**QUALCOMM®**

# Driving the
# Gigabit LTE Evolution

Qualcomm Technologies, Inc.

February 2017

Immersive VR & AR

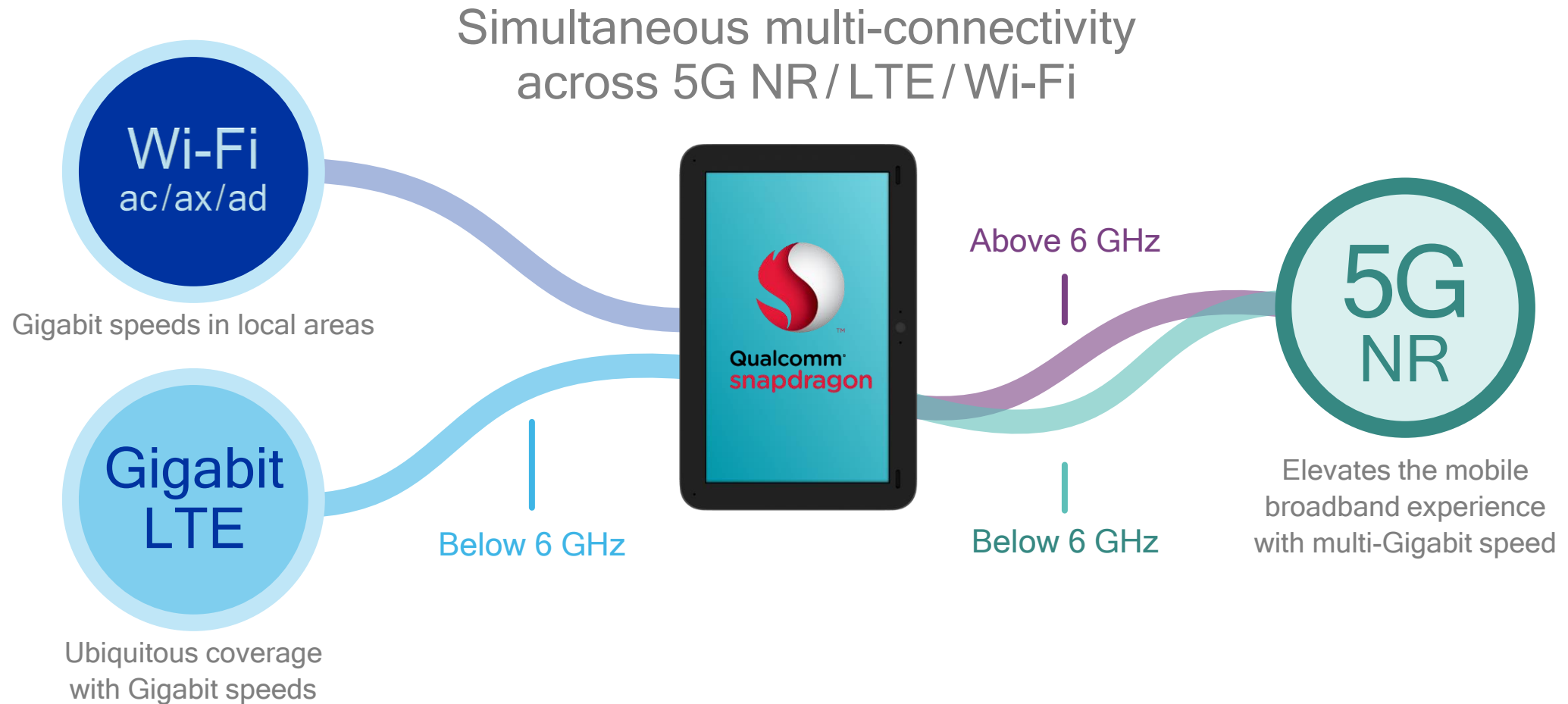Fiber-like connectivity

# Gigabit LTE

Essential to the 5G
mobile experience

Rich entertainment

Instant apps

# 5G mobile experience requires ubiquitous Gigabit speeds

## Achieved by multi-connectivity that fully leverages LTE & Wi-Fi investments

Simultaneous multi-connectivity
across 5G NR / LTE / Wi-Fi

Wi-Fi
ac/ax/ad

Gigabit speeds in local areas

Gigabit
LTE

Ubiquitous coverage
with Gigabit speeds

Qualcomm
snapdragon
™

Above 6 GHz

Below 6 GHz

Below 6 GHz

5G
NR

Elevates the mobile
broadband experience
with multi-Gigabit speed

# X16

LTE Modem

The world's first Gigabit Class LTE mobile device and network

Learn more at: https://www.qualcomm.com/x16

NETGEAR

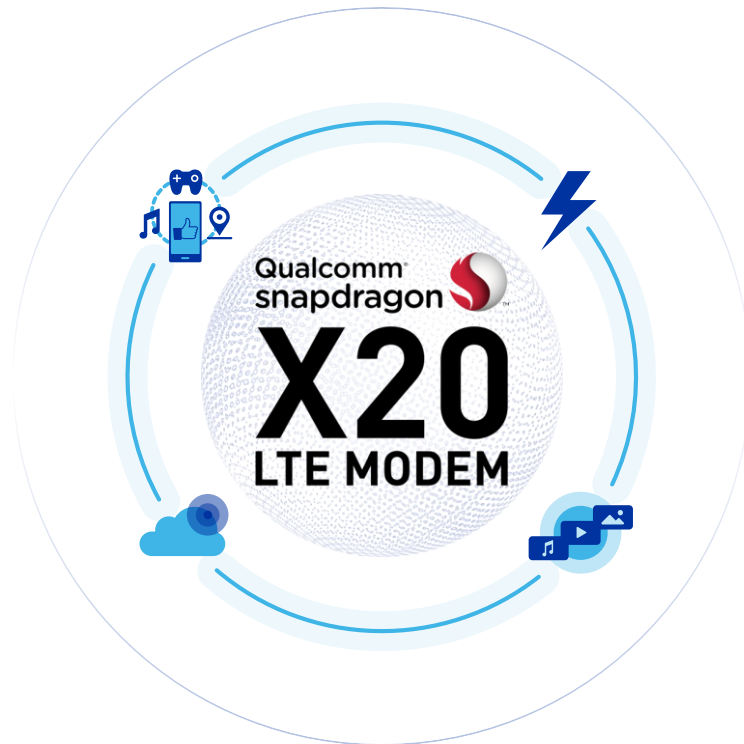Qualcomm® snapdragon™

ERICSSON

# Qualcomm® Snapdragon™
# 835

## With the integrated Snapdragon X16 LTE modem

- 4x20MHz Carrier Aggregation
