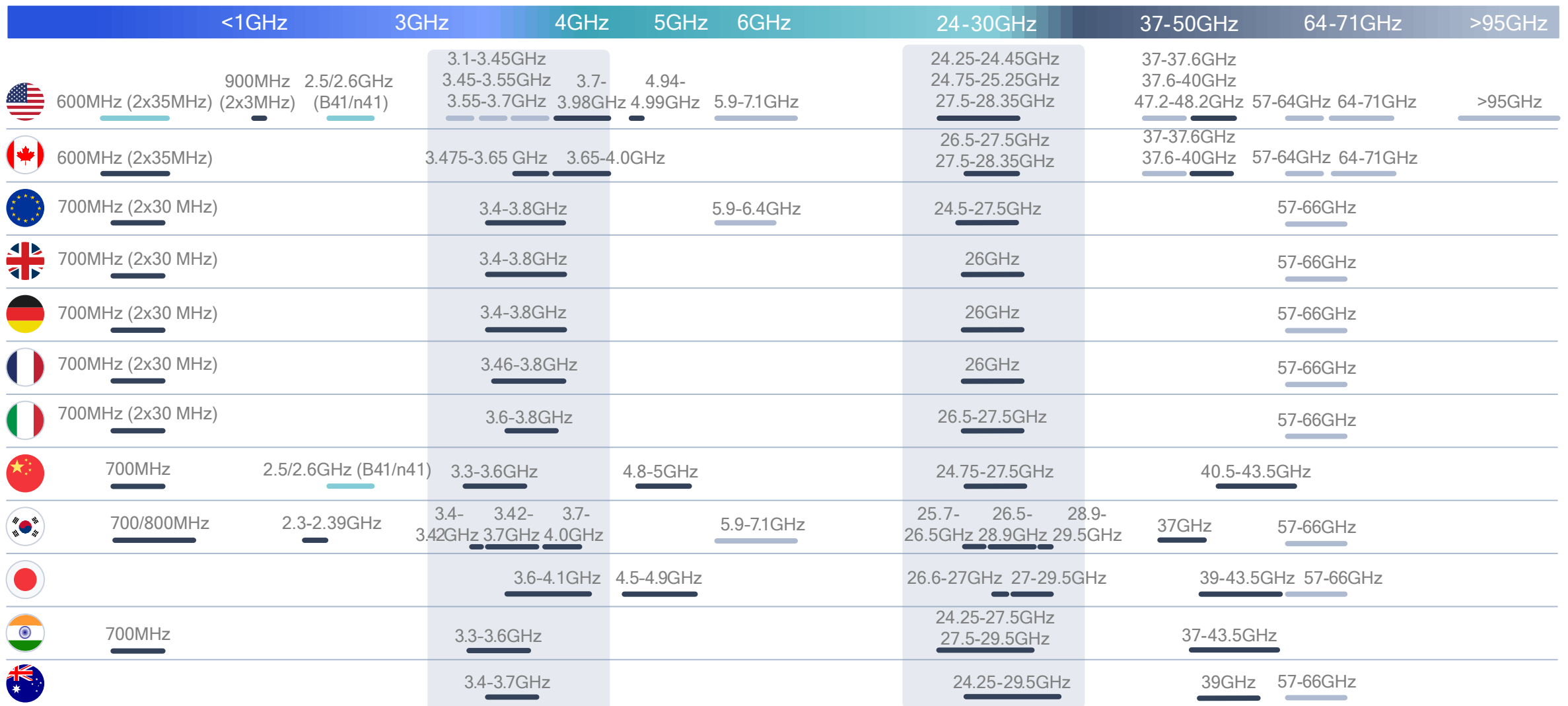


December 2020

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Qualcomm

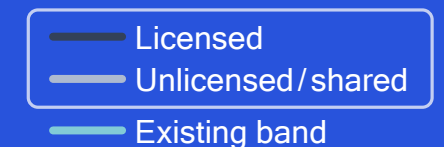
Global update on spectrum for 4G & 5G



Global snapshot of allocated/targeted 5G spectrum

5G is being designed for diverse spectrum types/bands

New 5G band



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

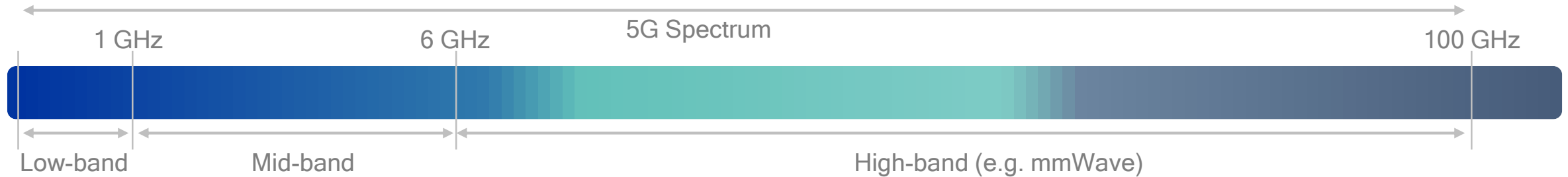
— Available now
— Under study / review

Frequency Band	Availability	Region	Frequency Band	Availability
5.2-5.8 GHz	Available now	United States	57-71GHz	Under study / review
5.2-5.8 GHz	Available now	Canada	57-71GHz	Under study / review
5.2-5.9 GHz	Under study / review	European Union	57-71GHz	Under study / review
5.2-5.9 GHz	Available now	United Kingdom	57-71GHz	Under study / review
5.2-5.7 GHz	Available now	Germany	57-71GHz	Under study / review
5.2-5.7 GHz	Available now	France	57-71GHz	Under study / review
5.2-5.7 GHz	Available now	Italy	57-71GHz	Under study / review
5.2-5.3; 5.7-5.8 GHz	Under study / review	China	59-64GHz	Under study / review
5.2-5.8 GHz	Available now	South Korea	57-64GHz	Under study / review
5.2-5.7 GHz	Available now	Japan	57-66GHz	Under study / review
5.2-5.5; 5.7-5.9 GHz	Under study / review	India		
5.2-5.8 GHz	Available now	Australia	57-66GHz	Under study / review



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 completed in March 2017

- 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
- FCC allocated 2 x 3 MHz in 900 MHz for broadband, principally for utilities
- Spectrum availability timing aligns with 5G

Mid-band

