The essential role of Gigabit LTE & LTE Advanced Pro in a 5G World

Qualcomm Technologies, Inc.

February 2017

Our vision for 5G is a unifying connectivity fabric

Delivering always-available, secure cloud access

Enhanced mobile broadband

Mission-critical services

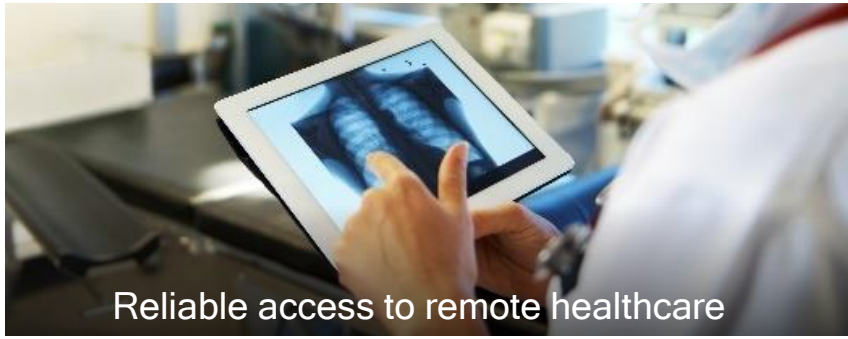
Massive Internet of Things

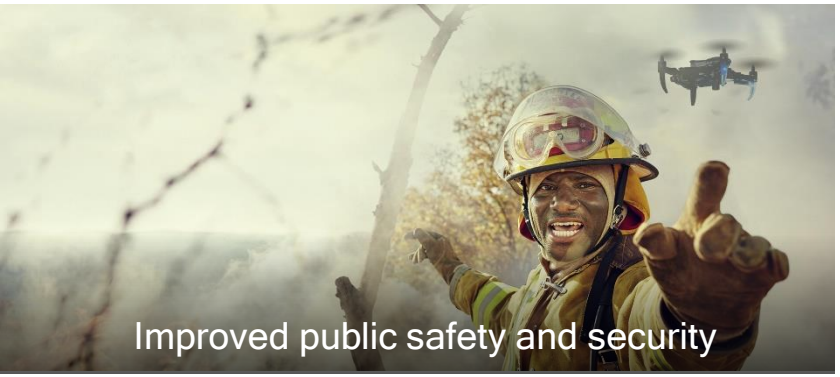
Unifying connectivity platform for future innovation

Convergence of spectrum types/bands, diverse services, and deployments,
with new technologies to enable a robust, future-proof 5G platform

5G will redefine a wide range of industries

A platform for new connected services–existing, emerging and unforeseen

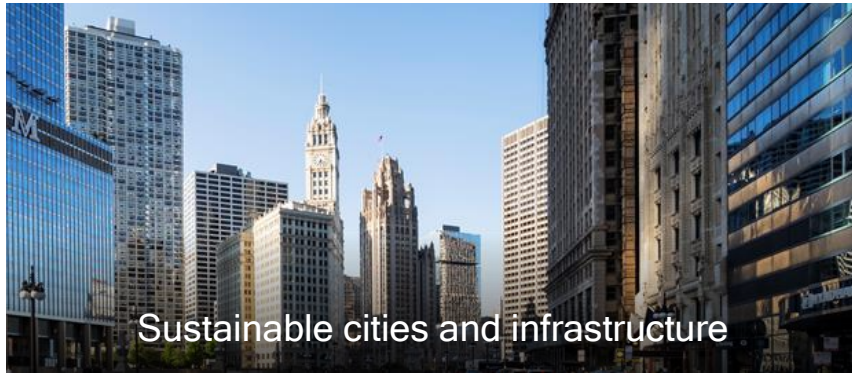




>$12 Trillion

Worth of goods and services by 2035

Learn more at: 5G Economy Study



LTE Advanced Pro establishes the foundation for 5G

Providing essential services from Day 1 and early expansion into new verticals

Gigabit LTE is essential to the 5G mobile experience

Ensuring seamless user experience with ubiquitous coverage

LTE IoT, C-V2X, ULL are expanding the mobile ecosystem today

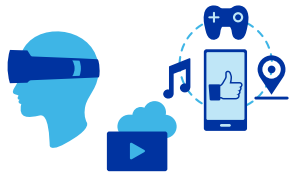
Connecting new industries and enabling new services

LTE Advanced Pro leadership is the key to 5G success

World's 1st LTE Advanced Pro modem: Qualcomm® Snapdragon™ X16

Provides essential services to 5G from Day 1

LTE Advanced Pro will be submitted with 5G NR to meet IMT-2020[1] requirements

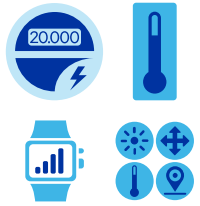


Gigabit LTE and LAA

Provides coverage foundation essential to the 5G mobile experience; LAA globalizes the Gigabit LTE opportunity

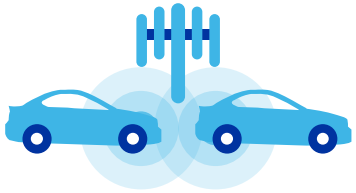
Voice (VoLTE)

Delivers 5G voice services from Day 1 leveraging the ubiquitous LTE networks



LTE IoT

Starts to connect the massive Internet of Things in 2017, ahead of further optimized 5G NR massive IoT



Cellular V2X (C-V2X)

Establishes foundation for safety use cases. Trials starting in 2017. Rel-15+ V2X will introduce complementary capabilities

Ultra-low latency

Brings ubiquitous low-latency communication for command & control, paving the path to 5G NR mission-critical services

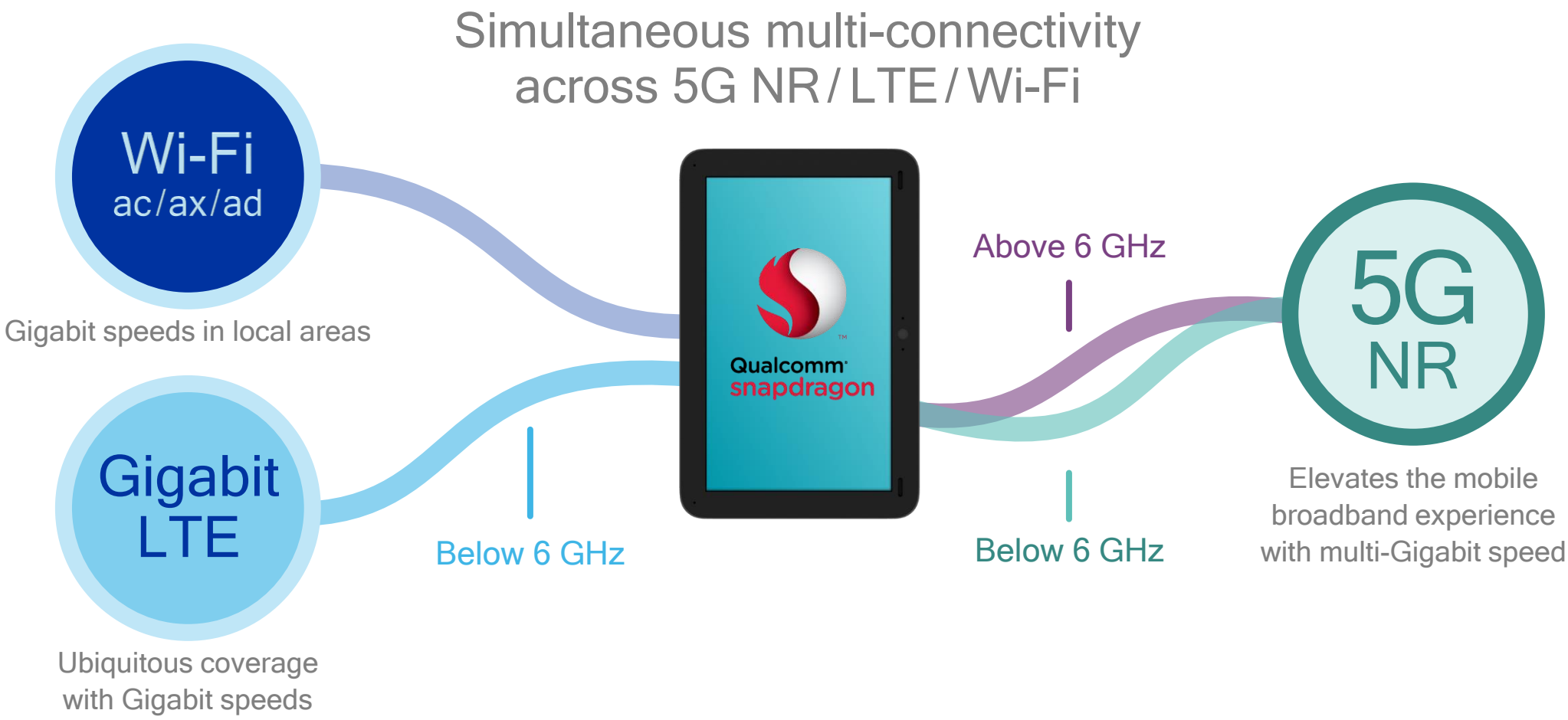
Also digital TV, public safety, drone communication, and more…