- 4x4 MIMO and 256-QAM
- 1st with LTE License Assisted Access

# Introducing Qualcomm Snapdragon X20

## Qualcomm Technologies' second generation Gigabit LTE modem

**Built on a leading-edge 10nm FinFET process**

**Up to 1.2 Gbps - Cat 18 DL**
Up to 12 spatial streams; 4x4 MIMO on 3 LTE carriers; 5x20 MHz carrier aggregation

**Up to 150 Mbps - Cat 13 UL**
via 2x20MHz CA and 64-QAM

**License Assisted Access – Gigabit Globalization**
Reducing licensed requirement to 10 MHz; up to 80 MHz on unlicensed spectrum

**Support for CBRS – Shared spectrum**
New spectrum sharing paradigm to enhance existing networks, support new ones
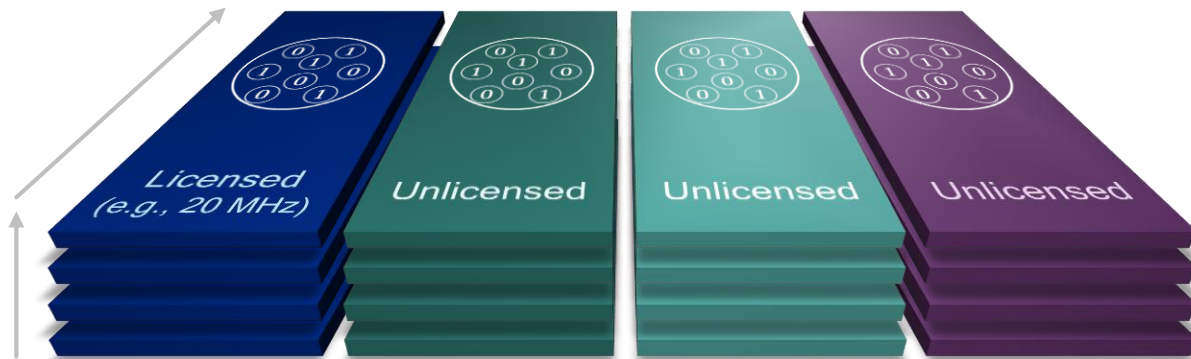
**Dual SIM Dual VoLTE (DSDV) – Dual IMS**
Bringing the benefits of HD and Ultra HD Voice to popular Dual SIM feature

# Achieving Gigabit LTE and beyond

**Higher peak rates by adding more, higher-efficiency ~100 Mbps streams[1,2]**

**New Gigabit LTE device categories**

Utilizing higher-order modulation (256-QAM)

Adding up to 4 MIMO layers

Licensed (e.g., 20 MHz)