CBRS¹, 3.4-3.5 GHz, 3.7-3.98 GHz, 4.94-4.99 GHz

- Opened 150 MHz in 3.5 GHz band with 3-tier sharing with incumbents, PAL², GAA³
- In Sep 2019, FCC approved initial GAA deployments and in Sep. 2020, FCC completed PAL auction
- In Mar 2020, FCC allocated 3.7-4.0 GHz. Auction scheduled for Dec. 2020
- In Sep 2020, FCC adopted NPRM for 3.45-3.55 GHz and for 4.94-4.99 GHz. Auction of 3.45-3.55 GHz targeted for Dec 2021
- NTIA and FCC are studying repurposing of 3.1-3.45 GHz for commercial use

High-band

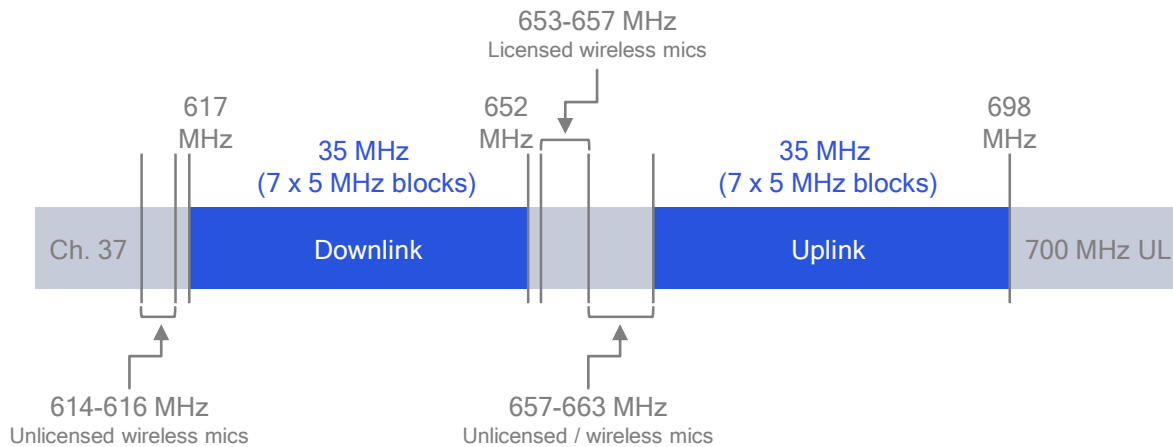
FCC has completed 3 mmWave auctions, including most recently the largest auction in history

- In 2016, FCC allocated 10.85 GHz in multiple mmWave bands⁴, 70% of newly opened spectrum is shared or unlicensed
- In Nov 2017, FCC adopted second order allocating 24.25-24.45, 24.75-25.25 GHz, and 47.2-48.2 GHz
- In Jun 2018, FCC proposed making 25.25-27.5 and 42-42.5 GHz for flexible wireless use
- FCC has held auctions in 28 & 24 GHz bands
- In Mar 2020, FCC has completed the auction for upper 37, 39, & 47 GHz bands
- FCC is considering rules for 70/80/90 GHz, and FCC has opened spectrum above 95 GHz

¹ Citizen Broadband Radio Services; ² Priority Access Licenses to be auctioned; ³ General Authorized Access; ⁴ 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 LTE initially deployed in areas already clear of TV stations and is now being used for 5G



600 MHz Spectrum

Meeting 5G timeline

Completed auction in March 2017; process of clearing the spectrum & repacking TV stations to end in 39 months. Process is on track.

