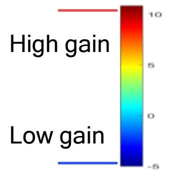
UE antenna module design for coverage

Design objectives

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



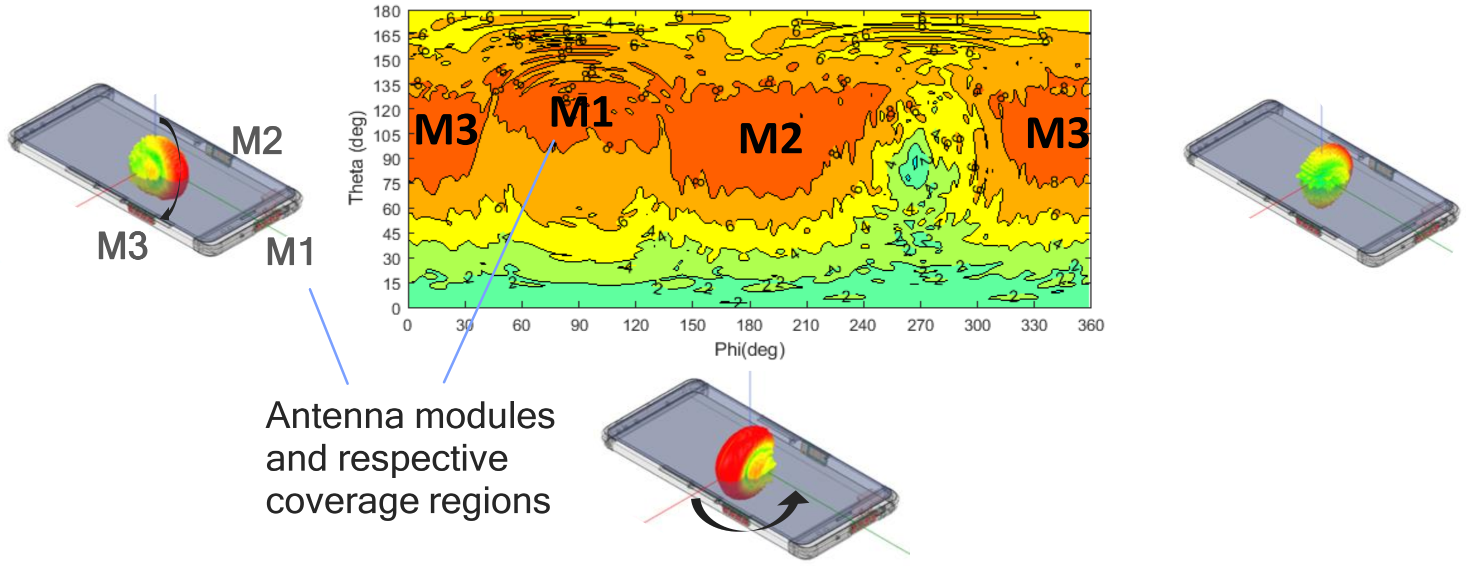
Multiple antenna modules provide nearly spherical coverage for both polarizations

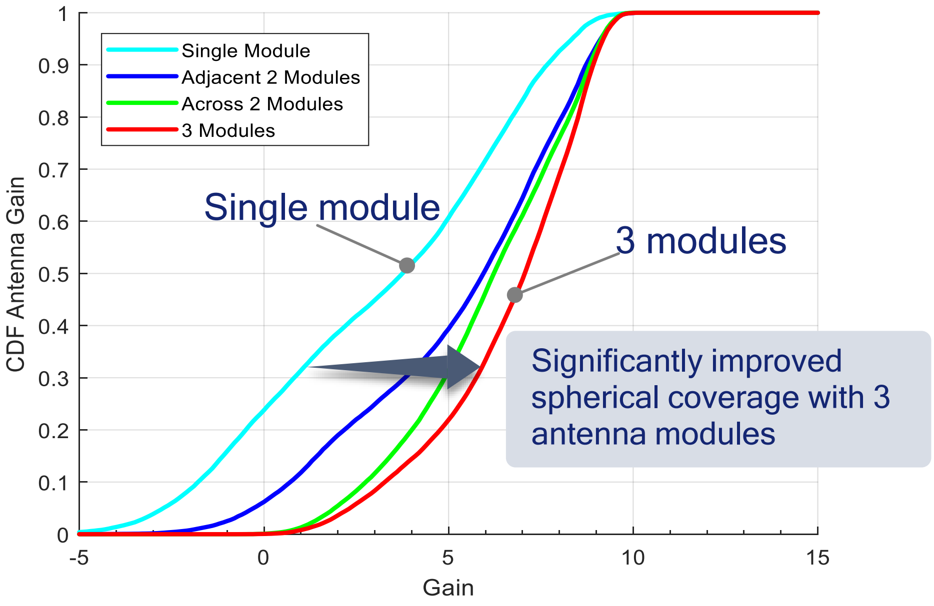


Source: Qualcomm Technologies, Inc.

