

Qualcomm

# Making 5G NR mmWave a commercial reality

In your smartphone and beyond

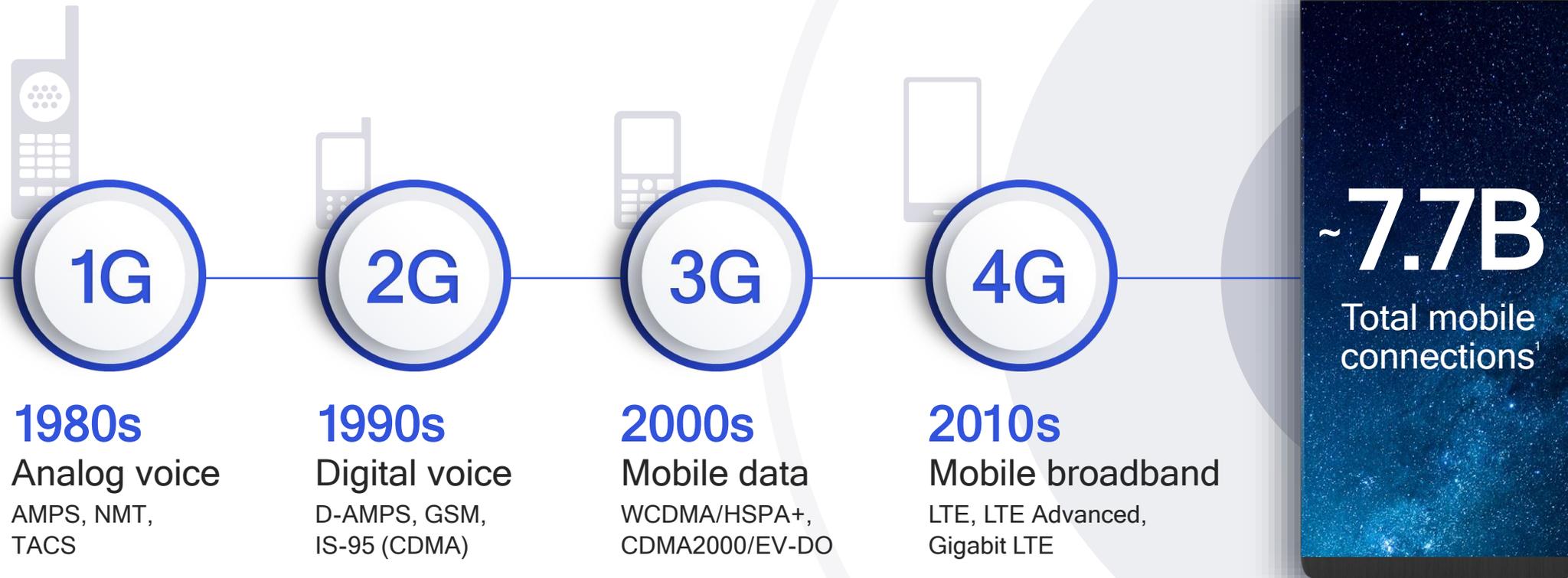
April 2018

@qualcomm\_tech



5G

# Mobile is the largest technology platform in human history





5G will address the insatiable demand for mobile broadband

Over 30x growth in mobile data traffic from 2014 to 2020

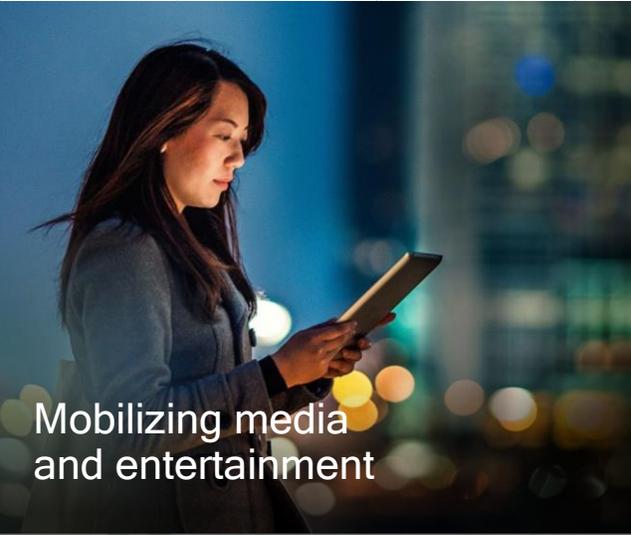


~8B Gigabytes

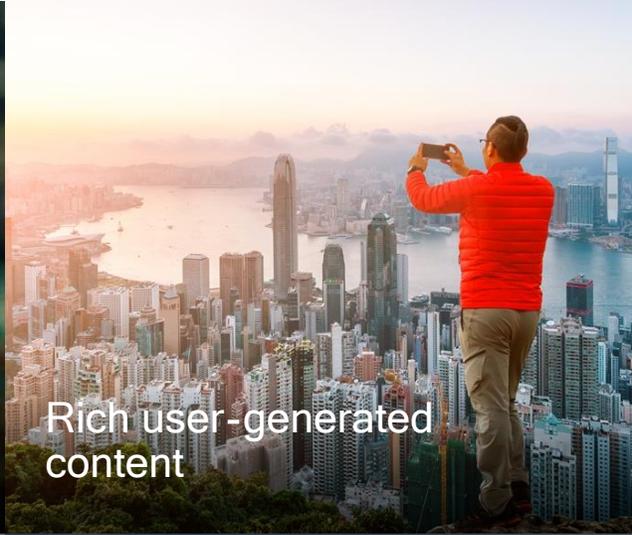
Daily global mobile data traffic in 2020



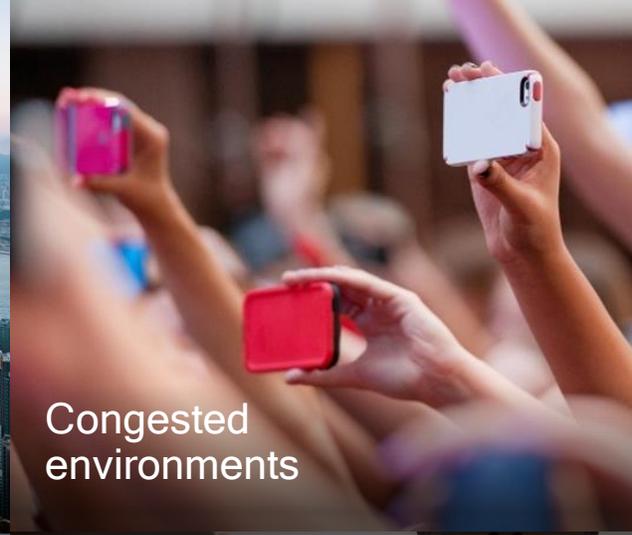
Over 75% of mobile data traffic from multi-media streaming in 2020



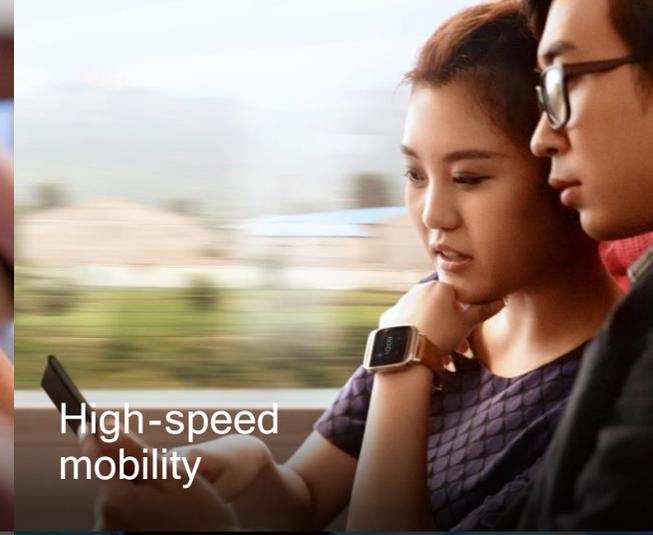
Mobilizing media and entertainment



Rich user-generated content



Congested environments



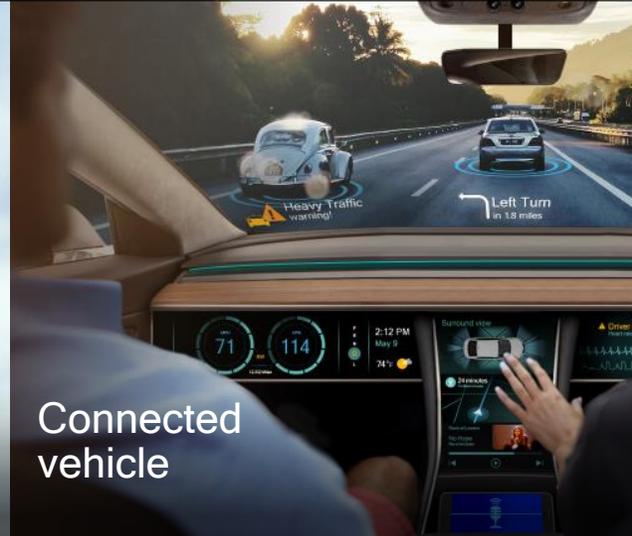
High-speed mobility



Connected cloud computing



Immersive experiences



Connected vehicle



Augmented reality



# 5G is essential for next generation mobile experiences

- Fiber-like data speeds
- Low latency for real-time interactivity
- More consistent performance
- Massive capacity for unlimited data



5G Consumer Survey of smartphone owners:



1,002



1,010



1,000



1,006



1,002



824



5,844  
WW total



Consumer excitement is building for 5G smartphones

>86%

Need or would like faster connectivity on next smartphone

~50%

Likely to purchase a phone that supports 5G when available

Top 3 reasons for 5G:

10x faster speeds

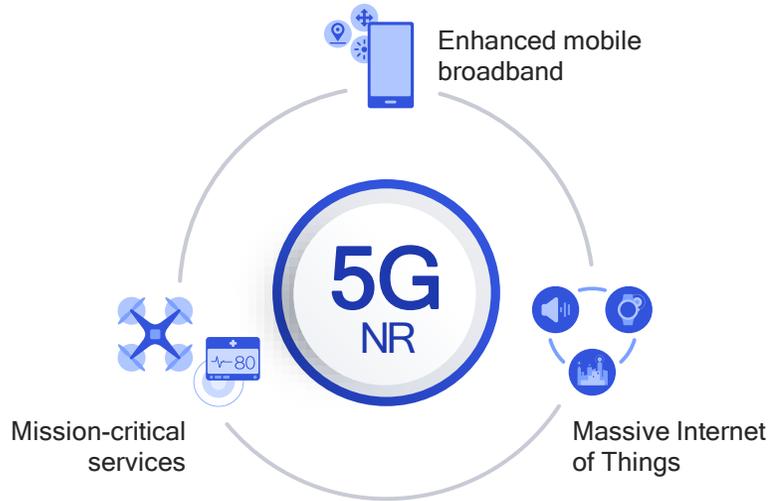
10x quicker response time

More cost-effective data plans

Source: "[Making 5G a reality: Addressing the strong mobile broadband demand in 2019 and beyond](#)," September 2017, jointly published by Qualcomm Technologies, Inc. and Nokia.

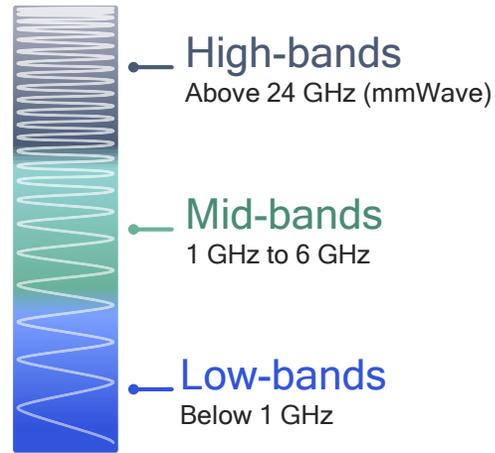


# Designing a unified, more capable 5G air interface



## Diverse services

Scalability to address an extreme variation of requirements



## Diverse spectrum

Getting the most out of a wide array of spectrum bands/types



## Diverse deployments

From macro to indoor hotspots, with support for diverse topologies

Learn more: [www.qualcomm.com/5G-NR](http://www.qualcomm.com/5G-NR)

# A unifying connectivity fabric for future innovation

A platform for existing, emerging, and unforeseen connected services

# First 5G NR standard complete – the global 5G standard

Approved study items



Rel-15 work items

Rel-16 work items

Release 17+ evolution

NSA

IoT

Field trials

Standalone (SA)



Phase 1  
Commercial launches

Phase 2  
Commercial launches

Accelerate eMBB deployments,  
plus establish foundation for  
future 5G innovations

Deliver new fundamental 5G NR  
technologies that expand and  
evolve the 5G ecosystem