1 ITU Recommendation ITU-R M.2083-0, September, 2015


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



X16 LTE Modem

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

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

Qualcomm® Snapdragon™

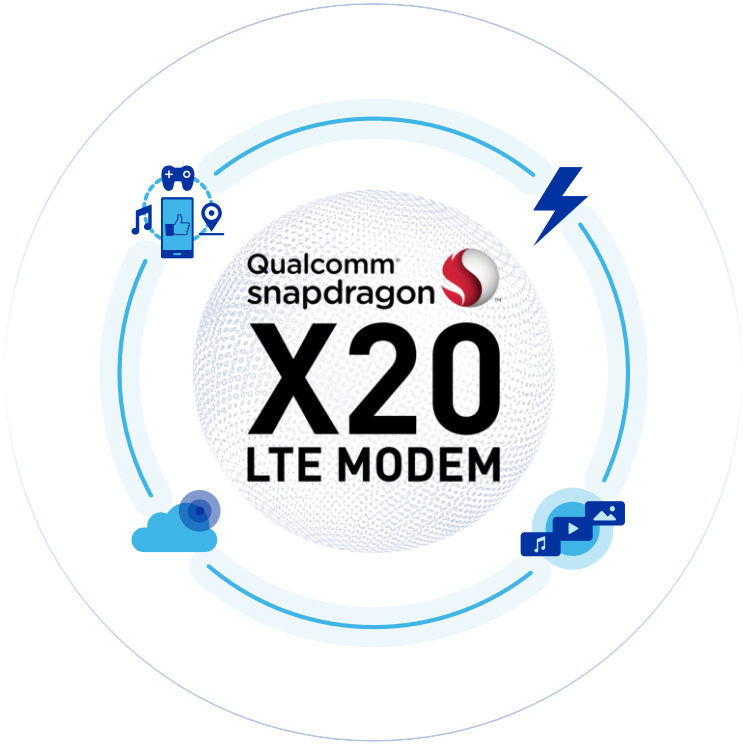
835

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

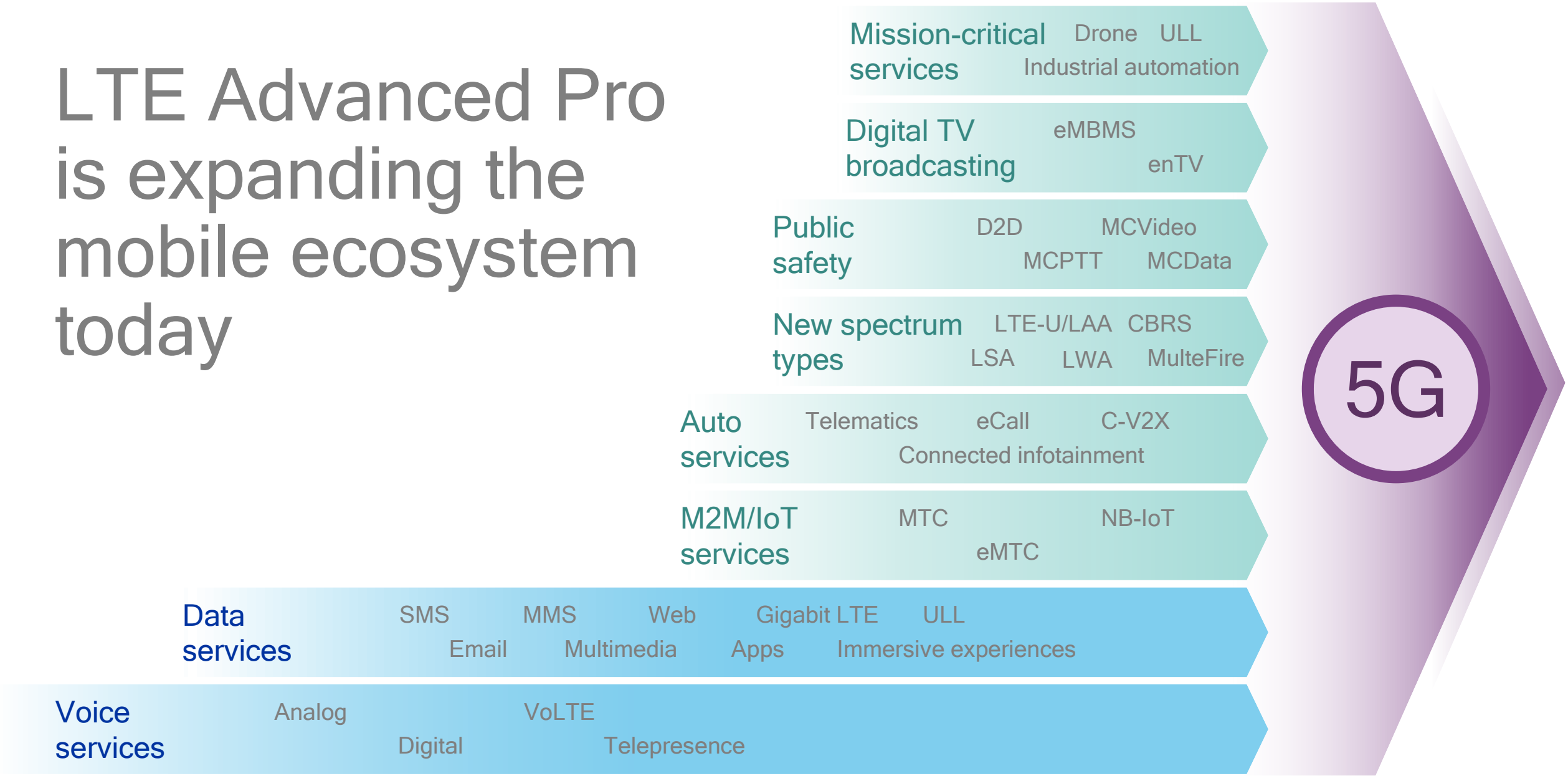
Support for CBRS – Shared spectrum

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

LTE Advanced Pro is expanding the mobile ecosystem today



LTE IoT starts to connect the massive IoT in 2017

To become a key 5G service pillar ahead of 5G NR massive IoT

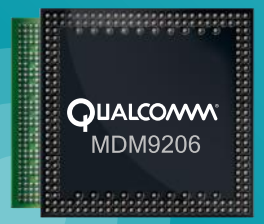
Coexistence with today's mobile broadband services

- Reduced complexity
- Multi-year battery life
- Deeper coverage
- Higher node density

Two new narrowband technologies in Rel-13, evolving further in Rel-14+

eMTC — Scales down LTE to address the broadest range of IoT use cases

NB-IoT — Optimizes to lowest cost/power for delay-tolerant, low-throughput IoT use cases



MDM9206

Flexible chipset platform for eMTC (Cat-M1) / NB-IoT (Cat-NB1)

Learn more at: https://www.qualcomm.com/lte-iot

- Global dual-mode solution–single SKU
- Multiple design wins across industry-leading OEMs
- Cat-M1 modules commercially available today
- Software upgrade to Cat-NB1 support

MDM9206 is a product of Qualcomm Technologies, Inc.

C-V2X establishes the foundation for safety use cases

Rel-15+ V2X will augment Rel-14 V2X with complementary and new capabilities

Rel-14 V2X

Direct communication for V2X safety use cases

V2V / V2P / V2I[1]

Network communications for situational awareness

V2N[2]

Rel-15+ V2X

Complementary capabilities (e.g., sensor sharing); interworking with Rel-14

Initial C-V2X spec. completed[3] in 2016

Broad industry support–5GAA

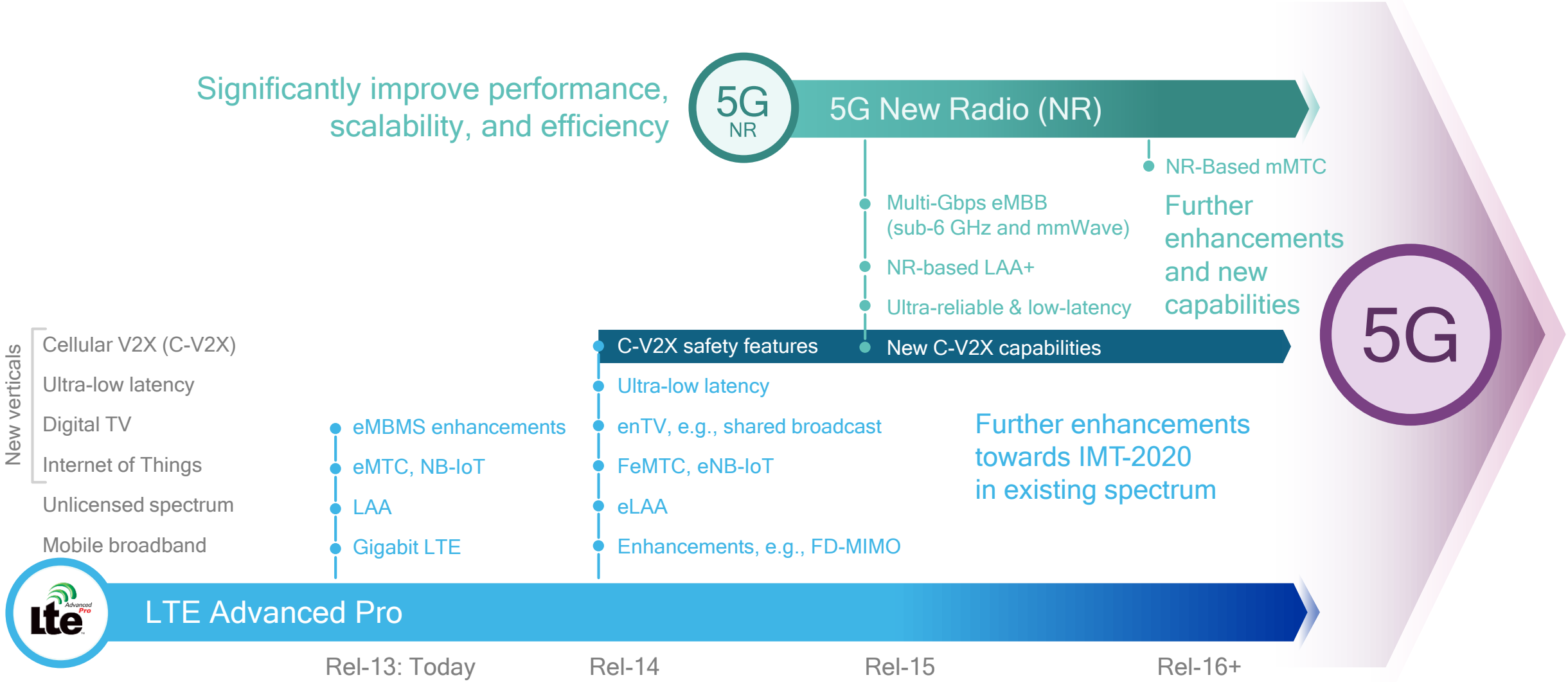
Trials starting in 2017

Learn more at: https://www.qualcomm.com/c-v2x

1. Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P); 2. Vehicle-to-Network (V2N); 3. V2V standardized as part of Rel-14

LTE Advanced Pro establishes the foundation for 5G

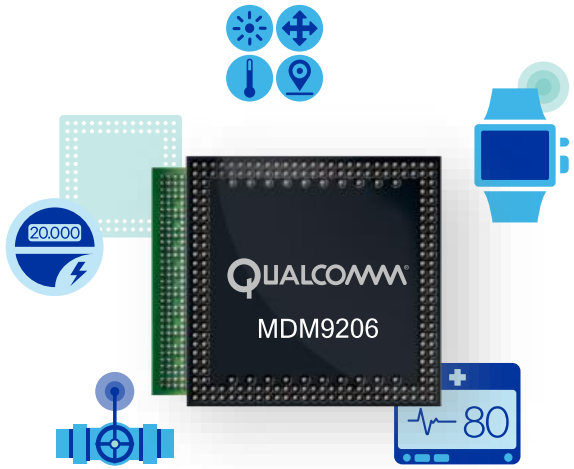
Pioneering 5G NR technologies and verticals



Leading the way with LTE Advanced Pro

World's first Gigabit LTE device and network launch

Achieved Gigabit-class download speeds on Telstra's commercial LTE network



Broad industry adoption of Cat-M1 and Cat-NB-1

Secured design wins across the majority of industry's operators and module OEMs

C-V2X trials starting in 2017

Announced the first C-V2X trial with Audi and others based on 3GPP Rel-14

World's first LAA and eLAA trials

Conducted over-the-air LAA trial with DT in Nov. 2015 and eLAA with SKT in Sep. 2016

Driving the Gigabit LTE evolution

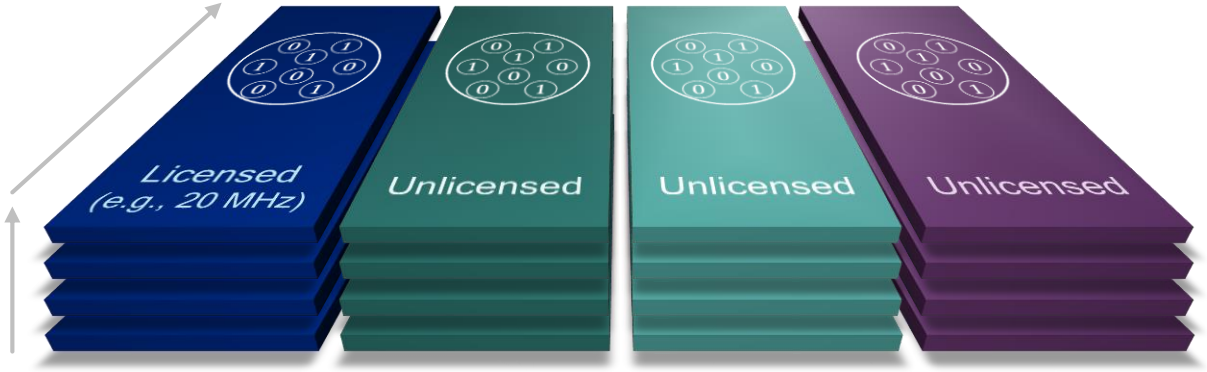
3GPP Release 13 and beyond

Achieving Gigabit LTE and beyond

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

Utilizing higher-order modulation (256-QAM)