Greater capacity and wider coverage

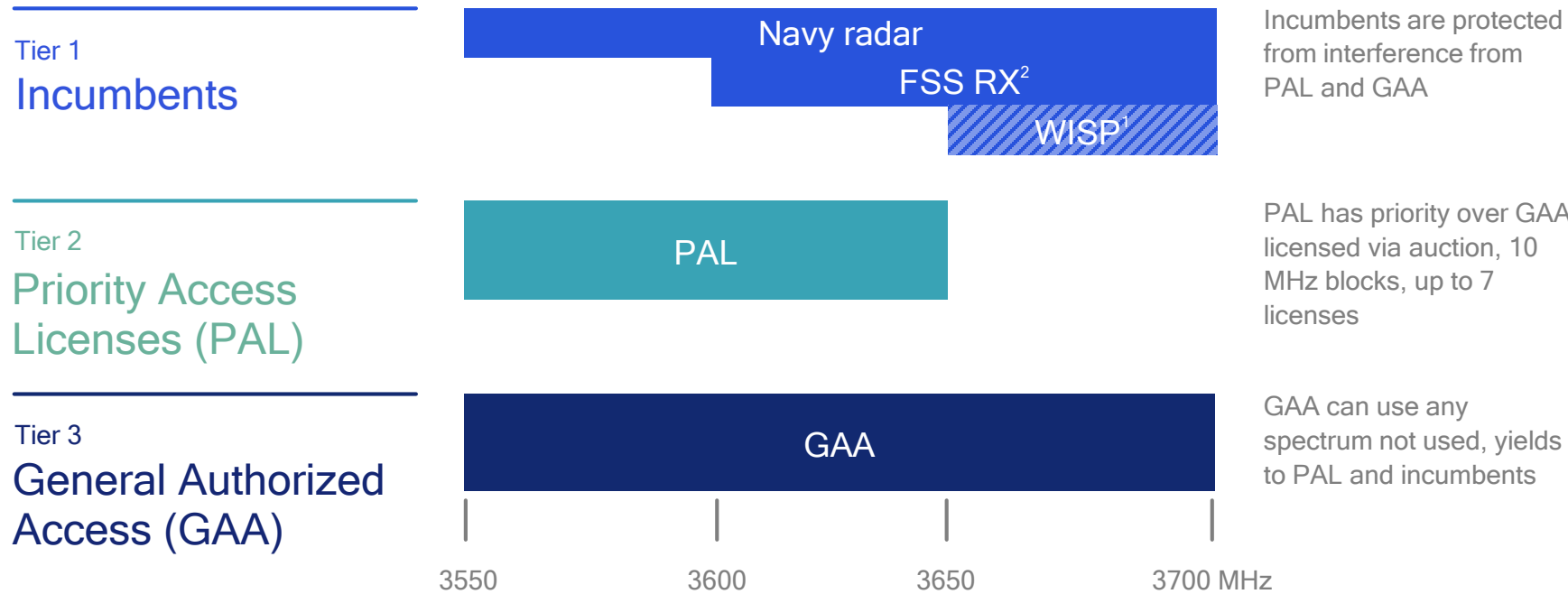
Low-band spectrum is optimized for long-range macro deployments - optimal for connecting the wide-area IoT and more

Broad industry support

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



Mid-band: CBRS in use and FCC about to begin C-Band auction



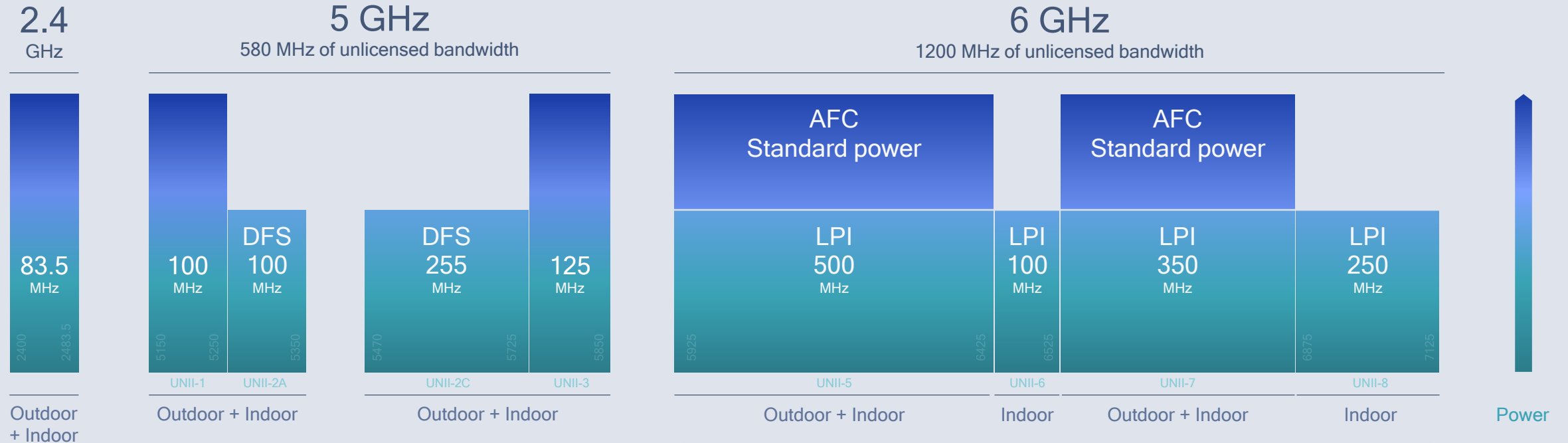
FCC optimized rules in October 2018, allowed initial GAA deployments in September 2019, and PAL auction completed in August 2020

