Qualcomm

San Diego, CA

May 31, 2023

Global 5G spectrum update and innovations for future wireless systems

@QCOMResearch

Today’s Agenda

ONE

Global 5G deployments are well underway, using low, mid, and mmWave spectrum bands

TWO

More spectrum is needed for future wireless growth; our spectrum innovations can open new capacity

THREE

We are advancing novel spectrum sharing technologies that can realize new levels of utilization and efficiency

FOUR

Questions?

Global 5G deployments are well underway

Using low, mid, and mmWave spectrum bands

Transportation

Manufacturing

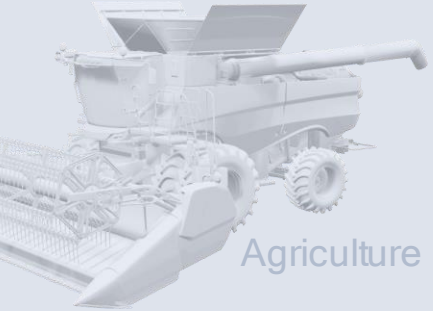
Industrial

Retail

Energy

Driving digital transformation across industries

5G will enable $13.1 Trillion in global sales activity in 2035



Agriculture

Public safety

Smart cities

Healthcare

Entertainment

Source: The 5G Economy, an independent study from IHS Markit, commissioned by Qualcomm Technologies, Inc., November 2020

5G

continues to expand globally

245+
operators with 5G commercially deployed

270+
additional operators investing in 5G

1B+
5G connections globally

6B+
5G smartphones to ship between 2020-2026

1,800+
5G devices launched or in development

Sources: 5G commercial networks, operators investing in 5G, 5G devices launched: GSA, Mar 2023; 2023 5G connection projections - average of Ericsson (Feb 2023) and GSMA Intelligence (Feb 2023); 5G cumulative smartphone shipments - average of CCS Insight (Sept 2022), IDC (Dec 2022), and Strategy Analytics (Oct 2022).

5G operates in all spectrum types / bands

Lifeblood of wireless communications

Licensed spectrum

Exclusive use

Remains the industry's top priority

Shared spectrum

New shared spectrum paradigms

e.g., 3.5 GHz USA, 3.8-4.2 GHz UK, 37-37.6 GHz USA

Unlicensed spectrum

Shared use

e.g., 5 GHz / 6 GHz / 60 GHz global

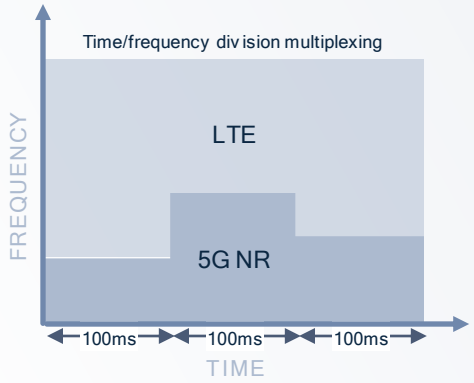
HIGH BANDS
ABOVE 24 GHz (mmWAVE)

MID BANDS
1 GHz – 7 GHz

LOW BANDS
BELOW 1 GHz

Dynamic Spectrum Sharing

(DSS) has allowed 5G to be deployed in existing LTE brands



Efficient spectrum use with low sharing overhead

5G NR to avoid resources used by LTE

No impact to legacy LTE devices

Global 4G LTE spectrum landscape

EUROPE
- 450/ 800/ 900 MHz (FDD)
- 1800/ 2100 MHz (FDD)
- 2600 MHz (FDD/ TDD)

U.S. / CANADA
- 600/ 700/ 850 MHz (FDD)
- 1700/ 1900 MHz (FDD)
- 2300/ 2600 MHz (FDD/ TDD)
- 2500 MHz (TDD)

MENA
- 800/ 1800 MHz (FDD)
- 2300 MHz (TDD)
- 2600 MHz (FDD/ TDD)

CHINA
- 800/ 1800/ 2100 MHz (FDD)
- 1900/ 2300/ 2500/ 2600 MHz (TDD)

SOUTH KOREA
- 850/ 900 MHz (FDD)
- 1800/ 2100/ 2600 MHz (FDD)

JAPAN
- 700/ 850/ 900 MHz (FDD)
- 1500/ 1800/ 2100 MHz (FDD)
- 2500/ 3500 MHz (TDD)

INDIA
- 850/ 1800 MHz (FDD)
- 2300 MHz (TDD)

SE ASIA
- 700/ 850/ 900 MHz (FDD)
- 1800/ 2100/ 2600 MHz (FDD)
- 2300 MHz (TDD)

LATIN AMERICA
- 700 MHz (FDD)
- 1700/ 1800/ 1900 MHz (FDD)
- 2600 MHz (FDD/ TDD)

AUSTRALIA
- 700/ 850/ 900 MHz (FDD)
- 1800/ 2100/ 2600 MHz (FDD)
- 2300 MHz (TDD)

Source: Qualcomm Internal

Global snapshot of allocated/targeted 5G spectrum

5G is being designed for diverse spectrum types/bands

NEW 5G BAND
- Licensed
- Unlicensed / shared

	<1GHz	3GHz	4GHz	5GHz	6GHz	24-30GHz	37-50GHz	60GHz	>95GHz	
	600MHz (2x35MHz)	900MHz (2x3MHz) 2.5/2.6GHz (B41/n41)	3.1-3.45GHz 3.45-3.55GHz 3.55-3.7GHz 3.7-3.98GHz	4.94-4.99GHz	5.9-7.1GHz	24.25-24.45GHz 24.75-25.25GHz 27.5-28.35GHz	37-37.6GHz 37.6-40GHz 42-42.5GHz 47.2-48.2GHz	57-71GHz	>95GHz	
	600MHz (2x35MHz)		3.475-3.65 GHz 3.65-4.0GHz		5.9-7.1GHz	26.5-27.5GHz 27.5-28.35GHz	37-37.6GHz 37.6-40GHz	57-71GHz	>95GHz	
	700MHz (2x30 MHz)		3.4-3.8GHz		5.9-6.4GHz	24.5-27.5GHz		57-66GHz		
	700MHz (2x30 MHz)		3.4-3.8GHz		5.9-6.4GHz	24.25-27.5 GHz	40.5-43.5 GHz	57-66GHz		
	700MHz (2x30 MHz)		3.4-3.8GHz		5.9-6.4GHz	26GHz		57-66GHz		
	700MHz (2x30 MHz)		3.46-3.8GHz		5.9-6.4GHz	26GHz		57-66GHz		
	700MHz (2x30 MHz)		3.6-3.8GHz		5.9-6.4GHz	26.5-27.5GHz		57-66GHz		
	700MHz 900MHz 2GHz (n1) 2.5/2.6GHz (B41/n41)		3.3-3.6GHz	4.8-5GHz		24.75-27.5GHz	37-43.5GHz			
	700/800MHz	2.3-2.39GHz	3.4-3.7GHz 3.7-4.0GHz	4.72-4.82GHz	5.9-7.1GHz	25.7-26.5GHz 26.5-28.9GHz 28.9-29.5GHz	37GHz	57-64GHz		
	700/800MHz	2.3 GHz	3.6-4.1GHz	4.5-4.9GHz	5.9-6.4GHz	27-29.5GHz		57-66GHz		
	600MHz (2x40 MHz) 700MHz (2x30 MHz)		3.3-3.67GHz			24.25-27.5GHz				
		2.3 GHz	3.4-3.7GHz 3.7-4.0GHz		5.9-6.4GHz	24.25-29.5GHz	39GHz	57-66GHz		

RECENT HIGHLIGHTS

5G Global Spectrum Status

North America

UNITED STATES

- Multiple bands in commercial deployment from all major mobile operators, e.g., 600 MHz, 2.5/2.6 GHz, 3.5 GHz, 28 GHz, as well as other existing bands using DSS
- 4.9 GHz band targeted for public safety use with non-commercial secondary use
- 5.9 GHz band for automotive safety - waiver granted by FCC to permit initial C-V2X deployments
- 6 GHz band (5.9-7.1 GHz) for unlicensed operations (e.g., Wi-Fi and 5G NR-U)
- 5030 MHz band (5030-5091 MHz) for UAS operations
- Lower 37 GHz band - advanced spectrum sharing possibilities

CANADA

- Multiple bands in commercial deployment from major mobile operators, such as 600 MHz, 3.5 GHz, and other mobile bands using DSS
- Looking to open 3.9 GHz band and 26, 28, and 38 GHz bands for exclusive use and for non-competitive local (NCL) licensing
- Above 95 GHz bands opened by ISED for unlicensed operations

Source: GSA

RECENT HIGHLIGHTS

5G Global Spectrum Status

Central America

South America

ARGENTINA

- 5G Auction announced for 2023 (no specific date) for the 3.3-3.6 GHz band.

