



Spectrum for 4G and 5G

Qualcomm Technologies, Inc.
August, 2017



Using all available spectrum types and spectrum bands

Licensed spectrum

Exclusive use

Over 40 bands globally for LTE



Shared spectrum

New shared spectrum paradigms

Example: 2.3 GHz Europe / 3.5 GHz USA



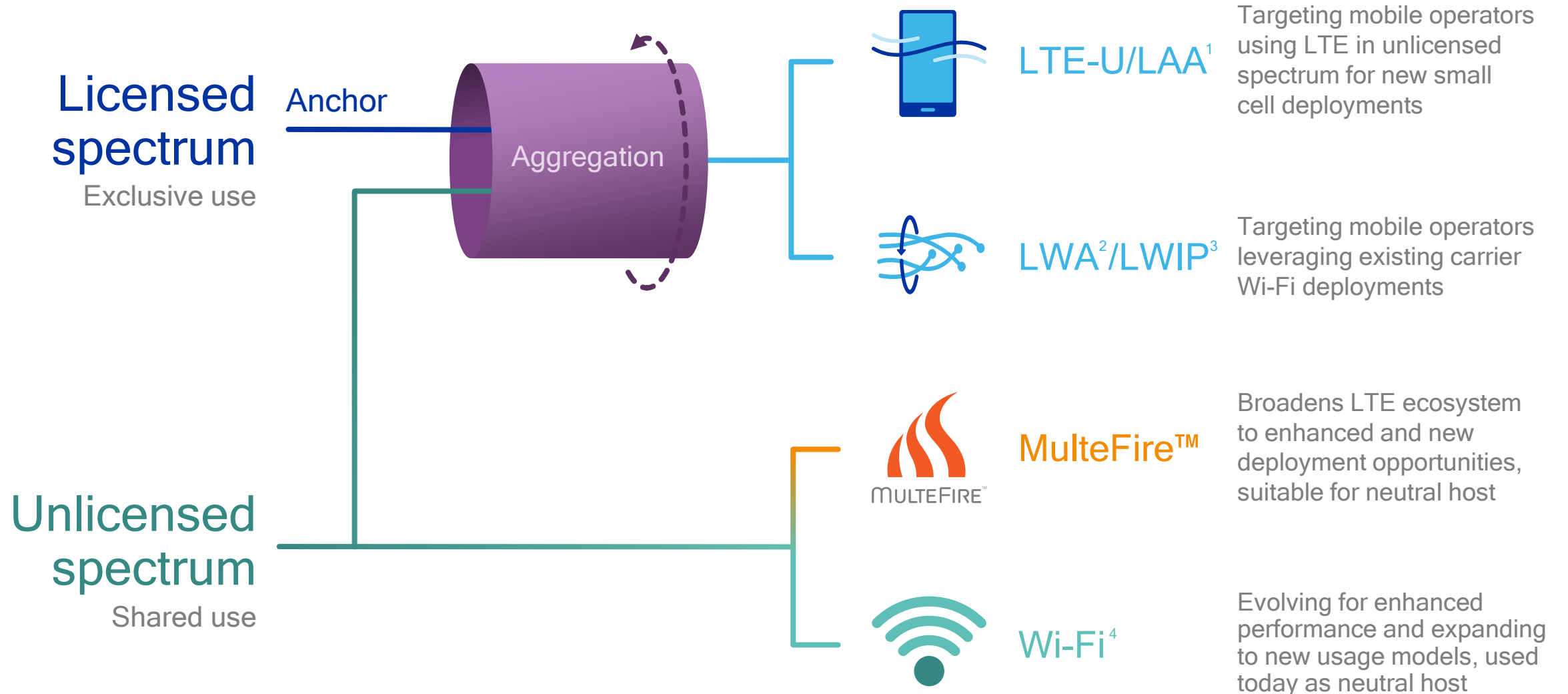
Unlicensed spectrum

Shared use

Example: 2.4 GHz / 5 GHz / 60 GHz global



Making best use of shared/unlicensed spectrum

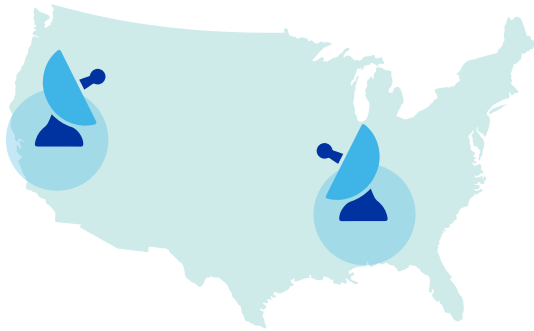


1. Licensed-Assisted Access (LAA), also includes enhanced LAA (eLAA); 2. LTE WLAN Link Aggregation (LWA); 3. LTE WLAN radio level integration with IPsec tunnel (LWIP); 4. 802.11ac / .11ad / .11ax / .11ay

New opportunities with shared/unlicensed spectrum

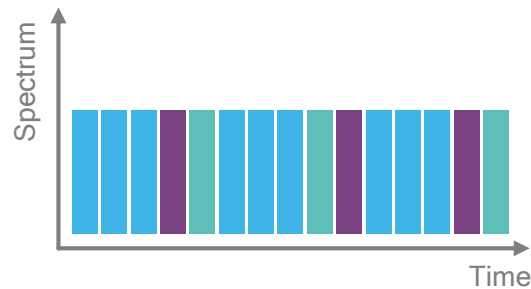
Unlocking more spectrum

Shared spectrum can unlock spectrum that is lightly used by incumbents



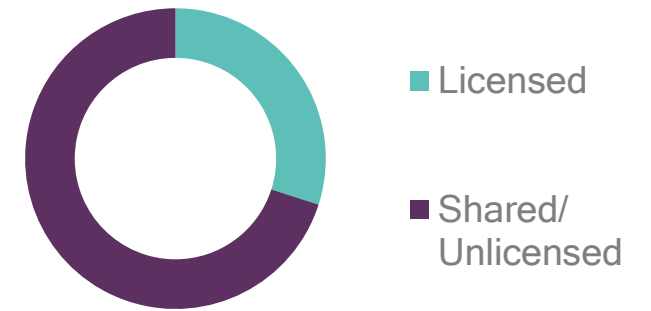
New spectrum sharing innovations

Spectrum sharing has the potential to increase spectrum utilization



A lot of spectrum may be shared/unlicensed

FCC 2016 decision on high-band spectrum included a significant portion of shared/unlicensed¹



¹ FCC ruling FCC 16-89 on 7/14/2016 allocated 3.25 GHz of licensed spectrum and 7.6 GHz of shared/unlicensed spectrum.

Spectrum sharing valuable for wide range of deployments

More spectrum to aggregate

Extreme bandwidths and more capacity

Enhanced local broadband

Neutral host, neighborhood network...

Private networks

Enterprise, Industrial IoT...