We are here

Continue to evolve LTE in parallel as essential part of the 5G Platform

2017

2018

2019

2020

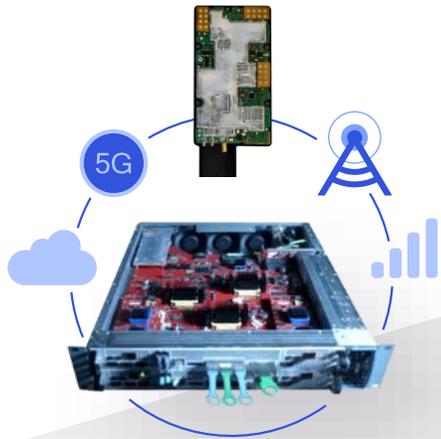
2021

2022

# Making 5G NR a commercial reality for 2019

For standard-compliant networks and devices

Qualcomm



## Best-in-class 5G prototype systems

Designing and testing 5G technologies for many years



## 5G NR standards and technology leadership

Our technology inventions are driving the 5G NR standard



## 5G NR interoperability testing and trials

Leveraging prototype systems and our leading global network experience



## Modem and RFFE leadership

Announced the Qualcomm Snapdragon X50 5G modem family

————— LTE foundational technologies —————>

# Mobilizing 5G NR mmWave

The new frontier for enhanced  
mobile broadband

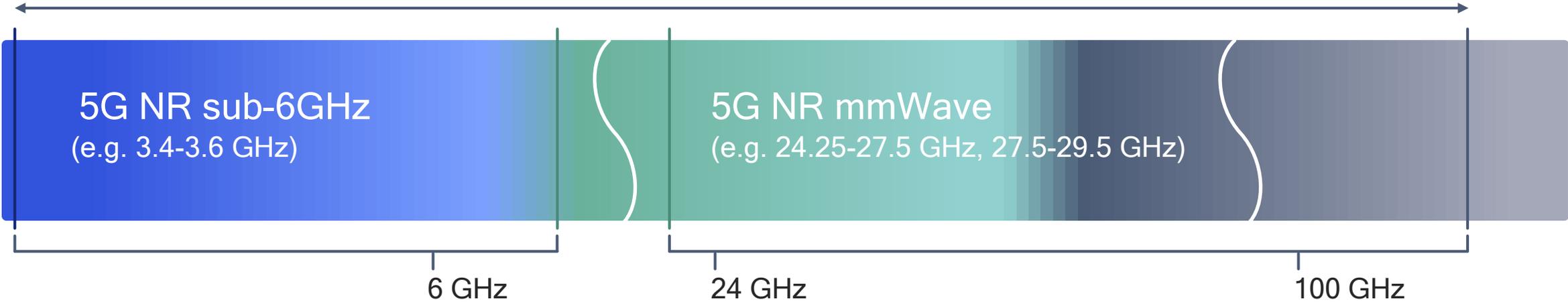


# The large bandwidth opportunity for mmWave

The new frontier for enhanced mobile broadband



Unified design across diverse spectrum bands/types

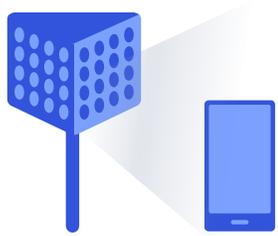


**Multi-Gbps data rates**  
With large bandwidths (100s of MHz)

**Much more capacity**  
With dense spatial reuse

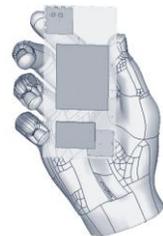
**Excels in wider bandwidths**  
Opens up new opportunities

# Overcoming numerous wireless challenges to mobilize mmWave



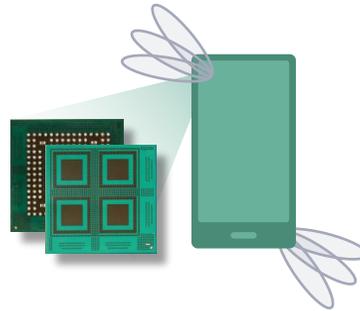
## Coverage

Innovations to overcome significant path loss in bands above 24 GHz



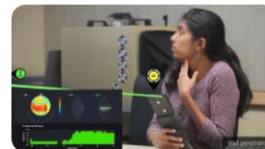
## Robustness

Innovations to overcome blockage from hand, body, walls, foliage, etc.



## Device size/power

Innovations to optimize mmWave design for smartphone form factor



# 1989

We proved them wrong.

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

# 2017

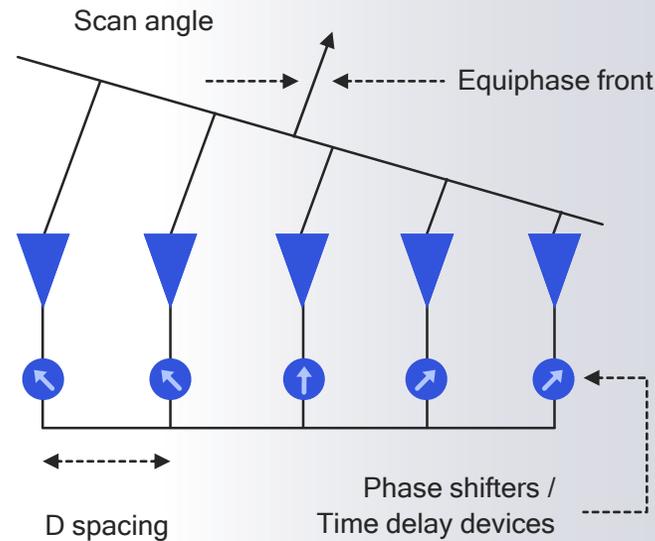
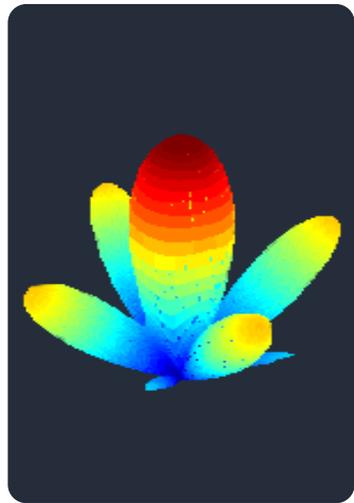
Proving them wrong, again.

Many argue mmWave is too complex for a smartphone. Many say it just won't work for mobile deployments.

# Pushing wireless boundaries is in our DNA

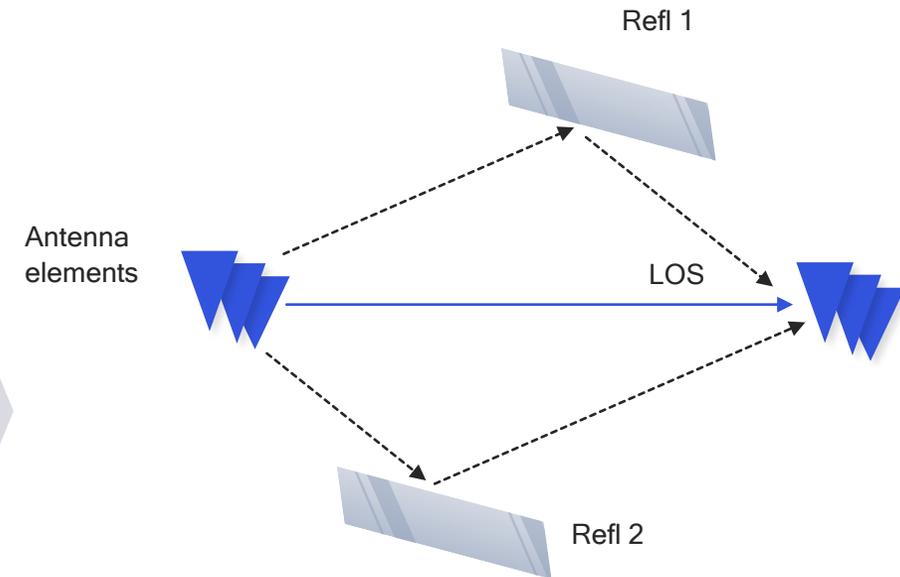
# 5G NR utilizes smart beamforming and beam tracking

To increase mmWave coverage and minimize interference



## High-gain directional antenna arrays

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

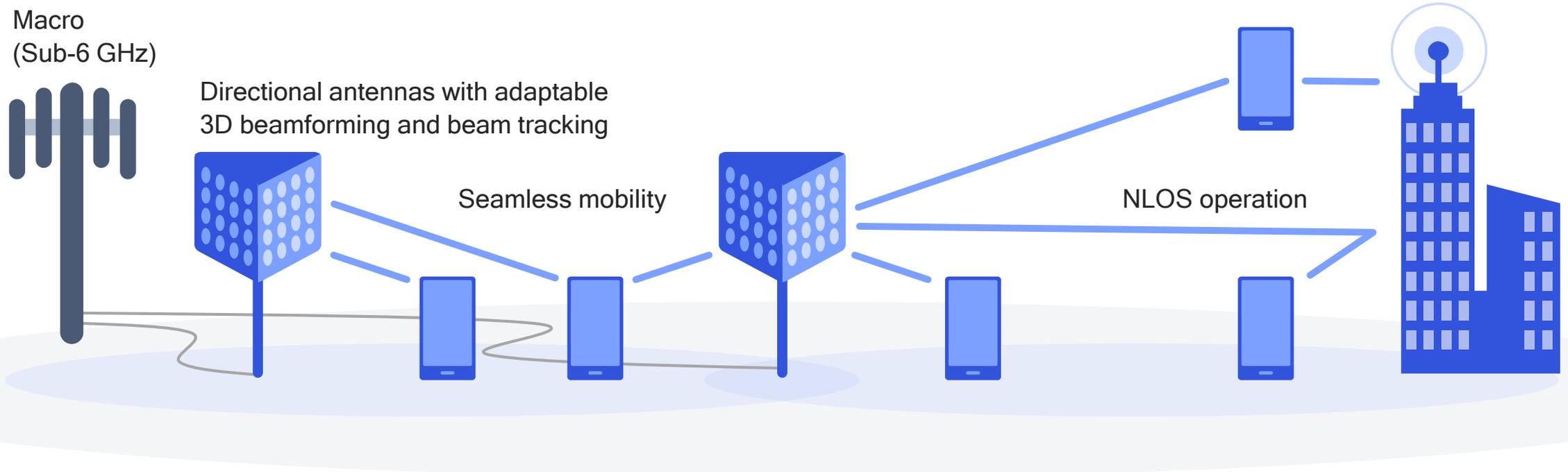


## Beam switching/steering/tracking

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

# Mobilizing mmWave with 5G NR technologies

Key properties for robust mmWave operation in a NLOS mobile environment



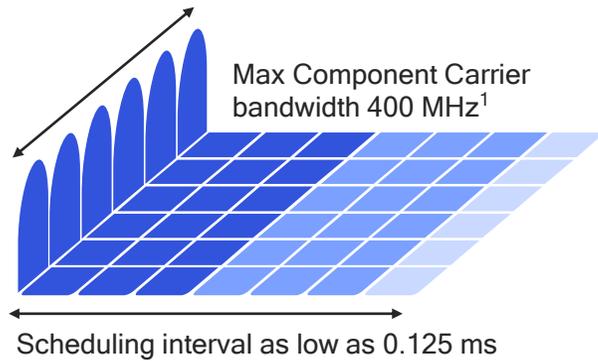
Very dense network topology and spatial reuse (~150-200m ISD)

Fast beam steering and switching within an access point

Architecture that allows for fast beam switching across access points

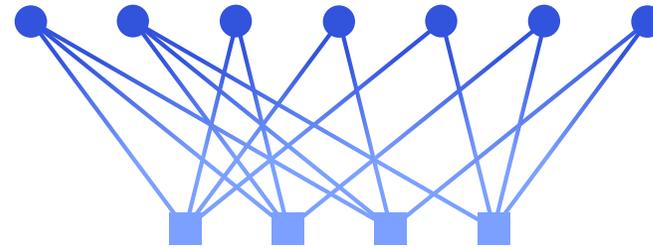
Tight integration with sub-6 GHz (LTE or NR)

# 3GPP Rel-15 delivers key 5G NR mmWave technologies



## Scalable OFDM numerology and TTI

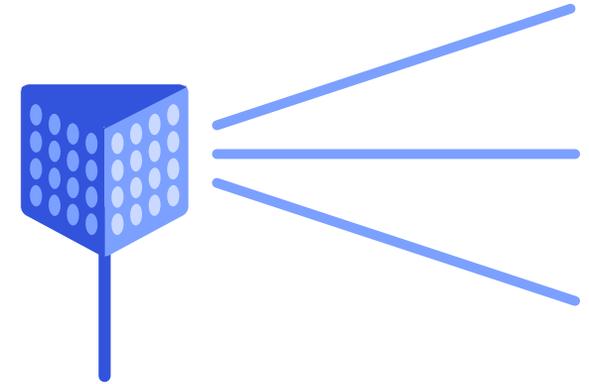
Optimized design for wide bandwidths and fast beam-switching/steering/tracking



Example ME-LDPC<sup>2</sup> Basegraph

## Advanced LDPC Coding

Advanced LDPC channel codes are more cost/power efficient than today's LTE Turbo codes at higher data rates