Unlicensed

Unlicensed
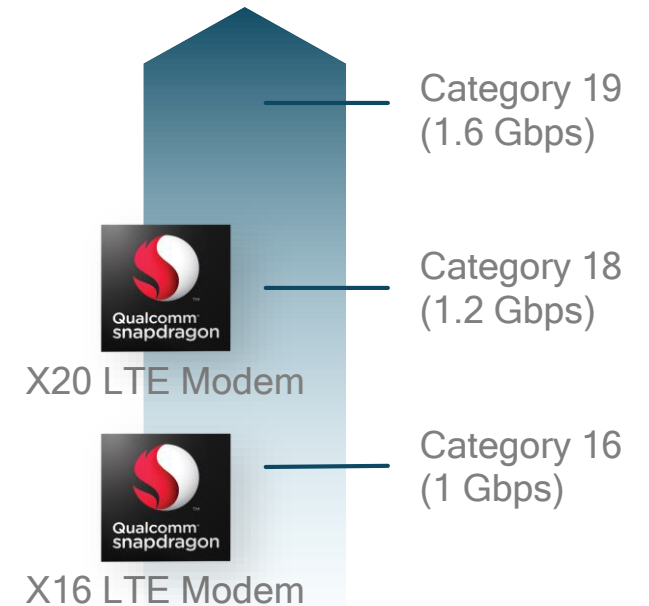
Unlicensed
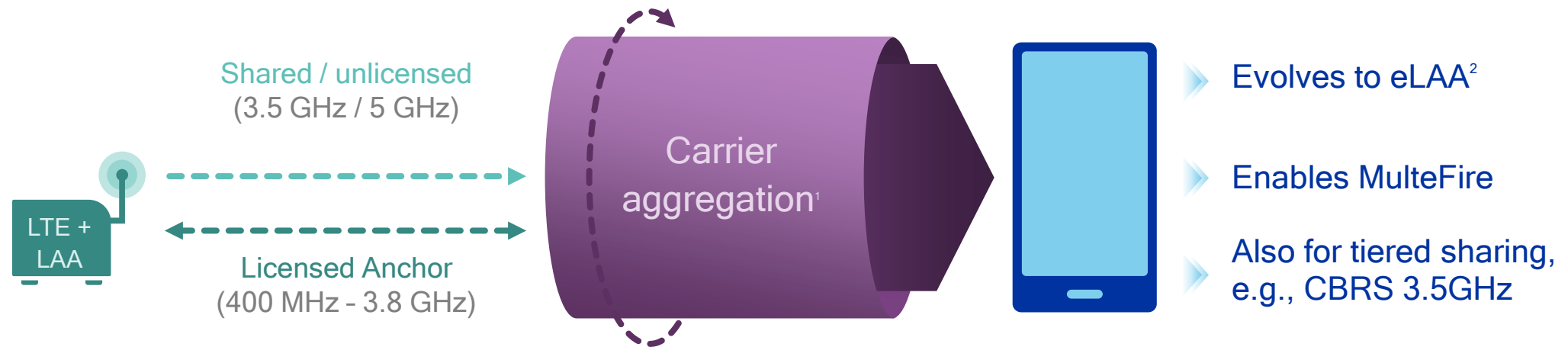
1st LTE Carrier    2nd LTE Carrier    3rd LTE Carrier    4th LTE Carrier

Aggregating more carriers across licensed and unlicensed with LAA[3]

Category 19 (1.6 Gbps)

Category 18 (1.2 Gbps)

X20 LTE Modem

Category 16 (1 Gbps)

X16 LTE Modem

# LAA a key enabler of Gigabit LTE–paving the path to 5G NR

**LTE + LAA**

Shared / unlicensed
(3.5 GHz / 5 GHz)

Licensed Anchor
(400 MHz – 3.8 GHz)

Carrier aggregation[1]

Evolves to eLAA[2]