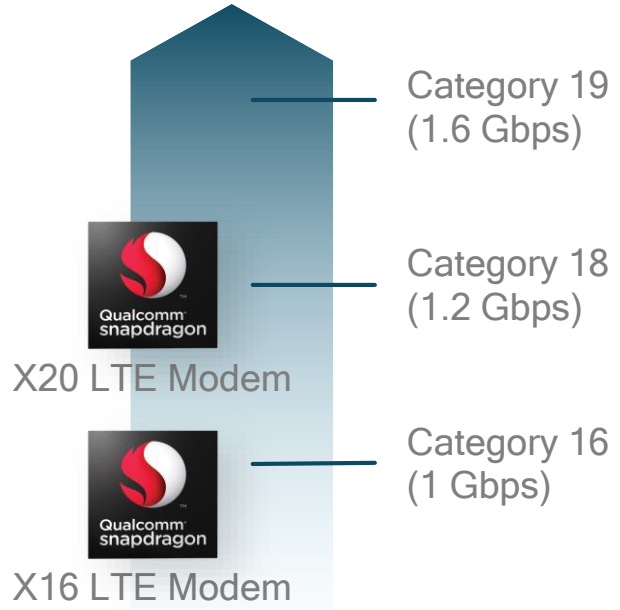
Adding up to 4 MIMO layers



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

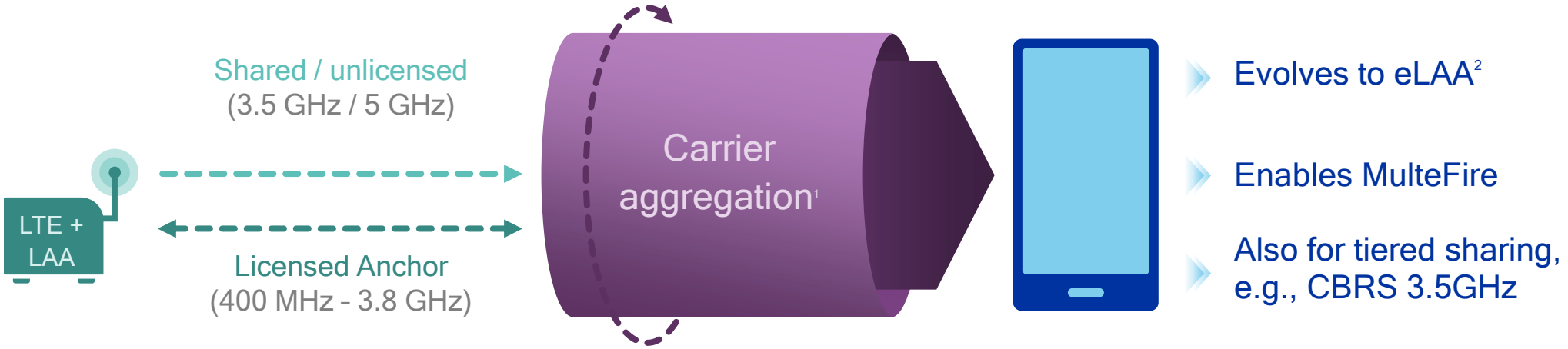
Aggregating more carriers across licensed and unlicensed with LAA[3]

New Gigabit LTE device categories



Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.; 1. Example configuration per 3GPP specification; 2. Each data stream ~100 Mbps per 20 MHz stream with 256-QAM; 3. Licensed Assisted Access

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



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]

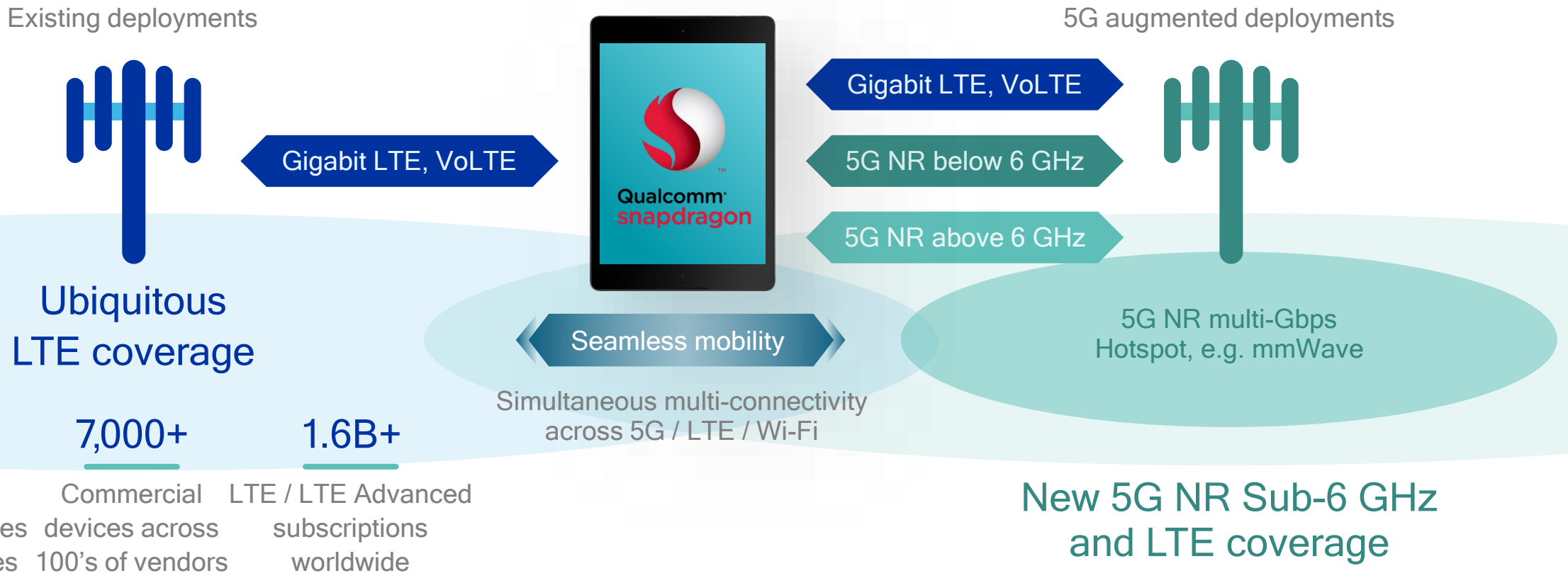
Authorized Qualcomm Technologies in Sept. 2016 and subsequently granted others

Learn more at: www.qualcomm.com/laa

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.; 1. Aggregation of unlicensed downlink and uplink is possible with either licensed TDD or licensed FDD; 2. eLAA defined in Rel-13/14 which adds the uplink; 3. Listen-Before-Talk; 4. FCC blog by Julius Knapp | Chief, Office of Engineering and Technology, see https://www.fcc.gov/news-events/blog/2016/09/23/industry-makes-progress-unlicensed-lte-coexistence

Gigabit LTE is essential to the 5G mobile experience

Multi-connectivity fully leverages LTE investments and provides VoLTE service



Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.

Source: GSA (www.gsacom.com)–Oct 2016 on network launches, Dec 2016 on subscriptions, Jan 2017 on commercial devices

Evolving Gigabit LTE in multiple dimensions

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

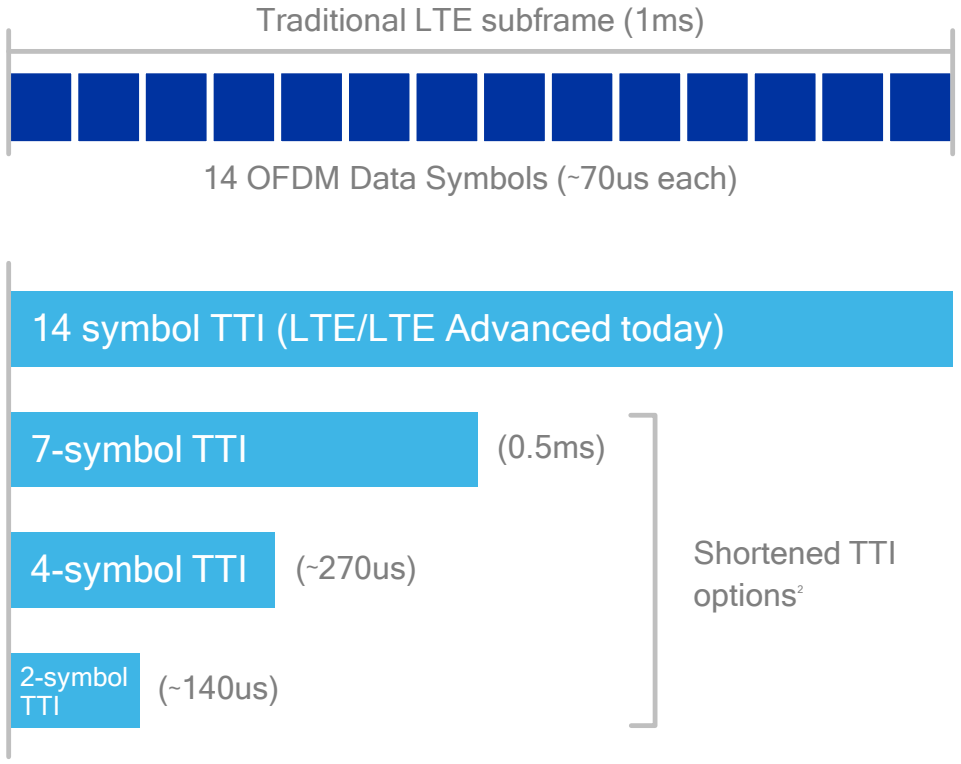
Paving the path for mission-critical services

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

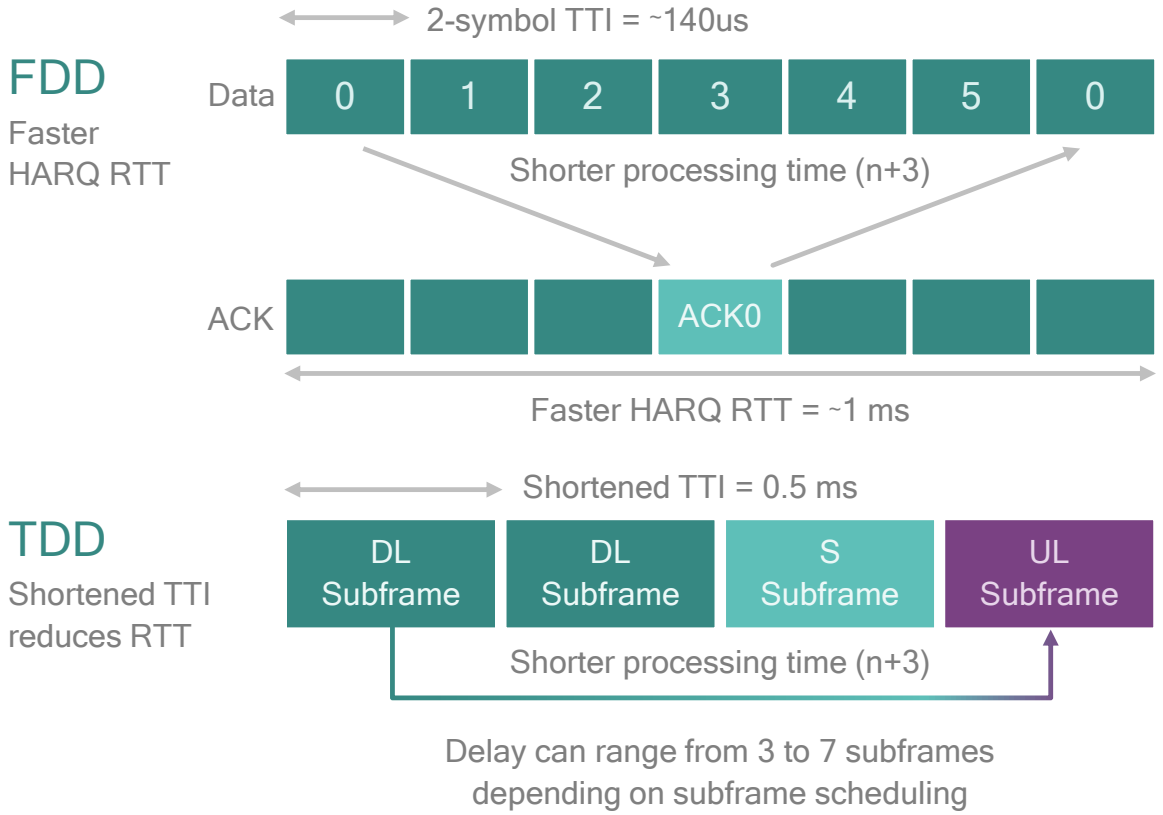
New FDD/TDD design delivers latency in the 1ms range[1]

Reducing turnaround time with shorter TTI and more efficient HARQ processing

Shorter transmission time interval (TTI)