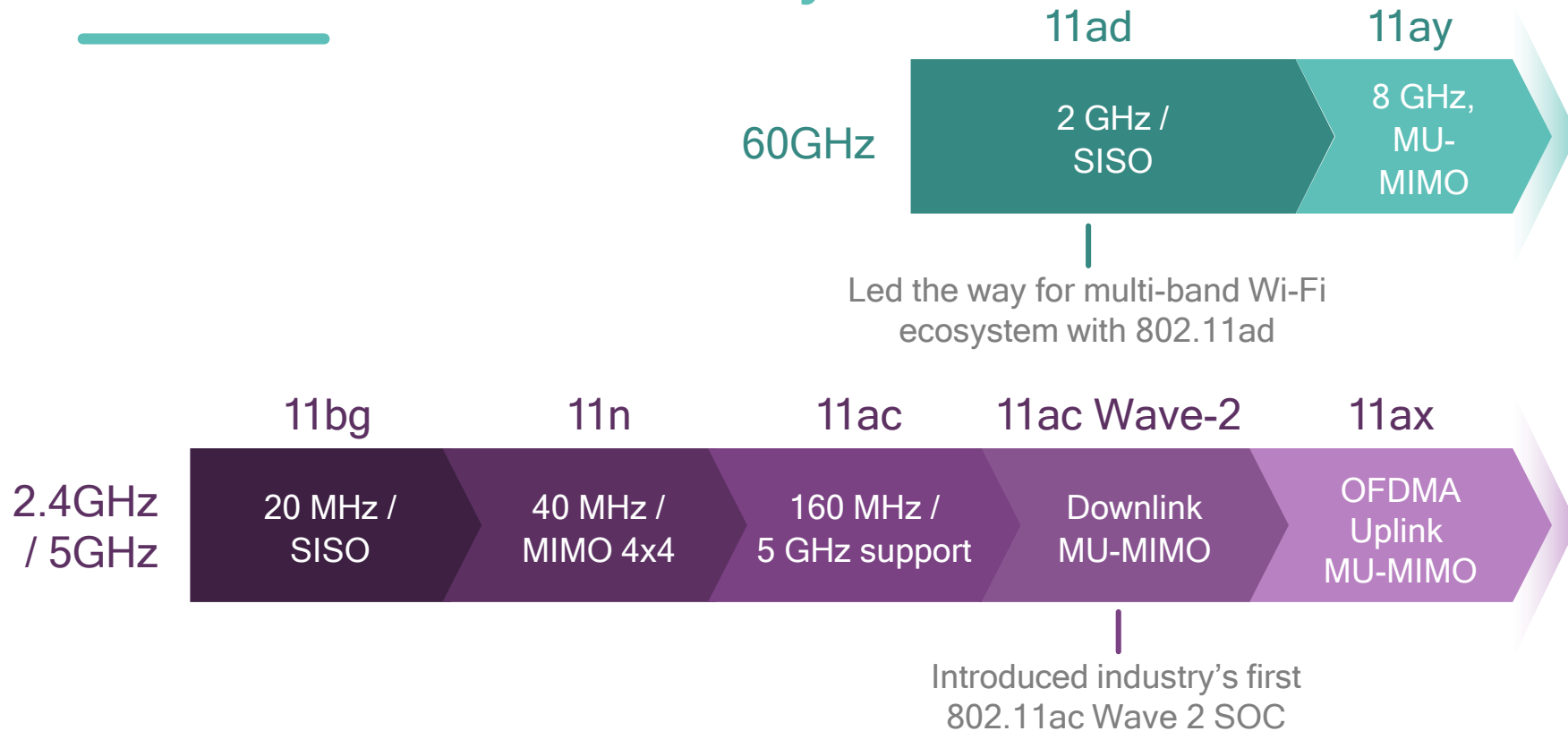


← Enhancing existing deployments, e.g., LAA¹ →

← New types of deployments, e.g., MulteFire™ or LTE-based tech. in CBRS² →

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

Qualcomm Technologies leading the way with Wi-Fi in the mobile industry



Pioneering shared spectrum technologies in LTE



LSA¹

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



LTE-U

We designed the original technology which was then commercialized by the LTE-U Forum, and is now being deployed by T-Mobile US



LAA²

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



MULTEFIRE™

A founder of the MulteFire Alliance, first OTA connection Oct. 2016 & Release 1.0 specification Jan. 2017



A founder of the CBRS³ Alliance and a key contributor to coexistence

LTE-U and LAA are ready for commercial deployment

Specifications ready, FCC authorized, LBT globally, and available in products



Specifications finalized and published

LTE-U Forum published the LTE-U specs in Q1 2014, 3GPP published Rel. 13 standard with LAA in Q1 2016



FCC authorized devices for US deployments

FCC has granted equipment authorization for both LTE-U¹ and LAA²



LAA for global deployments

Listen-before-talk (LBT) is used by both LAA and Wi-Fi globally in the 5 GHz unlicensed band

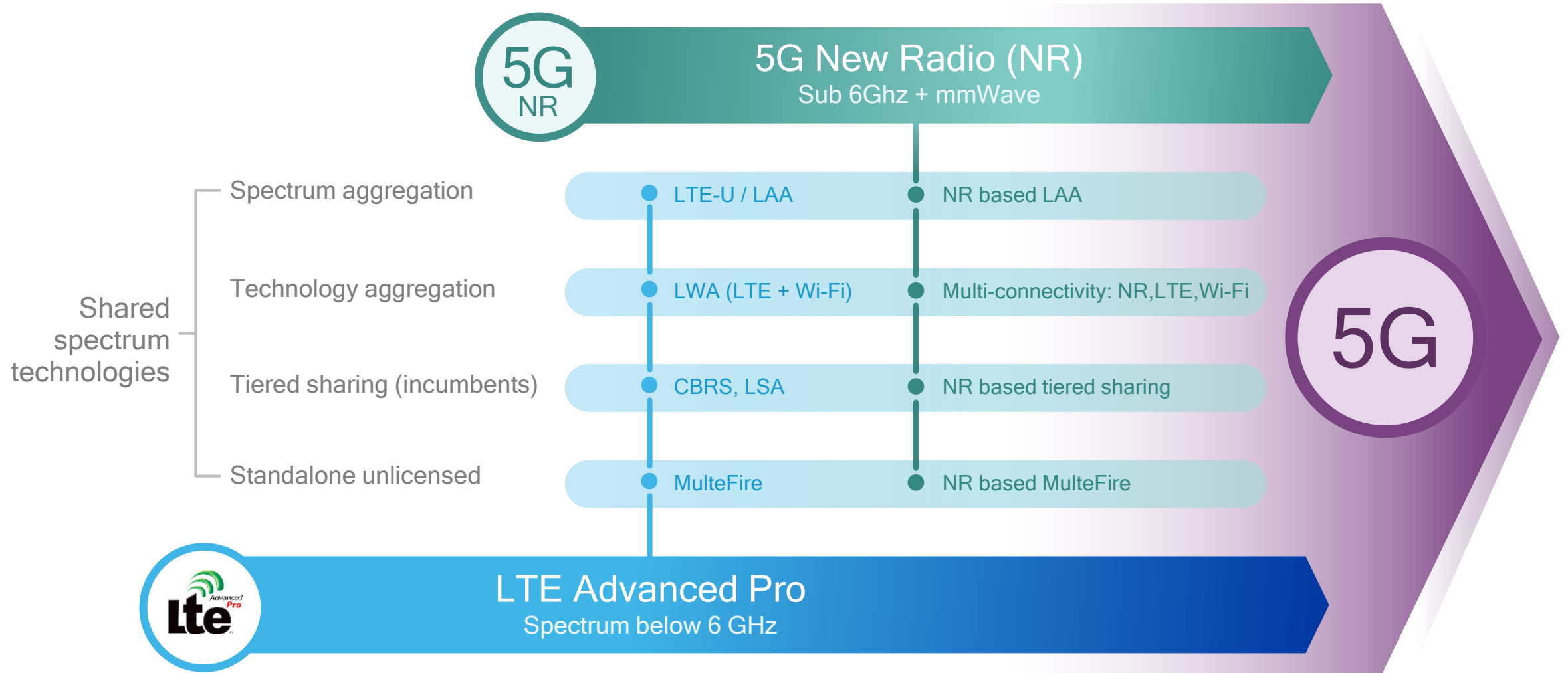


Supported by Qualcomm[®] Snapdragon[™] LTE modems

LTE-U starting with X12 LTE modem; LAA starting with X16 LTE modem in Snapdragon 835 mobile platform