Enables MulteFire

Also for tiered sharing, e.g., CBRS 3.5GHz

**Commercial launches in 2017**

Supported in our chipsets, e.g., Qualcomm® Snapdragon™ X16 processor

**Common LBT[3] ensures fair sharing**

Industry-wide LBT agreement in ETSI that applies to LAA, Wi-Fi, MulteFire

**FCC granted first equipment certification[4]**

Authorized Qualcomm Technologies in Sept. 2016 and subsequently granted others
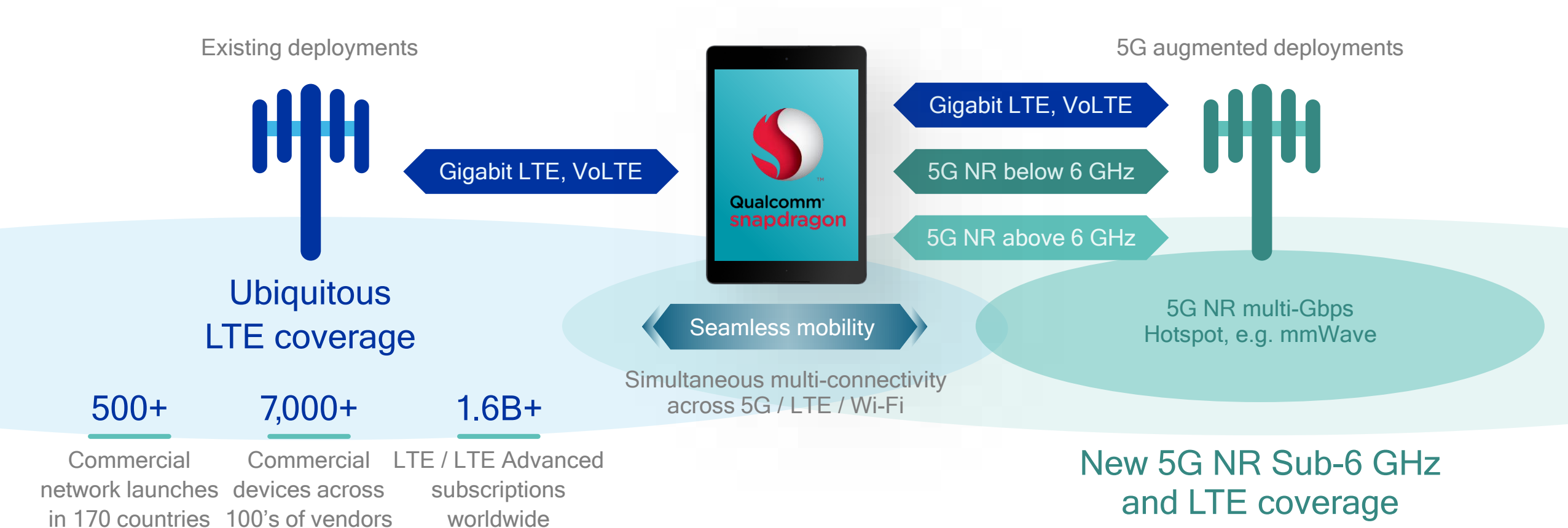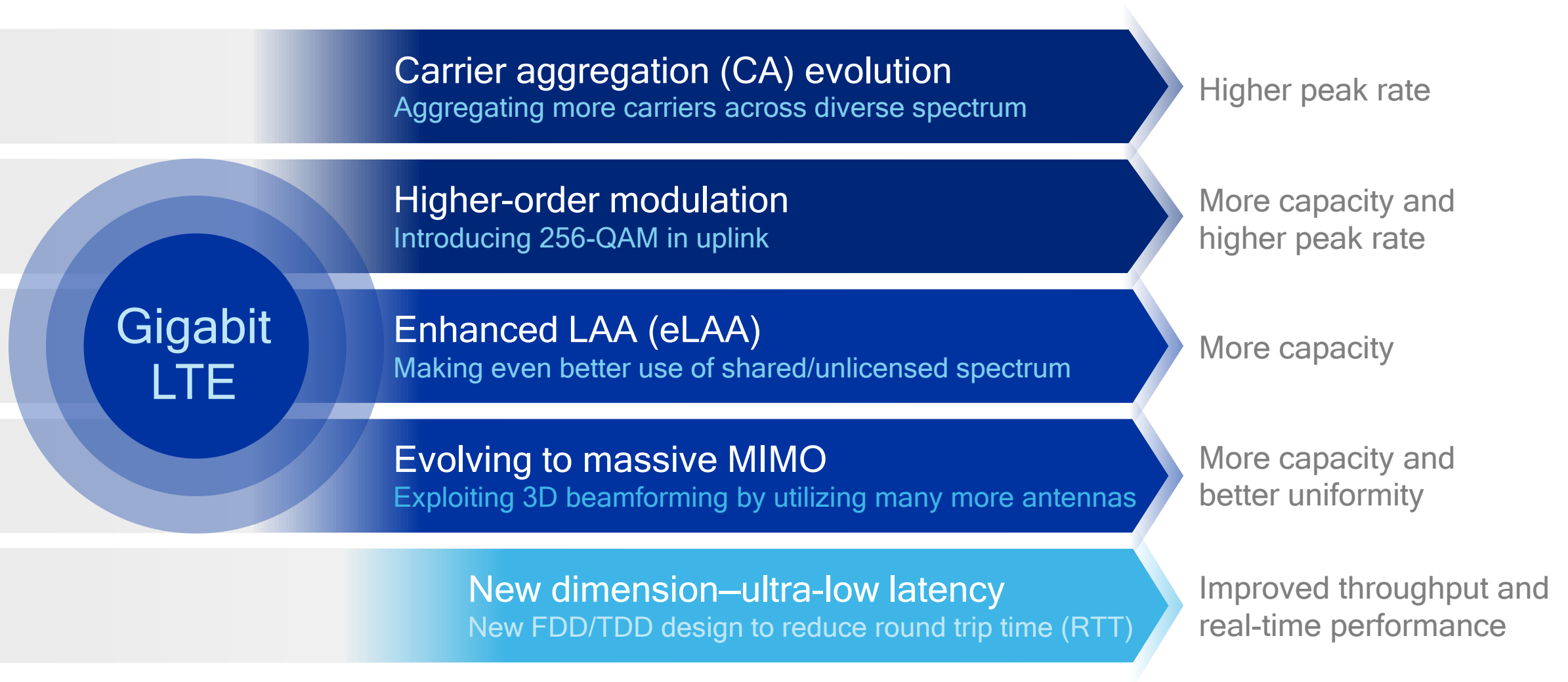
Learn more at: www.qualcomm.com/laa

# Gigabit LTE is essential to the 5G mobile experience
## Multi-connectivity fully leverages LTE investments and provides VoLTE service

Existing deployments

5G augmented deployments

Gigabit LTE, VoLTE

Gigabit LTE, VoLTE

5G NR below 6 GHz

5G NR above 6 GHz

**Ubiquitous
LTE coverage**

5G NR multi-Gbps
Hotspot, e.g. mmWave

Seamless mobility

Simultaneous multi-connectivity
across 5G / LTE / Wi-Fi

**500+**
Commercial
network launches
in 170 countries

**7,000+**
Commercial
devices across
100's of vendors

**1.6B+**
LTE / LTE Advanced
subscriptions
worldwide

**New 5G NR Sub-6 GHz
and LTE coverage**

Qualcomm
snapdragon

# Evolving Gigabit LTE in multiple dimensions

**Gigabit LTE**

**Carrier aggregation (CA) evolution**
Aggregating more carriers across diverse spectrum

Higher peak rate

**Higher-order modulation**
Introducing 256-QAM in uplink

More capacity and higher peak rate

**Enhanced LAA (eLAA)**
Making even better use of shared/unlicensed spectrum

More capacity

**Evolving to massive MIMO**
Exploiting 3D beamforming by utilizing many more antennas

More capacity and better uniformity

**New dimension—ultra-low latency**
New FDD/TDD design to reduce round trip time (RTT)

Improved throughput and real-time performance

# Towards ultra-low latency in the ~1ms range with LTE

## New ultra-low latency improvements proposed in Rel-14+

### Improved throughput performance

By addressing TCP/UDP throughput limitations (e.g., TCP slow start)