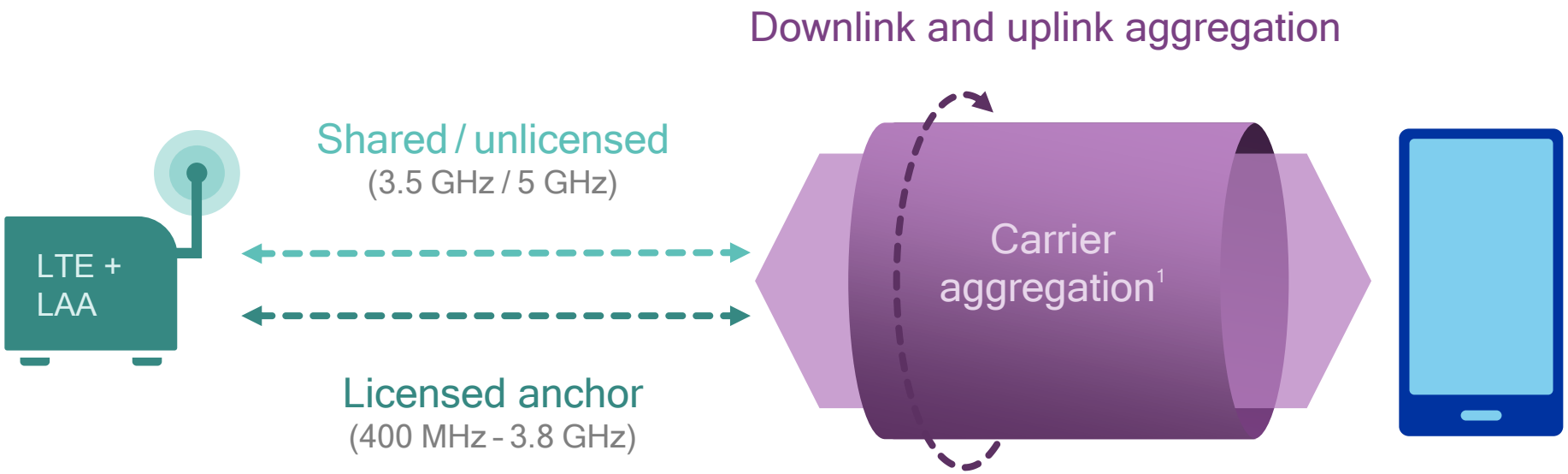
Significantly lower round trip time (RTT)



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



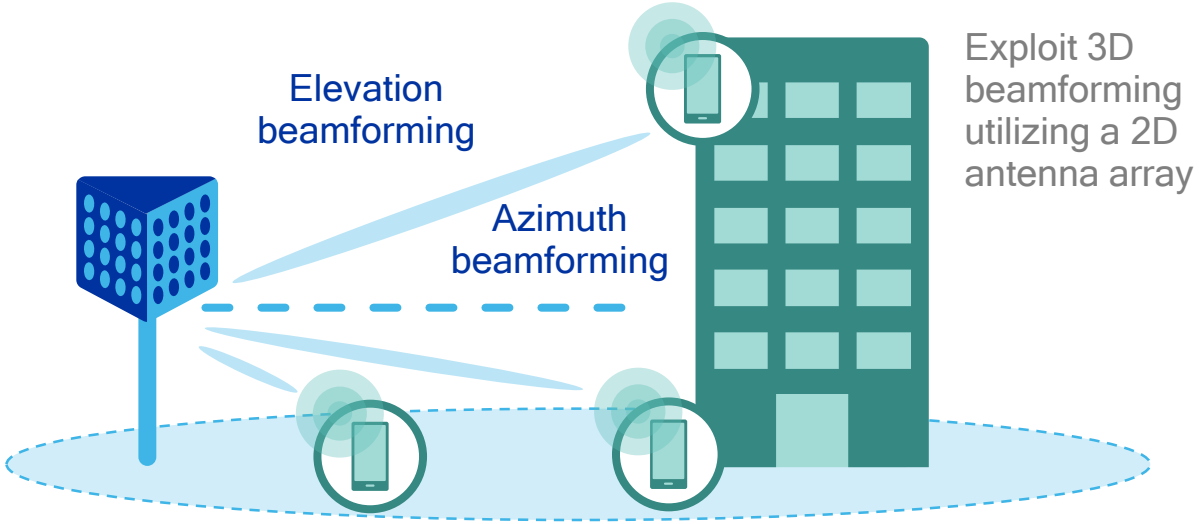
Release 13 – LAA
- Downlink aggregation
- Fair Wi-Fi coexistence using LBT[2]
- ~2x performance over Wi-Fi[3]

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

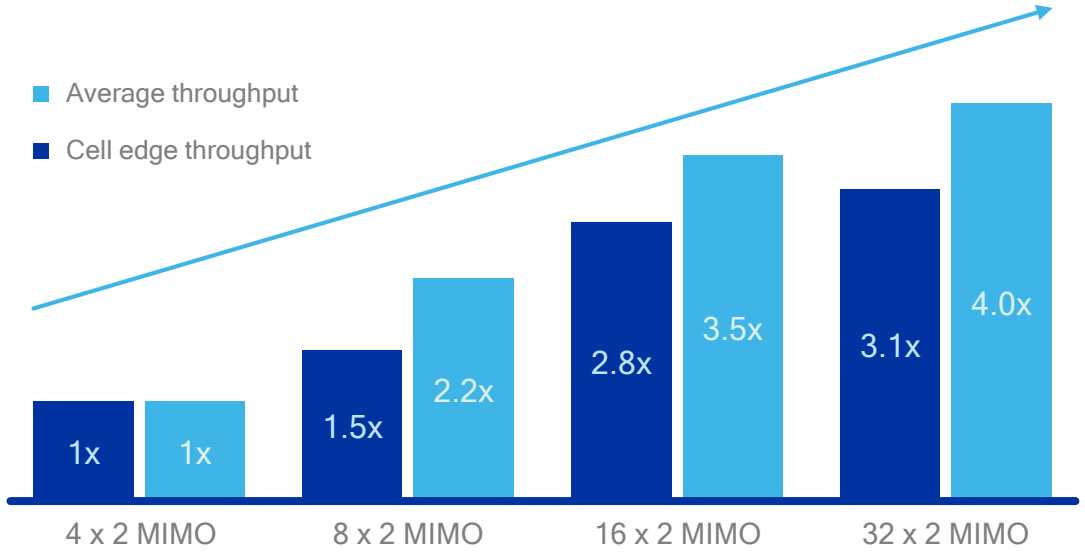
1. Aggregation of unlicensed downlink and uplink is possible with either licensed TDD or licensed FDD; 2. Listen-Before-Talk 3. Assumptions: Dense deployments provides ~2x better capacity and range. 3GPP LAA evaluation model based on TR 36.889, two operators, 4 small-cells per operator per macro cell, 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



Exploit 3D beamforming utilizing a 2D antenna array



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

Source: Qualcomm Technologies, Inc. simulations; 3D-Urban Microcell (3D-UMi) scenario with 70% loading, using 10 MHz bandwidth @ 2 GHz, UE traveling at 3 km/h, with advanced CSI- design specified in Rel-14

1 Includes reference signal overhead reduction and advanced codebook design for higher resolution beamforming

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

New spectrum technologies that utilize new bands and wider bandwidths

mmWave spectrum[2]

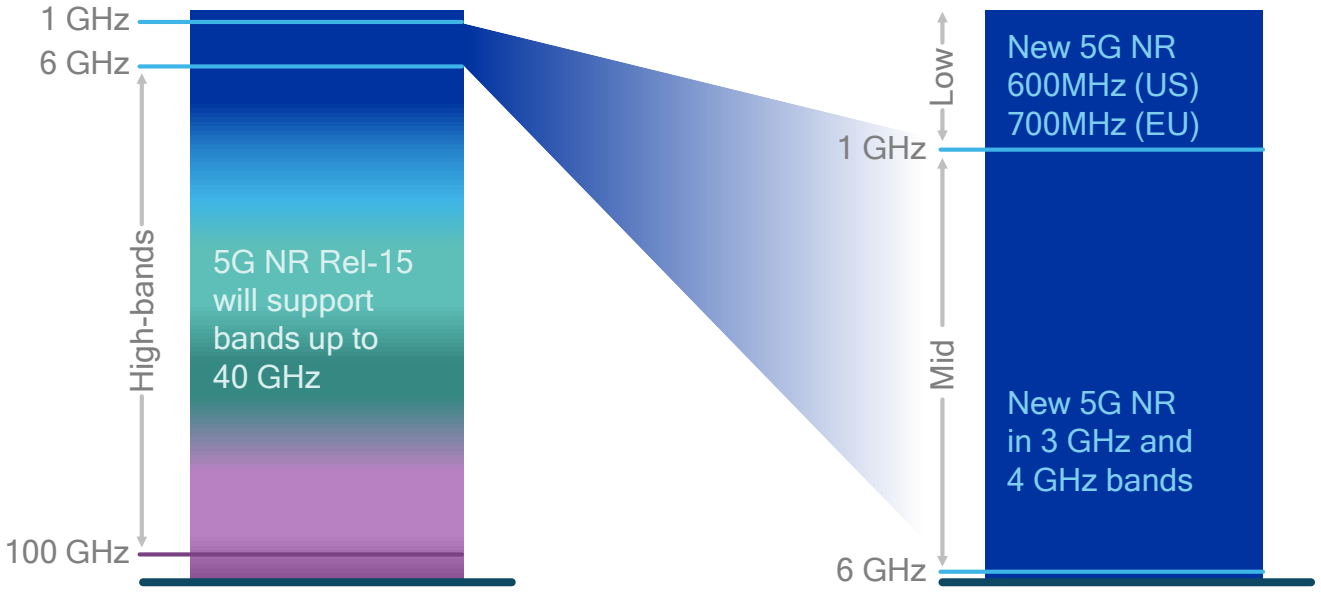
LTE in existing sub-6 GHz bands provides the anchor

New sub-6 GHz spectrum

Expanding to higher frequencies leveraging existing cell sites

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

1. 3GPP Rel-16+ will bring continued eMBB evolution, plus new features for massive IoT and mission-critical; 2. 3GPP Rel-15 focused on spectrum bands up to ~40 GHz; Rel-16+ will bring support for bands up to ~100 GHz

5G NR will take mobile broadband to the next level

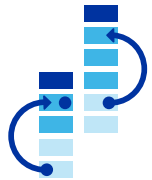
5G NR

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

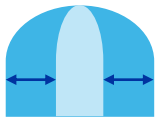
LDPC to deliver higher efficiency for larger block data transmissions

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

1. 3GPP Rel-16+ will bring continued eMBB evolution, plus new features for massive IoT and mission-critical; 2. 3GPP Rel-15 focused on spectrum bands up to ~40 GHz; Rel-16+ will bring support for bands up to ~100 GHz