BRAZIL

- Assigned 3.3-3.7 GHz and 26 GHz. Reserved 3.7-3.8 GHz for local networks.
- Considering and consulting on 4.8-5.0 GHz band.

COLOMBIA

- 5G Auction scheduled for Q3 2023 in the 3.3-3.7 GHz and 26 GHz bands.

CHILE

- Assigned 3.3-3.4 GHz, 3.6-3.65 GHz, and 26 GHz for 5G. 3.4-3.6 GHz pending reorganization.
- 3.75-3.8 GHz range reserved for local networks.

MEXICO

- Assigned 3.4-3.45 and 3.45-3.55 GHz for 5G.
- Evaluating 3.3-3.4 GHz and 26 GHz. Trying to recover the 3.3-3.35 GHz range.

PERU

- Fragmented assignment 3.4-3.6 GHz.
- Evaluating 3.3-3.4 GHz, 3.6-3.8 GHz, and 26 GHz bands

URUGUAY

- Assigned 27.5-28.25 GHz for 5G (via temporary assignments).
- Auction rules approved for 3.3-3.4 GHz, and 3,6-3,8 GHz bands. Auction expected in Q2 2023.

Source: GSA

RECENT HIGHLIGHTS

5G

Global Spectrum Status

Europe

U.K.
- Assigned 3.4-3.8, 3.8-4.2 for private networks
- 26 GHz, 40 GHz authorization framework under definition

ITALY
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz

FRANCE
- Assigned 3.4-3.8 GHz
- Test licenses for 26 GHz band

SPAIN
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz - including dedicated spectrum for private networks

SWEDEN
- Assigned 3.4-3.8 GHz - including dedicated spectrum for private networks
- Local licensing in 24.25-25 GHz

GERMANY
- Assigned 3.4-3.7 GHz, 3.7-3.8 GHz for private networks
- 26 GHz licenses issued on demand on a local basis

FINLAND
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz - including dedicated spectrum for private networks

GREECE
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz

SLOVENIA
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz band

CROATIA
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz band

ROMANIA
- Assigned 3.4-3.8 GHz
- Planned assignment for 26 GHz

ESTONIA
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz

CZECH REP.
- Assigned 3.5-3.8 GHz, local license 3.4-3.5GHz

DENMARK
- Assigned 3.4-3.8 GHz
- Assigned 26 GHz

Source: GSA

RECENT HIGHLIGHTS

5G Global Spectrum Status

China

East Asia

Oceania

MAINLAND CHINA

- Assigned 700MHz, 3.4-3.6 GHz, 4.8-5.0 GHz for 5G
- Allocated 3.3-3.4 GHz for shared indoor use
- Refarming 900 MHz 2G/4G band for 5G
- Identify IMT service in 24.75-27.5 GHz and 37-43.5GHz (portion thereof)

HONG KONG

- Assigned 3.3-3.6 and 4.84-4.92 GHz
- Allocated 400 MHz per operator in 26/28 GHz, with 400 MHz reserved for local licensing

TAIWAN

- Assigned 3.3-3.57 GHz for 5G
- Assigned 27.9 - 29.5 GHz, with 27.0-27.9 GHz held for future allocation
- 4.8-4.9 GHz planned for local networks

JAPAN

- Allocated 3.6-4.1 GHz, 4.5-4.6 GHz, and 27-28.2, 29.1-29.5 GHz to 4 operators
- 4.6-4.8 GHz planned for local licensing
- 4.8-4.9 GHz planned for assignment
- 4.9-5 GHz, 26.6-27 GHz, and 28.3-29.1 GHz 39.5-43.5 GHz are being planned

SOUTH KOREA

- Allocated 3.4-3.7 GHz and 26.5-28.9 GHz
- On-going consideration for 3.7-3.8 GHz band
- MSIT plans to allocate additional 5G spectrum

AUSTRALIA

- Assigned 3.4-3.7 GHz
- 3.7-4.2 GHz, 4.4-4.5 GHz, 4.8-5.0 GHz under on-going consultation
- 26 GHz mmWave band for local licensing and wide-area allocation

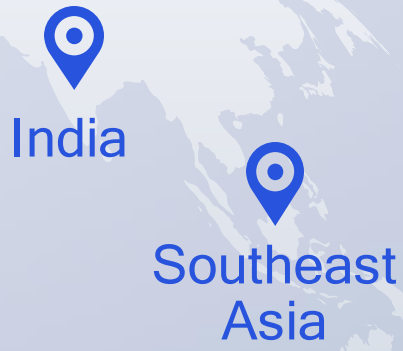
NEW ZEALAND

- Assigned 3.4-3.59 GHz and 3.59-3.8 GHz
- 26/28 GHz mmWave under consideration

Source: GSA

RECENT HIGHLIGHTS

5G Global Spectrum Status



INDIA

- Assigned spectrum across all bands for 5G, including 600, 700 MHz, 3.4-3.67 MHz and 26 GHz to 4 operators
- 800, 900 MHz, 1.8, 2.1, 2.3, and 2.5 GHz bands currently used for 4G, but expected to become 5G bands

SINGAPORE

- Assigned upper mid-band 3.45-3.65 GHz to two operators with 100 MHz each
- Assigned mmWave in 26.25-29.5 GHz for 4 operators with 800 MHz each
- Consulting on 4.4-5.0 GHz band

MALAYSIA

- Planning to assign 3.5 GHz and 26/28 GHz band, which was delayed from 2020

THAILAND

- Assigned 2.5 GHz TDD spectrum for 5G
- Assigned 26 GHz spectrum to 4 operators
- Planning to assign 3.4-3.7 GHz

INDONESIA

- Conducted trials in 28 GHz
- Targeting 2.3 GHz band for sub-7 GHz
- Consultation for 3.3-3.6 GHz in upper mid-band and mmWave in 26/28 GHz bands

PHILIPPINES

- Assigned 3.3-3.8 GHz in mid-band
- mmWave spectrum under consideration

VIETNAM

- Planning to assign 3.6-4.0 GHz, with temporary assignment for testing in 3.7-3.8 GHz band
- On-going consultation on 4.4-4.8 GHz
- Planning to assign 26/28 GHz

Source: GSA

Global snapshot of spectrum optimized for industrial IoT / vertical / private network use

Local licensing or sharing

USA	3.5 GHz CBRS, exclusive & shared licenses 37 - 37.6 GHz shared spectrum/ local licenses, under evaluation
GERMANY	3.7 - 3.8 GHz 24.25 - 27.5 GHz, local licenses
U.K.	3.8 - 4.2 GHz 1781.7-1785/ 1876.7-1880 MHz 2390 - 2400 MHz 24.25 - 26.5 GHz, local licenses
SWEDEN	1780-1785/ 1875-1880 MHz 3720 - 3800 MHz 24.5 - 25.1 GHz
FINLAND	2300 - 2320 MHz Sub-licensing of 3.4 - 3.8 GHz 24.5 - 25.1 GHz
NETHERLANDS	3410 - 3450 MHz for local industrial use 3750 - 3800 MHz available with restrictions 2.3 - 2.4 GHz (licensed shared access online booking system) Local private service to migrate to 3400-3450 MHz or 3750-3800 MHz by 2026
FRANCE	2575 - 2615 MHz 26.5 - 27.5 GHz (test licenses)
CZECH REP.	3.4 - 3.6 GHz, 2*20 MHz, Allocated in 2020 with a leasing option
BRAZIL	703 - 708 / 758 - 763 MHz (Infrastructure segment) 1487 - 1517 MHz, 2390-2400 MHz, 2485 - 2495 MHz 3.7 - 3.8 GHz 27.5 - 27.9 GHz
CHILE	2300 - 2325 MHz (already has requests from ports and mining sectors) 3.75 - 3.8 GHz
NEW ZEALAND	Licenses in 2575 - 2620 MHz may be assigned for localized use
AUSTRALIA	1755-1785 MHz in remote areas 1920-1980 MHz in remote areas 3.7 - 4.0 GHz for local area licensing 24.25 - 27.5 GHz and 27.5 - 29.5 GHz for local licensing
CHINA	Issued the first local 5G trial license in 5925-6125 MHz and 24.75-25.15 GHz to COMAC
SINGAPORE	Each operator has acquired 800 MHz of 26/ 28 GHz spectrum to deploy local networks
HONG KONG	24.25 - 28.35 GHz (400 MHz) available for local licenses
JAPAN	2,575 - 2,595 MHz and 1,888.5 - 1,916.6 MHz (NSA anchor) 4.6 - 4.9 GHz (4.6 - 4.8 GHz indoor only, 4.8 - 4.9 GHz outdoor possible) & 28.2 - 29.1 GHz (Outdoor use; total 250 MHz 28.2 - 28.45 MHz) Uplink heavy TDD config. using semi-sync allowed in sub-6 & 28 GHz
SOUTH KOREA	4.72 - 4.82 GHz and 28.9 - 29.5 GHz for 5G specialized local applications
TAIWAN	4.8 - 4.9 GHz for 5G local private and enterprise licenses