Ushering in new spectrum sharing paradigms with 5G

Pioneering spectrum sharing technologies with LTE today

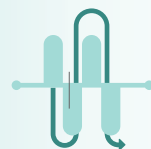


Learn more at: <http://www.qualcomm.com/spectrum-sharing>

5G NR

5G NR will natively support all different spectrum types

NR shared spectrum will support new shared spectrum paradigms



Licensed Spectrum

Exclusive use



Shared Spectrum

New shared spectrum paradigms



Unlicensed Spectrum

Shared use

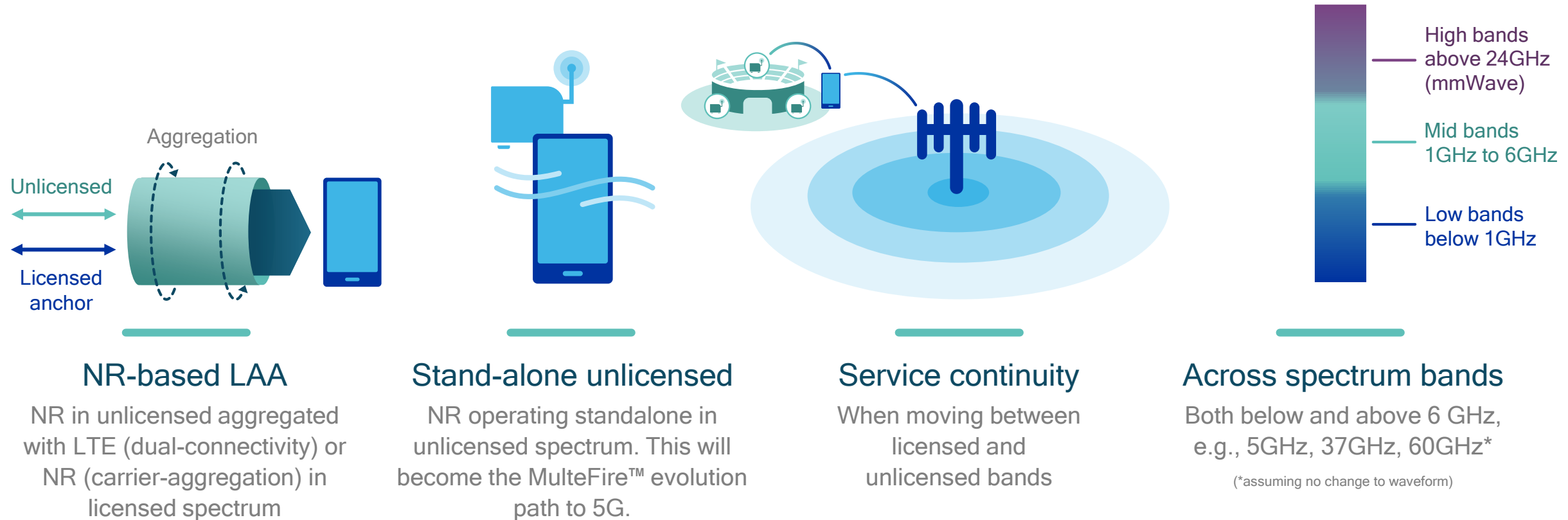
High bands above 24 GHz (mmWave)
Extreme bandwidths

Mid bands 1GHz to 6 GHz
Wider bandwidths for e.g. enhanced mobile broadband & mission-critical

Low bands below 1 GHz
Longer range for e.g. mobile broadband and massive IOT

3GPP study on 5G NR operation in unlicensed spectrum

First time 3GPP studies cellular technology operating stand-alone in unlicensed¹



Designing with fair co-existence in any unlicensed spectrum: NR/NR, NR/LTE, NR/Wi-Fi

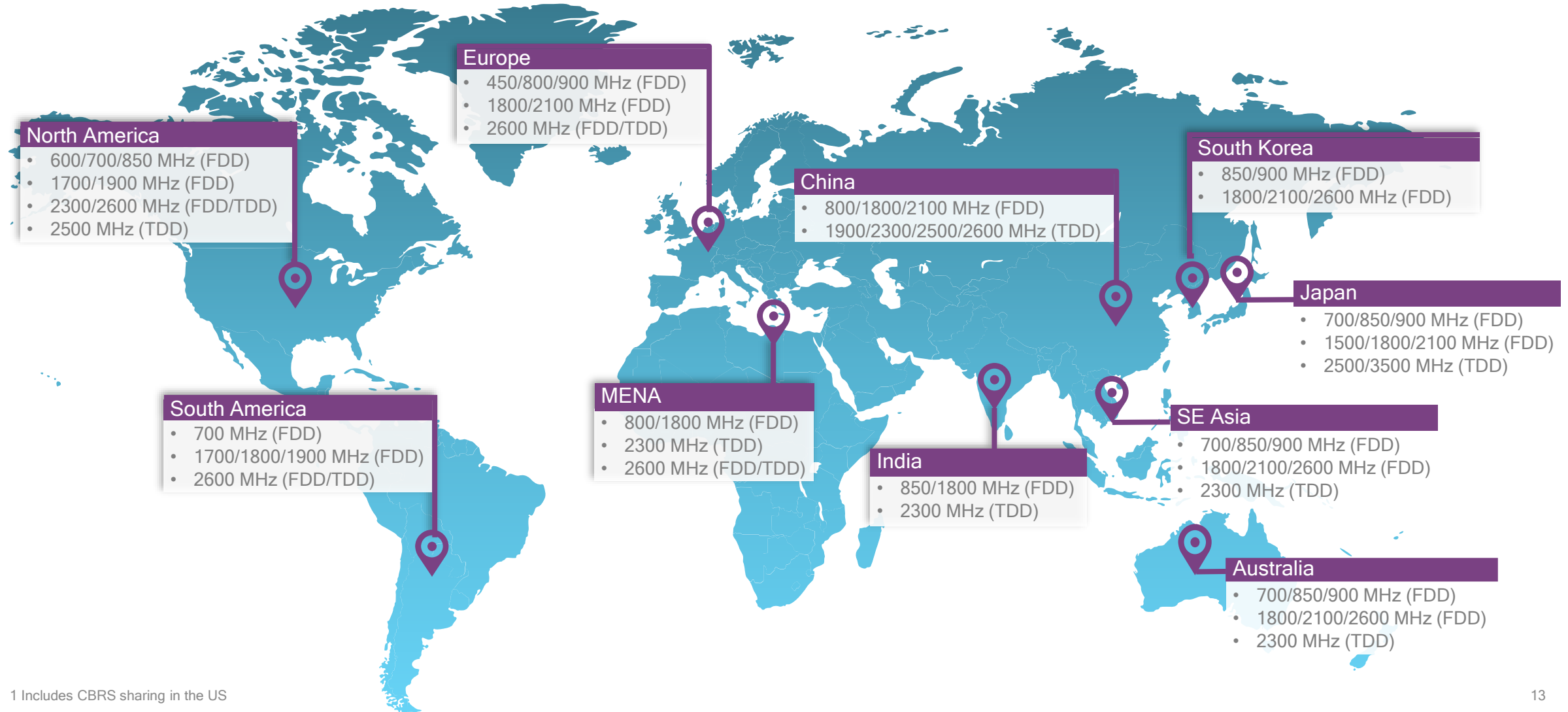
¹ Study item in Rel. 15 (RP-170828), which could be followed by a work item that is completed in Rel. 16.