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

FCC to start C-Band auction (3700-3980 MHz – 280 MHz) in December 2020, 100 MHz to be clear by December 2021 and 180 MHz to be clear by December 2023

6 GHz brings new unlicensed bandwidth for Wi-Fi and 5G

Standardized for 5G NR-U in the United States



1200 MHz  

A massive amount of new unlicensed spectrum is now available in the U.S. for Wi-Fi 6E and 5G



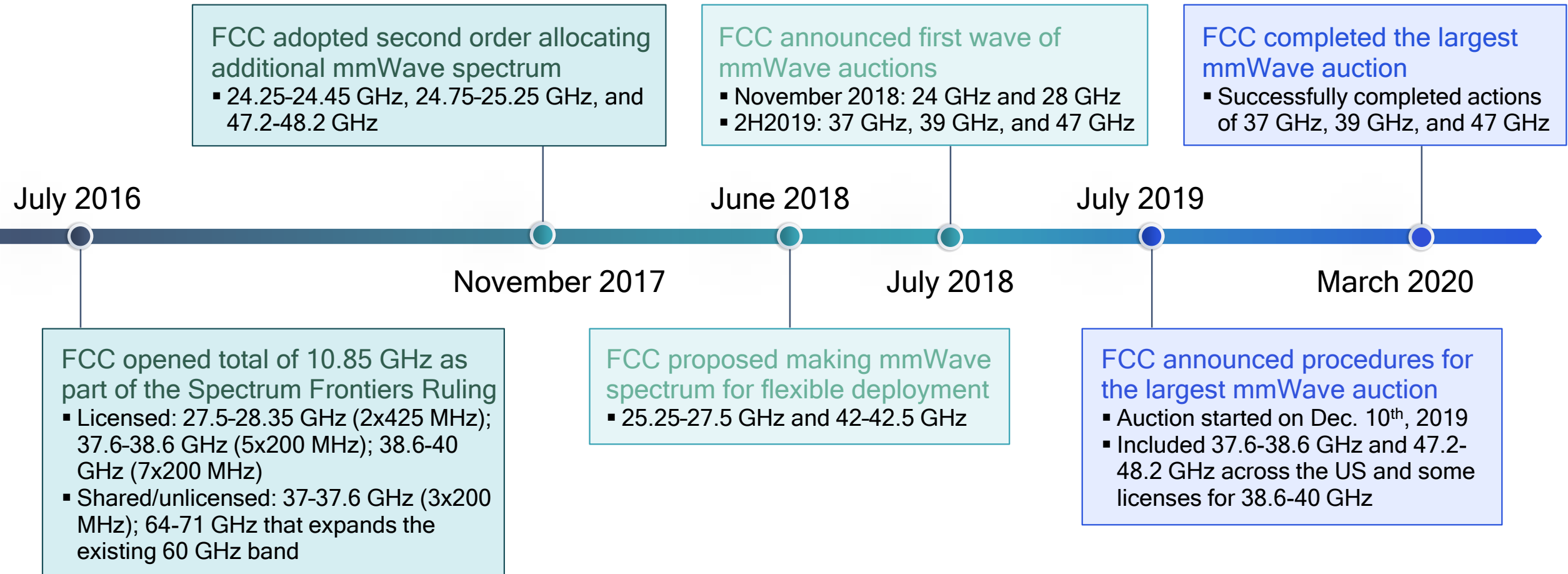
Technologies that will power
the future of connectivity

Multi-gigabit Throughput
Ultra Low Latency
Massive Capacity





High-band: FCC rapidly bringing mmWave spectrum to market





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: 700 MHz, mid: 3.4-3.8 GHz, high: 24.25-27.5 GHz)