### Better user experience for real-time applications

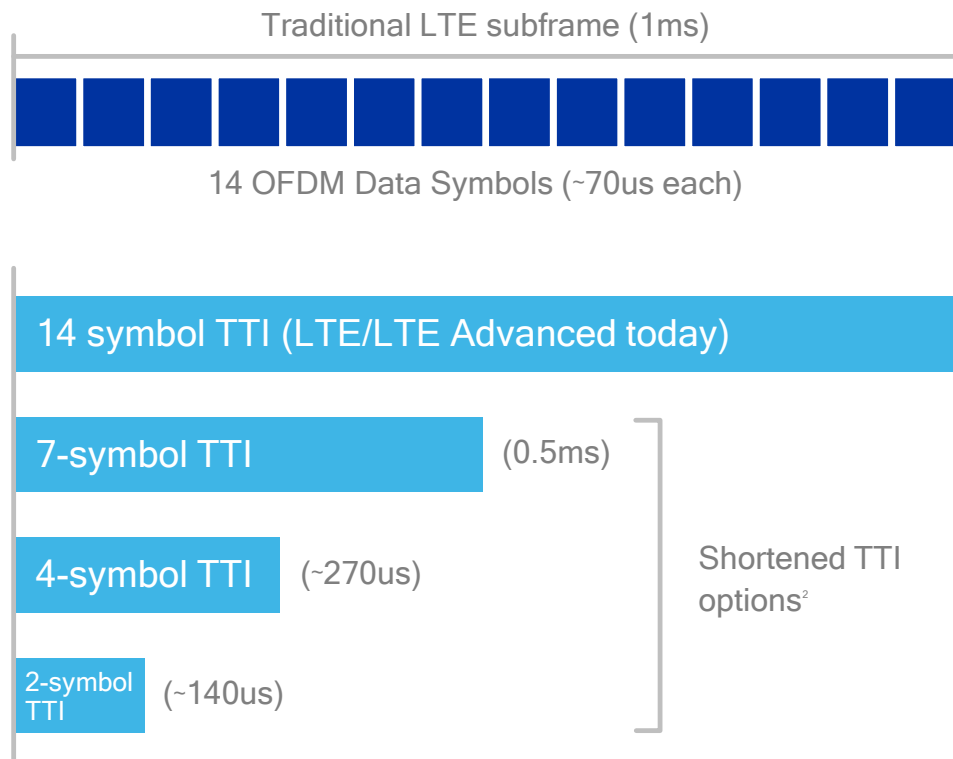Such as reducing packet and call setup delay for Voice- or Video-over-IP applications

### Paving the path for mission-critical services

Optimizing for lower-latency, high-reliability command & control of drones, robotics, industrial equipment

# New FDD/TDD design delivers latency in the 1ms range[1]

## Reducing turnaround time with shorter TTI and more efficient HARQ processing

### Shorter transmission time interval (TTI)

Traditional LTE subframe (1ms)

14 OFDM Data Symbols (~70us each)

14 symbol TTI (LTE/LTE Advanced today)

7-symbol TTI (0.5ms)

4-symbol TTI (~270us)

2-symbol TTI (~140us)

Shortened TTI options[2]

### Significantly lower round trip time (RTT)

**FDD**
Faster HARQ RTT

2-symbol TTI = ~140us

Data: 0 | 1 | 2 | 3 | 4 | 5 | 0

Shorter processing time (n+3)

ACK: ACK0

Faster HARQ RTT = ~1 ms

Shortened TTI = 0.5 ms

**TDD**
Shortened TTI reduces RTT

DL Subframe | DL Subframe | S Subframe | UL Subframe

Shorter processing time (n+3)

Delay can range from 3 to 7 subframes depending on subframe scheduling
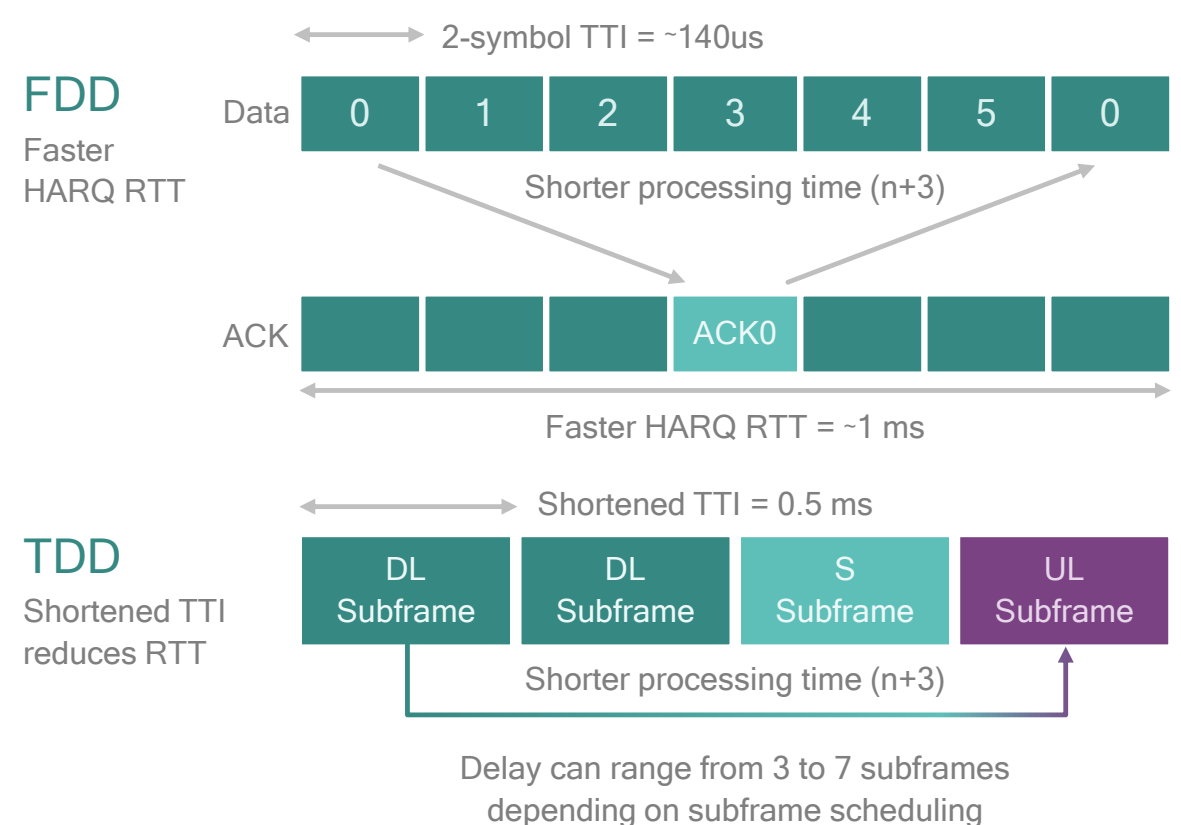
1. Over-the-air latency based on LTE / LTE Advanced HARQ RTT today ≥ 8ms; LTE Advanced Pro = ~1ms based on 2 symbol TTI and n+3 turnaround time; 2. 7-symbol TTI supported for DL/UL TDD; 2/7-symbol TTI supported for DL FDD; 2/4/7-symbol TTI supported for UL FDD