Pioneering shared spectrum technologies in LTE

New spectrum sharing paradigms–opportunity to innovate

Licensed spectrum

Exclusive use

Over 40 cellular bands globally to date

Shared spectrum

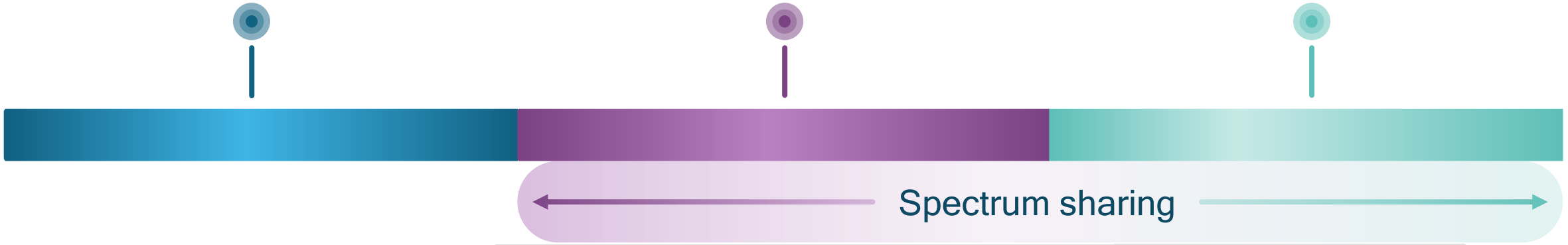
New shared spectrum paradigms

Example: 2.3 GHz Europe / 3.5 GHz USA

Unlicensed spectrum

Shared use

Example: 2.4 GHz / 5 GHz / 60 GHz global



Unlocks more spectrum

Increases spectrum utilization

New deployment scenarios

Spectrum sharing valuable for wide range of deployments

Spectrum aggregation

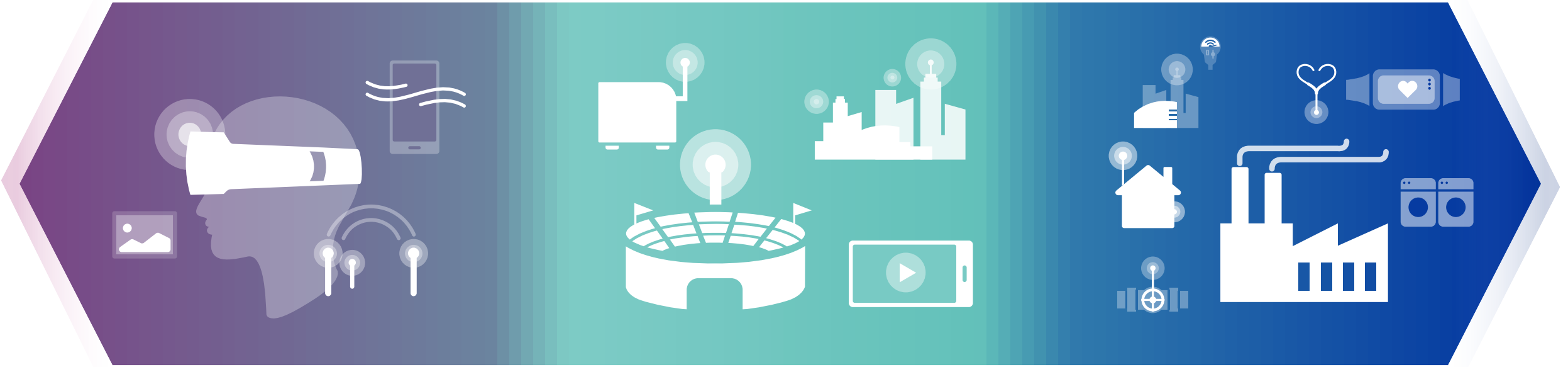
Extreme bandwidths and more capacity

Enhanced local broadband

Neutral host, neighborhood network…

Private networks

Enterprise, Industrial IoT…

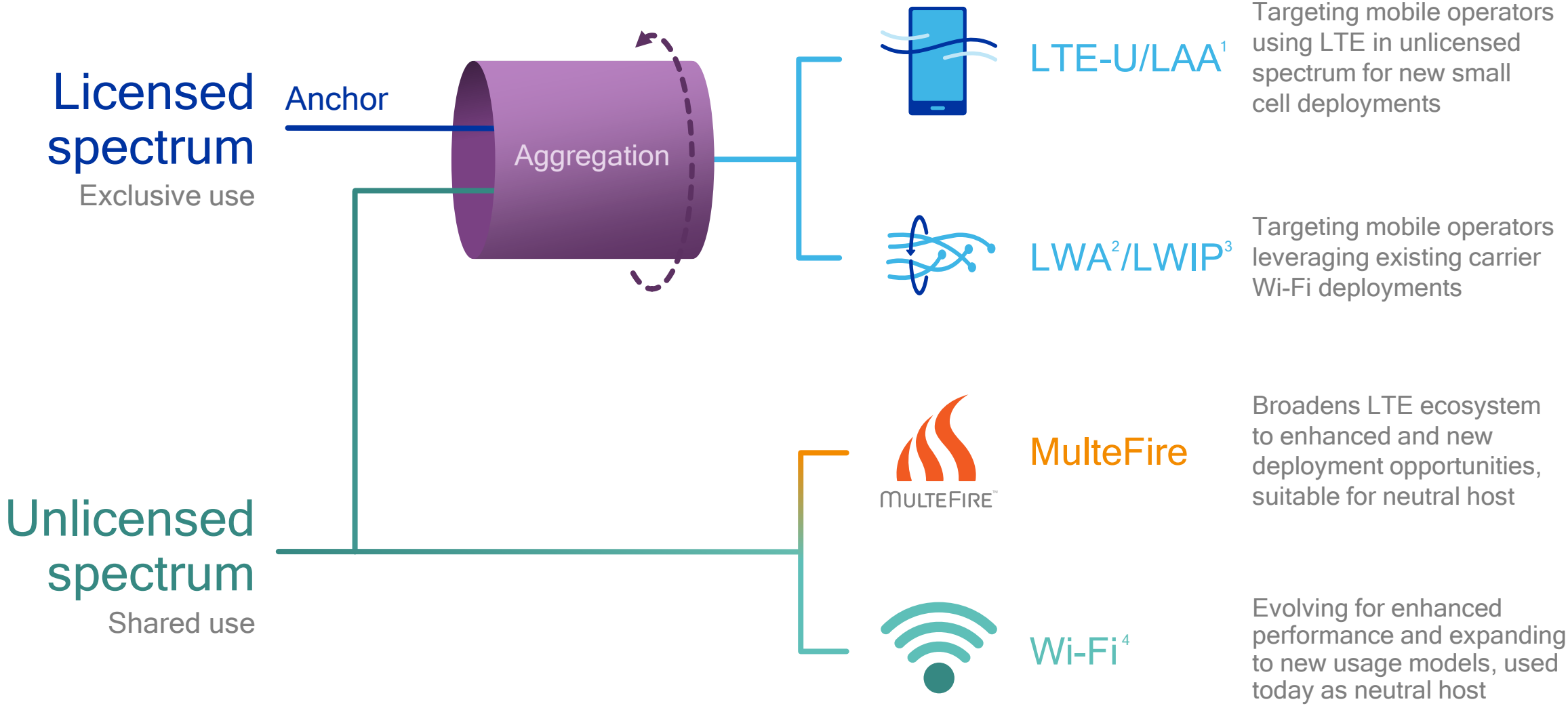


Enhancing existing deployments, e.g., LAA[1]

New types of deployments, e.g., MulteFire™ or LTE-based tech. in CBRS[2]

1) Licensed-Assisted Access (LAA); 2) Citizen Broadband Radio Service (CBRS)–a 3-tier shared spectrum where multiple LTE-based technologies are supported: LTE-TDD, MulteFire and LAA

Making best use of shared/unlicensed spectrum



1. Licensed-Assisted Access (LAA), also includes enhanced LAA (eLAA); 2. LTE Wi-Fi Link Aggregation (LWA); 3. LTE Wi-Fi radio level integration with IPsec tunnel (LWIP); 4. 802.11ac / .11ad / .11ax / .11ay

MulteFire™ provides the best of both worlds

LTE technology operating solely in unlicensed or shared spectrum

LTE-like performance

- Enhanced capacity and range
- Seamless mobility
- Robust user experience
- Hyper-dense, self-organizing
- LTE security
- VoLTE, LTE IoT, LTE broadcast...

Harmoniously coexist with Wi-Fi and LTE-U/LAA[1]

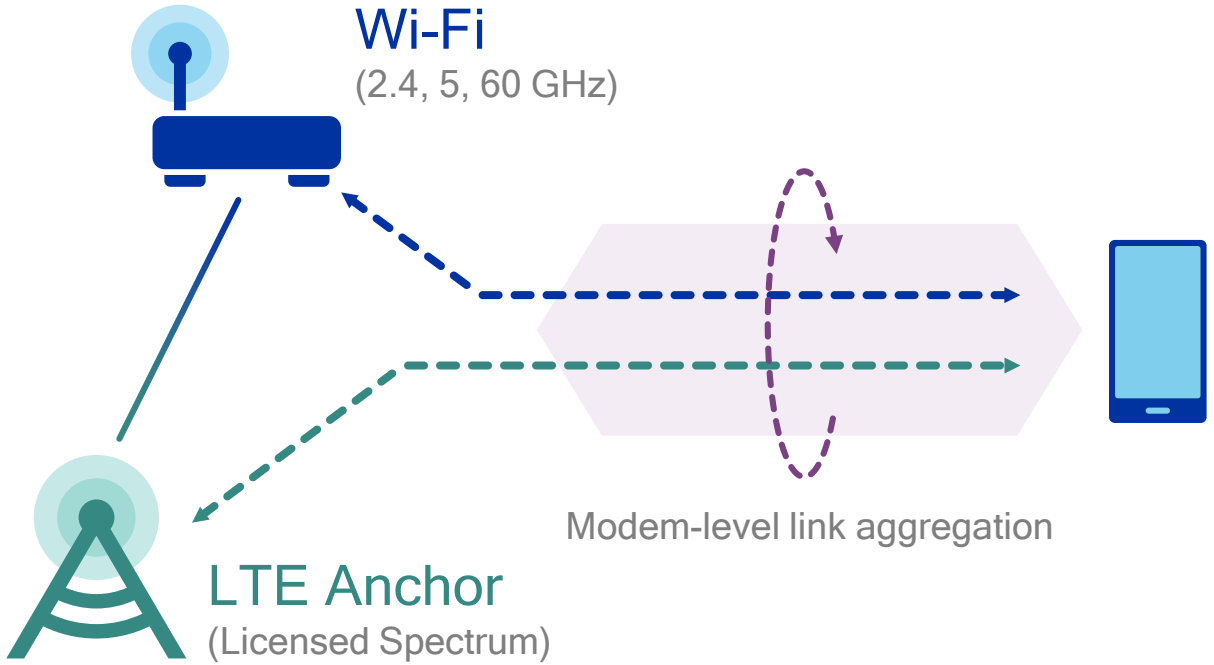
Wi-Fi-like deployment simplicity

- Unlicensed spectrum, e.g., 5 GHz
- Suitable for neutral hosts
- Leaner, self-contained architecture
- Over-the-air contention

1. Including enhanced LAA (eLAA)

LTE Wi-Fi Aggregation for existing and new carrier Wi-Fi

Uplink and downlink data aggregation in 2.4/5/60 GHz to boost data rate and capacity



Robust user experience

Licensed anchor for control and mobility

Unified network

Operator LTE network in full control of Wi-Fi

Higher data speeds

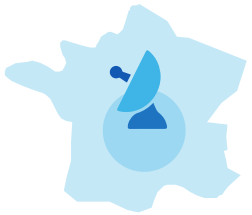
Simultaneously using both LTE and Wi-Fi links

Aggregating new spectrum bands

Including support for 802.11ad (60 GHz) in Rel-14 for higher throughput and more capacity

Notes: Aggregation on modem level (PDCP level), also leveraging dual connectivity defined in Rel-12; Control over X2-like interface needs to be supported by Wi-Fi AP. No change to LTE and Wi-Fi PHY/MAC. No change to core network

Pioneering shared spectrum technologies in LTE



LSA[1]

Technically extensive pilot in France with Ericsson and Red in Jan 2016

LTE-U

We designed the original proposal, commercialized by the LTE-U forum

LAA[2]

First over-the-air trials, LAA with DT Nov. 2015 and eLAA with SKT Sep. 2016

MULTEFIRE™

A founder of the MulteFire Alliance, first over-the-air connection Oct 2016

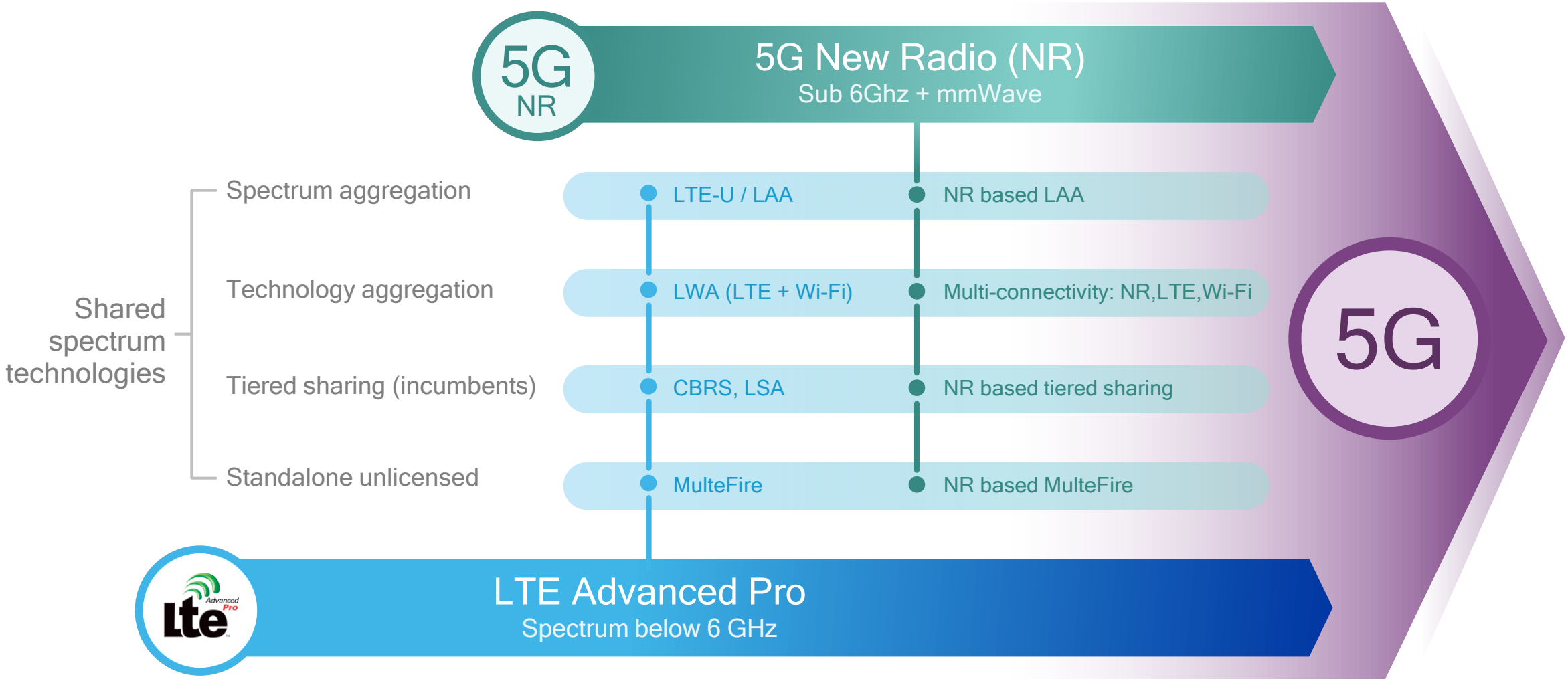
CBRS[3]