UE antenna module design for coverage

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

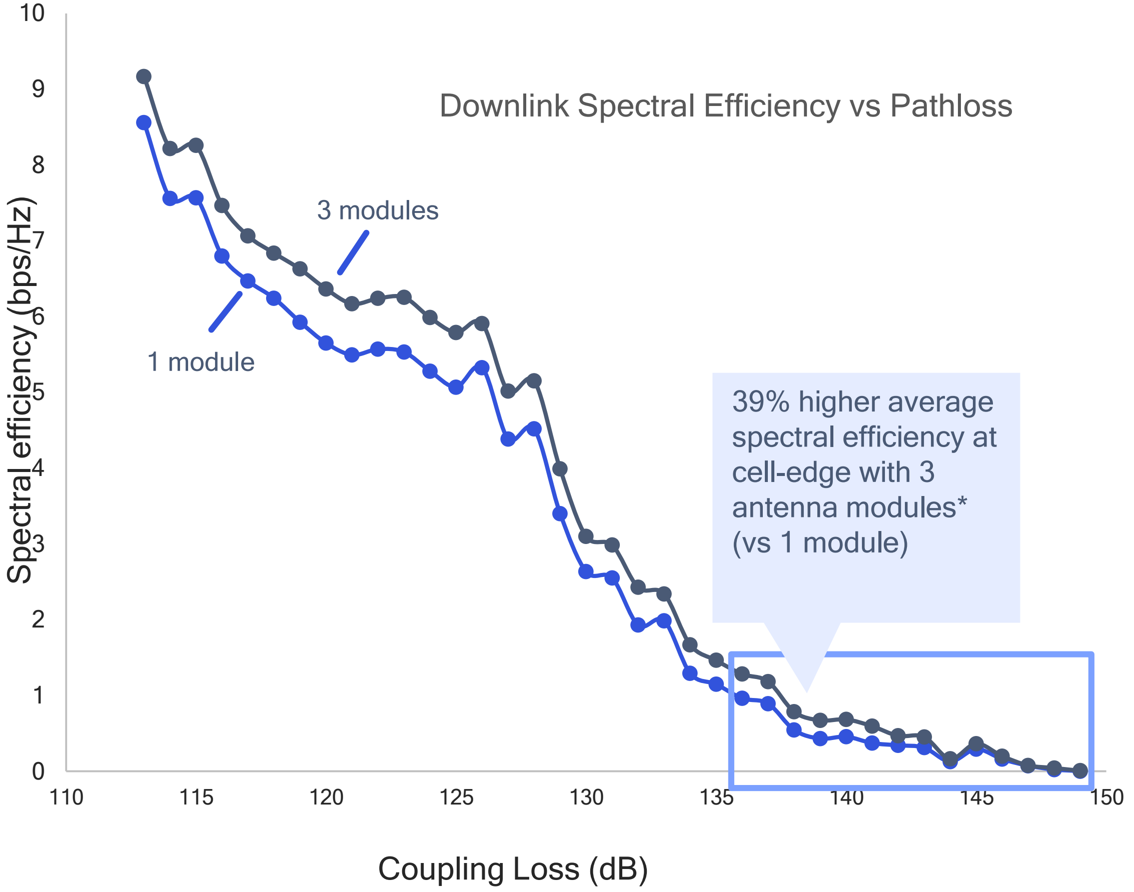




Source: Qualcomm Technologies, Inc.