Source: GSA, MFA

Enabling 5G sidelink for public safety and commercial use cases

Targeting 4.9 GHz PS band in US

4940 to 4990 MHz band in Jan. 2023 FCC NPRM[1]

Primary public safety spectrum to support first responders during emergencies

Sidelink is 3GPP standardized and supports priority and preemption for public safety while allowing secondary commercial uses

Enabling sidelink in all devices will greatly improve public safety services throughout the country, including where there is no cellular coverage

1 Notice of Proposed Rulemaking

More spectrum is needed for future wireless growth

Our spectrum innovations can open new capacity

Spectrum is the “lifeblood” of future wireless innovations

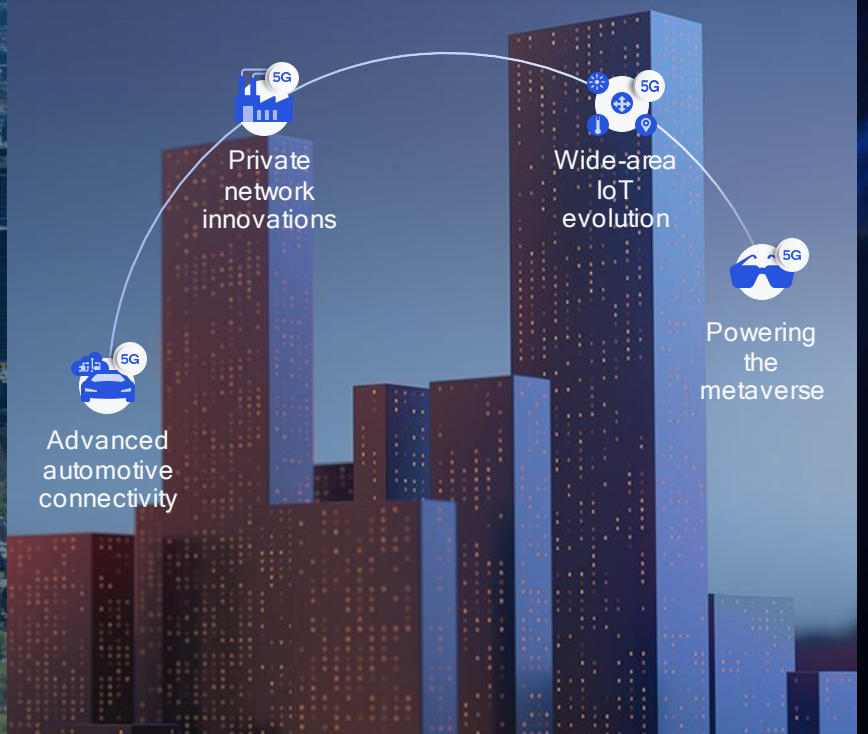
Fully realize the 5G potential and lay groundwork for the 6G future

Immediate Term

Focus on commercializing 5G mmWave in a timely manner to meet rapidly growing capacity and user experience requirements

Short-to-Medium Term

Focus on opening additional lower-band capacity to fuel the growth of 5G Advanced use cases

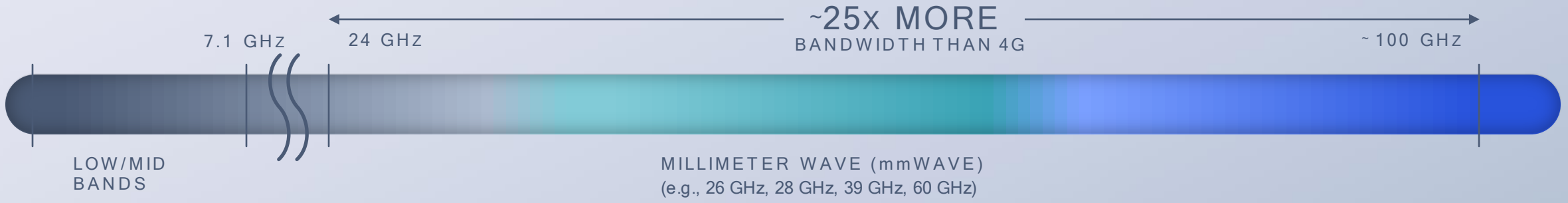


Longer Term

Focus on identifying, studying, clearing, and allocating new bands for sustained growth into 2030 and beyond

5G mmWave can address near-term capacity needs

Complementing low/mid-band to deliver meet massive bandwidths for broadband and beyond



Fixed wireless access
Urban cities, suburban towns, rural villages

Indoor enterprises
Offices, auditoriums, manufacturing

Transportation hubs
Airports, train terminals, subway stations

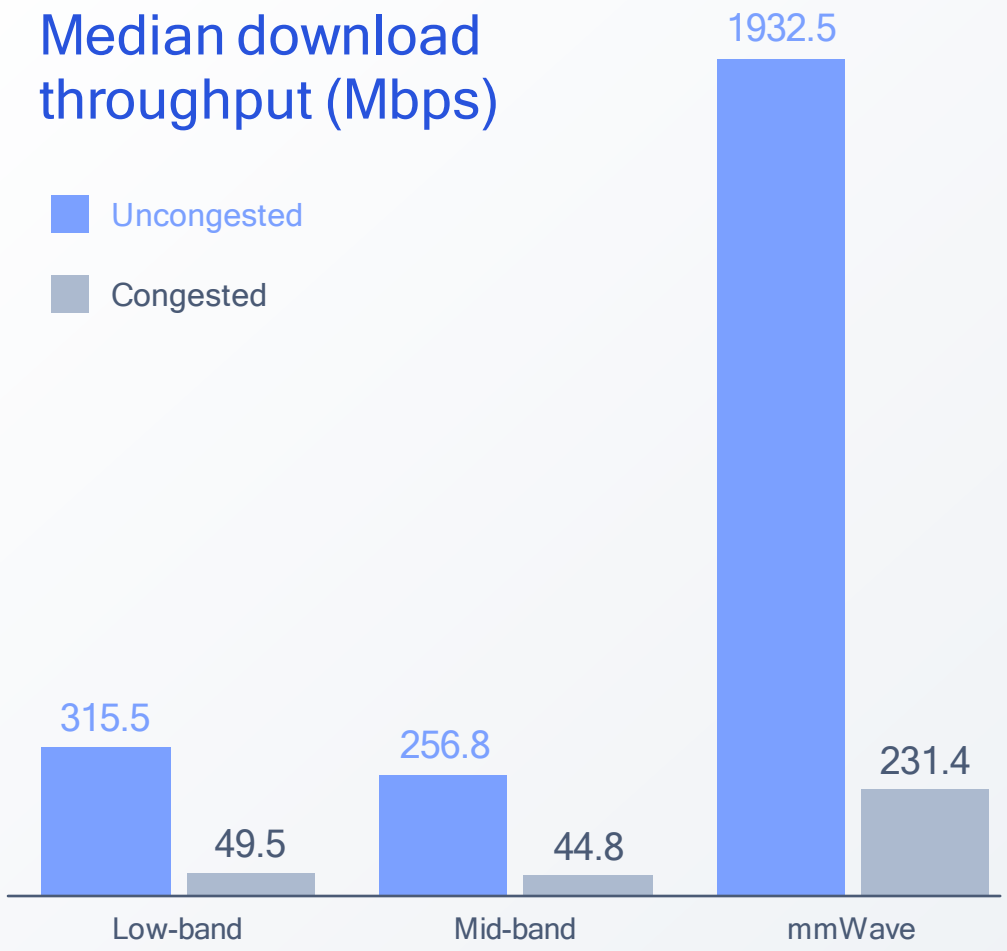
Indoor / outdoor venues
Conventions, concerts, stadiums

Industrial IoT
Factories, warehouses, logistic hubs

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

Much more capacity
With dense spatial reuse

Lower latency
Bringing new opportunities



5G mmWave serves congested areas with high-level performance

RootMetrics study shows mmWave can deliver
more uniform user experiences
even in congested network

mmWave provides
speeds 4-5x faster than those of low-band and mid-band
in congested conditions

mmWave delivers on the promise of providing
extreme capacity and blazing-fast speeds under heavy network loads

Source: https://www.rootmetrics.com/en-US/content/mmwave-cutting-through-congestion

5G mmWave did the heavy lifting at Super Bowl 57

5G mmWave carried 73% of all indoor cellular downlink traffic[1,2,3]

Ubiquitous 5G mmWave coverage in the stadium with two mmWave bands[2]