## Advanced beamforming and beam tracking techniques

Directional 3D antenna arrays to increase coverage at high spectrum bands



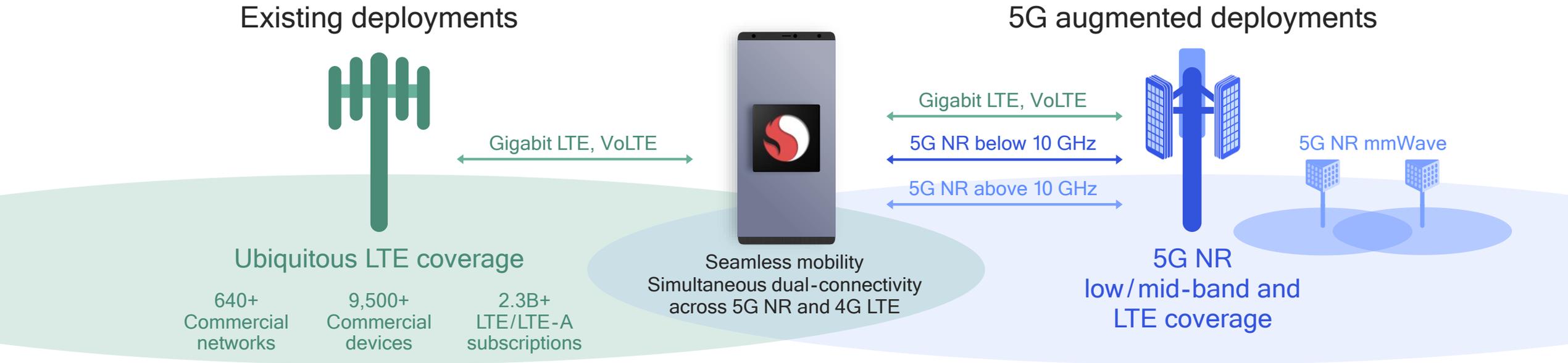
Our technology inventions are driving Rel-15 specifications

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

Download the 3GPP Release-15 5G NR design presentation to learn more – [link](#)

# Dual connectivity to fully leverage LTE investments

## Gigabit LTE provides the coverage foundation for 5G NR mmWave



Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. Source: GSA ([www.gsacom.com](http://www.gsacom.com))—Oct 2017 on network launches, Oct 2017 on subscriptions, Nov 2017 on commercial devices

Enabling gigabit experiences everywhere

Providing VoLTE leveraging LTE's ubiquitous coverage

Supplementing 5G NR mid-band and mmWave

# We have performed extensive mmWave channel measurements and simulations



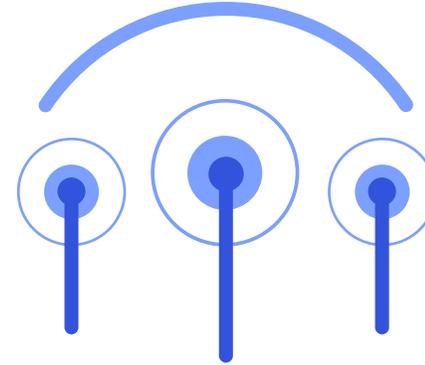
## Across mmWave frequencies

From 22 GHz to 67 GHz, including comparisons with 2.9 GHz



## Across deployment scenarios

Outdoor—both high and low density; Indoor—e.g. venue, residential; Outdoor-to-Indoor



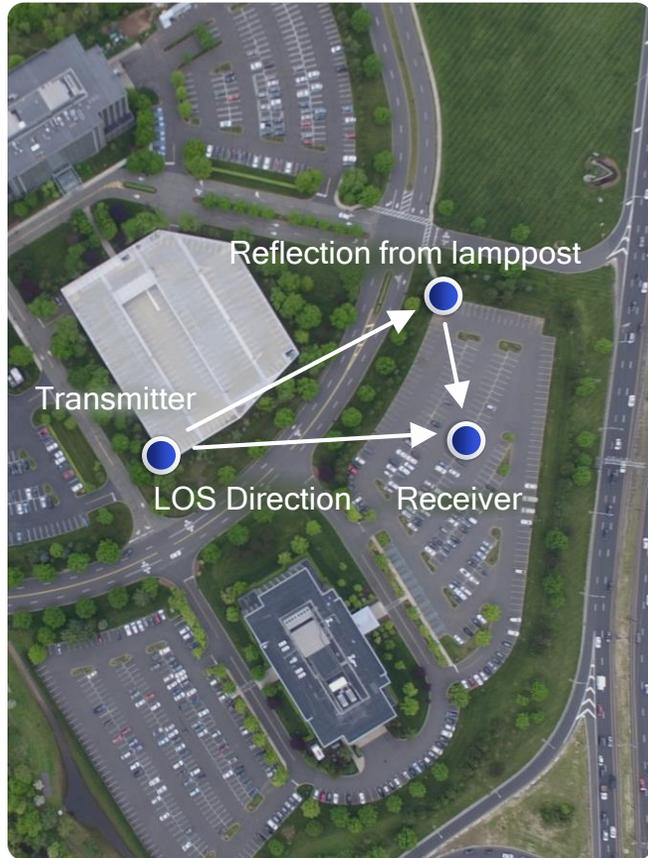
## Across different materials

Different foliage/trees, various construction materials, walls, humans, etc.

Drove our system design/algorithms and 3GPP contributions

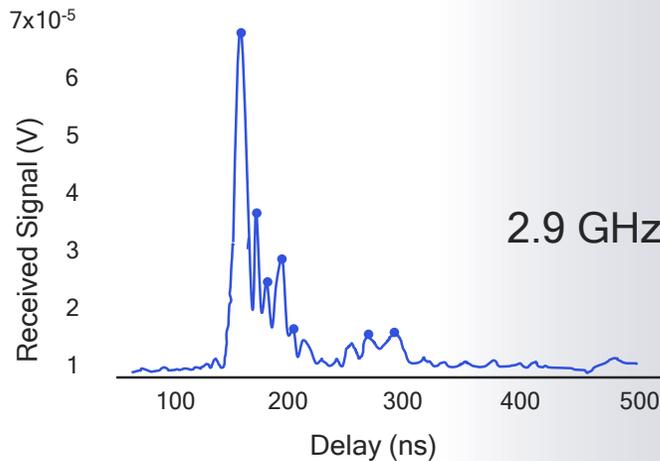
# Reflections provide alternative paths when LOS blocked

Based on Qualcomm Research outdoor mmWave channel measurements

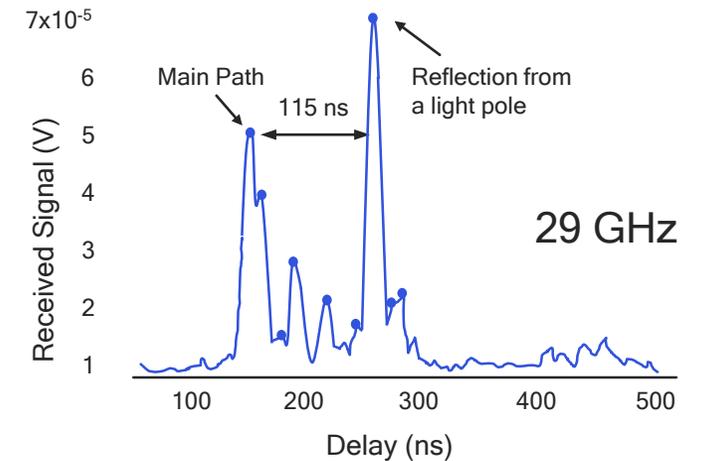


## Channel response from omni-directional antennas (Example measurement)

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)

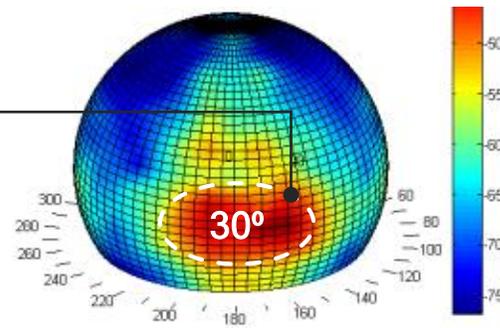
# 5G NR can leverage path diversity to overcome blockage

Based on Qualcomm Research spherical scan measurements

## Indoor office

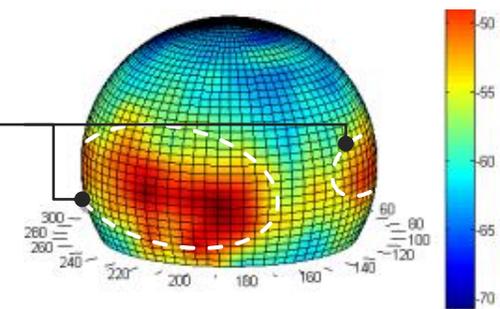
Diversity in elevation

Numerous resolvable paths in elevation



Diversity in Azimuth

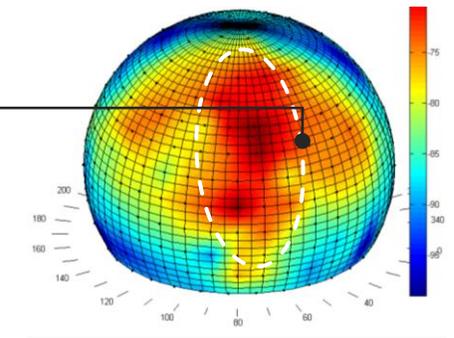
Significant path diversity in azimuth – Ability to withstand blockage events



## Outdoor

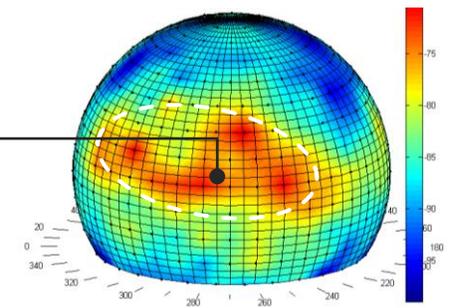
Diversity in elevation

Reflections from tall buildings result in wide elevation spread



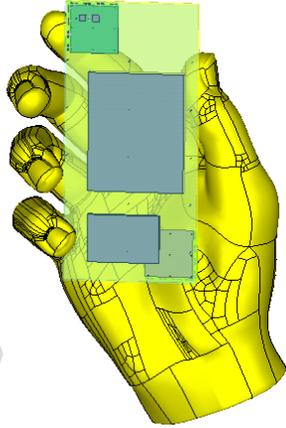
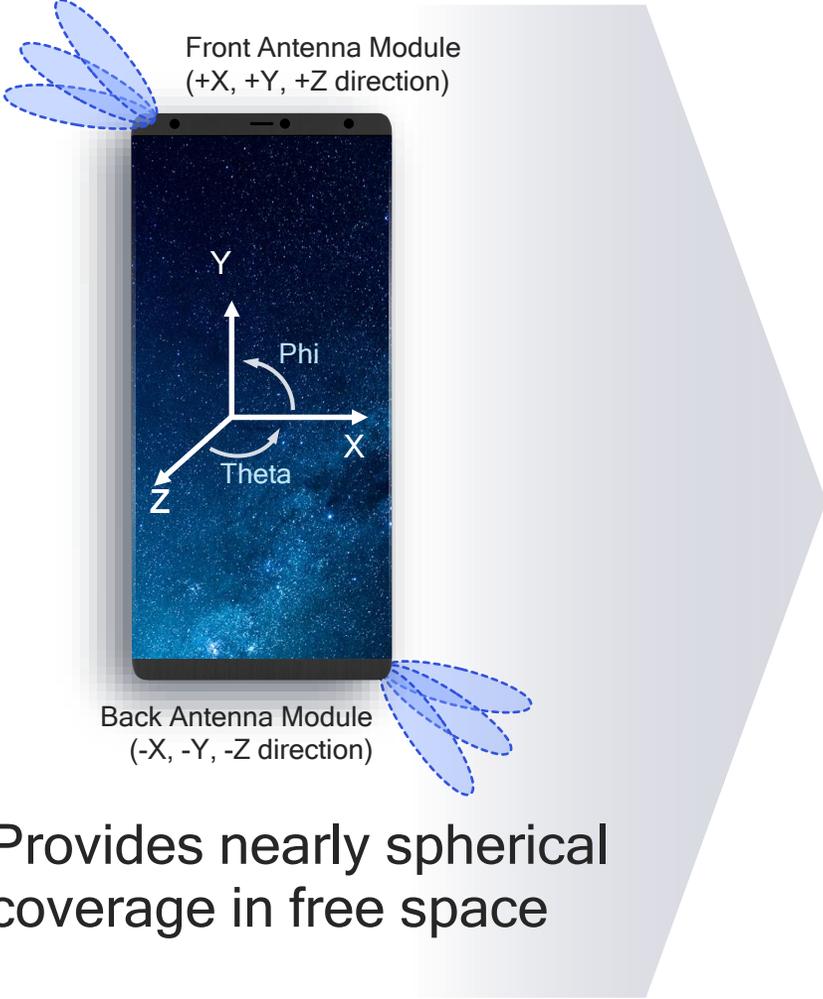
Diversity in Azimuth