# Continued licensed assisted access evolution

## Key enabler of Gigabit LTE using as little as 10 MHz of licensed spectrum

Downlink and uplink aggregation

Shared / unlicensed
(3.5 GHz / 5 GHz)

LTE + LAA

Carrier aggregation[1]

Licensed anchor
(400 MHz - 3.8 GHz)
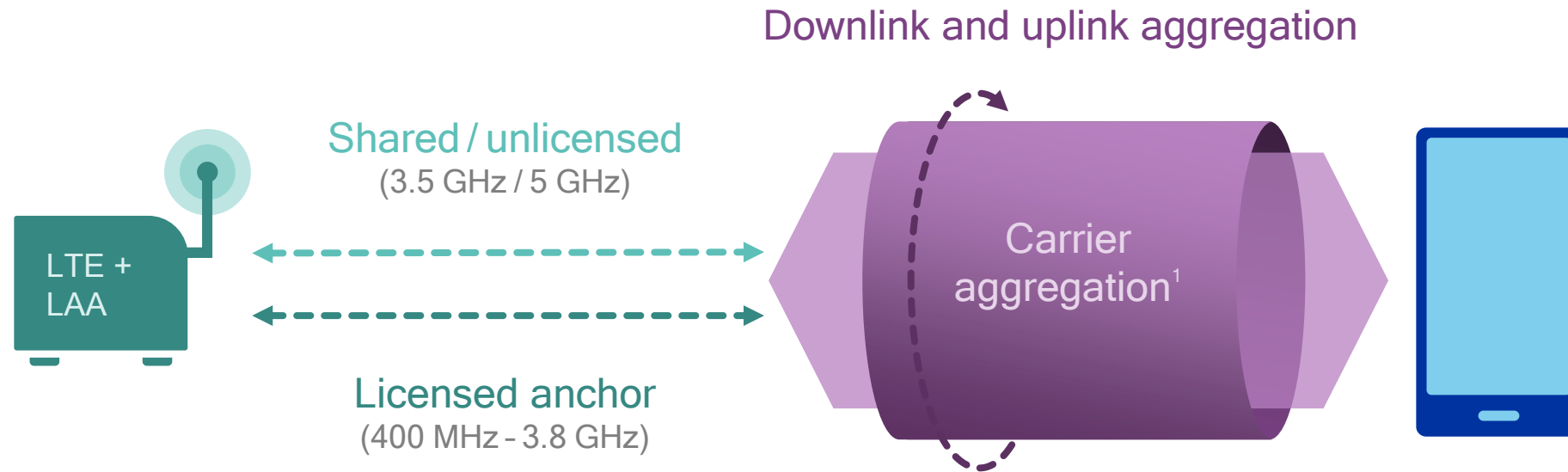
**Release 13 – LAA**
• Downlink aggregation
• Fair Wi-Fi coexistence using LBT[2]
• ~2x performance over Wi-Fi[3]

**Release 14 – eLAA**
• Adds uplink aggregation
• Complexity reduction[4]

1. Aggregation of unlicensed downlink and uplink is possible with either licensed TDD or licensed FDD; 2. Listen-Before-Talk 3. Assumptions: Dense deployments provides ~2x better capacity and range. 3GPP LAA evaluation model based on TR 36.889, two operators, 4 small-cells per operator per macro cell, outdoor, 40 users on same 20 MHz channel in 5 GHz, both uplink and downlink in 5 GHz, 3GPP Bursty traffic model 3 with 1MB file, LWA using 802.11ac, DL 2x2 MIMO (no MU-MIMO), 24dBm + 3dBi Tx power in 5 GHz for LAA eNB or Wi-Fi AP; 4. Complexity/cost reduction is also applicable to licensed LTE