64% of all users were mmWave capable

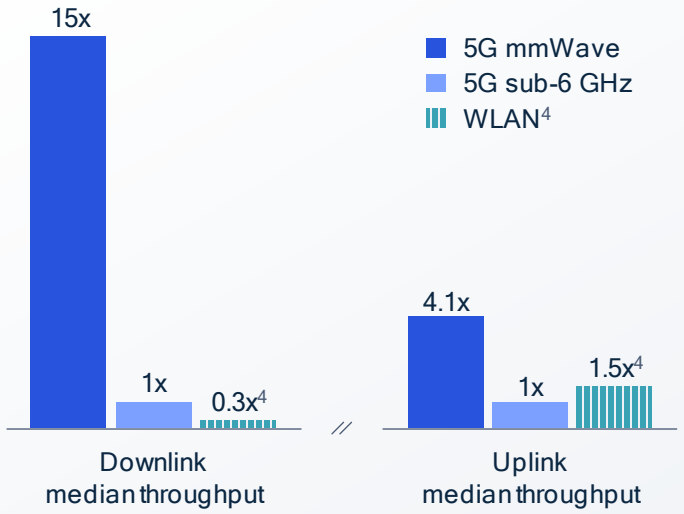
Excellent mmWave user experience

2.6 Gbps downlink average throughput per user

119 Mbps uplink average throughput per use

Excellent 5G network performance

138% more cellular traffic in the stadium compared to Super Bowl 56



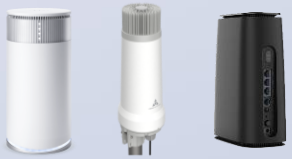
Bringing massive capacity and new experiences to venues

1. Data from the bowl seating area for 4G and 5G 2. 1600 MHz of mmWave spectrum activated (devices utilizing a maximum of 800 MHz in downlink) 3. 5G NR sub-6 GHz bands: 60 MHz in mid-band and 10MHz in low-band. LTE sub-6 GHz bands: 50 MHz with 4 DL CC CA 4. Multiple Wi-Fi locations did not have any throughput and those results are not shown here

mmWave is ready for global commercial accelerations

5G smartphones

CPEs



PCs

Modules

Hotspots & IoT

170+

5G mmWave devices launched or announced by 65+ vendors

Source: GSA, December 2022

Europe

Finland, Denmark, Italy, France. Germany, Spain, Sweden, Greece, Croatia, Slovenia, ...

Americas

United States, Canada, Brazil, Chile, Peru, Uruguay, ...

MEA

UAE, South Africa, Israel, Saudi Arabia, ...

Asia Pacific

Japan, South Korea, Taiwan, Australia, India, China, Singapore, Thailand, ...

50+

Countries assigned, planning to assign, or in ongoing consultation of 5G mmWave spectrum

Source: GSA, March 2023

ITU World Radiocommunication Conference 2023 (WRC-23)

Dubai, United Arab Emirates
20 November to 15 December 2023

Continue a spectrum pipeline ensuring the continued 5G growth across regions and enabling future 5G Advanced use cases

Key Agenda Items

1.1 – IMT in the 4.8-4.99 GHz band

Considers conditions for which the band 4800-4990 MHz could be used by terrestrial component of IMT. It addresses technical and regulatory conditions, such as power flux density (pfd) limits, which could protect aeronautical and maritime mobile services.

1.2 – IMT in the 3.5 GHz, 6 GHz, and 10-10.5 GHz bands

Considers identification of bands 3300-3400 MHz (Region 2 and amend footnote in Region 1), 3600 - 3800 MHz (Region 2), 6425-7025 MHz (Region 1), 7025-7125 MHz (globally), and 10.0-10.5 GHz (Region 2) for IMT including possible allocations to the mobile service on a primary basis.

1.3 – Mobile use of the 3.6-3.8 GHz band in Region 1

Considers possible primary allocation in Region 1 to the mobile service (except aeronautical) in the band 3600-3800 MHz.

1.5 – Consideration of sub-1 GHz spectrum in Region 1

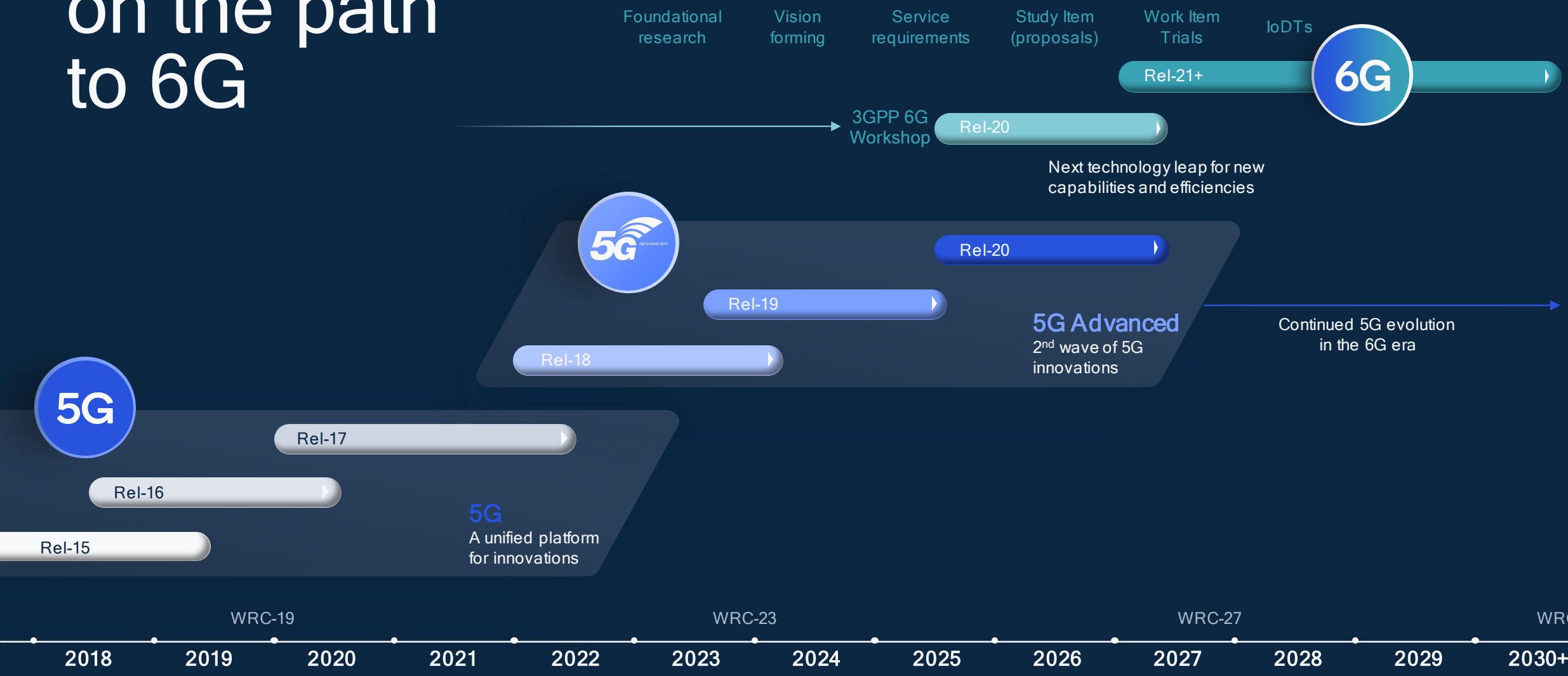
Reviews the spectrum use and needs of existing services in the band 470-960 MHz in Region 1 and considers possible regulatory actions in the band 470-694 MHz in Region 1.

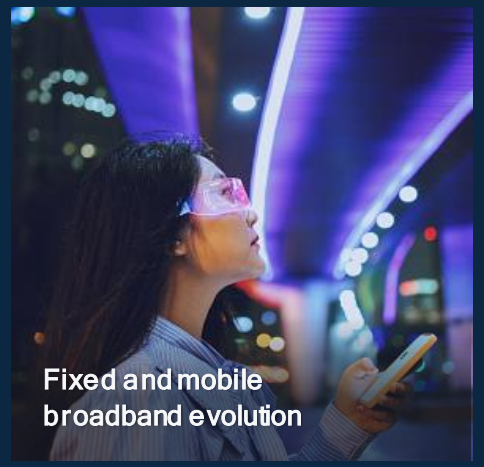
10 – Plan, support harmonization, and secure availability for new 6G coverage band

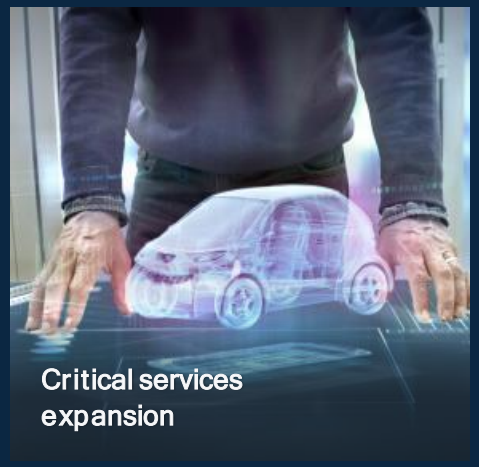
Proposing an agenda item for WRC-27 to study key upper mid-bands for 6G across all 3 regions, i.e., 7.125-15.35 GHz.