Foliage obstructed diffracted path – energy spread across wide azimuth

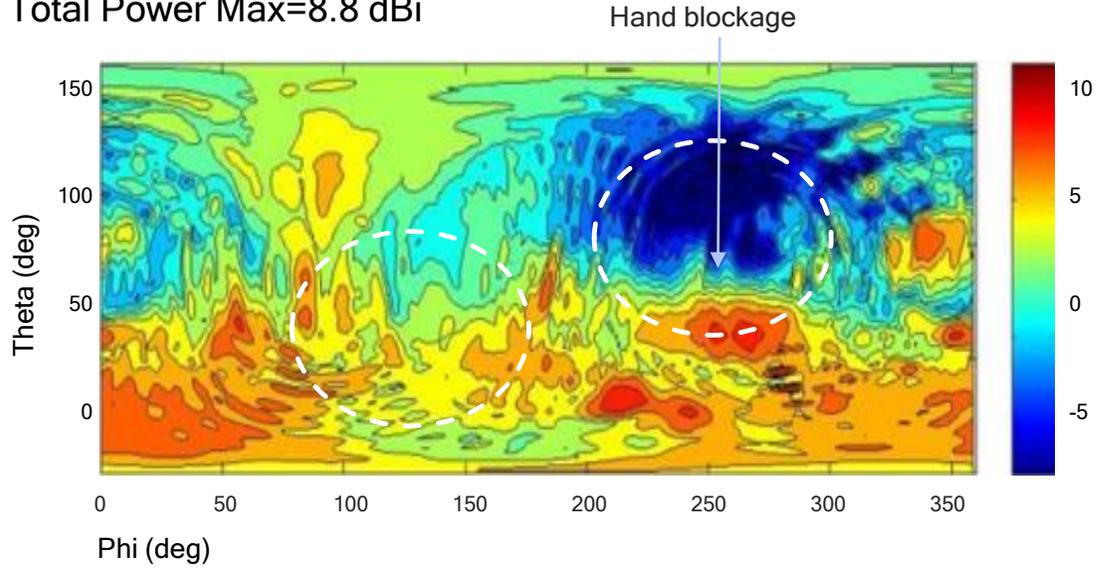


# 5G NR can also leverage UE antenna diversity

To overcome hand-blocking



Total Gain (dBi)  
Total Power Max=8.8 dBi



## Qualcomm Research Simulations

Mitigates hand-blocking and reduces impact of random user orientation

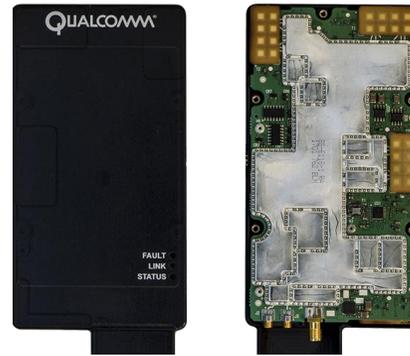
# Best-in-class 5G NR mobile prototype systems

Sub-6 GHz and mmWave



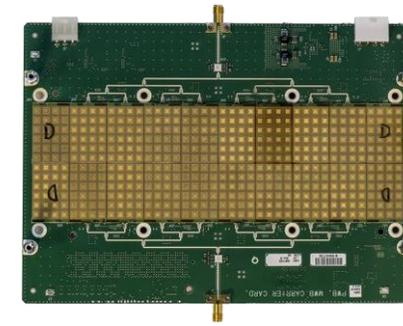
## 5G NR Baseband

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



- World's first announced 5G NR prototype – June 2016
- World's first 5G NR data connection – February 2017
- World's first interoperable 5G NR system – November 2017

# Demonstrating an optimized 5G NR mmWave RF Front-end design in smartphone form-factor

Based on 5G New Radio (NR) R-15 specification, showcasing adaptive beamforming & beam tracking

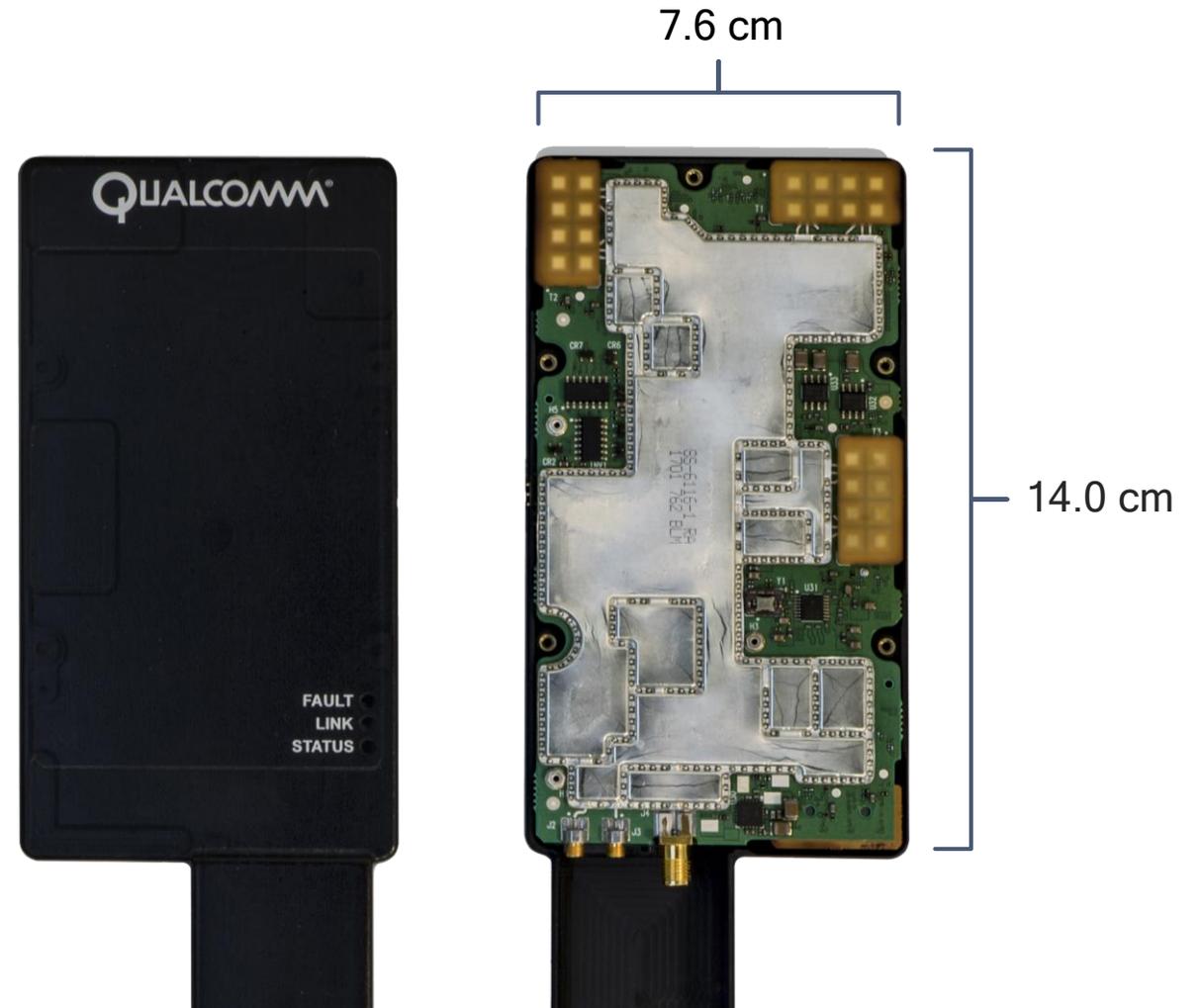
8x RFFE modules in 4x locations for testing flexibility; select different configurations to mimic real-world performance in mobile device form-factors

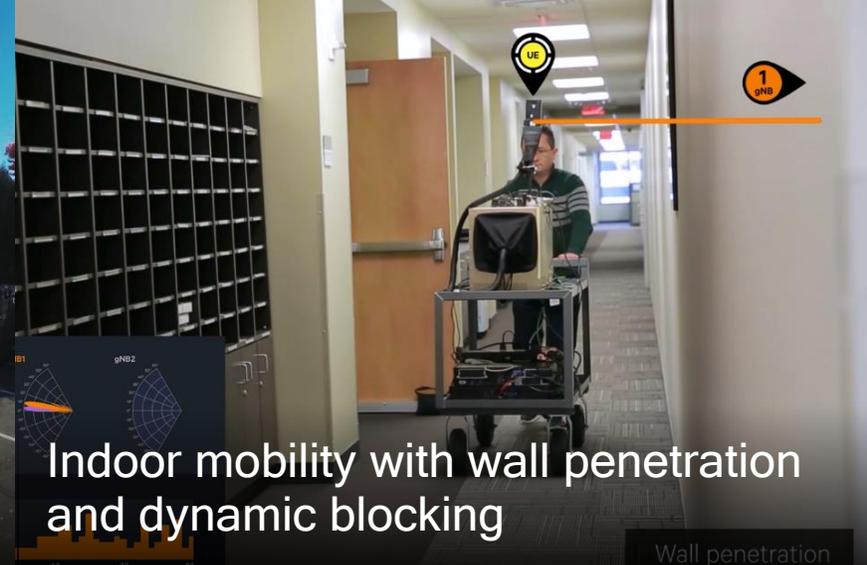
Each RFFE supports multiple selectable antenna sub-arrays in X, Y, and Z directions

Supporting 5G NR interoperability testing and over-the-air trials with global operators

Also provides mobile device OEMs an opportunity to gain an early start in optimizing their devices

## Qualcomm Research 5G NR mmWave UE Prototype

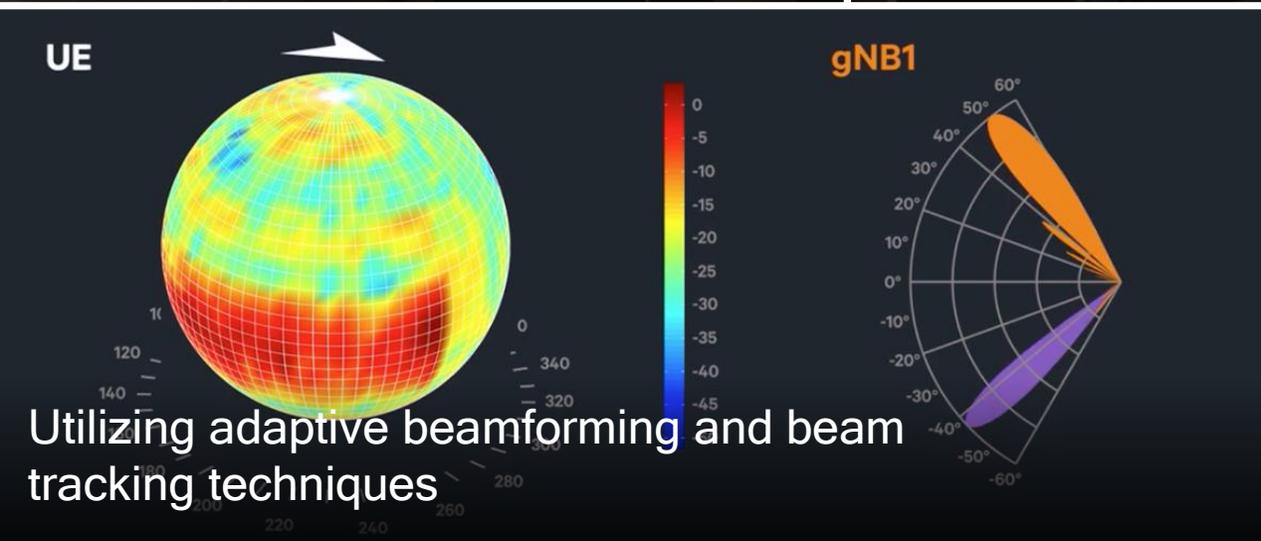




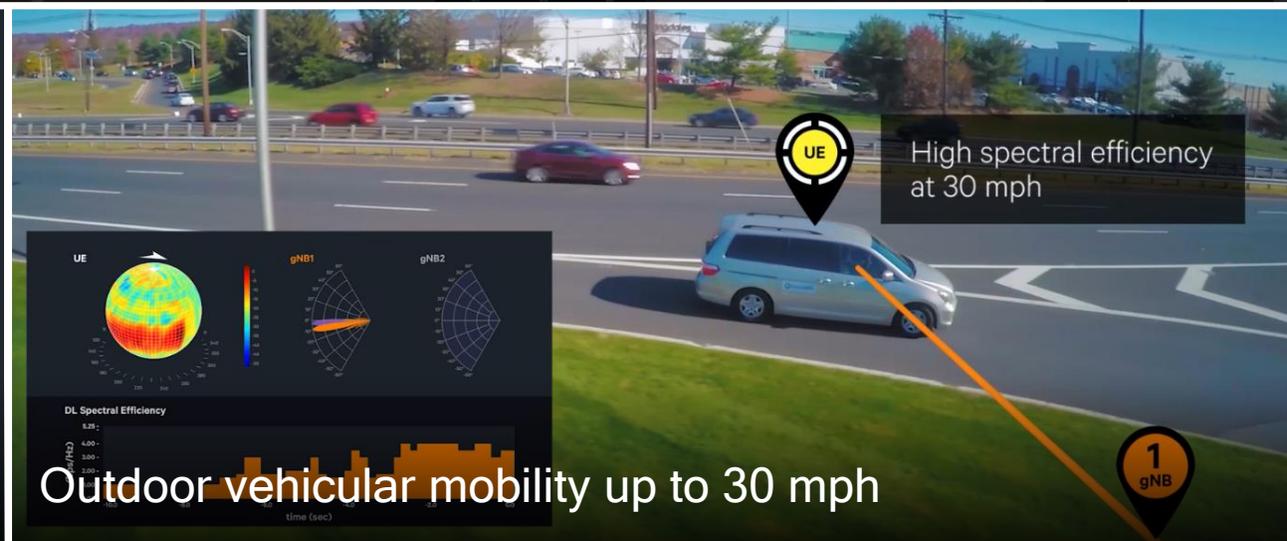
Handheld and in-vehicle UEs with hand-blocking