Global 4G & 5G spectrum update



Global 4G LTE spectrum landscape

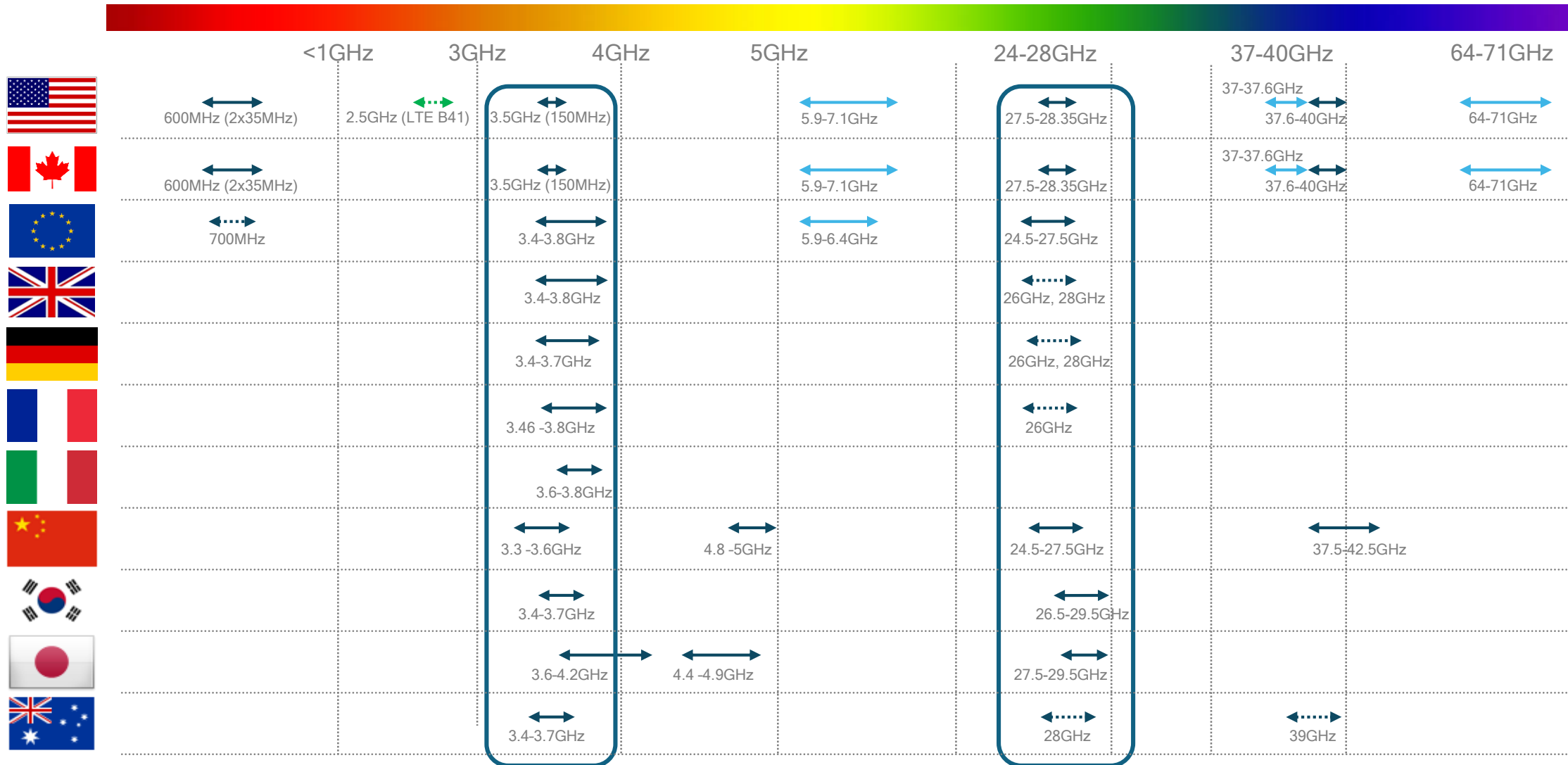
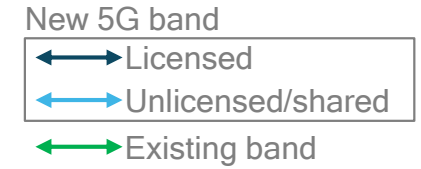
Mostly sub-3 GHz with some operators now testing/deploying in 3.5 GHz band¹



¹ Includes CBRS sharing in the US

Global snapshot of 5G spectrum

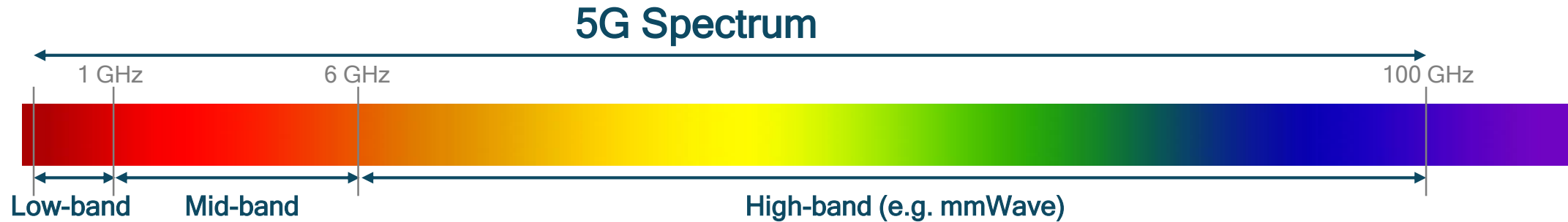
Around the world, these bands have been allocated or targeted





The FCC is driving key spectrum initiatives to enable 5G

Across low-band, mid-band, and high-band including mmWave



Low-band

Broadcast Incentive Auction

- Successfully auctioned a portion of the 600 MHz band that generated \$19.8B in proceeds after assignment phase
- Includes 70 MHz (2 x 35 MHz) of licensed spectrum and 14 MHz for unlicensed use
- Spectrum availability timing aligns with 5G

Mid-band

Citizens Broadband Radio Service

- Opening up 150 MHz in 3.5 GHz band
- 3-tier sharing with incumbents, PAL¹, GAA²
- FCC to improve PAL rules in 2017 to make them suitable for 5G
- CBRS Alliance formally launched to drive an LTE-based ecosystem

High-band

Spectrum Frontiers Ruling³

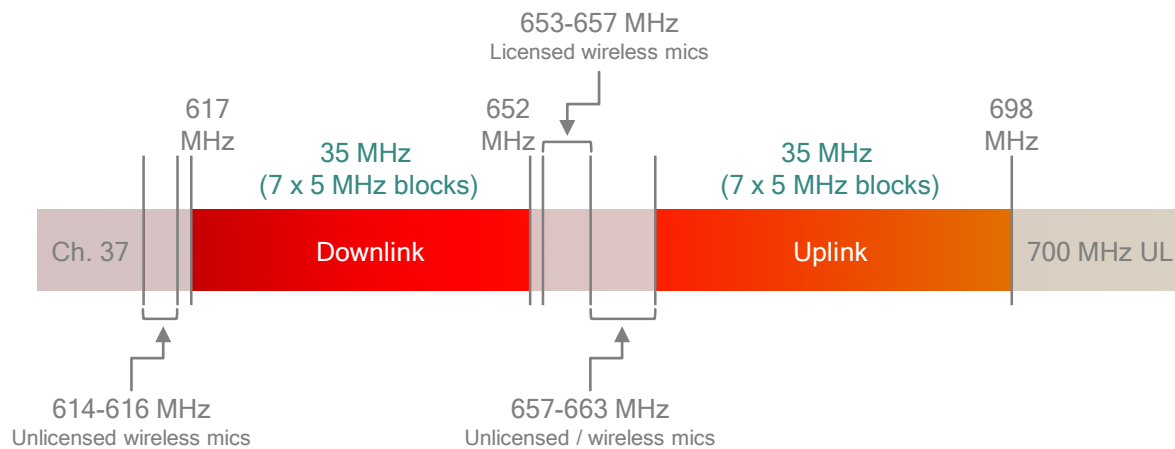
- Opening up 11 GHz in multiple mmWave bands
- 70% of newly opened spectrum is shared or unlicensed
- Unanimously approved by FCC with additional candidate bands identified for IMT-2020

¹ Priority Access Licenses to be auctioned; ² General Authorized Access; ³ FCC ruling FCC 16-89 on 7/14/2016 allocated 3.25 GHz of licensed spectrum and 7.6 GHz of shared/unlicensed spectrum.



Low-band: 600 MHz getting ready for 5G NR and LTE

Initially LTE in areas w/ cleared spectrum; 5G when spectrum is cleared of TV stations



600 MHz Spectrum

Meeting 5G timeline

Process of clearing the spectrum & repacking TV stations will take 39 months, thereby matching up with 5G NR deployment timetable (2020)

Greater capacity and wider coverage

Low-band spectrum is optimized for long-range macro deployments - optimal for connecting the wide-area IoT and more