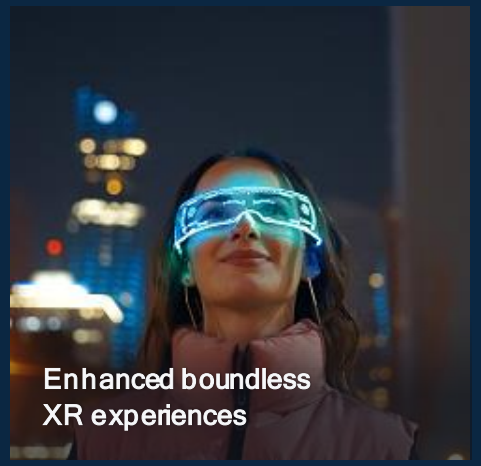
Region 1: Europe, Africa, the Commonwealth of Independent States, Mongolia, and the Middle East west of the Persian Gulf, including Iraq. Region 2: Americas including Greenland, and some of the eastern Pacific Islands. Region 3: Most of non-FSU Asia east of and including Iran, and most of Oceania.

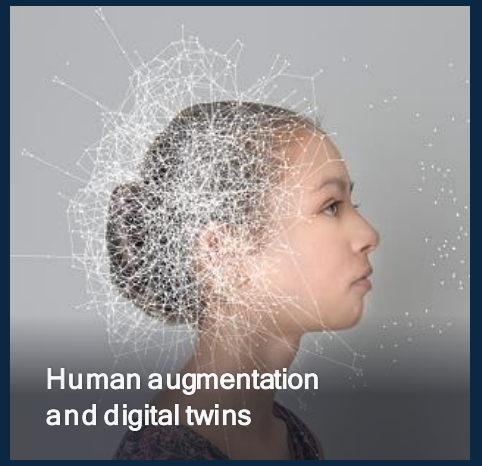
5G Advanced on the path to 6G











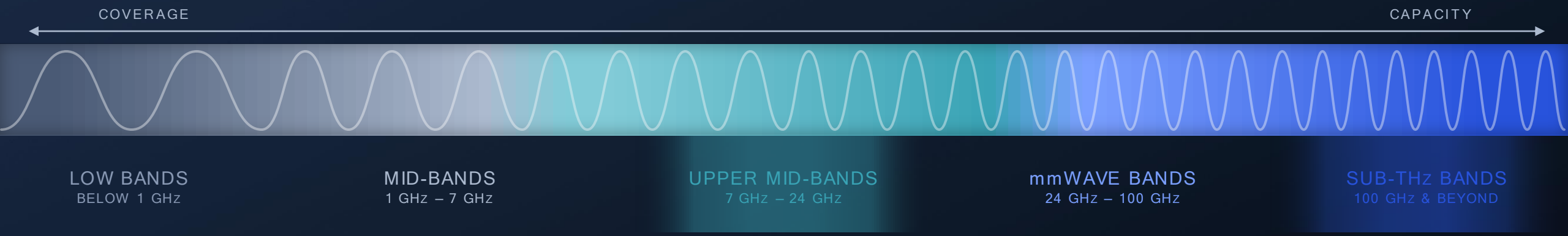
6G

Propelling next-level experiences and innovative use cases in the new era of the connected intelligent edge for 2030 and beyond

6G will need new mobile spectrum

Wide bandwidths (e.g., 500 MHz) will be key to success of next-generation wireless systems

Studies on new bands need to begin today in preparation for WRC-27 (e.g., focused on 7.1–15.3 GHz range)



LICENSED SPECTRUM

Exclusive spectrum remains mobile industry's top priority

UNLICENSED SPECTRUM

Shared use but no QoS guarantee

SHARED SPECTRUM

Evolving spectrum sharing to enable fair and more reliable shared operations

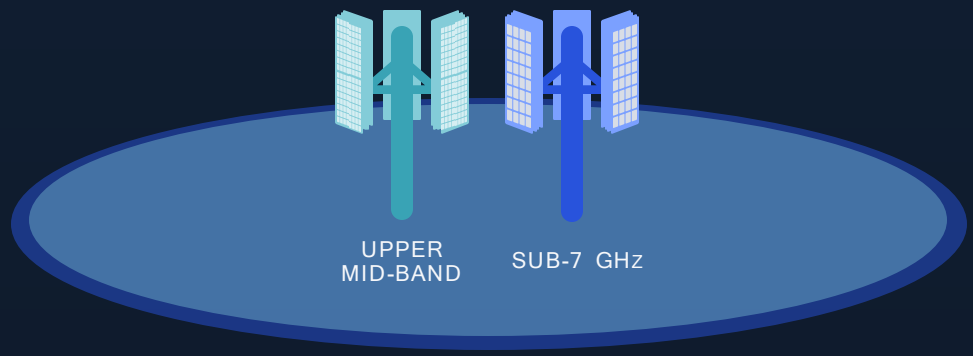
New upper mid-band brings order of magnitude more wide-area capacity

Offering larger contiguous bandwidths – targeting 500 MHz to 1 GHz licensed spectrum per operator for 2030 and beyond

Delivering new capacity for wide-area broadband (e.g., smartphones, smart cities, automotive, verticals)

Fueling scalable boundless XR user support in wide area through wider bandwidth availability

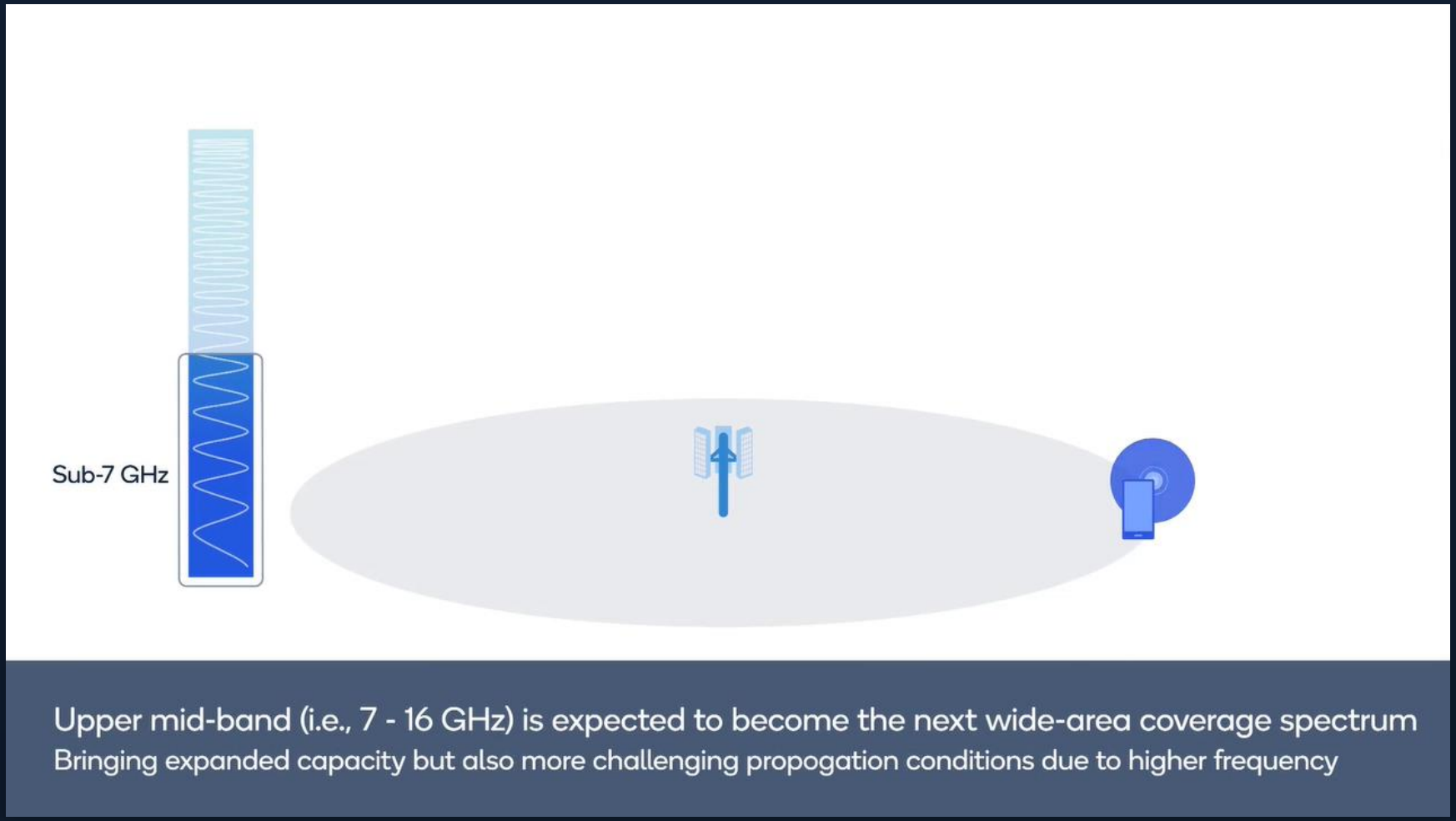
Supporting high-resolution RF sensing for new use cases (e.g., environmental monitoring, activity detection)



Opportunity to co-site with existing sub-7 GHz deployments for comparable coverage in higher band

Focusing on lower 9 GHz of the “FR3” Upper Mid-Band
i.e., 7 to 16 GHz

Wide-area coverage of sub-7 GHz with multi-Gbps capacity of mmWave



MWC’23 demonstration: Giga-MIMO in upper mid-band

Making sub-Terahertz spectrum viable for communications and beyond

Building on our mmWave experience to address key system challenges challenges at higher band spectrum

Use case feasibility

Evaluating diverse use cases, form factor requirements and how sub-THz can deliver effective solutions

System design

Building early prototypes to overcome implementation challenges (i.e., device formfactor, power consumption, etc.)