Multiple gNodeBs with seamless handovers

Indoor mobility with wall penetration and dynamic blocking



Utilizing adaptive beamforming and beam tracking techniques



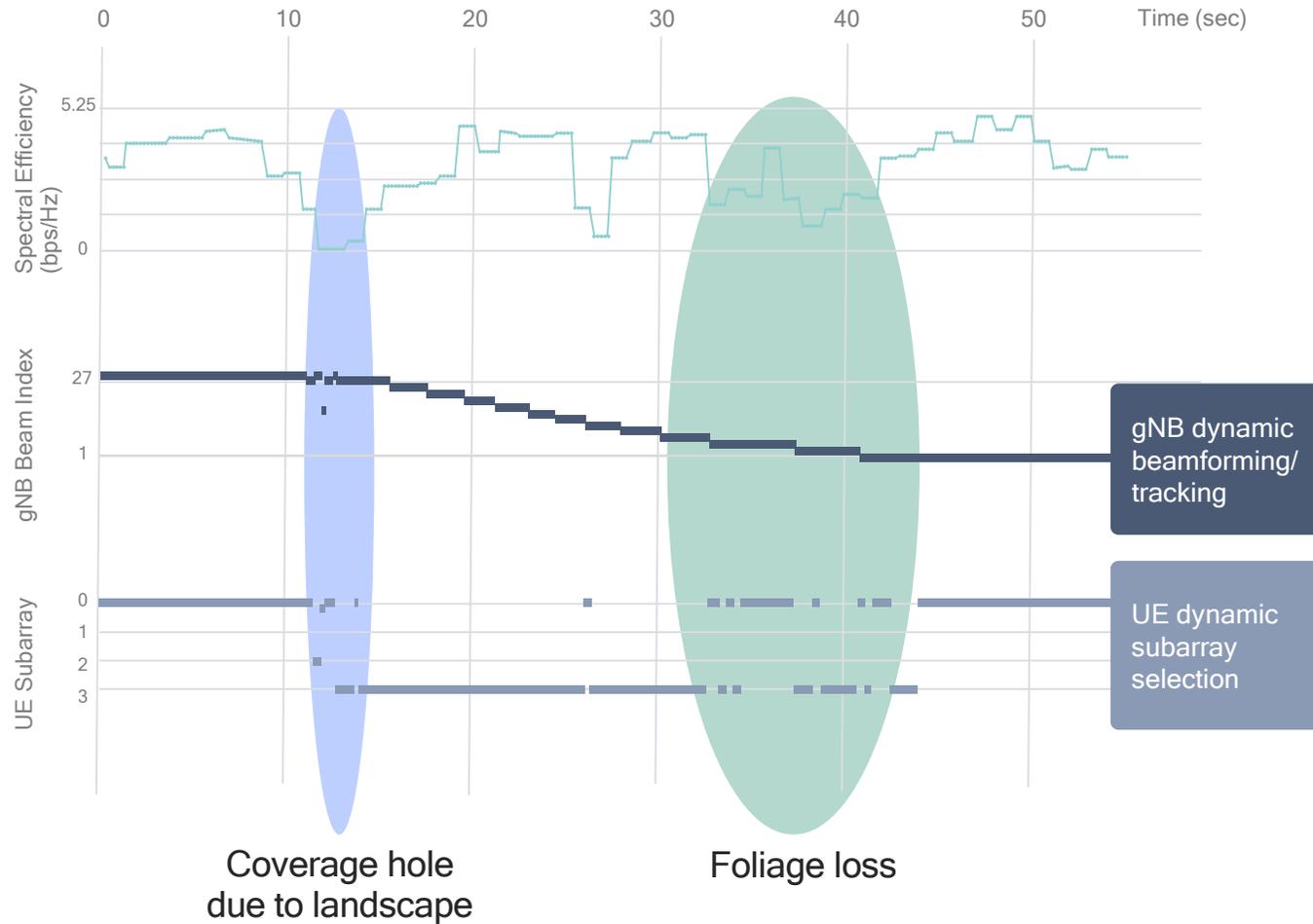
Outdoor vehicular mobility up to 30 mph

# Qualcomm Research 5G mmWave prototype

Showcasing robust mobile communications in real-world OTA testing

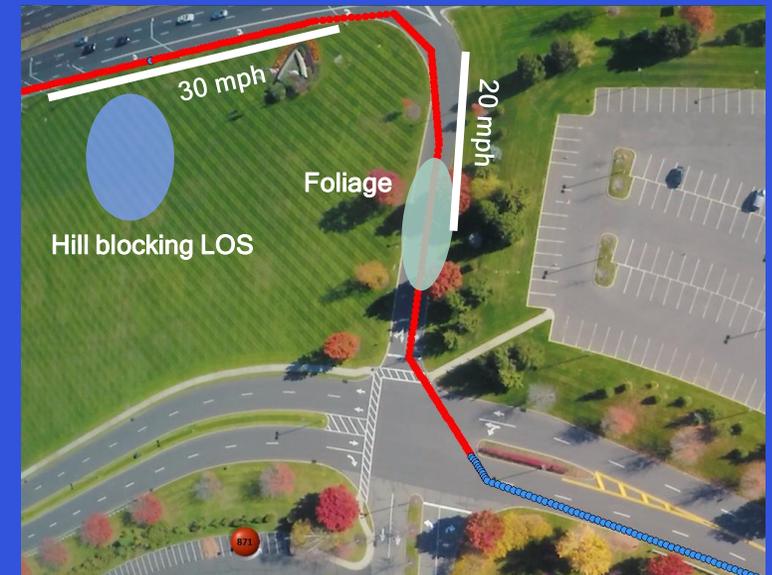
Watch video:  
[www.qualcomm.com/videos/mobilizing-mmwave-enhanced-mobile-broadband](http://www.qualcomm.com/videos/mobilizing-mmwave-enhanced-mobile-broadband)

# Outdoor OTA example test results



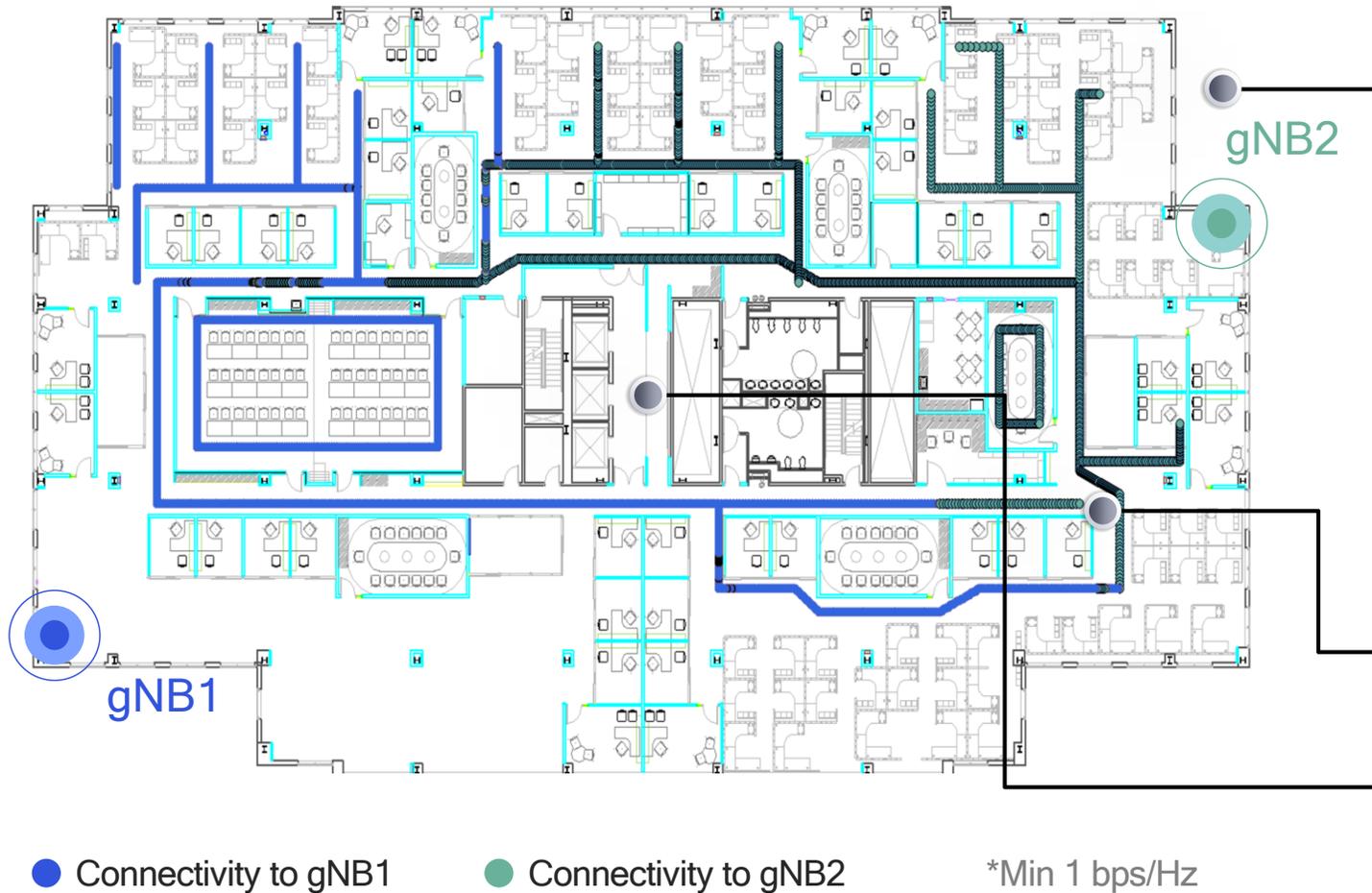
Demonstrating sustained mobile communications outdoors, with NLOS and device mobility

Qualcomm Research over-the-air outdoor testbed



# Indoor Office OTA example test results

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



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

# Industry-leading 5G NR interoperability testing

At the center of the 5G ecosystem, leading the way to 5G NR commercialization



**ZTE中兴**

World's first interoperable 5G NR sub-6 GHz data connection

November 2017



**ERICSSON**

World's first interoperable 5G NR mmWave data connection

December 2017

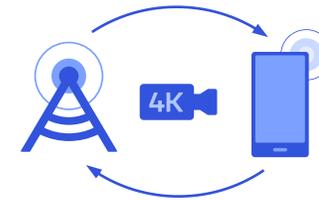


**NOKIA**

Successful multi-band 5G NR interoperability testing

Today

**SAMSUNG**  **HUAWEI**



**MOBILE**  
WORLD CONGRESS

Additional vendors, new functionality, L2 connectivity, and more

MWC 2018



World's first announced standard-compliant trials based on a 5G modem chipset

2H-2018

In collaboration with 20+ global mobile network operators



**ERICSSON**  **Qualcomm**

## Global mobile industry leaders achieve multi-band 5G NR interoperability

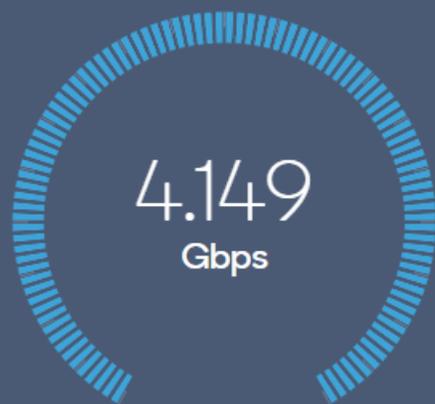
In collaboration with AT&T, NTT DOCOMO, Orange, SK Telecom, Sprint, Telstra, T-Mobile US, Verizon, and Vodafone

### Compliant with the 3GPP 5G NR standard

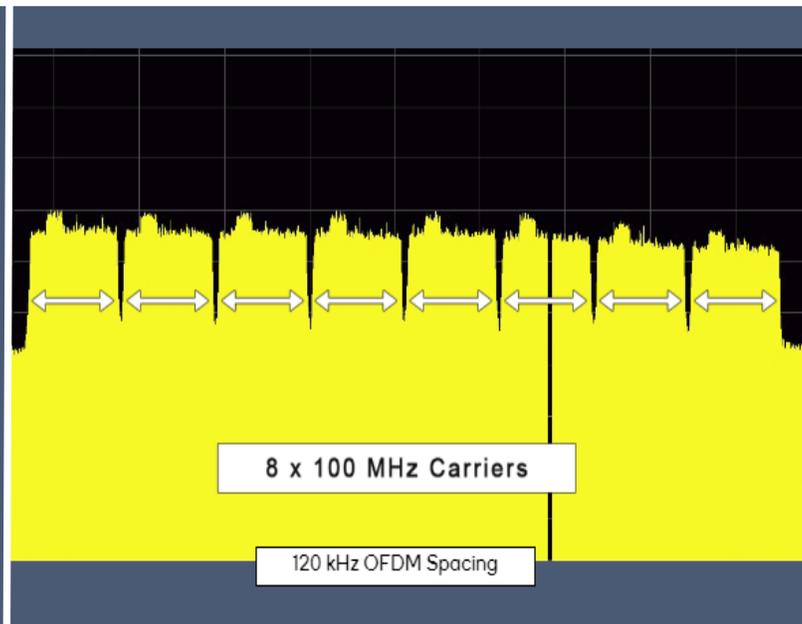
-  5G NR scalable OFDM air interface
-  5G NR low latency slot-based framework
-  5G NR advanced channel coding
-  8x100 MHz bandwidth, operating at 28 GHz  
100 MHz bandwidth; operating at 3.5 GHz

Watch video:

[www.qualcomm.com/videos/5g-nr-mmwave-interoperability-testing](http://www.qualcomm.com/videos/5g-nr-mmwave-interoperability-testing)