A founder of the CBRS Alliance and a key contributor to coexistence

1) Licensed Shared Access (LSA); 2) Licensed-Assisted Access (LAA), enhanced LAA (eLAA), Deutsche Telekom (DT), SK Telecom (SKT); 3) Citizen Broadband Radio Service (CBRS)

Ushering in new spectrum sharing paradigms with 5G

Pioneering spectrum sharing technologies with LTE today



Learn more at: http://www.qualcomm.com/spectrum-sharing

Expanding the mobile ecosystem to new verticals

Expanding mobile ecosystem by pioneering new verticals

Vehicle-to-everything (C-V2X)

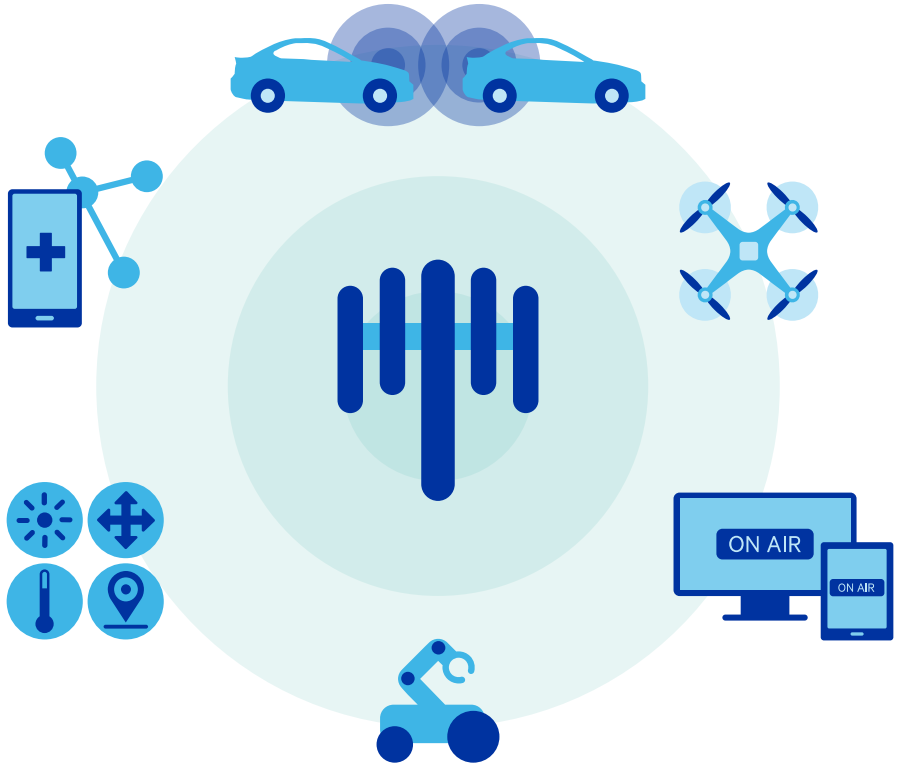
Give vehicles the ability to reliably communicate with each other and everything around them

Public safety

Leverage the vast LTE ecosystem for robust public safety communications

Drone communication

Enable a growing set of drone use cases leveraging extensive LTE coverage



Internet of Things

Scale down LTE for machine-type, low-power, wide-area communication

Digital TV broadcasting

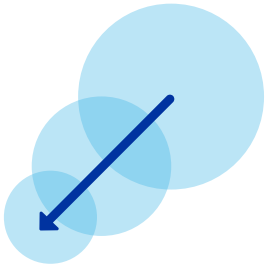
Evolve broadcast to deliver a converged TV network

Ultra-low latency

Bring ubiquitous low-latency communication for command & control, e.g., robotics, industrial equipment

LTE IoT starts to connect the massive IoT in 2017

To become a key 5G service pillar ahead of 5G NR massive IoT

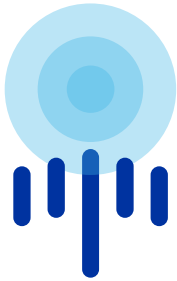


Reduced complexity

Narrowband(1.4 MHz or 200 kHz) plus further complexity reductions

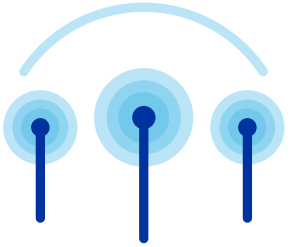
Multi-year battery life

Enhanced power save modes and more efficient signaling



Deeper coverage

Up to 20 dB better link budget for hard-to-reach locations



Higher node density

Optimizations to support a large number of devices per cell

Scaling down in complexity and power

New narrowband IoT technologies (3GPP Release 13+)

LTE Cat-4 and above
>10 Mbps
n x 20 MHz

LTE Cat-1
Up to 10 Mbps
20 MHz

LTE Cat-M1 (eMTC)
Variable rate up to 1 Mbps
1.4 MHz narrowband

Cat-NB1 (NB-IoT)
10s of kbps
200 kHz narrowband

Evolving to address a broader range of IoT use cases

Release 14+ enhancements are driving towards meeting IMT-2020 targets

Scaling up in performance/capability ⟵ ⟶ Scaling down in complexity/power

eMTC

Enhancing VoLTE
For wearables to more efficiently handle voice in half-duplex mode

Higher data rate
Supporting wider bandwidths, e.g., 5 MHz

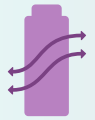
eMTC and NB-IoT

Single-cell multicast
Efficient OTA firmware update for large number of devices, e.g., sensors, meters

Device positioning[2]
Providing location services e.g., for mobile asset tracking and emergency call

Mobility enhancements[3]
Enabling devices to monitor and report channel conditions for inter-cell handovers

NB-IoT



Lower transmit power
New power classes[4] for devices with smaller batteries

Energy/latency reduction
Supporting 2 HARQ processes and larger transport blocks

1. Also supporting 10 HARQ processes and larger transport blocks; 2. NB-IoT supports UTDOA and OTDOA, eMTC supports OTDOA; 3. Full standard support for inter-frequency measurements for eMTC and power consumption optimization for connected mode mobility for NB-IoT; 4 New power class(es) to include, for example, 14 dBm

C-V2X will enable connected vehicles of the future

Giving vehicles the ability to communicate with each other and beyond

Vehicle-to-infrastructure (V2I)

e.g. traffic signal timing / priority

Vehicle-to-network (V2N)

e.g. real-time traffic / routing, cloud services

Vehicle-to-vehicle (V2V)

e.g. collision avoidance safety systems

Vehicle-to-pedestrian (V2P)

e.g. safety alerts to pedestrians, bicyclists

C-V2X establishes the foundation for safety use cases

Rel-15+ V2X will augment Rel-14 V2X with complementary and new capabilities

Common dedicated V2V/V2P/V2I frequency

PC5 interface e.g., location, speed

Direct communication (Works in-coverage and out-of-coverage)

To support Vehicle-to-Vehicle, Vehicle-to-Infrastructure, and Vehicle-to-Pedestrian use cases

- Beyond line-of-sight (100s of meters), e.g., around corner
- No SIM required; no network required
- Latency-sensitive use cases, e.g., V2V safety
- Network-connected infrastructure (V2I) can enable new business models

Single/multiple MNO managed networks

Uu interface e.g., accident 1 kilometer ahead

Network communication (Leveraging existing mobile networks)

V2X server can broadcast messages; vehicles can send messages to server via unicast–Vehicle-to-Network

- Wide area networks communications
- Leverages existing LTE networks
- More latency tolerant use cases, e.g., V2N situational awareness

Path to 5G enables a broad set of automotive use cases

C-V2X establishes the foundation for safety services

MBB

Anchor for the 5G mobile automotive experience

Gigabit LTE Today

Multi-gigabit downlink for streaming, VR/AR, and 3D/HD maps; and uplink for remote supervisory control

5G NR eMBB Rel-15+

IoT

LTE IoT Today

Enables remote sensing and control in deep coverage conditions

5G NR MIoT Rel-16+

New capabilities and further optimizations (e.g., multi-hop mesh for deeper coverage, lower power)

C-V2X Rel-14
Provides highly reliable, real-time communication for automotive safety use cases

C-V2X Rel-14 and Rel-15+
Augments Rel-14 with new and complementary capabilities (e.g., sensor sharing); while maintaining backward compatibility

Accelerating cellular drone communication technology

Announced trial with AT&T to prepare for wide-scale deployments

Testing drone operation over commercial LTE networks

Optimize LTE networks

Enhance commercial networks for drones without impacting terrestrial devices, proposed for Rel-15+

Inform regulators

Help inform positive developments in drone regulations

Accelerate 5G development

Specifically for massive deployments of mission-critical drone use cases

Learn more at: http://www.qualcomm.com/cellular-drones

eMBMS[1] delivers terrestrial Digital TV more efficiently

Compared to dedicated high-power broadcast network

Single broadcast

network for mobile and fixed devices –unicast for on-demand and interactivity

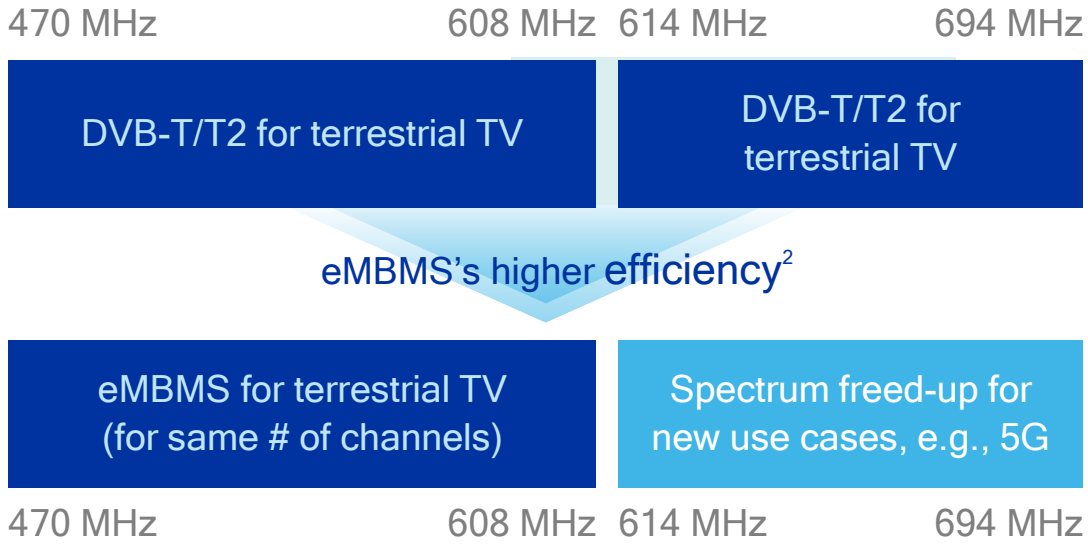
Efficiently deliver

content to new device types (e.g., receive-only); also supporting new waveform & dedicated carrier