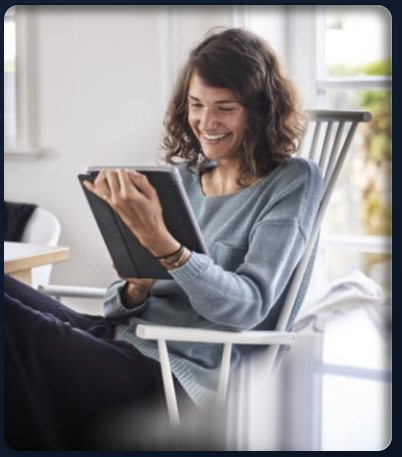
Propagation loss

Using intelligent beamforming to overcome path loss, penetration loss, foliage loss, and others

Sub-THz can unlock new and enhanced use cases

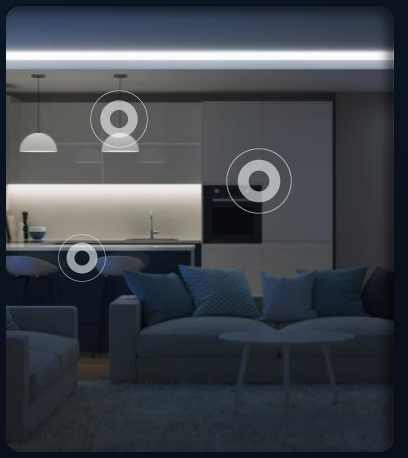
WIRELESS FRONTHAUL

WIRELESS DATA CENTER

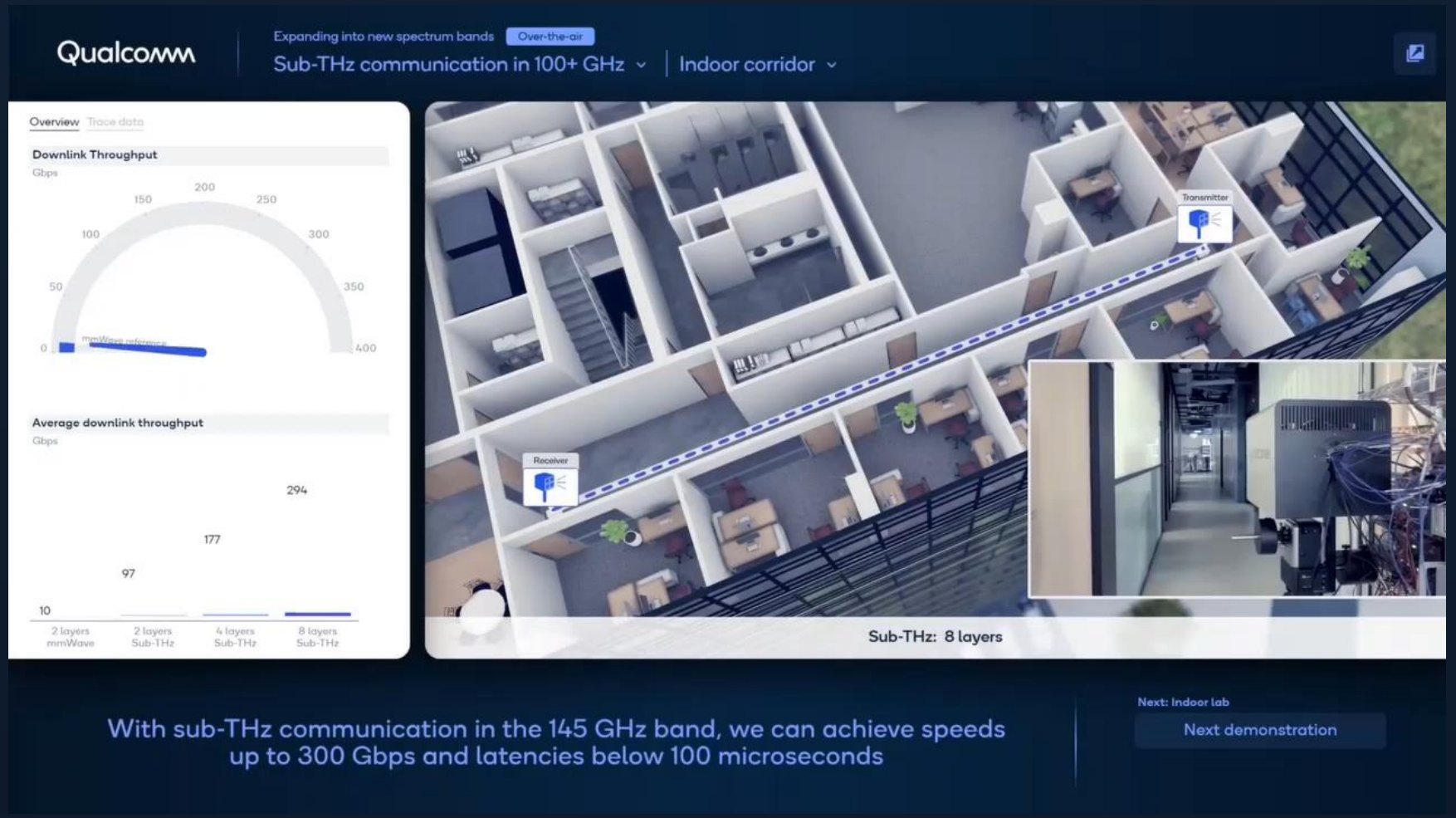


WIRELESS FIBER TO THE HOME

ULTRA-PRECISE POSITIONING



RADIO FREQUENCY SENSING



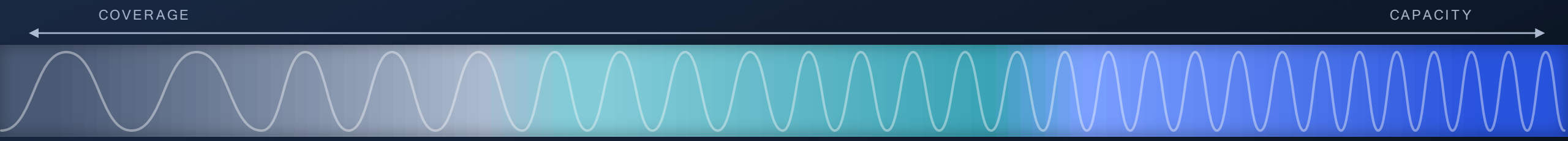
MWC’23 demonstration: Sub-THz (145 GHz) OTA testbeds