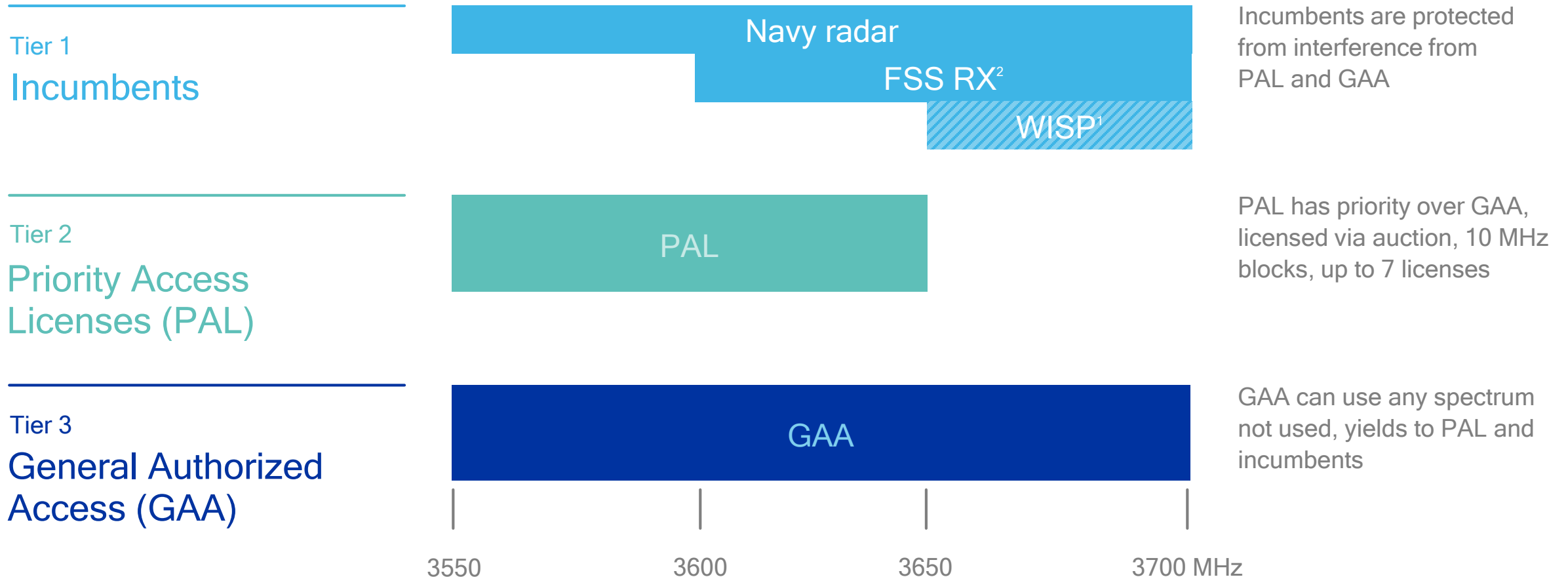
Broad industry support

Qualcomm Technologies is working closely with operators & OEMs to enable early launches, incorporating our industry-leading modem, transceiver, and RFFE



Mid-band: CBRS introduces a 3-tiered shared spectrum

FCC to optimize PAL rules in 2017 for 5G deployments



1 Wireless ISP transitioning from incumbent to PAL/GAA after 5 years; 2 Fixed satellite service - receiving only; 3) Citizen Broadband Radio Service (CBRS)



High-band: Spectrum Frontiers ruling for 5G mmWave

Shared and unlicensed spectrum is key for more bandwidths

Licensed access

- 27.5 - 28.35 GHz: 850 MHz (2x425 MHz)
- 37.6 - 38.6 GHz: 1 GHz (5x200 MHz)
- 38.6 - 40 GHz: 1.4 GHz (7x200 MHz)

Shared and unlicensed access

- 37 - 37.6 GHz: 600 MHz (3x200 MHz)
- 64 - 71 GHz: 7 GHz expansion of existing 60 GHz band

Total spectrum
= ~11 GHz

FCC also identified additional candidate bands for further comment

Including 24.25-24.35, 24.75-25.25, 31.8-33.4, 42-42.5, 47.2-50.2, 50.4-52.6, 71-76 GHz



European Commission driving a Gigabit Society¹

Deploying 5G across Europe by 2020 with pre-commercial trials starting in 2018



EC 5G Action Plan - published in Sept. 2016

- Early trials in 2017, pre-commercial trials from 2018
- Full commercial 5G services (one major city per country) in 2020
- All urban areas and major terrestrial transport paths with 5G coverage by 2025

Pioneer spectrum bands for 5G

- Low-band (700 MHz), mid-band (3.4-3.8 GHz), high-band (24.5-27.5 GHz)
- EC Mandate to CEPT focusing on 3.5 GHz and 26 GHz pioneering bands - target completion June 2018
- Additional EC Mandate to CEPT on extended L band (1427 - 1518 MHz) - target completion by end of 2017
- CEPT harmonization of the 26 GHz band ahead of WRC-19 (June 2018 target)
- 5G commercial services to use both 3.4-3.8 GHz and 26 GHz in Europe by 2020

Full set of 5G spectrum bands - agree on by end of 2017

- Works towards a recommended approach for the authorization of the specific 5G spectrum bands above 6 GHz - focus on the bands for WRC-19 (e.g., 31.8 - 33.4 GHz, 40.5 - 43.5 GHz in addition to 24.25 - 27.5 GHz)
- Maximizes spectrum sharing opportunities - sharing as regulatory tool central to European Electronic Communications Code



5G spectrum in Europe

Focus on mid-band (3.4-3.8 GHz) and 26 GHz (24-27 GHz) for 2017 and beyond

- EC RSC, CEPT, key European Member States are driving regulatory activities to accelerate 5G rollout in EU
- Intense regulatory activities for 3.4-3.8 GHz with auctions in 2017-2018; momentum building-up for 26 GHz



- Government 5G strategy for UK published in March 2017 - DCMS and HM Treasury
- Ofcom planning to auction 150 MHz in 3.4-3.6 GHz in Q3 2017 - more spectrum (110MHz) in 3.6 - 3.8 GHz in 2018/2019
- For mmWave, Ofcom has initiated a work program on 26 GHz band availability for early 5G deployment



- BenetzA planning to award 3.4-3.7 GHz in the forthcoming awarding process - expected in 2018
- For mmWave, BenetzA is designing a potential award of spectrum in the 26 GHz and 28 GHz bands



- ARCEP to award 340 MHz (3460-3800 MHz) of spectrum in 2018; ARCEP spectrum consultation included 26 GHz



- Italian government & AGCOM are working on auction rules for 3.6-3.8 GHz to allow 2x100 MHz and award the band in 2018
- Major 5G trials gov't program on 100 MHz of spectrum in 3.7-3.8 GHz; discussions on re-farming 3.4-3.6 GHz between MoD, MiSE, AGCOM
- AGCOM is also consulting on 5G mmWave spectrum



- Ireland successful auction of 350 MHz of spectrum for 5G



- In Spain, the 3.6-3.8 GHz band could be tendered according to market and operators needs from 2018
- Consultation ongoing on 5G Plan of Ministry for Digital Agenda; CNMC proposal to free up spectrum in the 3.4 - 3.8 GHz range
- Spain consulting on 26 GHz band - at least 1.4 GHz available for release in 2018



- Ficora is looking at "large-scale 5G tests" in 26 GHz, decided to make available up to 1 GHz for it in 2017



- PTS is looking at "large-scale 5G tests" in 26 GHz, decided to make available up to 1 GHz for it in 2017

Other countries: ▪ Belgium, Austria, Switzerland planning to release spectrum in 2018/2019 timeframe

eMBMS¹ delivers terrestrial Digital TV more efficiently

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



Single cellular broadcast network

Broadcast also for digital TV content and unicast for on-demand and interactivity



Addresses existing/new devices

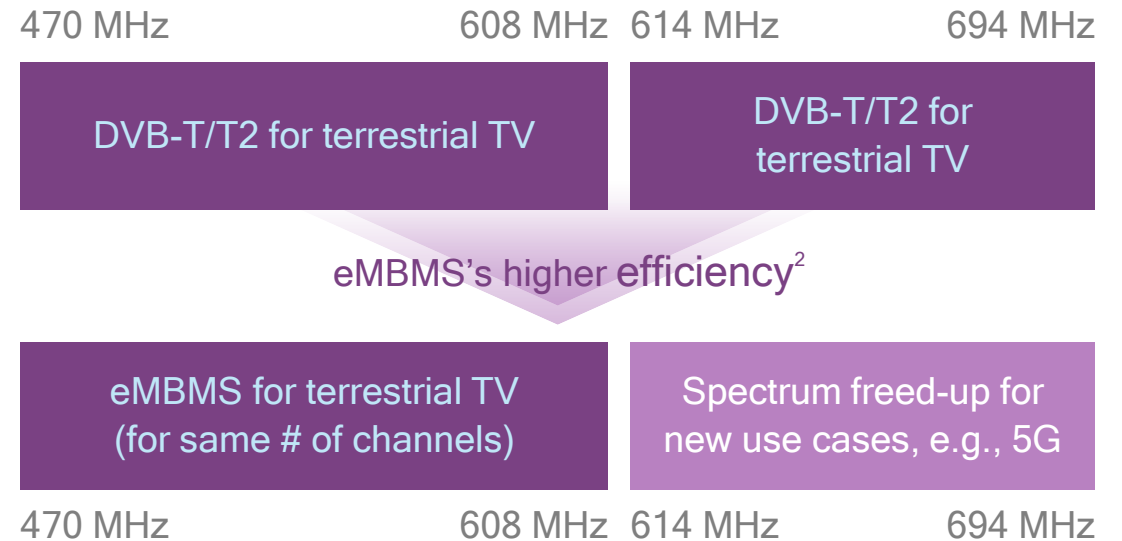
Content to new device types (e.g., receive-only fixed devices like a TV) and mobile devices