# Evolving to massive MIMO to increase coverage/capacity
## Delivering a more uniform user experience

Elevation beamforming

Azimuth beamforming

Exploit 3D beamforming utilizing a 2D antenna array

■ Average throughput
■ Cell edge throughput

| MIMO | Cell edge throughput | Average throughput |
|---|---|---|
| 4 x 2 MIMO | 1x | 1x |
| 8 x 2 MIMO | 1.5x | 2.2x |
| 16 x 2 MIMO | 2.8x | 3.5x |
| 32 x 2 MIMO | 3.1x | 4.0x |
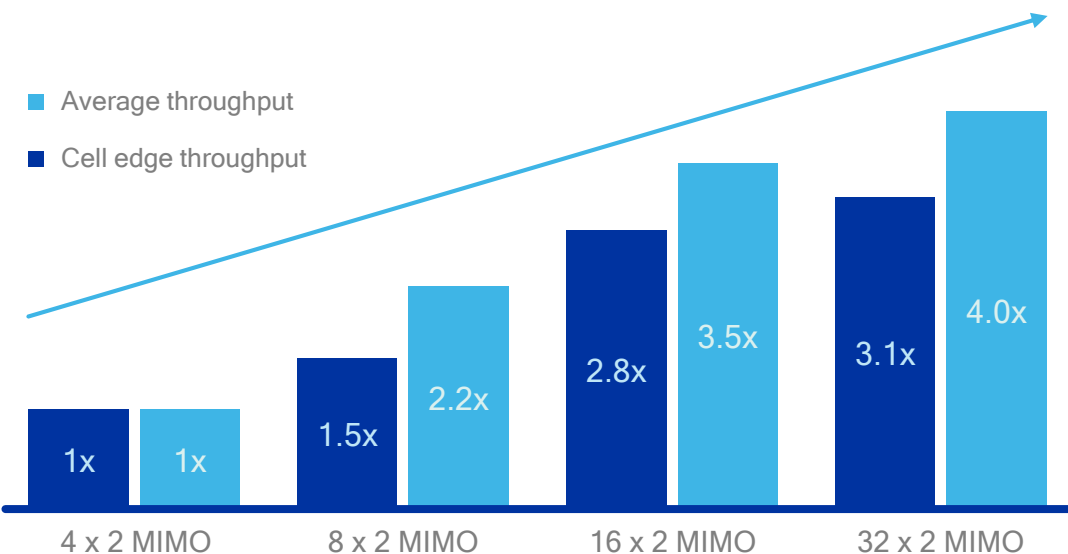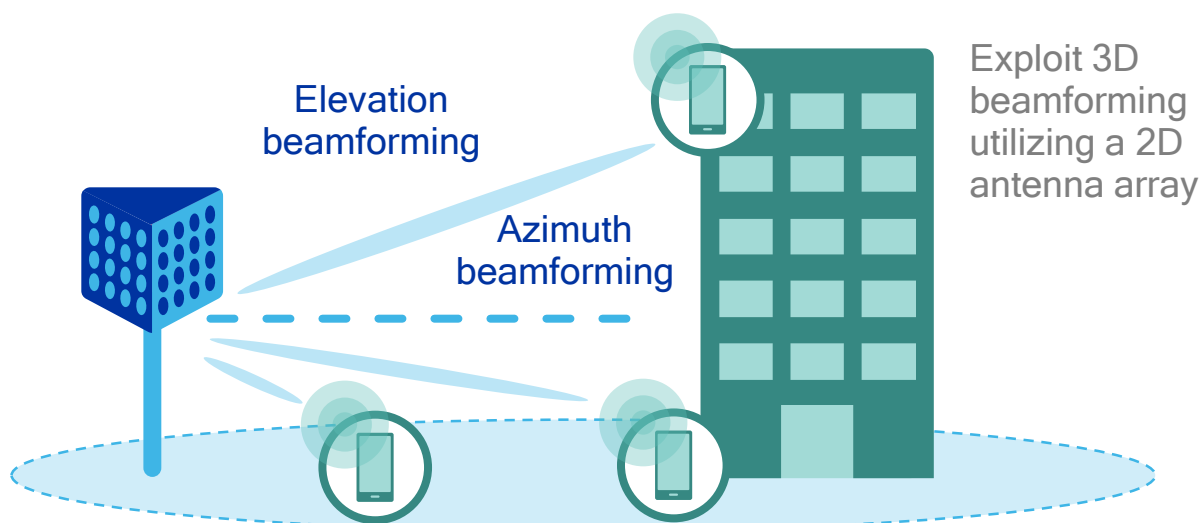
**Release 13 FD-MIMO**
2D codebook support for 8-, 12- and 16-antenna ports with reference signal enhancements for beamforming

**Release 14 Massive MIMO**
Support up to 32-antenna ports with improvements[1] to beamforming accuracy and efficiency for MU-MIMO