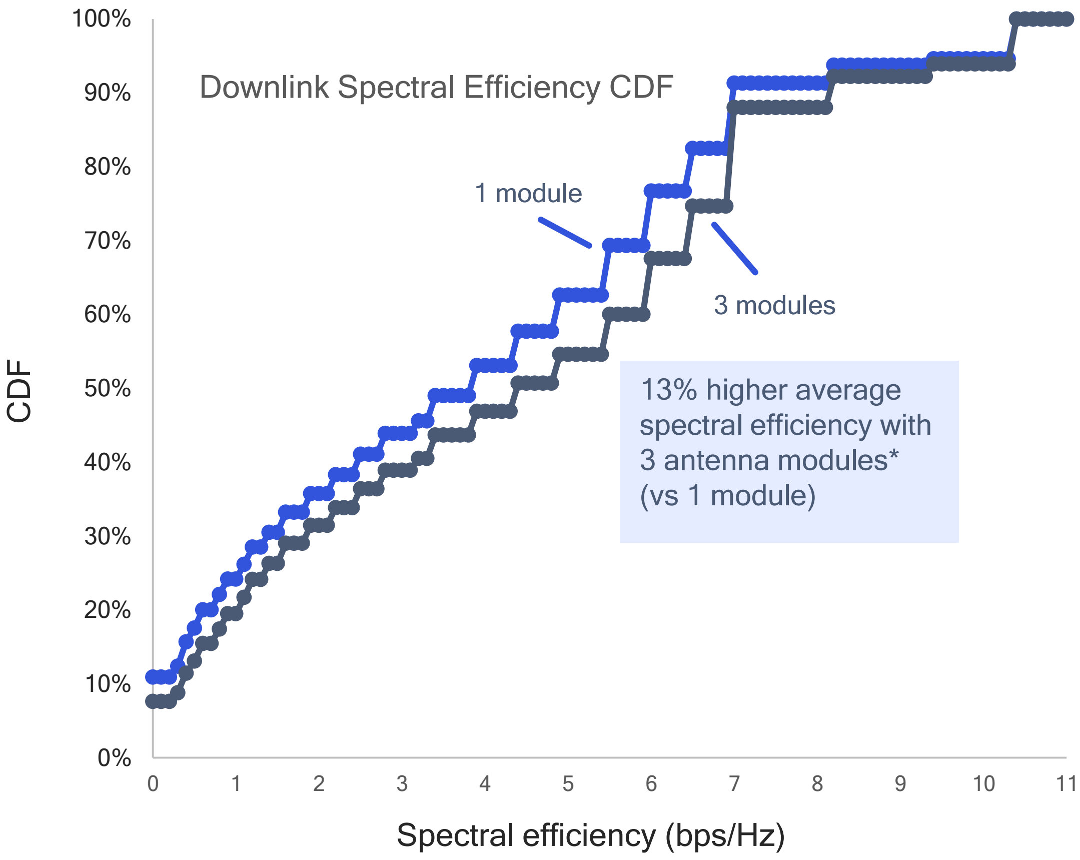
Number of antenna modules impact user experience and network performance

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.

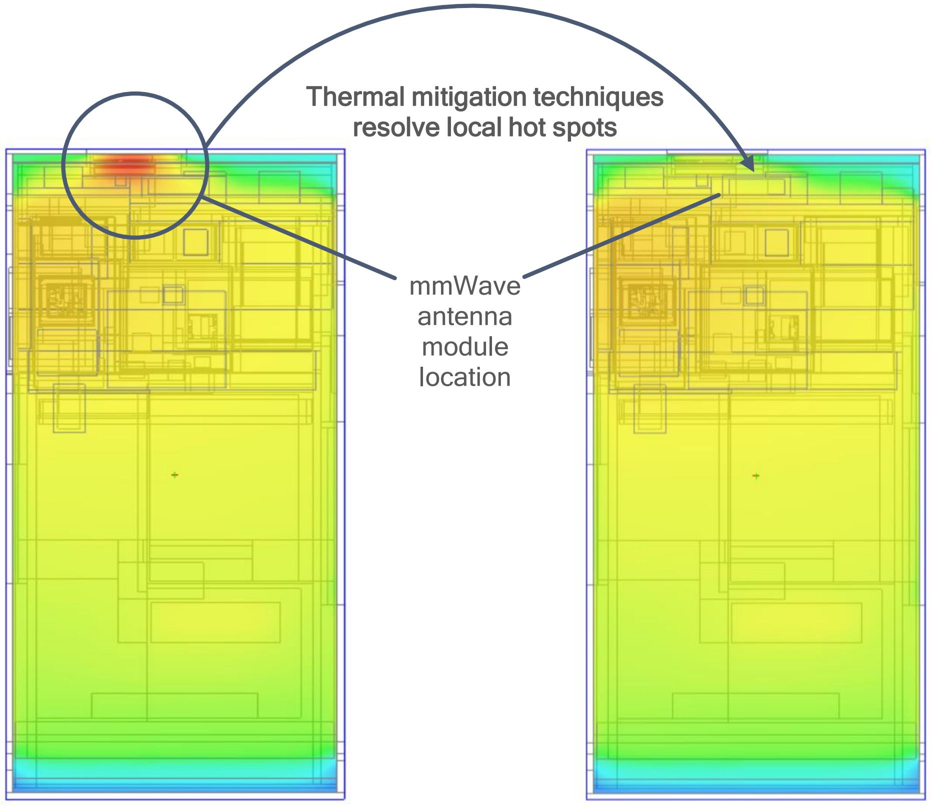
Addressing mmWave thermal design challenges