Shared broadcast delivery

To serve users from multiple providers and operators—enabling new media delivery

EU decision to harmonize 700 MHz by June 30th, 2020 for mobile broadband networks⁵



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 5. Introducing technology neutrality in 470-694 MHz, with priority for broadcasting services until 2030

Opening more spectrum for 5G is a global effort

5G spectrum status in key Asian markets and Australia



China

- Currently focusing on sub-6 GHz; approved trials at 3.4-3.6 GHz & 4.8-5 GHz, probably approve frequency planning in 3.3-3.4 GHz (indoor only)
- mmWave in longer term. Chinese gov't solicited public opinion for candidate bands of 24.75-27.5 GHz & 37-42.5 GHz non-exclusively in Jun'17
- Chinese government approved small scale trial frequencies usage in 24.75-27.5 GHz & 37-42.5 GHz mmWave ranges in Jul'17



Korea

- Phase 1 (2018+): 27.5-28.5 GHz & 3.4-3.7 GHz, also 26.5-29.5 GHz if 3GPP assigns it to 5G, auction expected in 2018
- Phase 2 (2018-2021): 2 GHz BW in 26.5-27.5 GHz, 28.5-29.5 GHz, or WRC-19 bands
- Phase 3 (2021-2026): Looking at another 1 GHz allocation



Japan

- Trials have started at 4.4-4.9 GHz & also looking at 3.6-4.2 GHz; mmWave: 27.5-29.5 GHz
- Official 5G bands: 3.7 GHz, 4.5 GHz (max 500 MHz in sub-6 GHz), and 28 GHz (max 2 GHz)
- Actual band(s) allocation and technical rules are expected in 2018



Singapore

- Regulator issued a public consultation on 5G spectrum, including bands below 1 GHz, between 1 and 6 GHz, and above 6 GHz.



Hong Kong

- Regulator announced plan to allocate low-band, mid-band (3.4-3.7 GHz) and mmWave (24.25-28.35 GHz) spectrum



Indonesia

- With recent 5G demonstration, the Indonesia minister hopes to allocate 2 GHz at 28 GHz
- Government would like to have a 5G demo/showcase for its hosting of the Asian Games in August 2018



Australia

- Planning for 3.4 to 3.7 GHz and also investigating mmWave bands
- Telstra has already announced trials in 2018 at the Commonwealth Games, using 28 and 39 GHz
- Many other governments in the region initiating 5G stakeholder consultations this year

Asia Pacific Telecommunity also driving 4G & 5G spectrum

Working on regional spectrum allocation, harmonization, and innovation



- Established in 1979, headquartered in Bangkok, Thailand
 - Founded on joint initiative of the UNESCAP¹ and ITU
 - 38 member countries and 130+ associate/affiliate members
- We are working within APG² with our ecosystem partners and regulators on planning for the next World Radio Conference (WRC-19) to develop regional proposals.
 - Also actively working within AWG³ to help drive regional spectrum harmonization, spectrum sharing studies, and to encourage innovation.

Opening more spectrum for 5G is a global effort

5G spectrum status in Middle East & Latin America



Middle East

- Pushing 700 MHz, 3.4-3.8 GHz, and 26 GHz as pioneer 5G bands in Middle East & North Africa
- UAE announced 3.4-3.6 GHz & 26 GHz as prime 5G bands
 - Demo in 2018 and commercial launch by Dubai Expo 2020
 - Etisalat already owns spectrum in 3.4-3.6GHz, also claiming that 1.4GHz should be 5G pioneer band
 - We are working with TRA and du to try to get 3.6-3.8GHz
- Qatar is also looking at local operators views regarding 3.4-3.8GHz for 5G; 100MHz per operator would be immediately available for demo in Doha in 2017 or 2018
- The preliminary conclusions of the ASMG (group of regulators in the region) are expected very soon



Latin America

- Studying bands identified at the WRC 2015 for IMT, including L-Band, 60 GHz, and other millimeter wave bands
- Targeting 3.4-3.6 GHz for 5G, but has been licensed in many countries in the 90's - concessions may be coming due
- We are supporting regulatory efforts in CITEL & ITU.

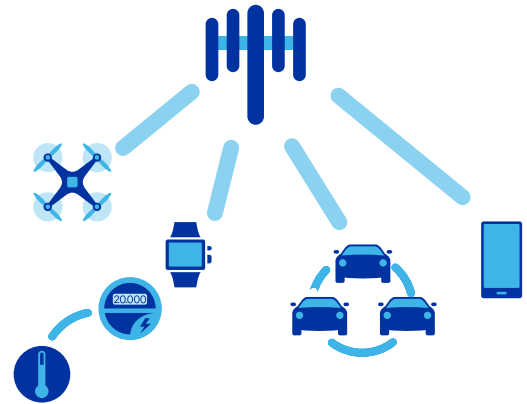
Anyone can talk
about 5G.
We are creating it.