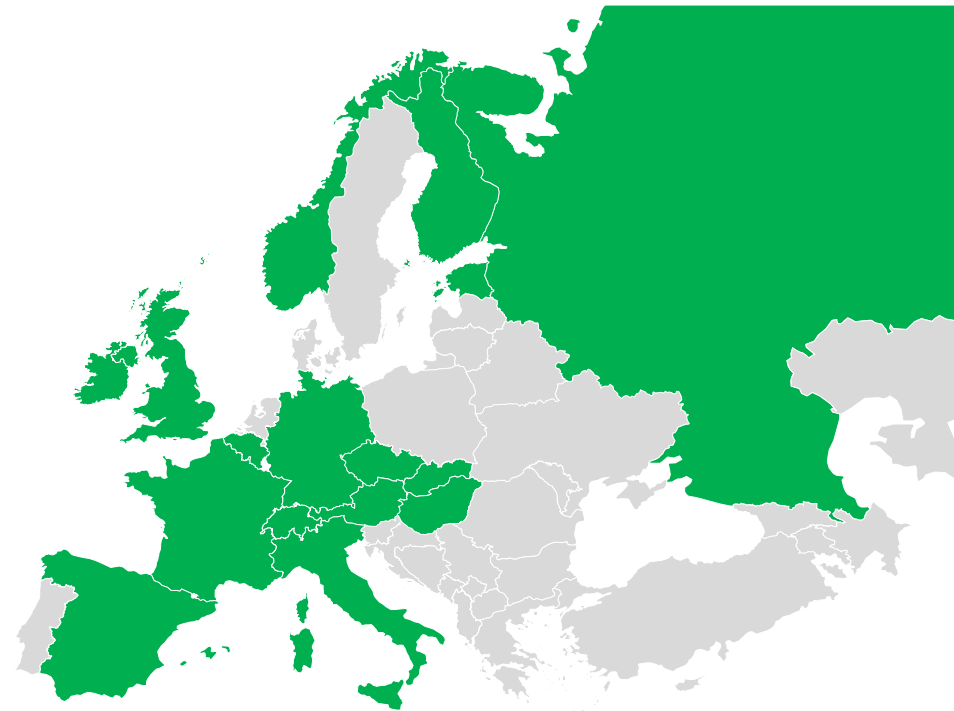
- EC Mandate to CEPT focusing on 3.5 GHz and 26 GHz pioneering bands – completed in 2018
- Additional EC Mandate to CEPT on extended L band (1427 - 1518 MHz) – completed in 2018
- CEPT harmonization of the 26 GHz band ahead of WRC-19 – completed in June 2018
- EC working on binding decision for EU Member States – completed in Q1 2019
- 5G commercial services to use both 3.4-3.8 GHz and 26 GHz in Europe – targeting 2020


Full set of 5G spectrum bands and implementation measures


- EC mandate to CEPT on the development of harmonized technical conditions suitable for 5G in the 900 MHz, 1.8 GHz, 2.6 GHz, and the paired terrestrial 2 GHz frequency bands – completed in 1H 2019
- RSPG² working on how to defragment 3.4-3.8 GHz band and on the impact of the future use of 5G in areas other than MBB³

5G spectrum status dashboard in Europe


Commercial targets focusing on 3.4-3.8 GHz and/or 26 GHz




 U.K.	Status
3.4 - 3.6 GHz (150 MHz)	Auctioned
3.6 - 3.8 GHz (120 MHz)	Q1 2021
3.8 - 4.2 GHz	Q4 2019 - Local
24.25 - 26.5 GHz	Q4 2019 - Local
24.25 - 27.5 GHz	2021


 Italy	Status
3.6 - 3.8 GHz	Auctioned
26.5 - 27.5 GHz	Auctioned - Club Use


 France	Status
3.46 - 3.8 GHz	Q4 2020
26 GHz	2021


 Spain	Status
3.6-3.8 GHz	Auctioned
26.5 - 27.5 GHz	2021


 Switzerland	Status
3.4 - 3.8 GHz	Auctioned
26.5 - 27.5 GHz	2022


 Germany	Status
3.4 - 3.7 GHz	Auctioned
3.7 - 3.8 GHz	Q4 2019 - Local
26 GHz	Q4 2020


 Russia	Status
26 GHz	Auctioned


 Greece	Status
3.4 - 3.8 GHz	Q4 2020
26.5 - 27.5 GHz	Q4 2020

 Sweden	Status
3.4 - 3.8 GHz	Q4 2020
26 GHz	2021

 Finland	Status
• 3.4 - 3.8 GHz	Auctioned
• 26 GHz	Auctioned

 Romania	Status
3.6-3.8 GHz	Q4 2020
26.5 - 27.5 GHz	2021

 Hungary	Status
3.6 - 3.8 GHz	Auctioned
26 GHz	2021

 Czech republic	Status
3.6 - 3.8 GHz	2020

 Ireland	Status
3.4 - 3.8 GHz	Auctioned

5G spectrum auctions in Europe – 700 MHz band



Awarded or ongoing auction

- Band awarded in 12 European countries: Austria, Germany, Hungary, Switzerland, France, Finland, Italy, Luxembourg, Sweden, Netherlands, Norway and Denmark