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

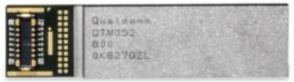
- Optimal positioning of antenna modules within device
- Use of appropriate materials for mounting, heat conduction and thermal spreading
- Advanced packaging technology for thermal performance



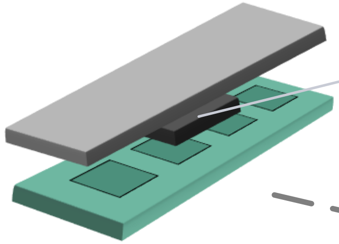
5G Qualcomm Reference Design example

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



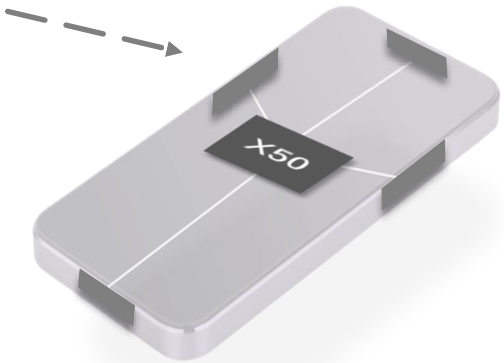
5G mmWave antenna module & transceiver chip



Qualcomm® SDR051 Integrated Circuit

Antenna modules

Support for multiple antenna modules and antenna switching



Intermediate Frequency

Baseband

Qualcomm snapdragon X50 5G modem

0011010
0000011
0011010
0011111
Digital

mm Wave
Trans-ceiver

Power Amps

Low Noise Amps

Switches

Snapdragon X50 5G mmWave architecture

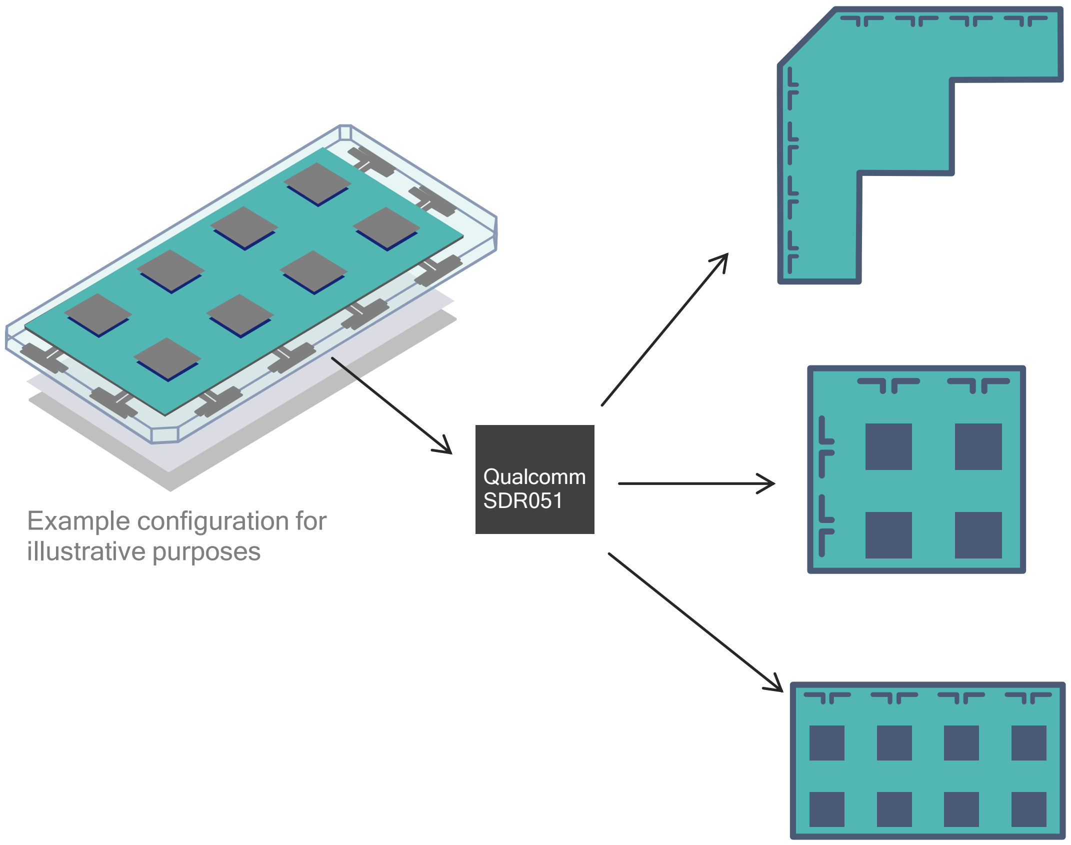
Integrated antenna array and RFFE for performance and ease-of-use