Qualcomm Research 5G NR end-to-end prototype systems

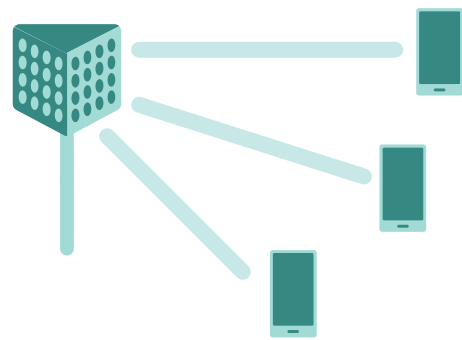
Sub-6 GHz

Ubiquitous coverage and capacity for a wide-range of 5G use cases



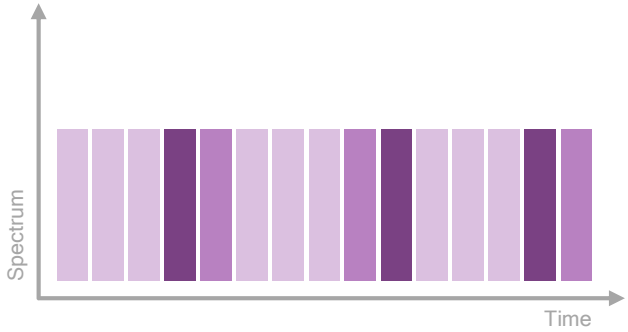
Mobilizing mmWave

Large bandwidths for extreme throughput and capacity



Spectrum sharing

More efficient utilization of, and access to, scarce resources



Accelerating 5G NR commercialization

Test, demonstrate and verify our 5G designs

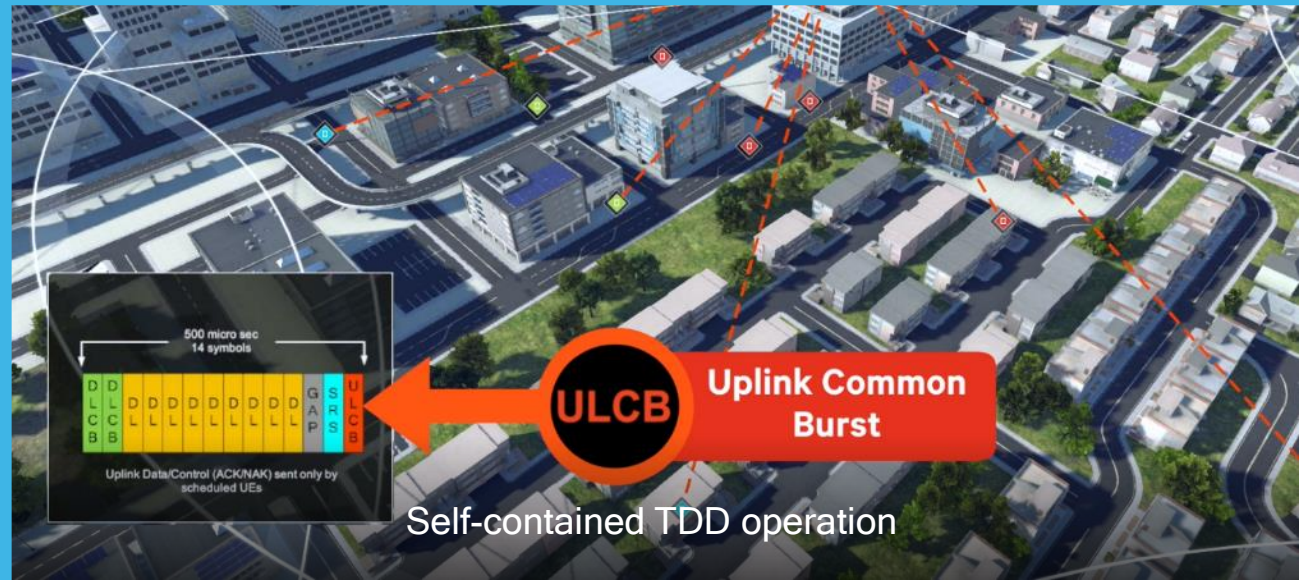
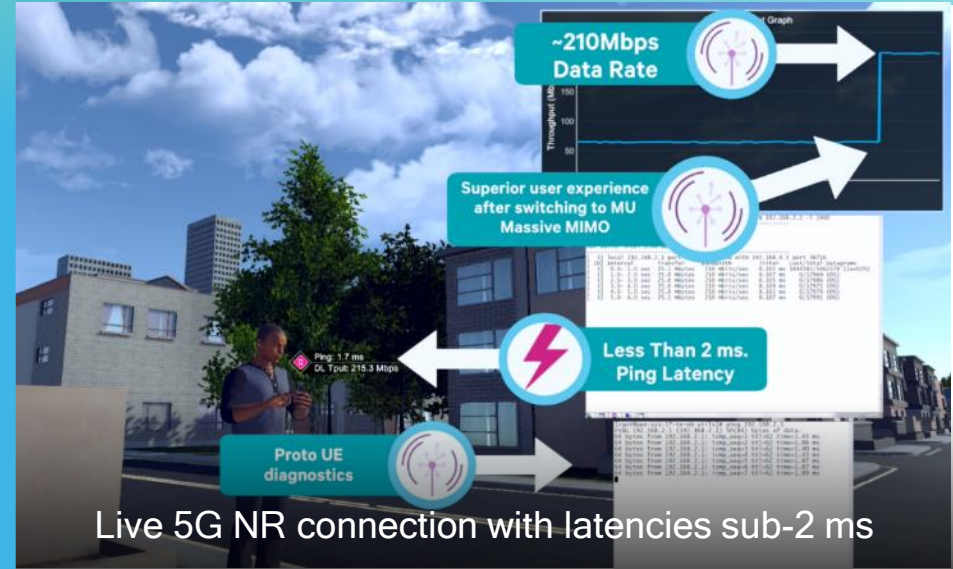
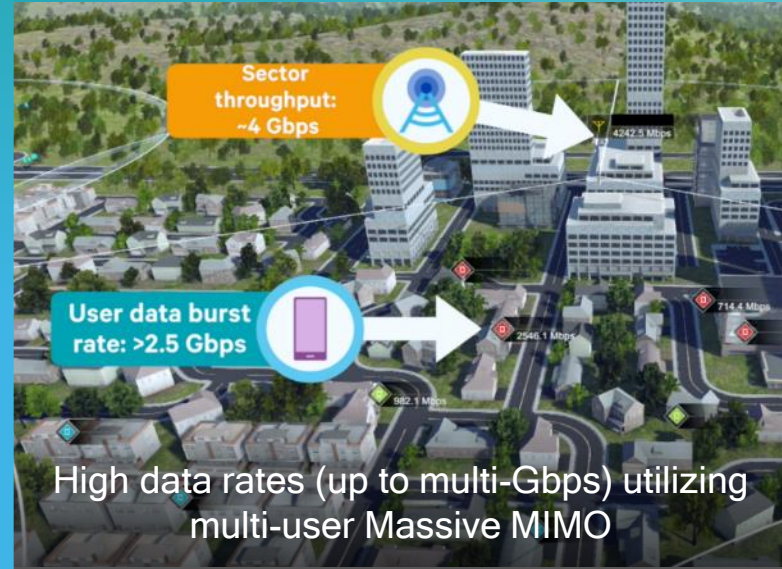
Drive and track 3GPP 5G NR standardization

Achieve impactful trials with network operators

Drive timely commercialization

Bringing new capabilities and efficiency to sub-6 GHz

Demonstrating advanced 5G NR technologies



Leading the way on 5G NR trials to accelerate deployments

Starting 2nd half of 2017 in collaboration with operators and infrastructure vendors