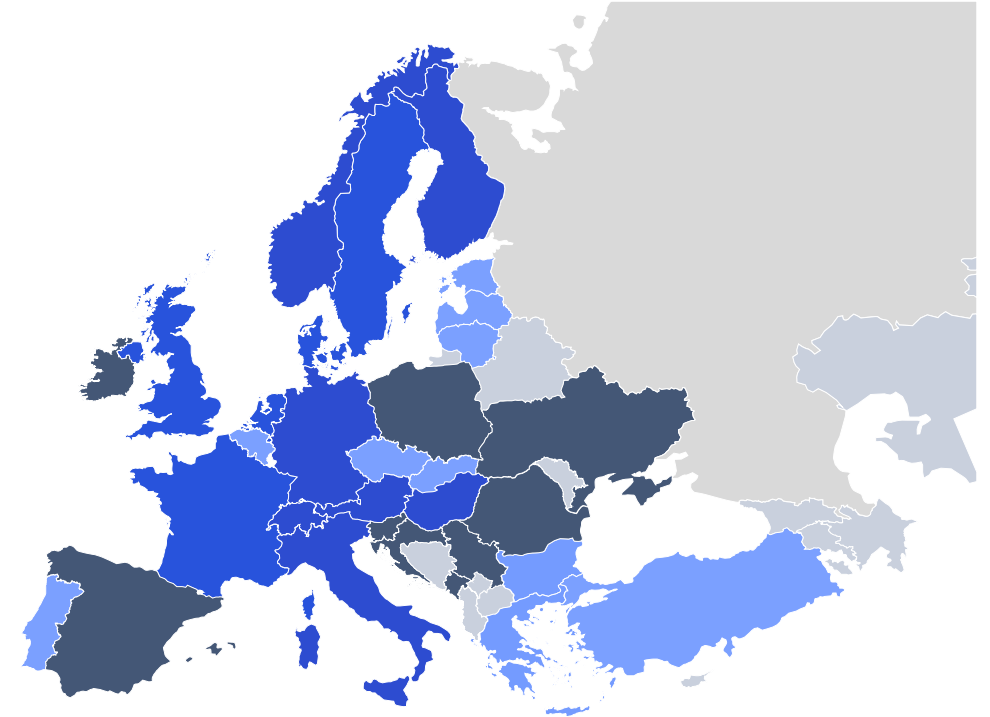
Expected to be awarded in 2020

- Additional 9 countries expected to award spectrum in 2020: Belgium, Bulgaria, Czechia, Estonia, Greece, Latvia, Lithuania, Slovakia and Turkey
- Latvia and Lithuania might have some spectrum restrictions until 2022



Expected to be awarded in 2021

- Additional 9 countries to award spectrum in 2021: Ireland, Poland, Spain, Slovenia, Croatia, Montenegro, Romania, Serbia, Ukraine



5G spectrum auctions in Europe – 3.4 to 3.8 GHz band



Awarded or ongoing auction

- Spectrum awarded in 17 European countries: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Luxembourg, Norway, Slovakia, Switzerland, Spain, Romania and UK



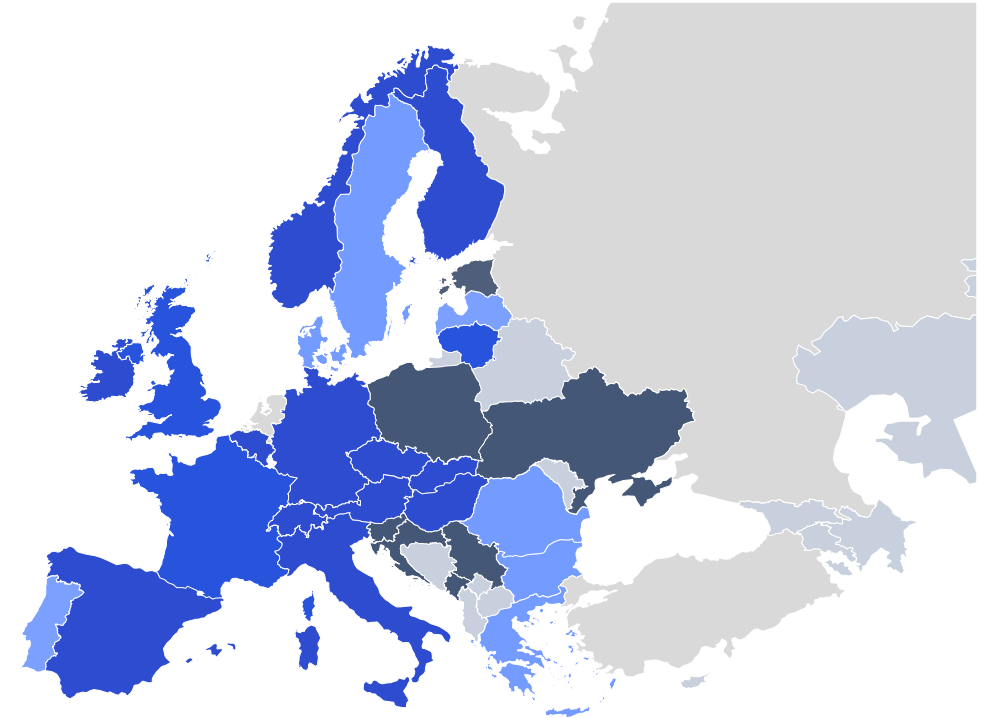
Expected to be awarded in 2020

- Additional 6 countries expected to award spectrum in 2020: Bulgaria, Denmark, Greece, Lithuania, Portugal, Sweden