We are advancing novel spectrum sharing technologies

Realizing new levels of utilization and efficiency

Spectrum sharing can work well in all spectrum types and bands

Critical for the success of next-generation wireless systems



LOW BANDS
BELOW 1 GHz

MID-BANDS
1 GHz – 7 GHz

UPPER MID-BANDS
7 GHz – 24 GHz

mmWAVE BANDS
24 GHz – 100 GHz

SUB-THz BANDS
100 GHz & BEYOND

LICENSED SPECTRUM

Exclusive spectrum remains mobile industry's top priority

UNLICENSED SPECTRUM

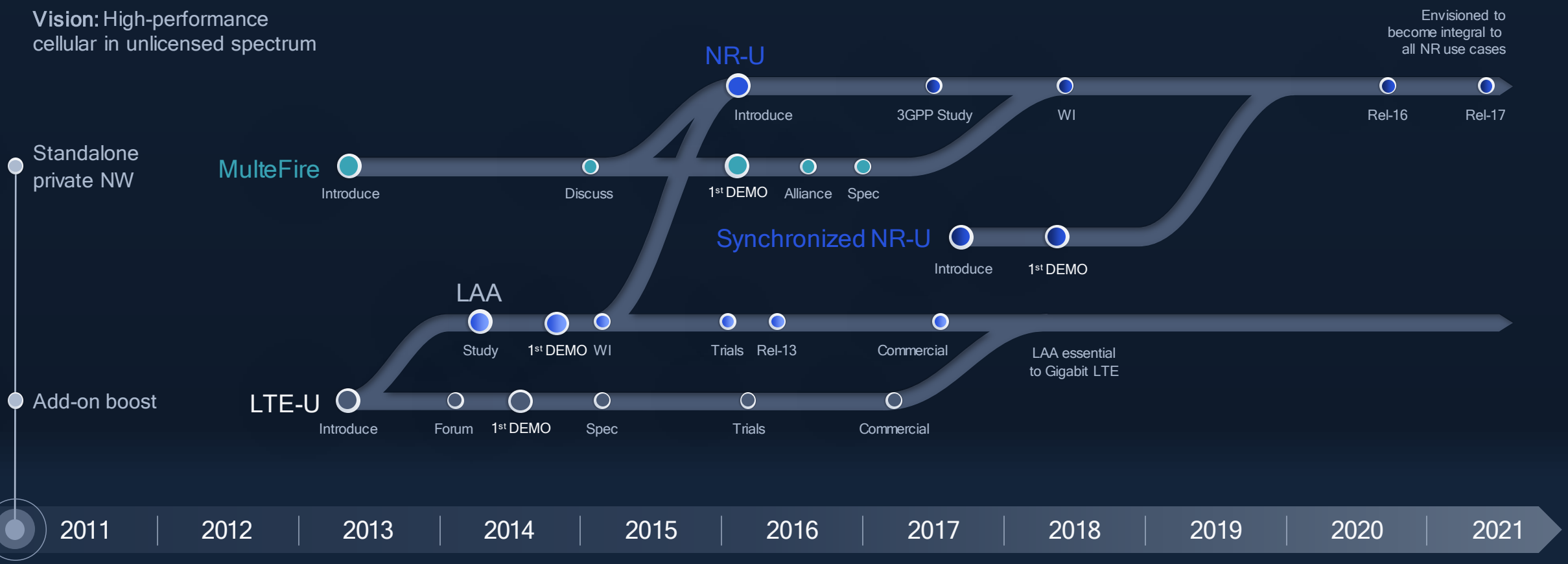
Shared use but no QoS guarantee

SHARED SPECTRUM

Evolving spectrum sharing to enable fair and more reliable shared operations

A decade of leadership in unlicensed spectrum

From LTE-U/LAA to NR-U

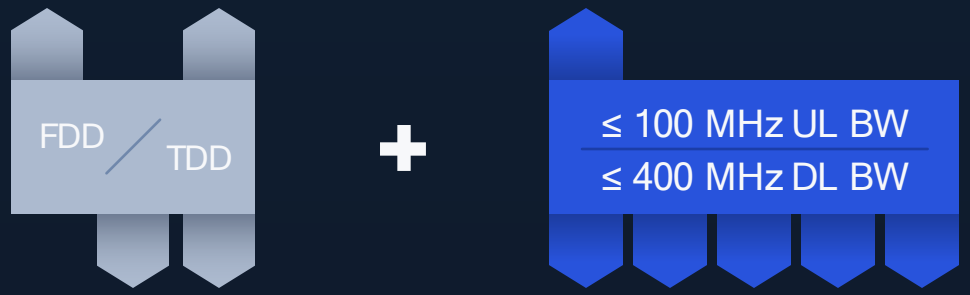


Continuous research, industry first over-the-air LAA, eLAA, MulteFire demos, co-existence with Wi-Fi

Rel-16 introduces NR in unlicensed spectrum

Anchored NR-U

Unlicensed spectrum is combined with other licensed or shared spectrum as anchor



LICENSED OR SHARED ANCHOR SPECTRUM

UNLICENSED NR-U SPECTRUM*

Standalone NR-U

Only unlicensed spectrum is used

UNLICENSED NR-U SPECTRUM*

Unlock more spectrum globally

New markets and verticals

New deployment scenarios

* Still under discussion in Rel-16

NR-U

Standardized in 5G NR Release 16:
First global cellular standard with both license-assisted and standalone use of unlicensed spectrum

< 1 GHz
Low-bands (sub-1)

1-7 GHz
Mid-bands (sub-7)

24+ GHz
High-bands (mmWave)

Unlicensed Spectrum Bands in 3GPP

- Available now
- Under study / review

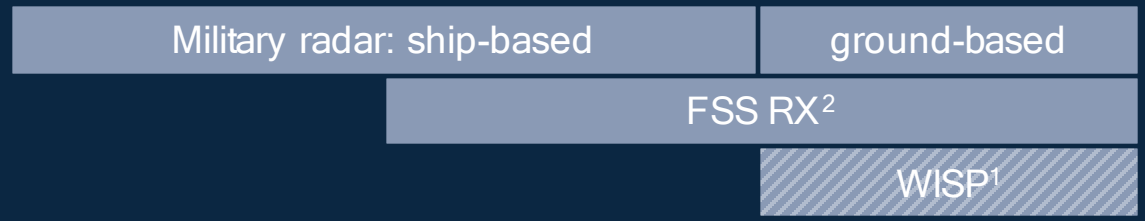
5.2-5.8 GHz		5.9-7.1 GHz	United States	57-71 GHz
5.2-5.8 GHz		5.9-7.1 GHz	Canada	57-71 GHz
5.2-5.9 GHz		5.9-6.4 GHz	European Union	57-71 GHz
5.2-5.9 GHz		5.9-6.4 GHz	United Kingdom	57-71 GHz
5.2-5.7 GHz		5.9-6.4 GHz	Germany	57-71 GHz
5.2-5.7 GHz		5.9-6.4 GHz	France	57-71 GHz
5.2-5.7 GHz		5.9-6.4 GHz	Italy	57-71 GHz
5.2-5.3; 5.7-5.8 GHz			China	59-64 GHz
5.2-5.8 GHz		5.9-7.1 GHz	South Korea	57-64 GHz
5.2-5.7 GHz		5.9-6.4 GHz	Japan	57-66 GHz
5.2-5.5; 5.7-5.9 GHz			India	
5.2-5.8 GHz		5.9-6.4 GHz	Australia	57-66 GHz

U.S. - 3.5 GHz CBRS provides a 3-tier shared spectrum paradigm

150 MHz for flexible use while protecting government incumbent systems

TIER 1

Incumbents



Incumbents are protected from interference from PAL and GAA

TIER 2

Priority Access Licenses (PAL)

PAL has priority over GAA, licensed via auction, 10 MHz blocks, up to 7 licenses

TIER 3

General Authorized Access (GAA)

GAA can use any spectrum not used, yields to PAL and incumbents

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

Evolution to licensed spectrum sharing for improved efficiency, flexibility, and user experience

Offering improved spectrum utilization and reduced spectrum cost

MNO can reuse spectrum of other MNOs when their spectrum is not in use

Building on years of 4G and 5G spectrum innovations

Unlocking new spectrum that may require non-exclusive licensing and sharing with primary users

Designing for efficient and coordinated spectrum sensing / sharing that improves overall system performance

Leveraging O-RAN architecture to allow operators to cost-efficiently offer service and preserve differentiations

(e.g., through O-RU sharing)

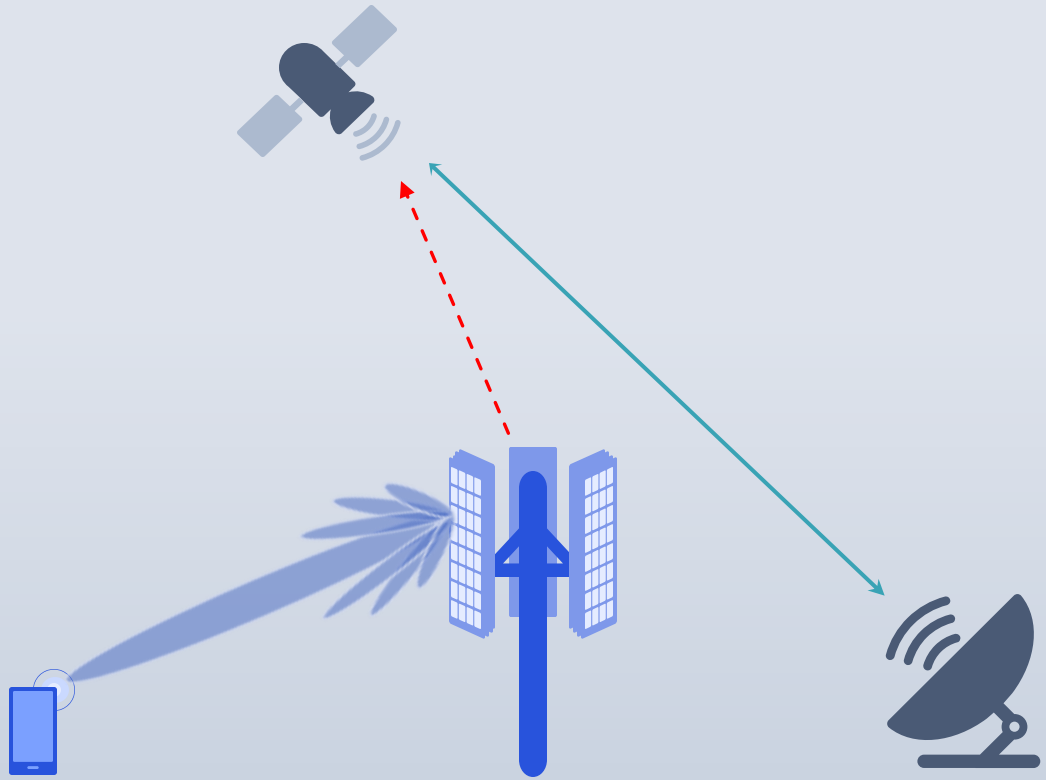
Utilizing adaptive AI/ML to address high-mobility scenario and public / private networks coexistence in the same band