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



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

5G NR mmWave technology evolution

Coming to 3GPP Rel-16 and beyond

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

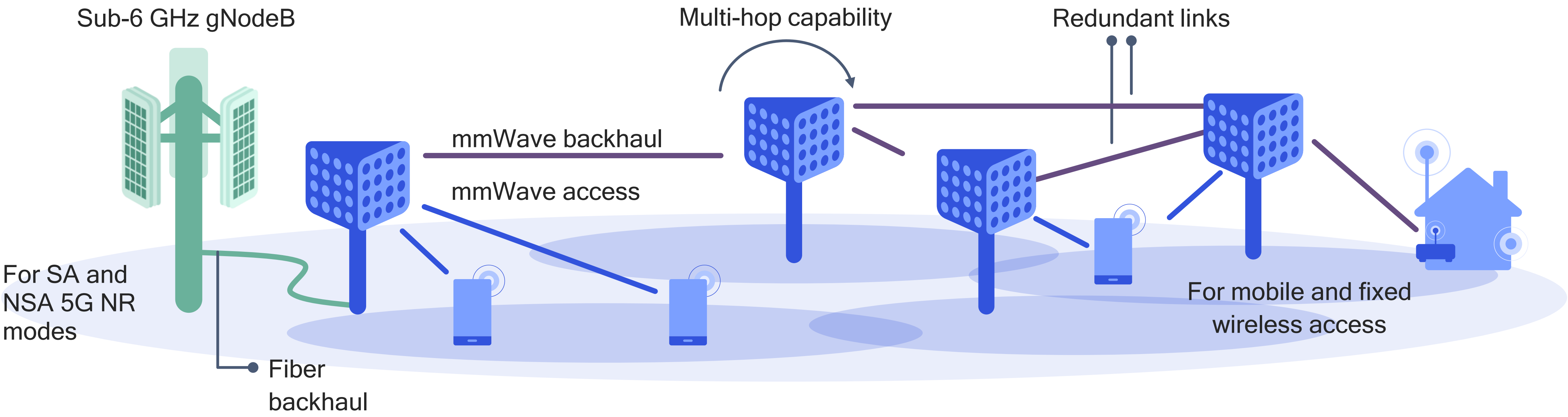
Power saving features

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



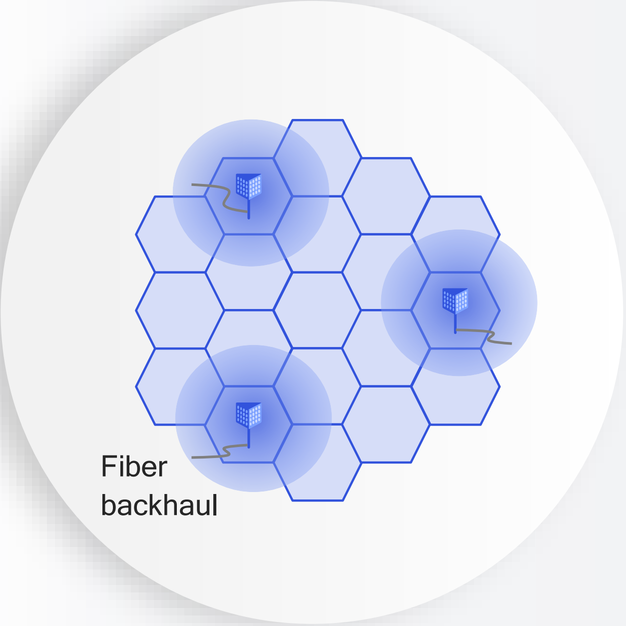
1 Integrated Access and Backhaul

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

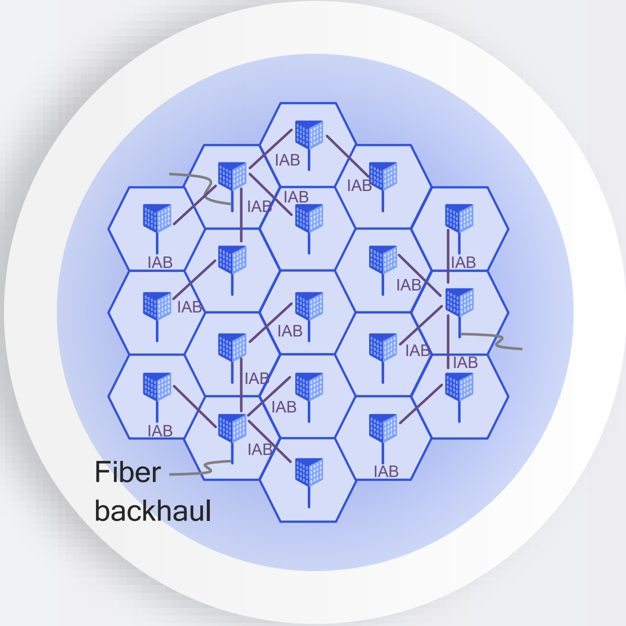
Supporting a flexible network deployment strategy

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



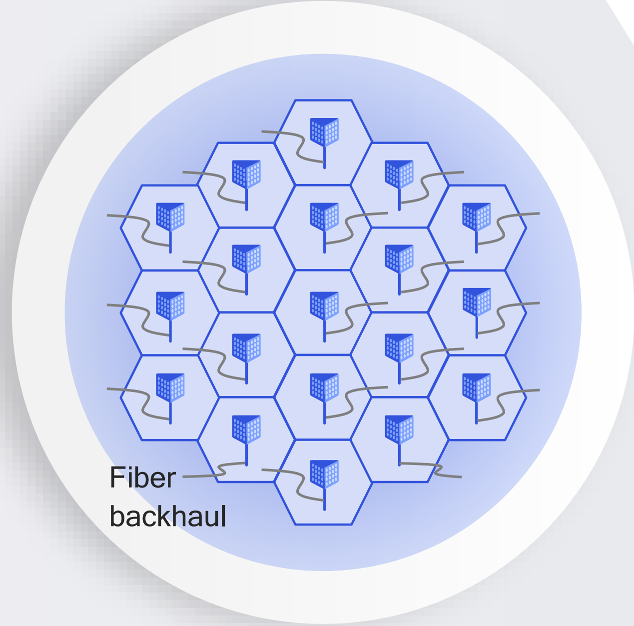
Early 5G NR mmWave deployments based on Rel-15