Expected to be awarded in 2021

- Additional 6 countries expected to award spectrum in 2021: Poland, Montenegro, Croatia, Slovenia, Serbia, Ukraine



5G spectrum auctions in Europe – 26 GHz band

● Auctioned or to be awarded on market demand

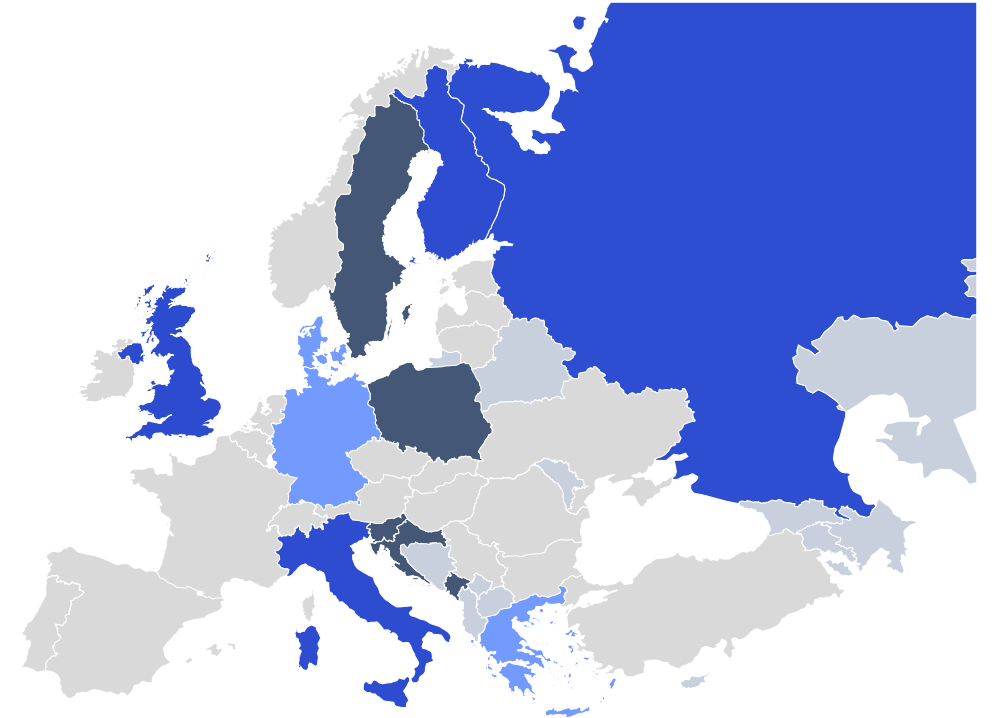
- Italy, Finland and Russia have awarded 26 GHz
- UK has made available based on market demand and indoor only, 24.5 - 26.5 GHz – the whole 26 GHz band expected in 2021

● Expected to be awarded in 2020

- Germany, Greece and Denmark are expected to award the band in 2020

● Expected to be awarded in 2021

- Slovenia, Sweden, Croatia, Montenegro, Poland expected to award the band in 2021



5G spectrum status in China, South Korea, and Japan

China



- MIIT officially allocated 700MHz (703-733/758-788MHz), 3.3-3.6 GHz & 4.8-5.0 GHz as 5G bands; in addition, 2.6 GHz (Band n41) has been allowed for both 4G & 5G deployments
- Chinese government approved 5G technology R&D trial frequencies usage in 24.75-27.5 GHz & 37-42.5 GHz mmWave ranges in Jul'17
- Chinese government supported global IMT identification in 5925-7125MHz, 24.75-27.5GHz, 40.5-43.5GHz and 66-71GHz frequency ranges in WRC19

South Korea



- MSIT has successfully completed 5G spectrum auction in June 2018 for both sub-7 and mmWave, including 3.42-3.7 GHz and 26.5-28.9 GHz
- The world first commercial 5G smartphone for sub-7 was launched in Apr'19. mmWave was commercially launched for smart factory in Jul'20
- Achieved over 7.9 million 5G subscribers as of Jul'20
- MSIT plans to allocate additional 5G spectrum in 2022-2023

Japan



- In Apr'19, MIC assigned new 5G spectrum, 3.6-4.2 GHz, 4.4-4.9 GHz and 27-29.5 GHz, to four operators
- All existing 4G spectrum bands, 700 MHz, 850 MHz, 900 MHz, 1.5 GHz, 1.8 GHz, 2.1 GHz (FDD), 2.5 GHz and 3.5 GHz (TDD) are available for 5G NR deployment
- Technical rules for private network bands in 2575-2595 GHz (NSA anchor) and 28.2-28.3 GHz have also been regulated. Additional private network bands in 1.9 GHz (NSA anchor), 4.6-4.9 GHz and 28.3-29.1 GHz will be regulated in Q4'20
- Technical rules for additional licensed spectrum (4.9-5 GHz, 26.6-27 GHz, 39.5-43.5 GHz) will be studied by 2021
- As per WRC-19 outcome, 7025-7125 MHz study will also be conducted