Giga-MIMO improves coexistence with other systems

Compared to previous generations, we expect 6G design to account for sharing with non 3GPP systems, i.e., implementing a “sharing by design” approach

Giga-MIMO allows tight control of very narrow beams in upper midbands that in the presence of incumbent systems can lead to new and more efficient coexistence approaches

Specific sharing mechanisms will depend on the target bands and incumbent systems



Flexible new 6G air interface design with native support for spectrum sharing

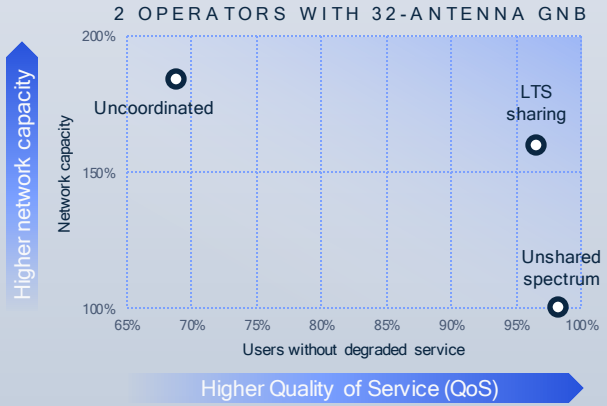
Advanced mmWave spectrum sharing

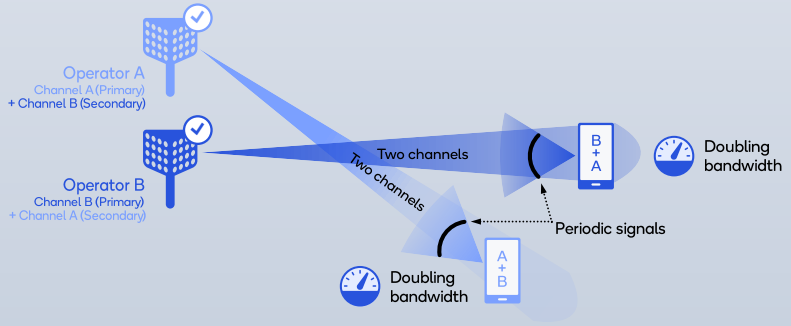
FCC Proposal for lower 37 GHz band

Driving continued mobile mmWave technology evolution

Showcasing advanced technology-neutral spectrum sharing in mmWave frequency bands

Outperforming uncoordinated spectrum sharing in quality of service



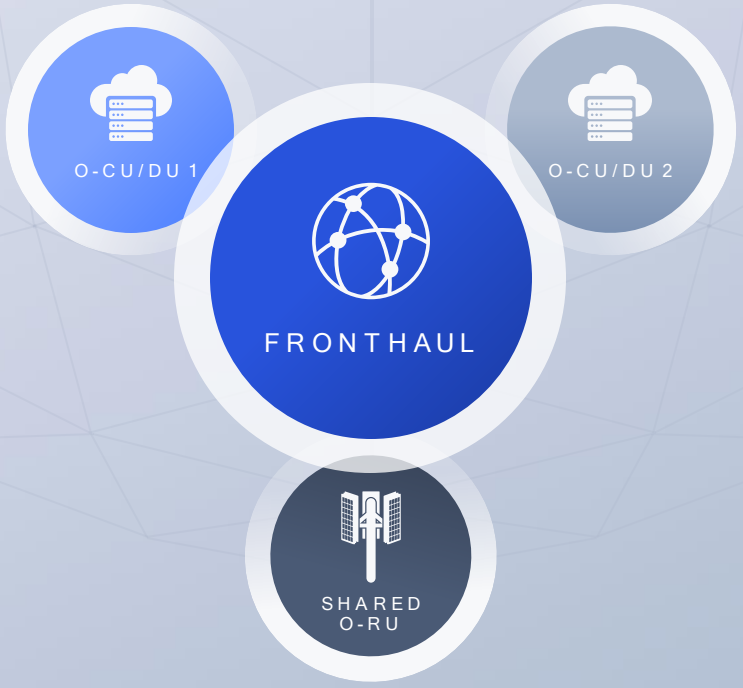


Combining the benefits of licensed and shared spectrum for higher network capacity and a better user experience

O-RAN

spectrum sharing

brings many benefits, including improved resource utilization, new deployment flexibilities, and more



Provides flexible, scalable framework for spectrum and equipment sharing while allowing service differentiation

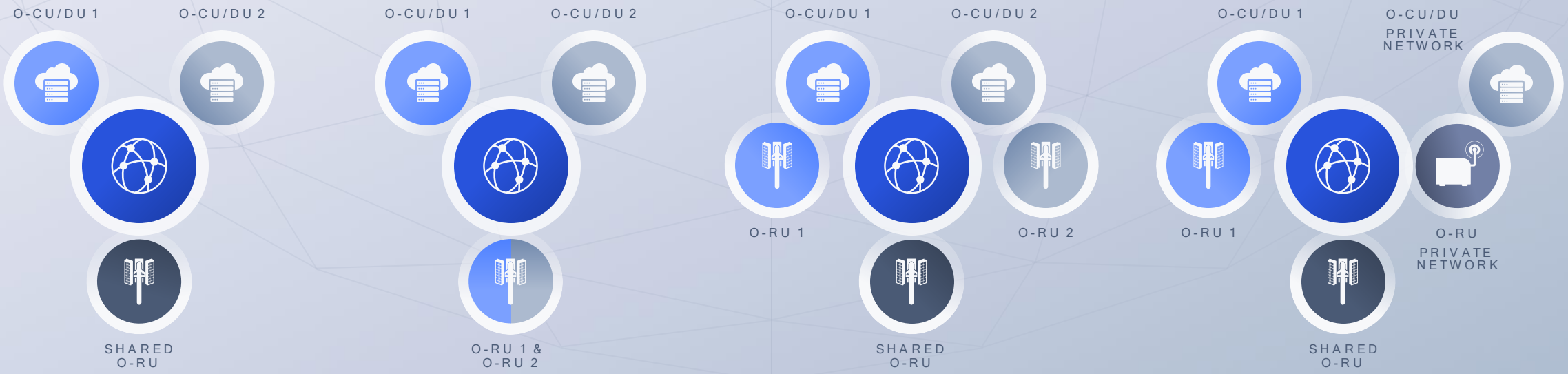
Improves spectrum utilization while supporting guaranteed QoS

Enables faster and more cost-efficient deployments

Promotes fair market competition with an open, standardized interface

Drives towards sustainability goals and closing the digital divide

O-RAN's flexible architecture offers multiple deployment possibilities



SHARED O-RU

Multiple MNOs can share O-RUs, spectrum can be owned by MNO(s) or a third party

INDIVIDUAL O-RU

MNOs can share spectrum and cell sites while still maintaining their own O-RUs

HYBRID O-RU

MNOs can share spectrum and have a mix of shared and owned O-RUs

PRIVATE NETWORK

Public MNOs and private networks share both spectrum and O-RUs

Improving access in unlicensed spectrum bands

FCC adopted Contention Based Protocol (CBP) rule for 6 GHz to provide protection to incumbent primary operations and regulate medium access

Synchronous access enables advanced spectrum utilization techniques

Supports advanced transmitter techniques, such as coordinated multi-point (CoMP)

Enables coexistence among multi-technology deployments

Coexists with asynchronous access devices

Synchronous access enables better spectral efficiency for 6 GHz unlicensed band

Global 5G

spectrum updates and innovations for future wireless systems

Global 5G deployments are well underway, using low, mid, and mmWave spectrum bands

More spectrum is needed for future wireless growth, our spectrum innovations can open new capacity

We are advancing novel spectrum sharing technologies that can realize new levels of utilization and efficiency

Thank you

Qualcomm

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