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



Widening 5G NR mmWave coverage using IAB

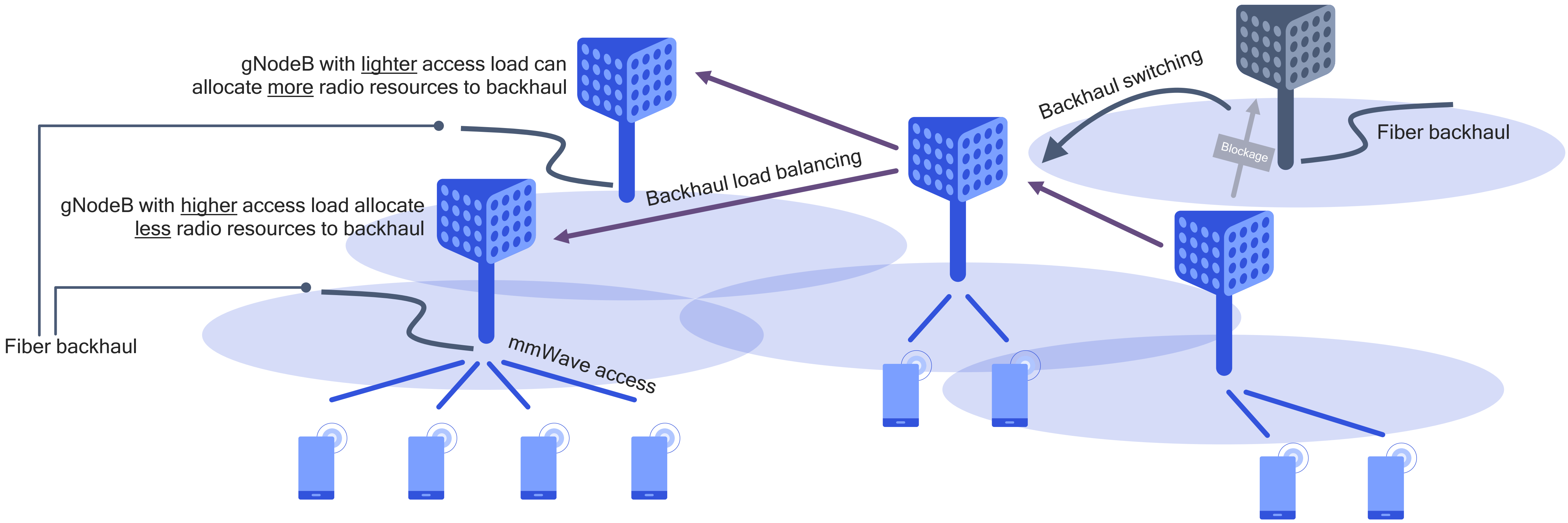
Starting to connect new 5G NR mmWave base stations using limited/existing fiber links