3GPP-compliant trials
and interoperability testing
at sub-6 GHz & mmWave



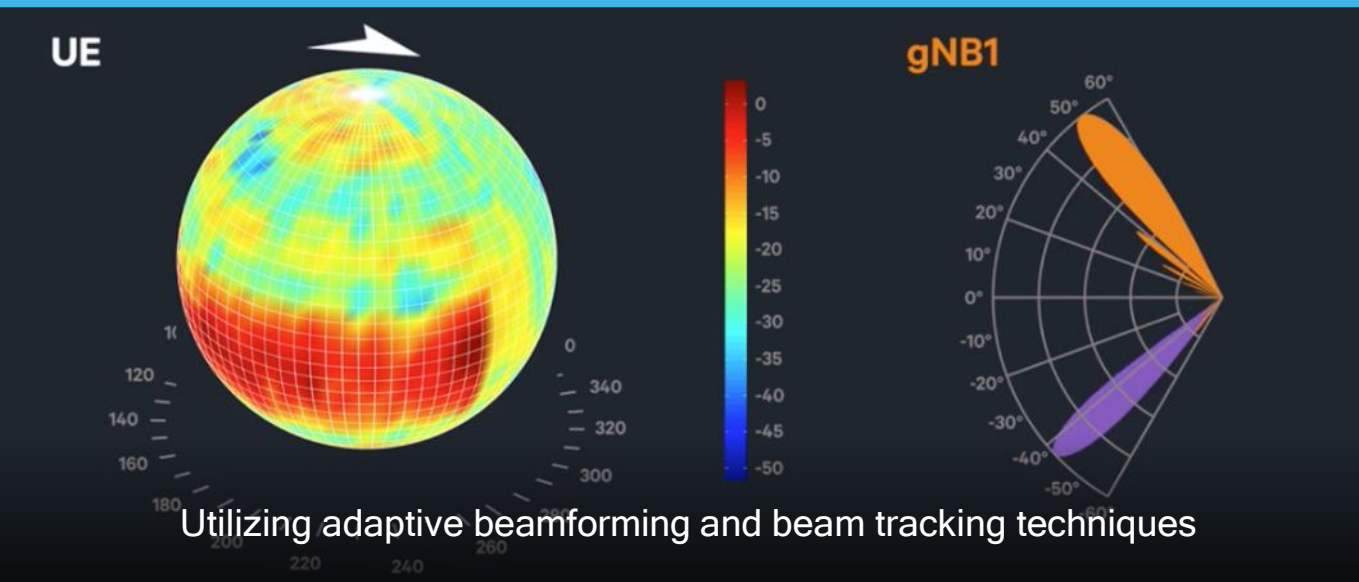
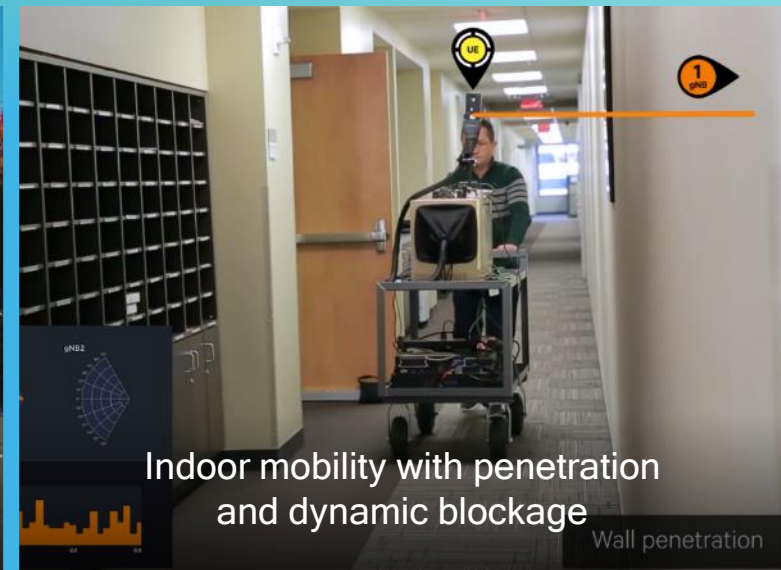
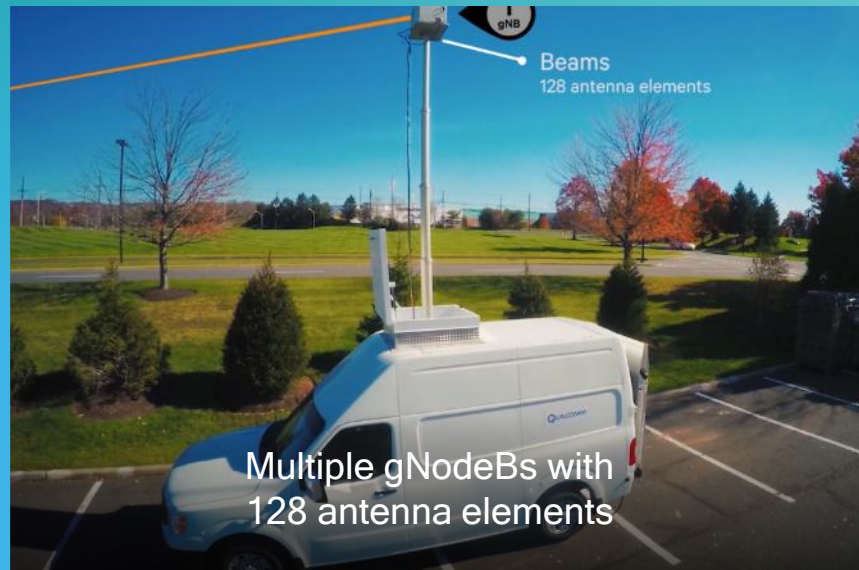
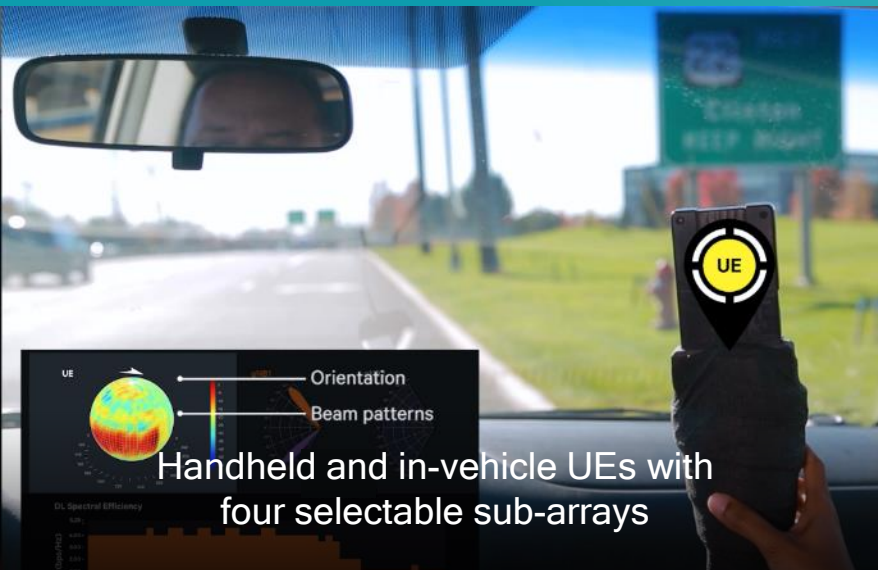
In collaboration with...



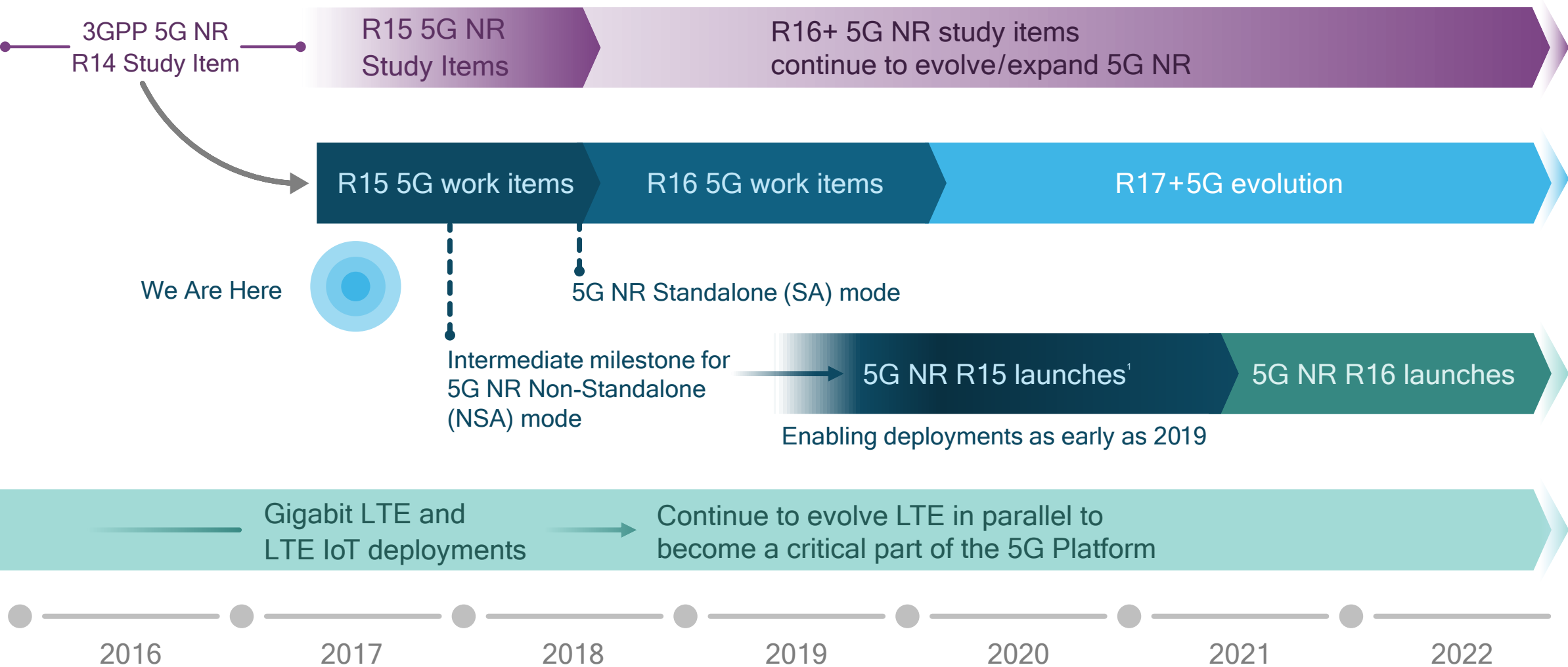
...and more to come

Mobilizing 5G mmWave in real-world environments

Demonstrating NLOS operation and robust mobility



Accelerating 5G NR, the global standard for 5G



1. Forward compatibility with R16 and beyond



We are accelerating the path to 5G NR

Best-in-class 5G prototype systems and testbeds



5G standards, technology and research leadership



Impactful trials and early deployments with network operators



Modem and RFFE leadership to solve 5G complexity



Snapdragon X50
5G Modem Family

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

Such as advanced channel coding, self-contained subframe, mobilizing mmWave, ...

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

Announced the world's first 5G NR multimode modems for premium smartphones in 2019

Learn more at www.qualcomm.com/5G

Thank you

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