**Downlink**  
Application Layer (Layer 2)

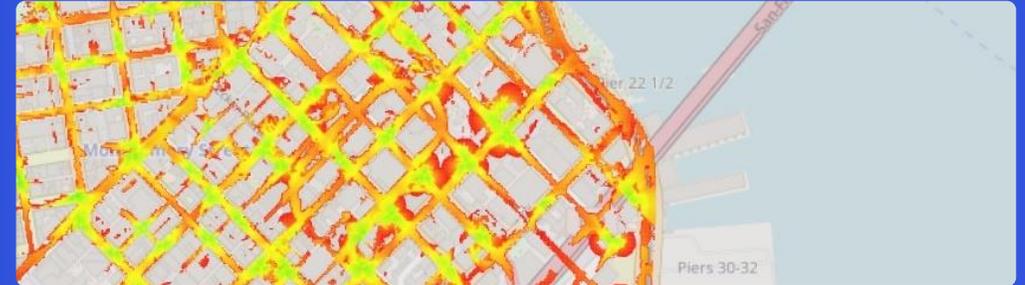


## Example: San Francisco

- >65% outdoor coverage
- >50% users above 1 Gbps



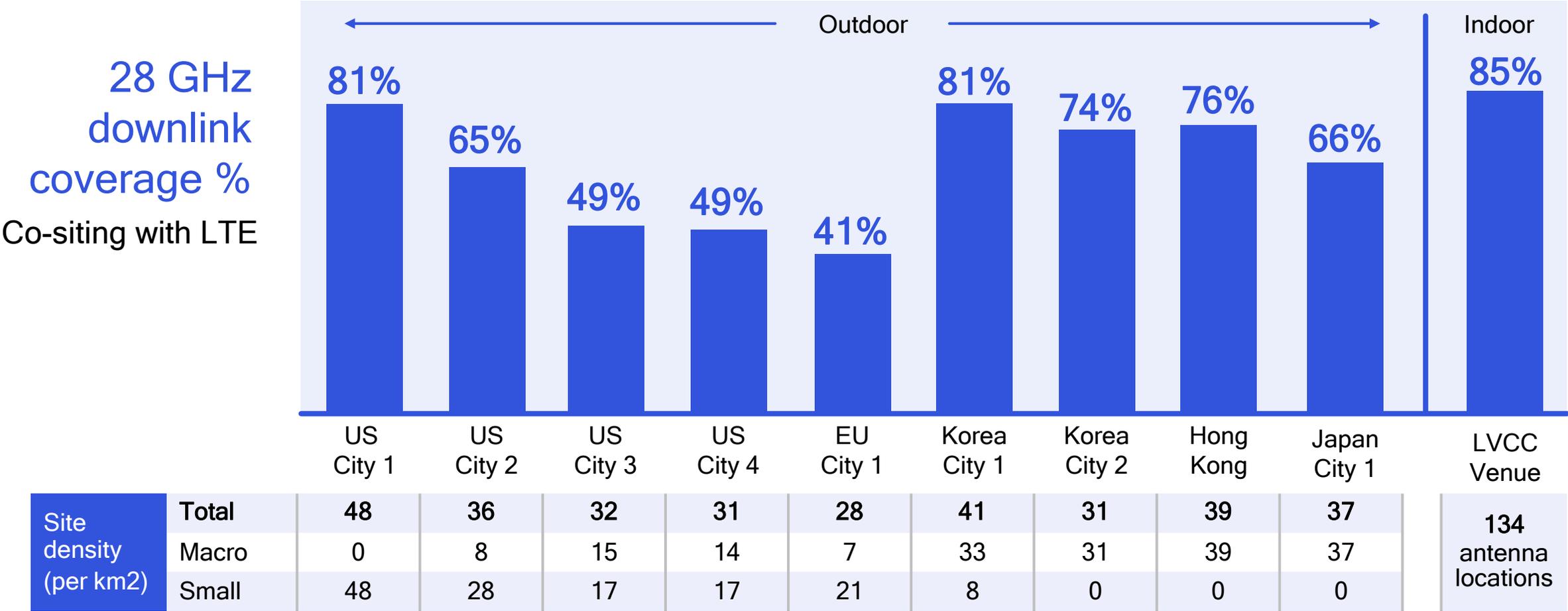
## Collaborating with global operators to simulate 5G NR mmWave coverage



- Significant outdoor coverage possible utilizing actual existing LTE sites (10+ global cities)
- Will further benefit from LTE infrastructure (LAA small cells) to support ongoing Gigabit LTE launches
- Outdoor coverage only; frees up sub-6 GHz resources for out-to-indoor capacity
- Based on our extensive over-the-air testing and channel measurements

# Significant 5G NR mmWave coverage via co-siting

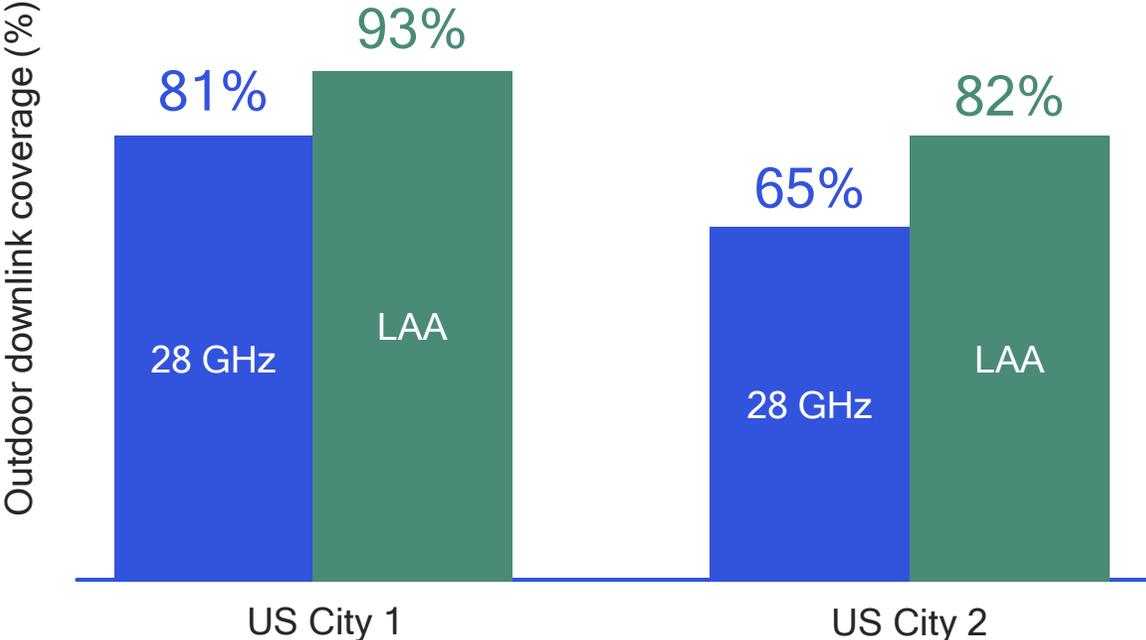
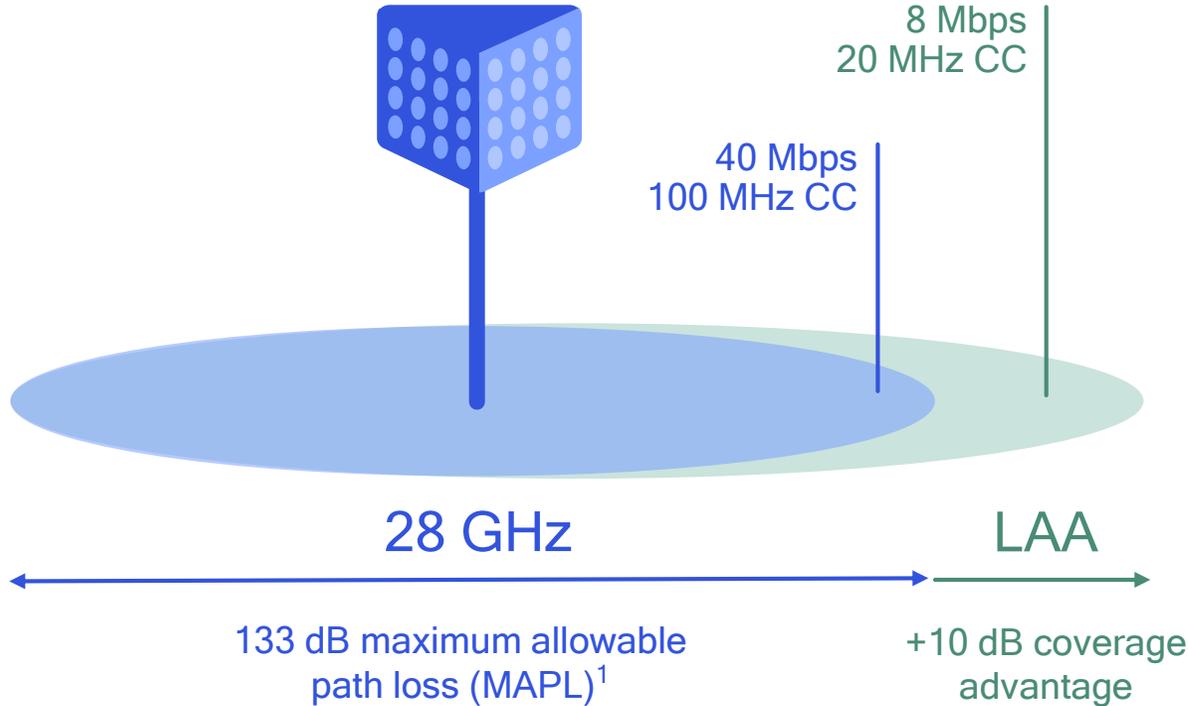
Simulations based on extensive over-the-air testing and channel measurements



Download whitepaper: [www.qualcomm.com/documents/white-paper-5g-nr-millimeter-wave-network-coverage-simulation](http://www.qualcomm.com/documents/white-paper-5g-nr-millimeter-wave-network-coverage-simulation)

# Leveraging LAA small cells used for Gigabit LTE to deliver significant 5G NR mmWave coverage

LAA vs. 28 GHz coverage<sup>2</sup>



Source: Qualcomm Technologies, Inc. 5G NR mmWave Network Coverage Simulation;

1. Link budget based on assumptions; additional variations possible due to temporary blockage – field measurements to follow; 2. Target spectral efficiency of 0.4 bps / Hz

# Commercializing mmWave in a smartphone form factor

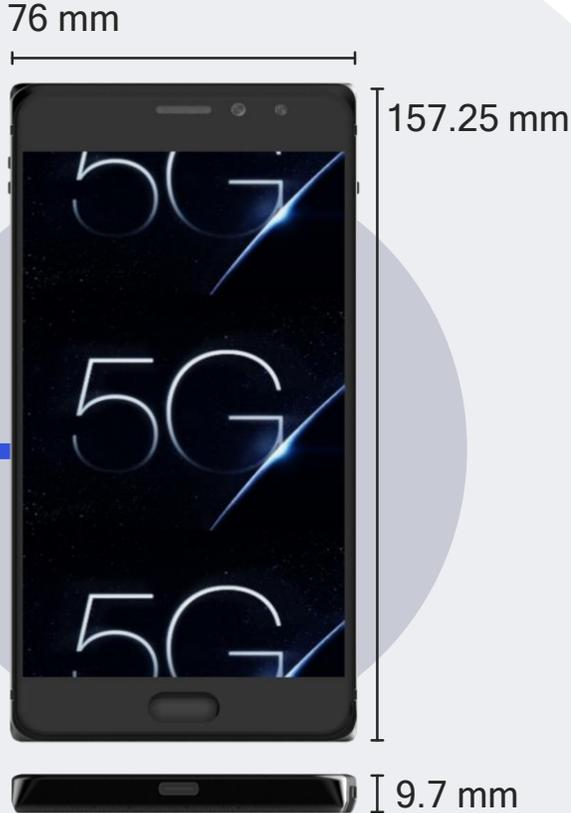


**mmWave (60 GHz) viability in handset form factor**

11ad in Asus Zenfone 4 Pro



**Qualcomm 5G NR mmWave prototype**



**5G NR mmWave Qualcomm Reference Design**

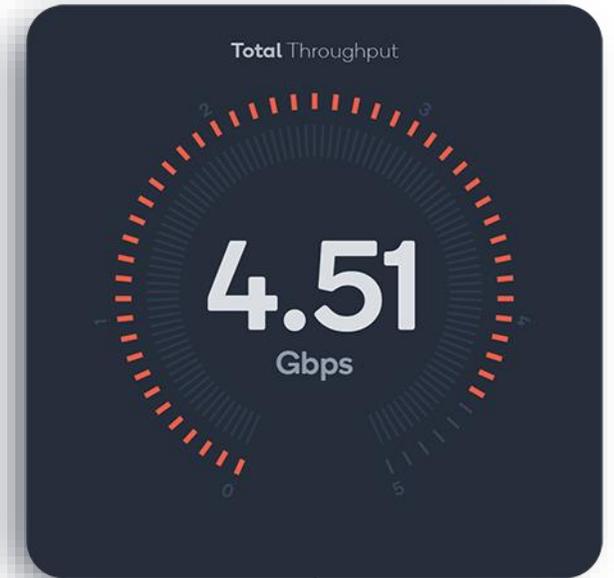


# Qualcomm snapdragon X50 5G modem

Continued, fast-paced  
progress towards  
commercial devices  
in the first half of 2019



October, 2017



February, 2018

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

Watch video: [www.qualcomm.com/videos/mmwave-worlds-first-5g-modem](http://www.qualcomm.com/videos/mmwave-worlds-first-5g-modem)

# Global Mobile Operators Select Qualcomm® Snapdragon™ X50 5G Modem for Mobile 5G NR Trials in 2018

World's First Announced Standard-Compliant Trials based on a 5G Modem Chipset for Mobile Devices, including Smartphone Form-Factors