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

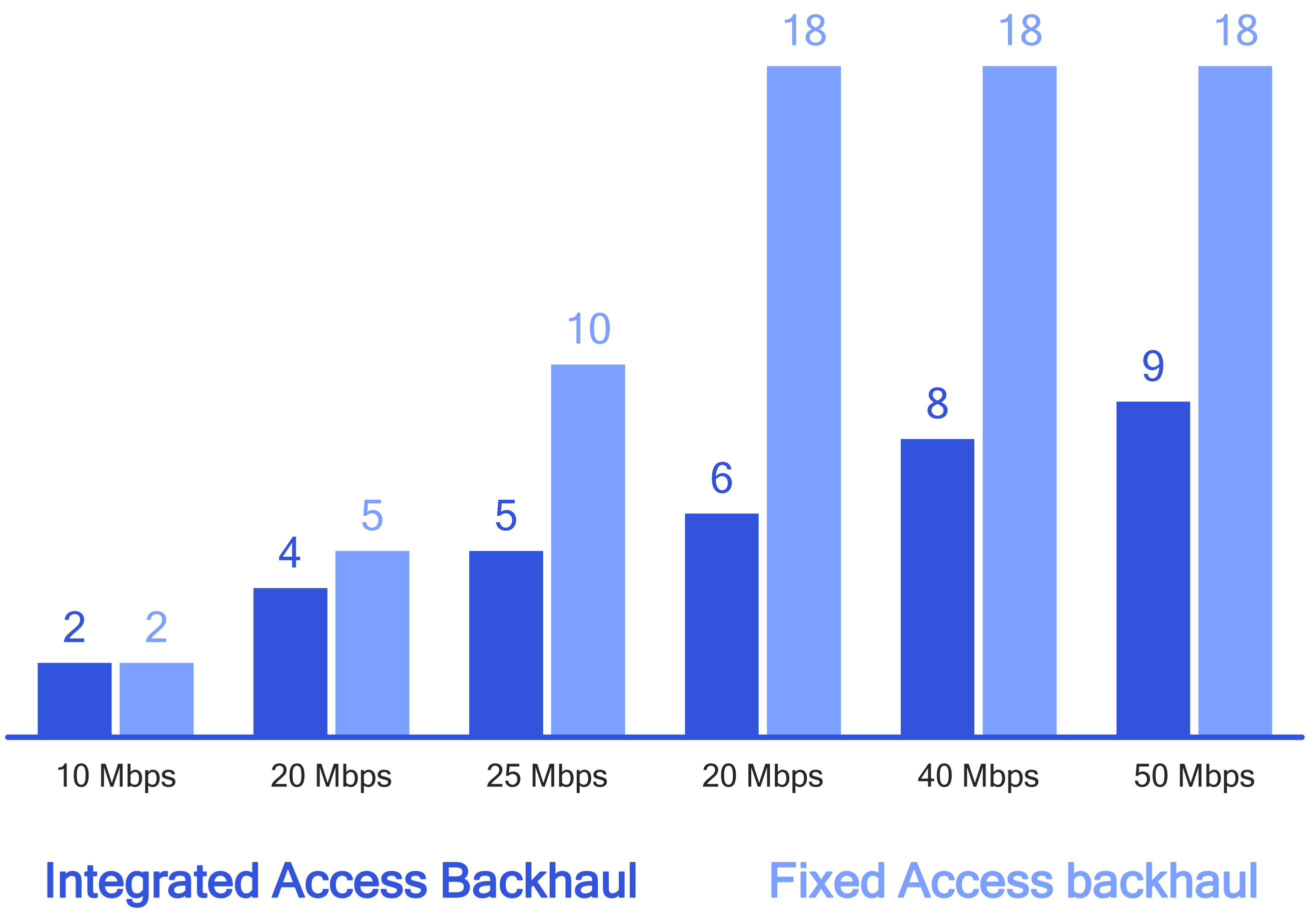
5G NR Integrated Access & Backhaul

Supports more flexible deployments and reduces network cost

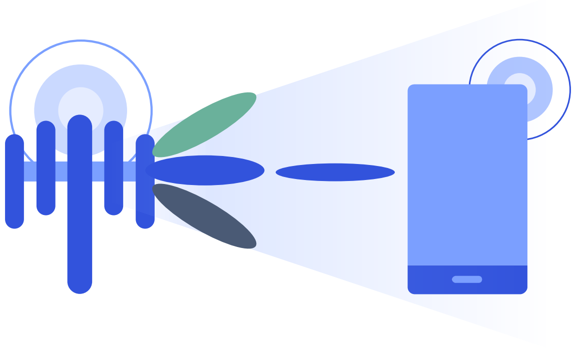
Fewer fiber drop points needed compared to fixed backhaul for a given traffic demand

Dynamically adjusts to changes in fiber drop locations and numbers

Number of fiber drops needed

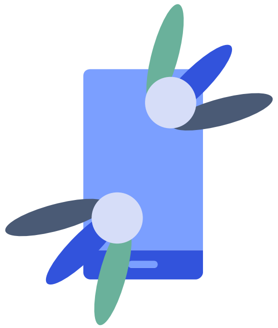


*Assumptions: 28 GHz band, 1GHz b/w, 18 base-stations; 200m ISD; 600 devices, uniform distribution; results obtained without any constraint on the number of hops



Improved reliability

- Supporting multi-beam repetitions