Shared broadcast

to serve users from multiple providers and operators–enabling new media delivery

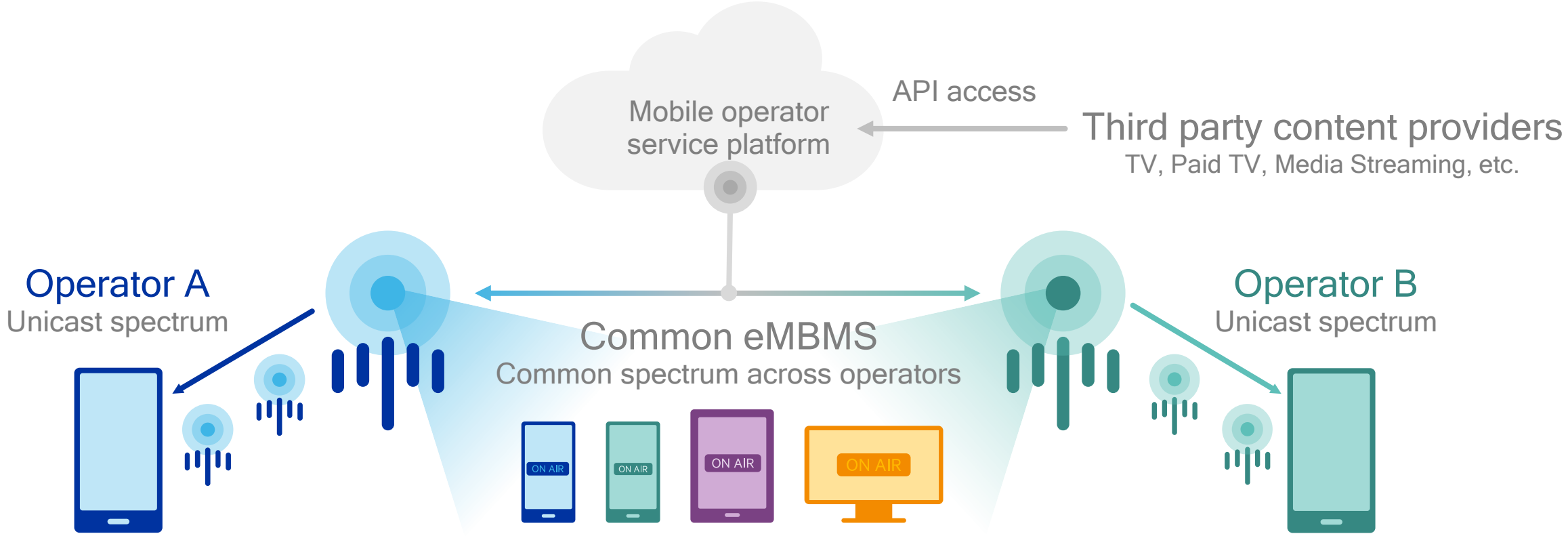
A strong candidate to deliver next-gen digital TV in Europe



1. Evolved Multimedia Broadcast Multicast Service; 2. ~2x more efficient than DVB-T/ATSC and provides longer range up to 15km (with further extended CP of 200 us and features such as 2x2 MIMO, 256 QAM, increased subframe limit); Assumptions: current broadcast technology operates in MFN mode with a frequency reuse of at least 4 with a spectrum efficiency of up to 4 bps/Hz inside each cell. This corresponds to an overall spectrum efficiency of approx. 1bps/Hz. Whereas eMBMS operates in SFN over the entire coverage area with a spectrum efficiency of up to 2bps/Hz

Shared broadcast for new media delivery models

Serve users from multiple providers and operators on common broadcast carrier



Users can access content even without subscription and SIM card

New and more efficient way to distribute operator-specific and 3rd party content (paid, free)

5G NR will continue the expansion into new verticals

By delivering even better efficiencies and new capabilities from Rel-15+

Massive Internet of Things

Scalable throughput
From kbps to multi-Gbps that provides new flexibilities to a wide range of devices

Extended coverage
For devices at hard-to-reach locations by supporting relays and managed multi-hop mesh

Lower power
More efficient and reduced signaling, such as device-centric mobility and on-demand broadcast

Higher node density
Better support for small data exchanges by using grant-free transmissions (e.g., RSMA[1])


Smart cities

Smart utilities


Connected retail


Connected buildings


Sensor networks


Asset tracking

Mission-critical services

Ultra-high reliability
Ultra-reliable transmissions that can be time multiplexed with nominal traffic through puncturing

Strong e2e security
Security enhancements to air interface, core network and service layer

Ultra-high availability
Multi-connectivity/redundant links for failure tolerance and extreme mobility

Low, bounded latency
Faster, more flexible frame structure and grant-free uplink access (e.g., RSMA)


Autonomous vehicles


Drones


Robotics


Medical


Industrial automation


Smart energy

1 Resource Spread Multiple Access

Anyone can talk about 5G.
We are creating it.

QUALCOMM®
Why Wait™

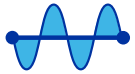
Qualcomm has led the evolution and expansion of LTE

Our fundamental systems-level inventions are leading the world to 5G

Carrier aggregation

Hybrid ARQ

Fast link adaptation



OFDMA, SC-FDMA waveforms

CoMP

CSFB

LTE-U/LAA/ eLAA

MulteFire

Lower power consumption technologies, e.g. DTX/DRX

LTE Broadcast (eMBMS)