Learn more: [www.qualcomm.com/news/onq/2018/02/14/our-5g-vision-closer-reality-ever](http://www.qualcomm.com/news/onq/2018/02/14/our-5g-vision-closer-reality-ever)

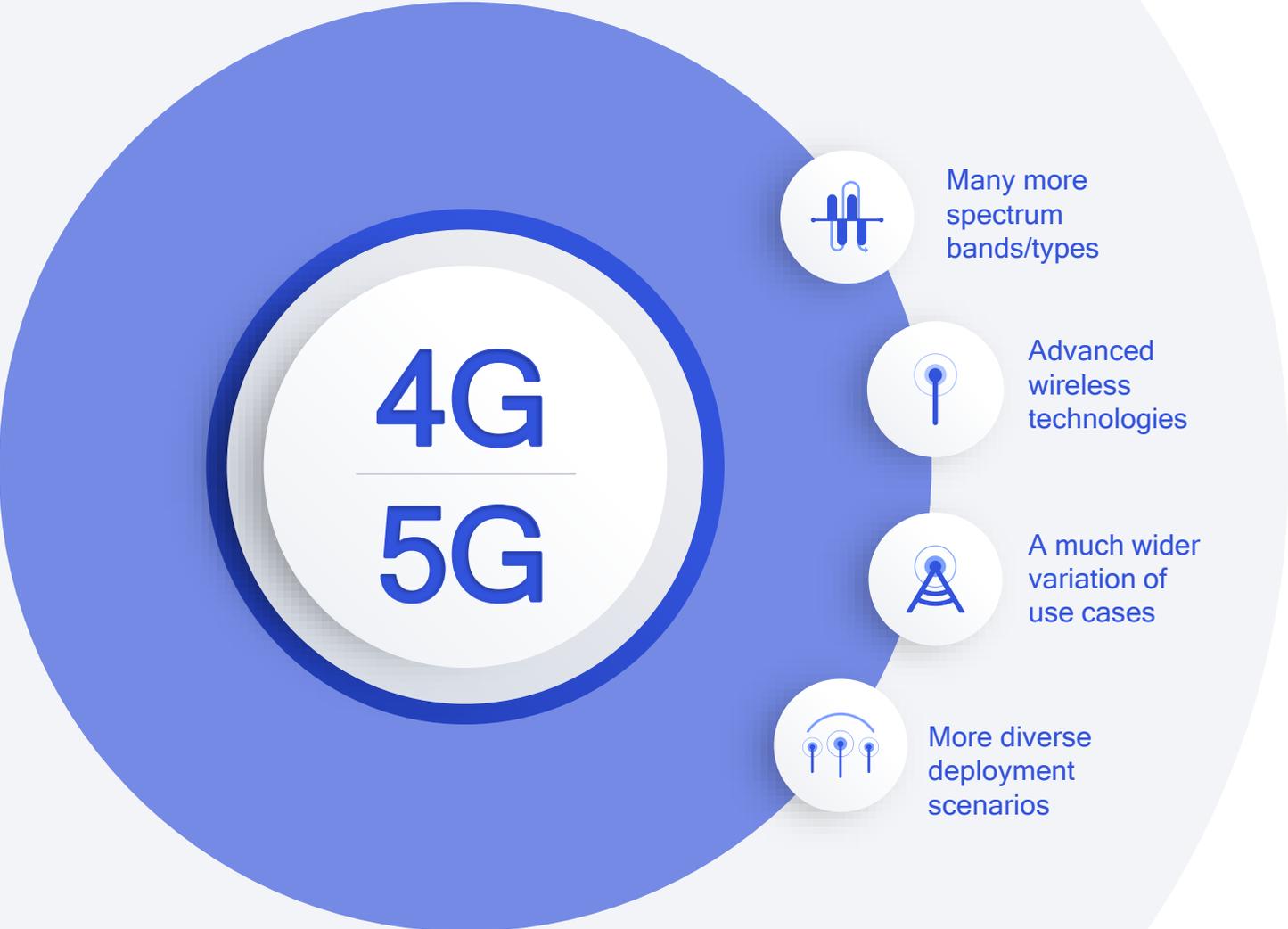
# Global OEMs Select Qualcomm® Snapdragon™ X50 5G NR Modem Family for Mobile Device Launches in 2019

Qualcomm and Mobile Device OEMs Focus on Delivering Next-Generation 5G Mobile Experiences with Low Latency, Extreme Capacity and Fiber-Like Connectivity to the Cloud



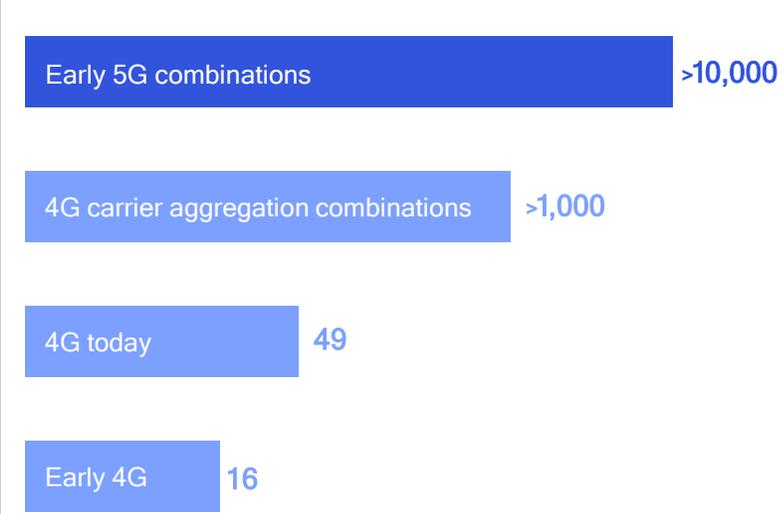
# Complexity of mobile RF systems is accelerating

Multi-mode 4G/5G impacts RF-Front End design



## Number of RF bands and band combinations

By technology generation



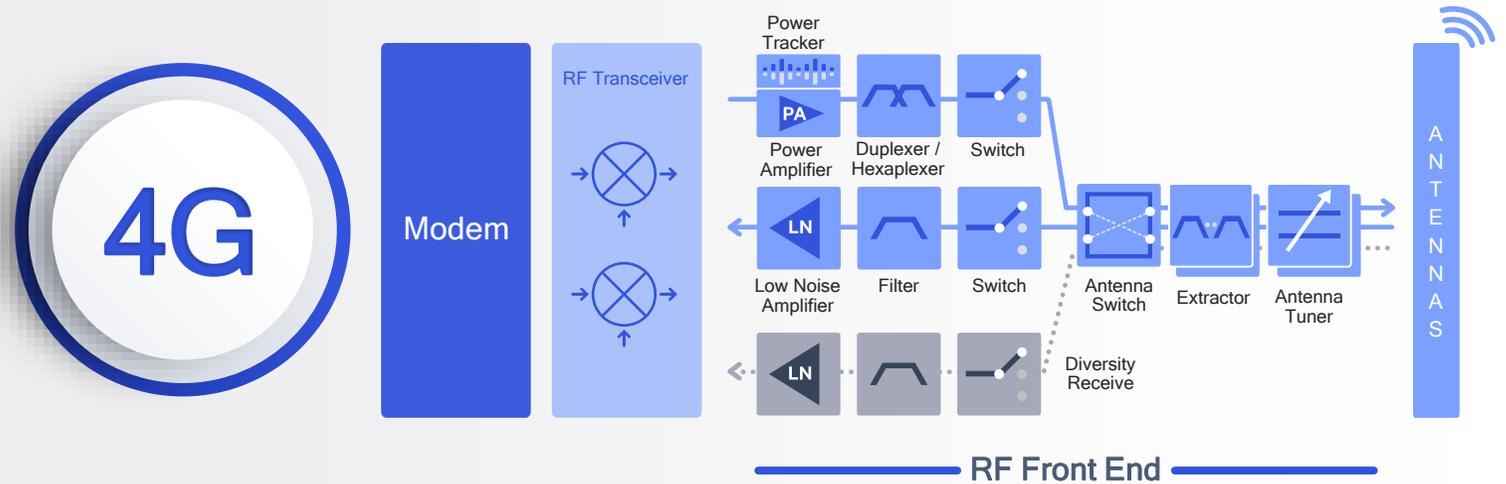
# Qualcomm RF Front End

Multimode 3G/4G/5G poses  
immense challenge

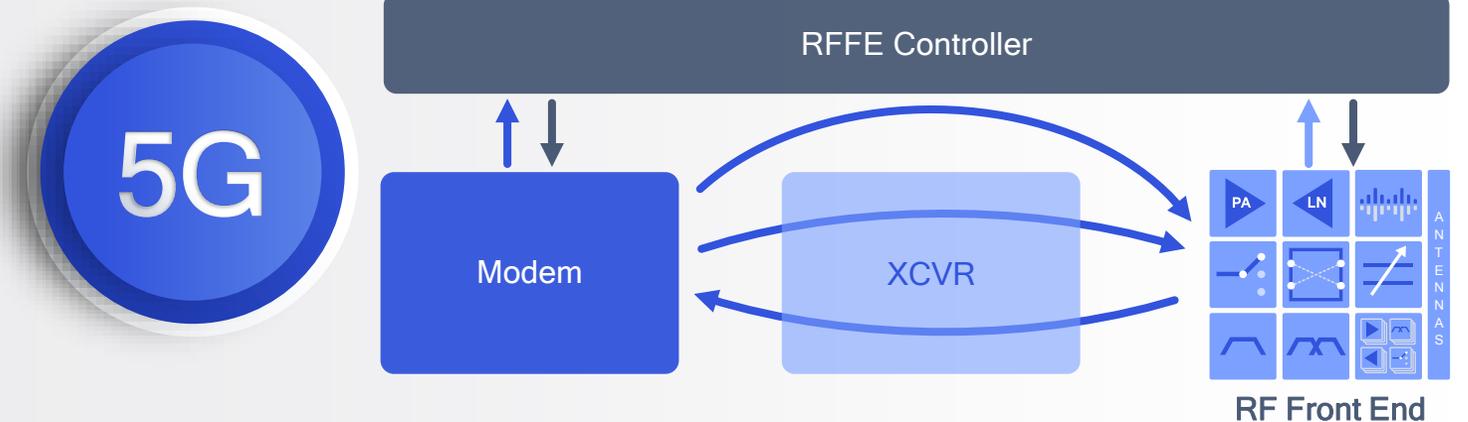
Qualcomm Technologies  
end-to-end system  
uniquely positions us to  
lead in 5G multimode RFFE

Learn more about RFFE:

[www.qualcomm.com/news/onq/2018/02/27/leading-rffe-revolution-paving-path-5g-success](http://www.qualcomm.com/news/onq/2018/02/27/leading-rffe-revolution-paving-path-5g-success)

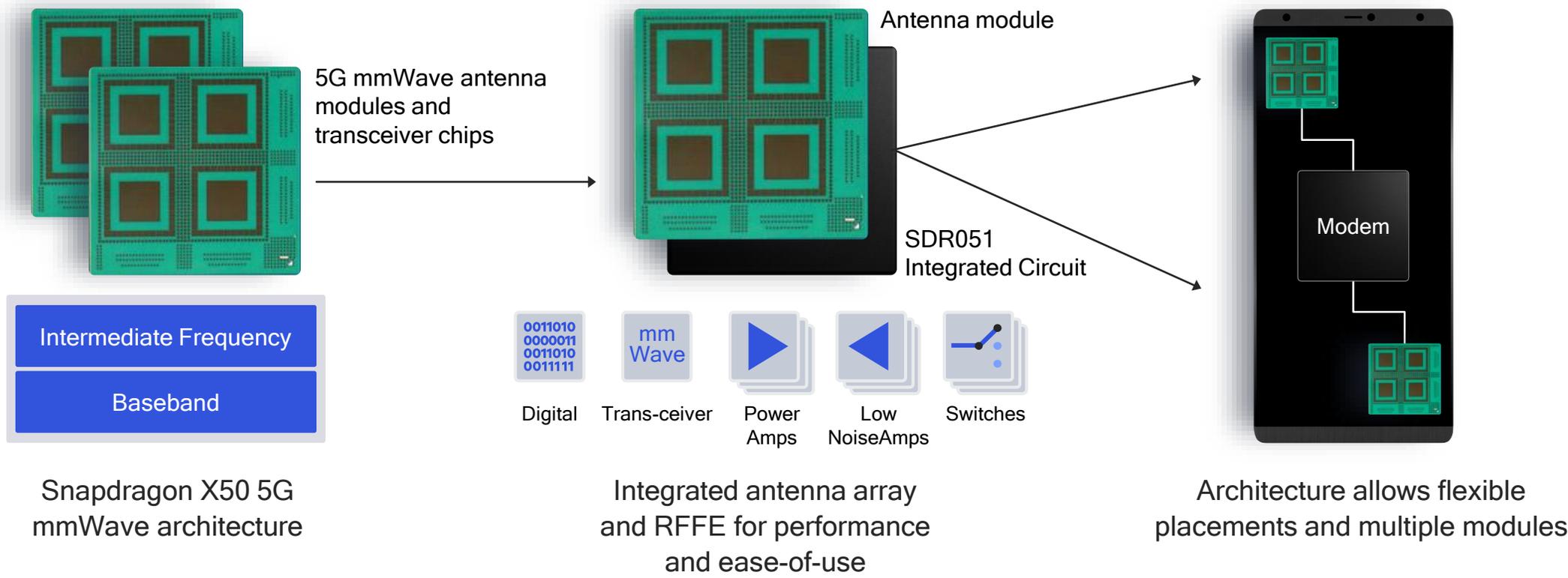


End-to-end approach needed to address growing complexity



Next gen end-to-end system dynamically tunes RFFE performance  
using modem intelligence and network information