- More robust beam failure recovery schemes[1] for both UL and DL



Higher performance

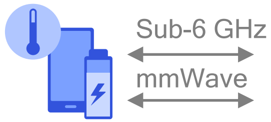
- Multiple antenna panels support to improve throughput and diversity
- UL/DL beam selection decoupled for optimal performance in both directions[2]

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

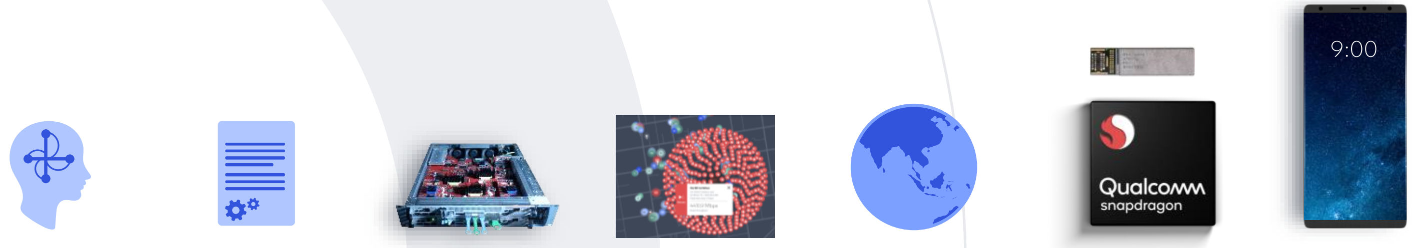
Antenna panels information is provided by the device to enable more power-efficient beam sweeping/switching

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!

Follow us on: f 🐦 in

For more information, visit us at:

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