Small cells interference management

LWA

Handover procedure

Small cell self-configuration techniques

Advanced MIMO technologies, e.g. UL MIMO

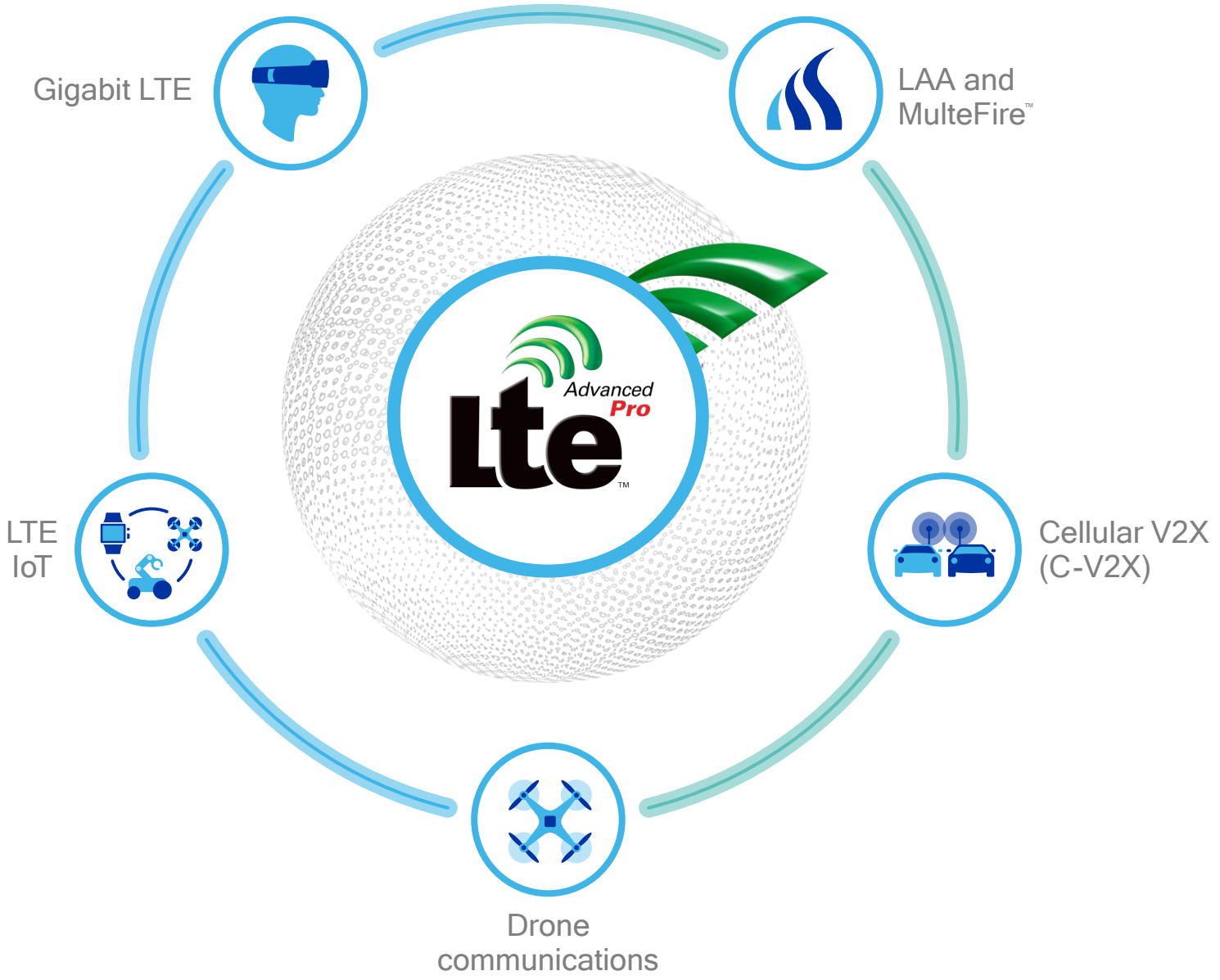
LTE Direct and C-V2X

Leading in 5G requires

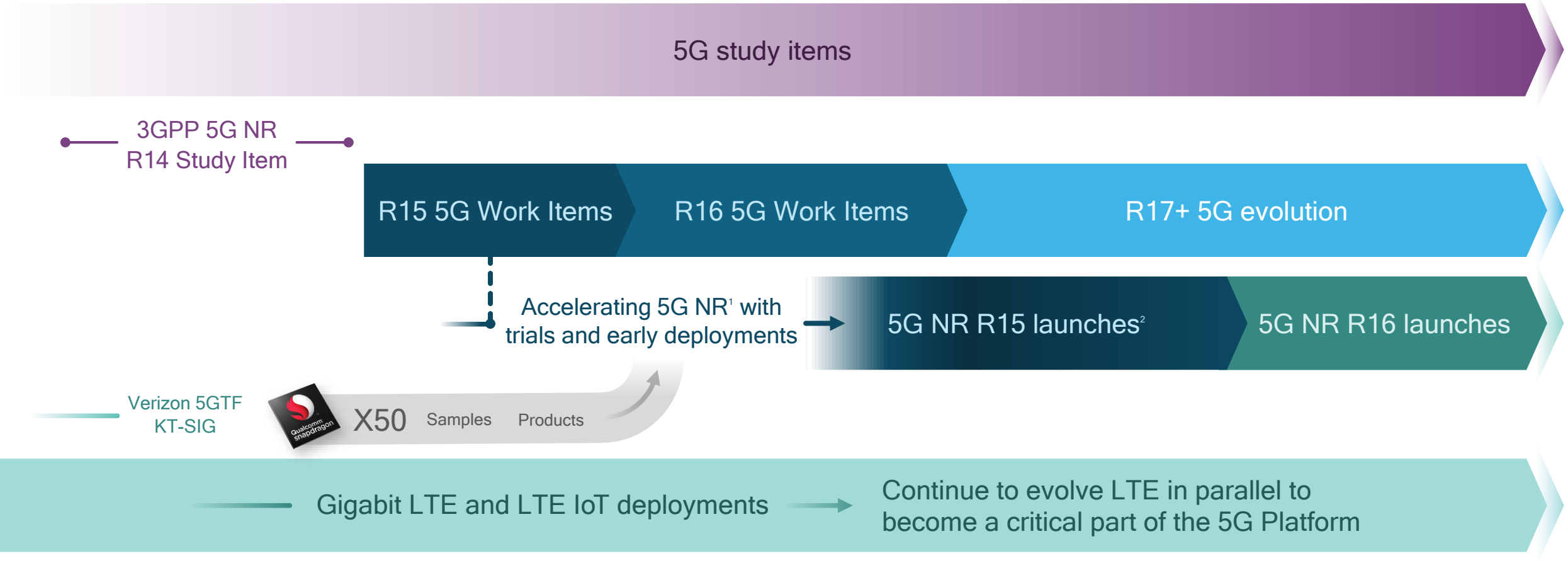
4G LTE leadership

Our LTE advancements will be essential to 5G

Pioneering technologies—expanding the mobile ecosystem



Accelerating 5G NR–The global standard for 5G

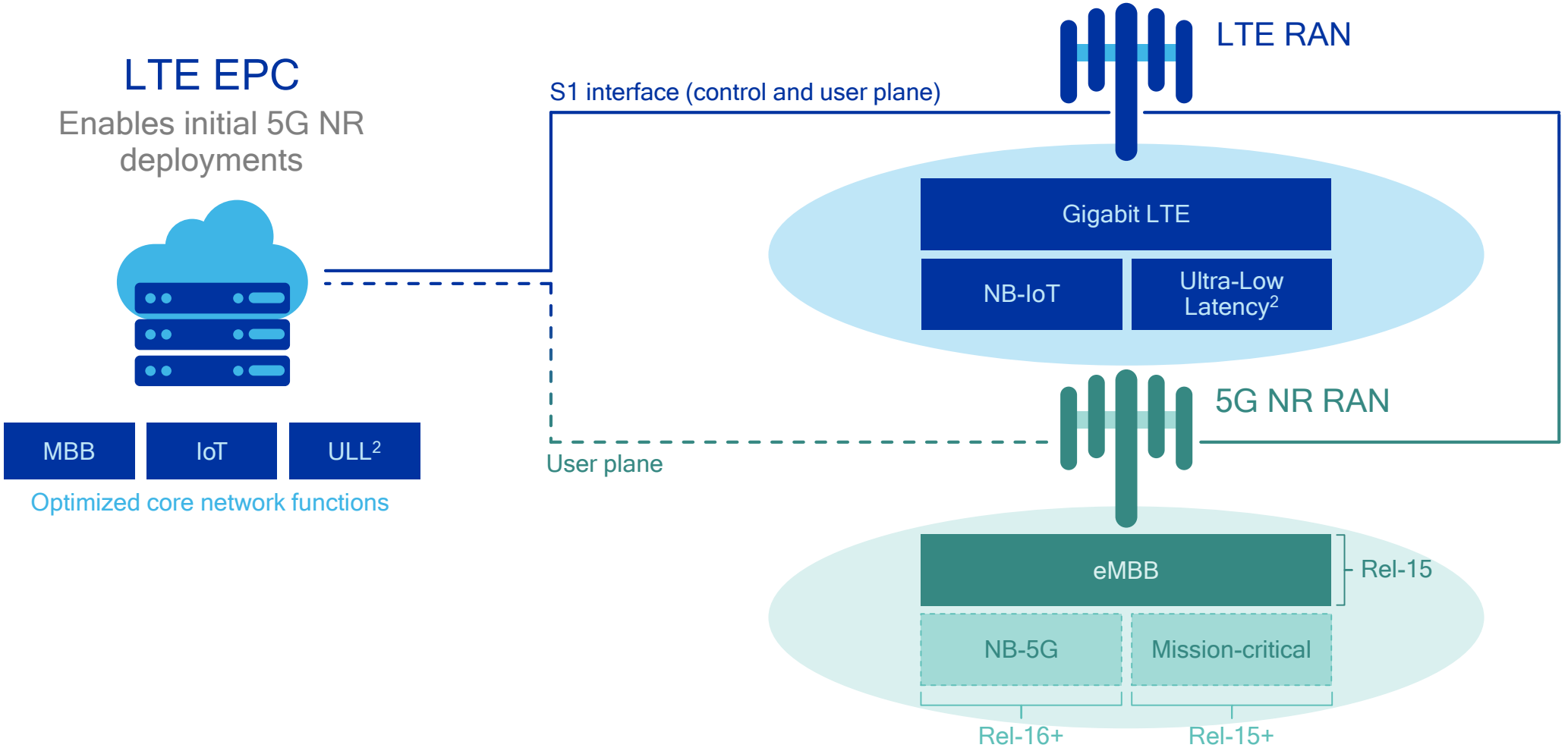


Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.; X50 sampling expected 2H 2017 Commercial devices expected in 1H 2018. Note: Estimated commercial dates.

1. The latest plenary meeting of the 3GPP Technical Specifications Groups (TSG#72) has agreed on a detailed workplan for Release-15; 2. Forward compatibility with R16 and beyond

Early availability of 5G NR thanks to NSA[1] architecture

3GPP also defining new 5G NextGen core network in parallel



Note: Accelerated 5G NR deployments using non-standalone LTE anchor enabled by Option 3/3a as defined in RP-161266 1. Non-stand-alone; 2. Evolving to URLLC in Rel-15+

We are designing a unified, more capable 5G air interface

Significantly improve performance, cost and energy efficiency

Diverse spectrum

- Licensed, shared licensed, and unlicensed spectrum
- Spectrum bands below 1 GHz,1 GHz to 6 GHz, and above 6 GHz (incl. mmWave)
- FDD, TDD, half duplex
- Device-to-device, mesh, relay network topologies

Diverse services and devices

- From wideband multi-Gbps to narrowband 10s of bits per second
- Efficient multiplexing of higher-reliability and nominal traffic
- From high user mobility to no mobility at all
- From wide area macro to indoor / outdoor hotspots

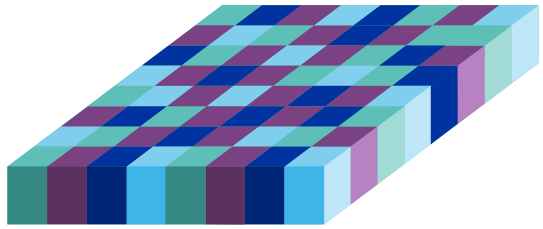
Diverse deployments

5G NR Rel-15[1] will establish the 5G foundation

For enhanced mobile broadband and Rel-15+ mission critical and massive IoT

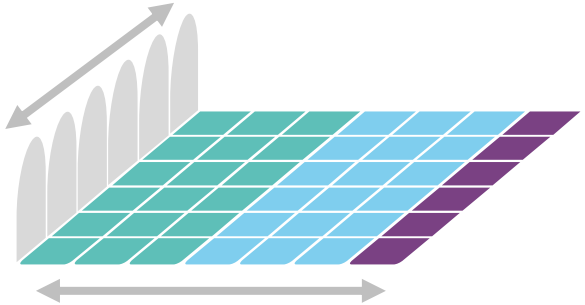
Optimized OFDM-based waveforms

With scalable numerology and TTI, plus optimized multiple access for different use cases



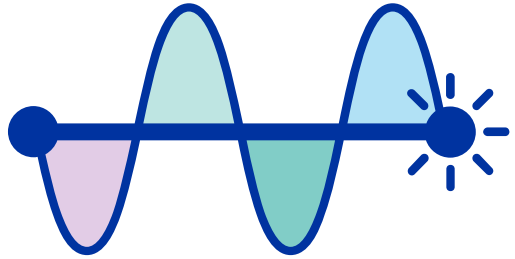
A common, flexible framework

To efficiently multiplex services and features with a dynamic, low-latency TDD/FDD design



Advanced wireless technologies

Such as massive MIMO, robust mmWave, advanced channel coding, and device-centric mobility



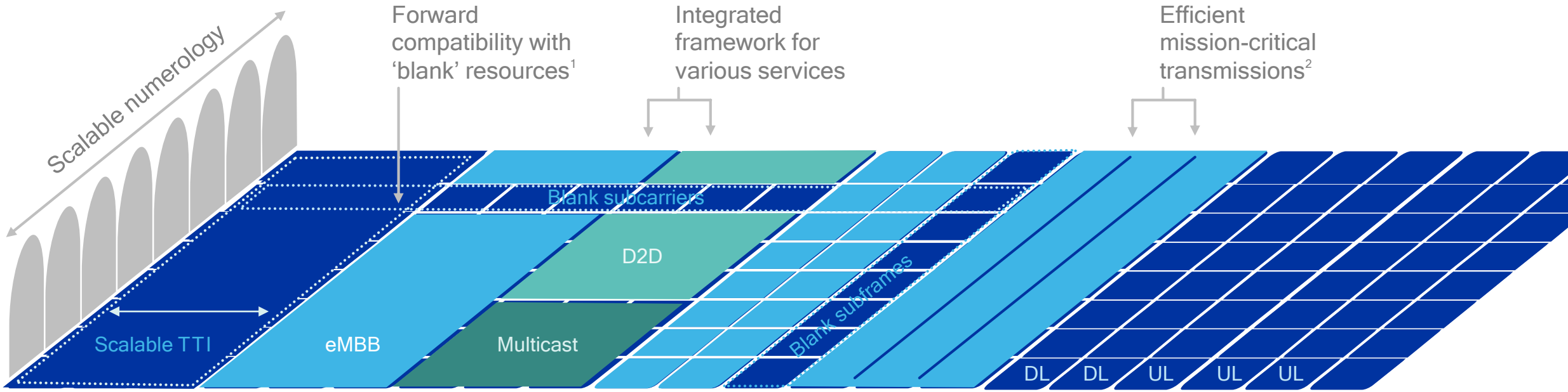
Unified design across spectrum types and bands

For licensed and shared/unlicensed spectrum bands both below 6 GHz and above 6 GHz[2]

1. 3GPP Rel-16+ will bring continued eMBB evolution, plus new features for massive IoT and mission-critical; 2. 3GPP Rel-15 focused on spectrum bands up to ~40 GHz; Rel-16+ will bring support for bands up to ~100 GHz

5G NR is a platform for future innovation

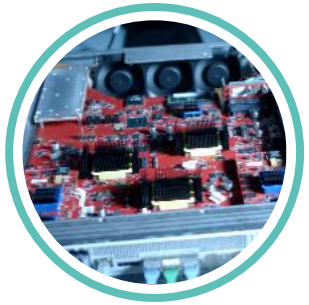
A flexible framework with forward compatibility that can support unknown services



1. By supporting blank sub-frames, blank resources may still be utilized, but are designed in a way to not limit future feature introductions;
2. Nominal 5G access to be designed such that it is capable to sustain puncturing from mission-critical transmission or bursty interference

An end-to-end system approach to make 5G a reality

Best-in-class 5G prototype systems and testbeds



Test, demonstrate and verify our innovative 5G designs to contribute to and drive standardization

5G standards, technology and research leadership

3GPP™
A GLOBAL INITIATIVE

Advanced channel coding, self-contained subframe, mobilizing mmWave, and more

Impactful trials and early deployments with network operators[1]

Over-the-air interoperability testing leveraging prototype systems and our leading global network experience

Modem and RFFE leadership to solve 5G complexity

Qualcomm snapdragon
X50
5G Modem

Roadmap to 5G significantly more complex and faster moving–builds upon our rich history of industry firsts

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. 1. Announced numerous 5G trials to-date that will help to accelerate 5G NR from-factor accurate devices

LTE Advanced Pro establishes the foundation for 5G

Providing essential services from Day 1 and early expansion into new verticals

Gigabit LTE and LAA
Essential to the 5G mobile experience

Voice (VoLTE)
Delivers 5G voice services from day one

LTE IoT
Starts to connect the massive IoT in 2017

Cellular V2X
Establishes safety use cases, trials in 2017

Ultra-low latency
Providing ubiquitous low-latency services

and more…

LTE Advanced Pro

5G

5G NR

Rel-15
Elevates mobile broadband experience and more capacity

Rel-15+
New mission-critical services

Rel-16+
Further optimizations for the Massive IoT

Learn more at:
http://www.qualcomm.com/lte-advanced-pro

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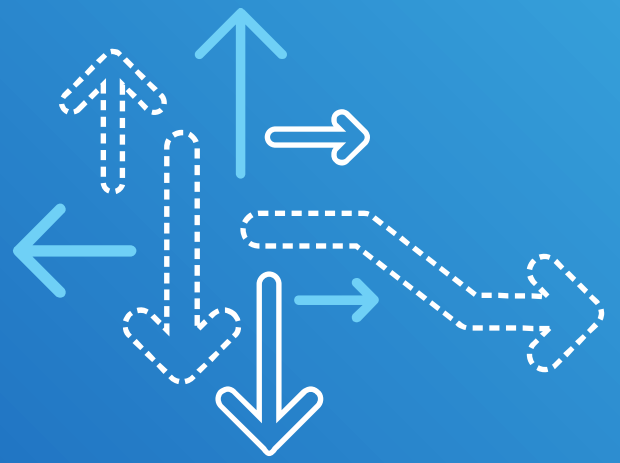

Thank you

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