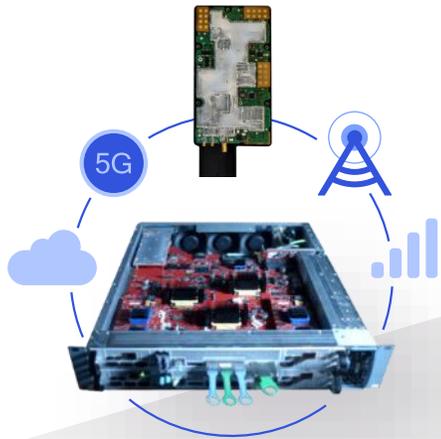
# Snapdragon X50 mmWave solution



# Making 5G NR a commercial reality for 2019

For standard-compliant networks and devices

Qualcomm



## Best-in-class 5G prototype systems

Designing and testing 5G technologies for many years



## 5G NR standards and technology leadership

Our technology inventions are driving the 5G NR standard



## 5G NR interoperability testing and trials

Leveraging prototype systems and our leading global network experience



## Modem and RFFE leadership

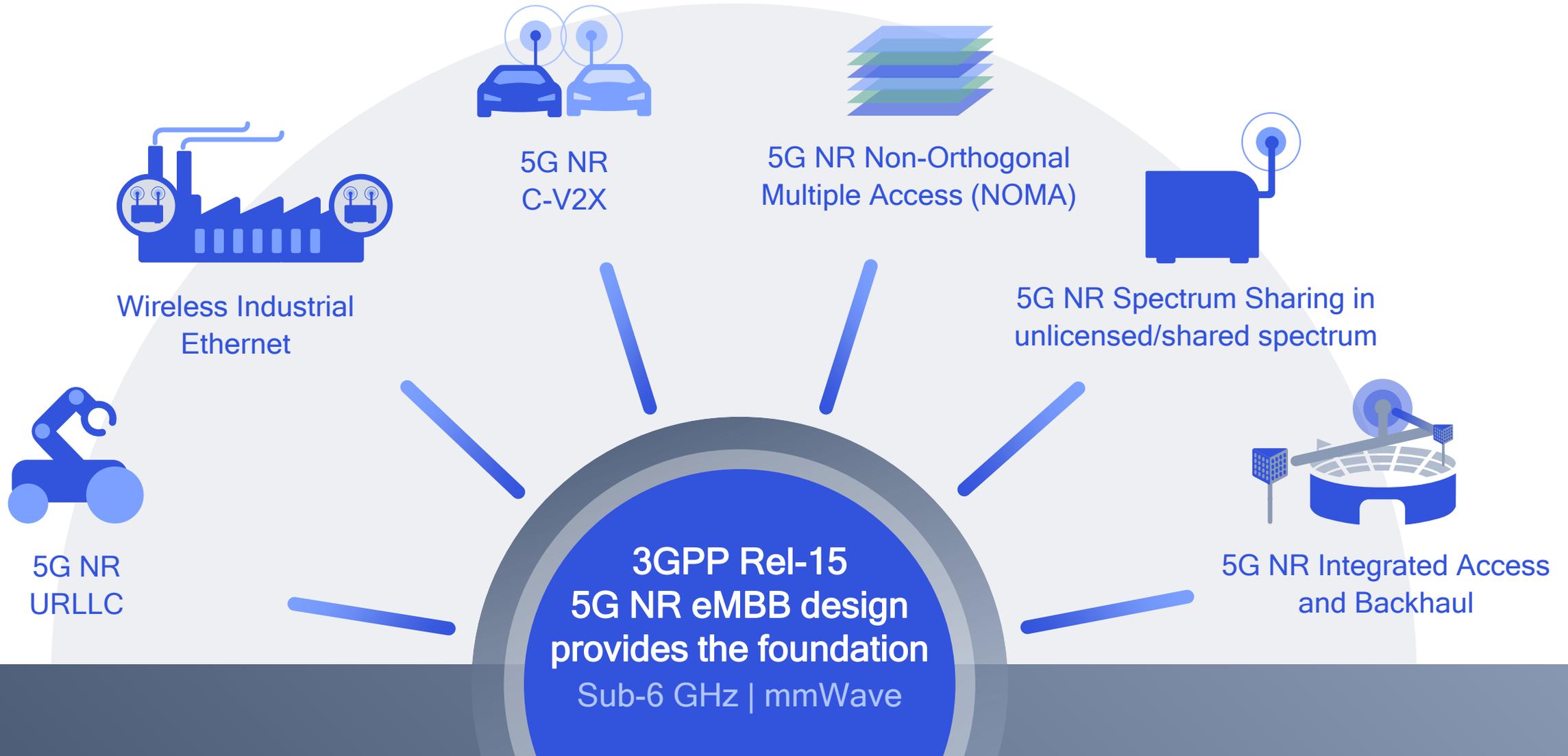
Announced the Qualcomm Snapdragon X50 5G modem family

LTE foundational technologies →

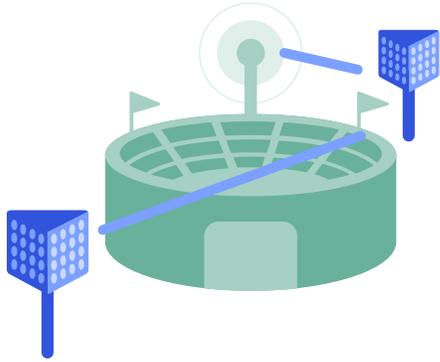
Download the “Making 5G NR a commercial reality” presentation to learn more – [link](#)

# Driving a rich 5G NR technology roadmap beyond eMBB

Download the 3GPP Release-16 5G NR overview presentation to learn more – [link](#)

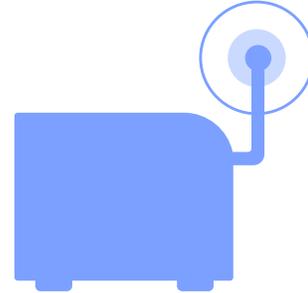


# 5G NR mmWave continuing to evolve beyond R15



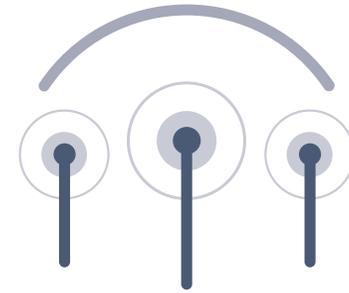
## Integrated Access and Backhaul

Rel-15 Study Item on enabling easy/low-cost deployment of small cells using mmWave spectrum for access and backhaul



## Unlicensed Spectrum

Rel-15 Study Item for both LAA and standalone operation (aka 5G MulteFire™) in sub-6 GHz and mmWave spectrum bands



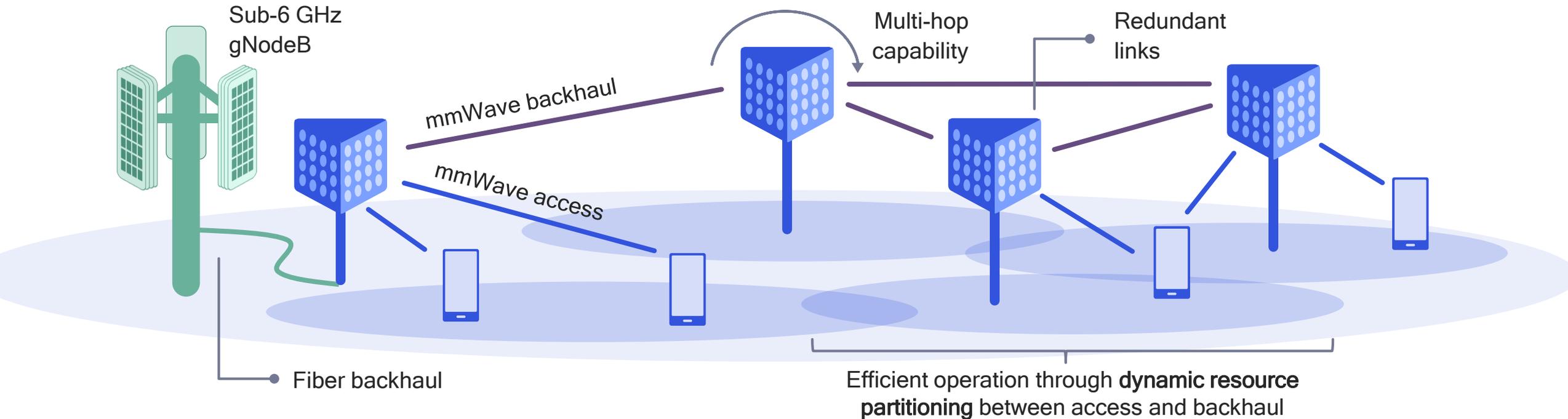
## Higher spectrum bands

Exploring the use of spectrum bands above ~40 GHz, including unlicensed spectrum in the 57 GHz to 71 GHz band

Bringing new capabilities, new spectrum bands and new deployment opportunities

# 5G NR mmWave IAB<sup>1</sup> for cost-efficient dense deployments

Improves coverage and capacity, while limiting backhaul cost



<sup>1</sup> Integrated Access & 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



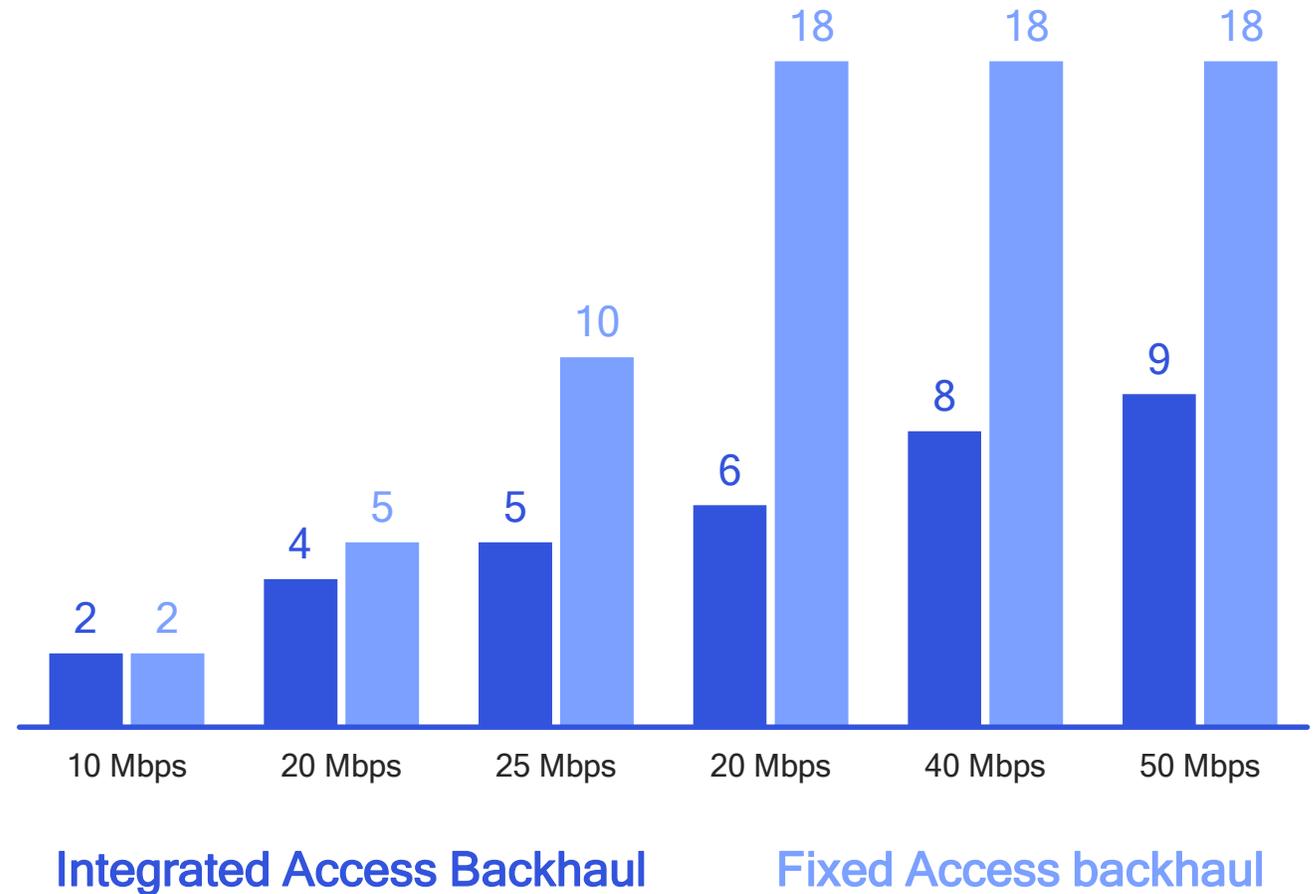
# 5G NR Integrated Access & Backhaul

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

Qualcomm

# 5G NR

5G is the foundation to what's next.  
We are the foundation to 5G.

Learn more at [www.qualcomm.com/5G](http://www.qualcomm.com/5G)



Making 5G NR  
a commercial reality  
for 2019 eMBB  
deployments



Driving the expansion  
of 5G NR ecosystem  
and opportunity

# Questions

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