**Further enhancements in Release 15 and beyond**

14

# 5G NR Rel-15[1] elevates the mobile broadband experience

## New spectrum technologies that utilize new bands and wider bandwidths

### mmWave spectrum[2]
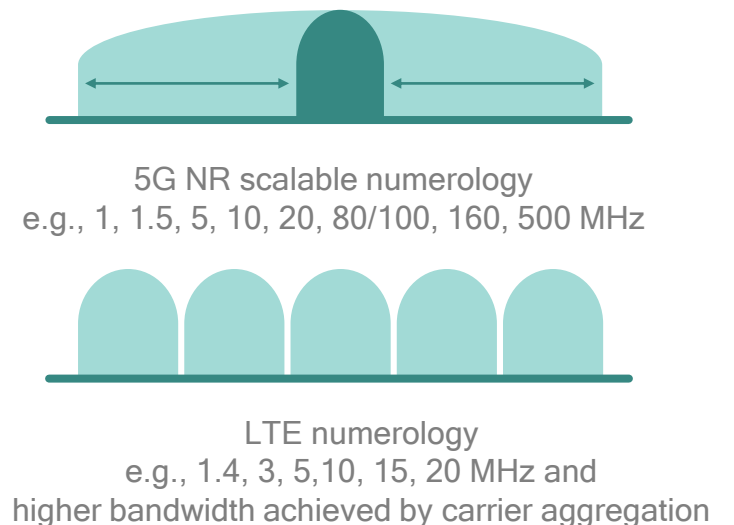LTE in existing sub-6 GHz bands provides the anchor

1 GHz
6 GHz

High-bands

5G NR Rel-15 will support bands up to 40 GHz

100 GHz
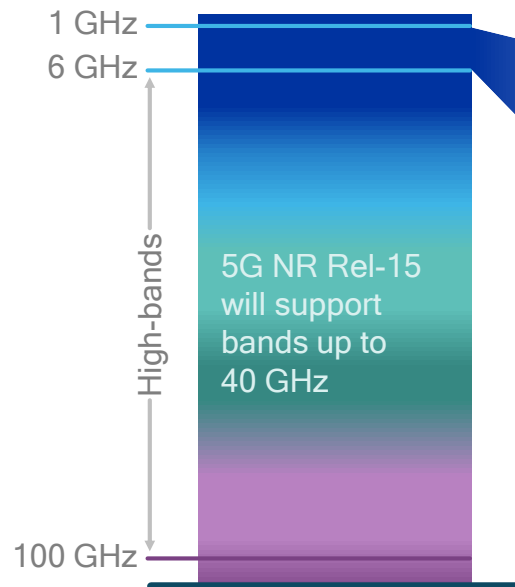
### New sub-6 GHz spectrum
Expanding to higher frequencies leveraging existing cell sites

Low

New 5G NR 600MHz (US) 700MHz (EU)

1 GHz

Mid

New 5G NR in 3 GHz and 4 GHz bands

6 GHz
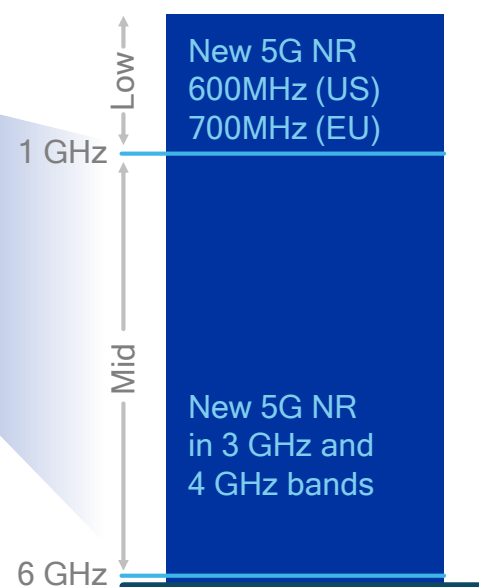
### Excels in wider bandwidths
Improved performance, efficiency, and ability to leverage even more antennas

5G NR scalable numerology
e.g., 1, 1.5, 5, 10, 20, 80/100, 160, 500 MHz

LTE numerology
e.g., 1.4, 3, 5,10, 15, 20 MHz and higher bandwidth achieved by carrier aggregation

# 5G NR will take mobile broadband to the next level

## 5G NR

### Enhanced mobile broadband

Extreme throughput

Ultra-low latency

Uniform experience
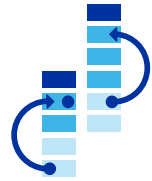
### New TDD/FDD design
Self-contained subframe, scalable TTI, advanced HARQ to significantly lower latency

### Massive MIMO
Reciprocity-based design to more efficiently increase capacity and coverage

### Advanced channel coding
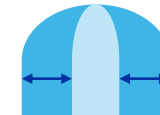LDPC to deliver higher efficiency for larger block data transmissions

### Device-centric mobility
Overhead reduction to improve mobility and energy efficiency

### Mobilizing mmWave
Using vast available amount of higher-band spectrum to deliver extreme broadband services

### Wider bandwidth
Scalable numerology to address diverse spectrum and deployments

### Shared spectrum
More efficient use of limited spectrum resources with new sharing paradigms

Learn more at: https://www.qualcomm.com/5g-nr

# Questions? - Connect with Us

www.qualcomm.com/wireless

www.qualcomm.com/news/onq

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http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp

http://www.slideshare.net/qualcommwirelessevolution
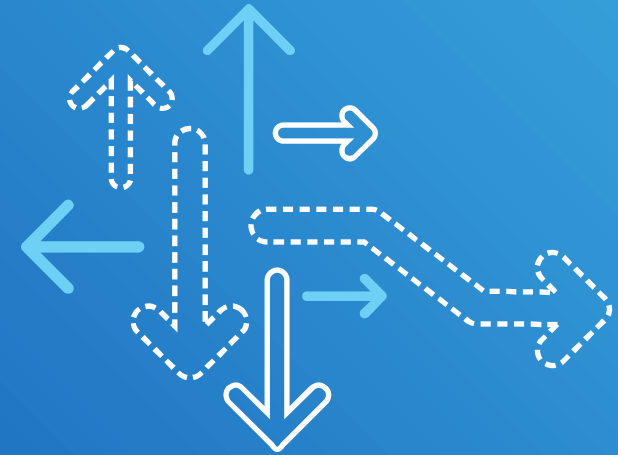
# Thank you

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