5G spectrum status in Oceania, South East Asia, and India

Australia



- 3.4-3.7 GHz allocated and 5G has been commercially deployed
- 3.7 - 4.2 GHz under consultation for 5G, FS, FSS deployment
- 26 GHz: spectrum allocation for 5G scheduled for March 2021
- 26/28 GHz: apparatus licenses for local 5G + FWA to start 1Q21

New Zealand



- 3.5 GHz: 3400-3590 MHz and 3590 - 3800 MHz access until 2022, longer term access to be provided prior to 2022
- mmWave 26/28 GHz under consideration

Hong Kong



- 3.3, 3.5, 4.8 GHz: 5G Spectrum allocated
- 26/28 GHz: 3 operators awarded 400 MHz each, with 400 MHz reserved for local licensing
- 5G commercially deployed from April 2020
- Additional 4.9 GHz spectrum under consultation

Taiwan



- 3.3, 3.5 GHz: 5G spectrum allocated
- 27.9 - 29.5 GHz: 5G spectrum allocated (27.0 - 27.9 GHz held for future allocation)
- 5G commercially deployed from July 2020
- 4.9 GHz spectrum planned for localized networks

Singapore



- 3.5 GHz: 5G spectrum allocated for 2 networks
- 800 MHz of mmWave allocated to 4 operators
- 5G deployed

Malaysia



- Government plan to allocate 3.5 GHz and 26/28 GHz spectrum in 3Q20 deferred to 1H21
- Operators have conducted 5G trials

Thailand



- 2.5 GHz TDD spectrum allocated for 2 networks
- 26 GHz spectrum allocated to 4 operators
- 28 GHz spectrum being considered
- 5G commercially deployed

Indonesia



- All operators conducted 5G trials in 28 GHz
- Government plans to conduct trial in 3.5 GHz
- Government announced that it will consult on 5G policy and sub 6 GHz, 26 GHz and finalize policy in 2020.

Philippines



- 3.5 GHz band assigned
- 5G deployed commercially in Manila
- mmWave spectrum under consideration by Government

Vietnam



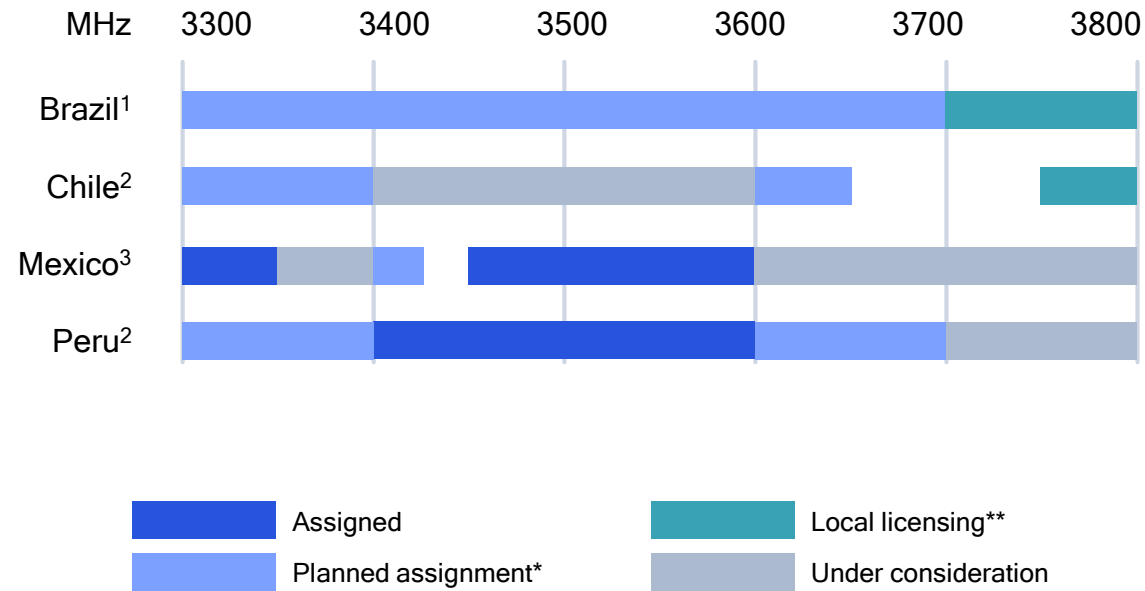
- Government has announced timeframe for planned commercialization in 2020
- 3.8 GHz and 4.8 GHz bands are under consultation
- 26/28 GHz in ongoing consultation process
- 5G trials underway by all 3 mobile network operators

India

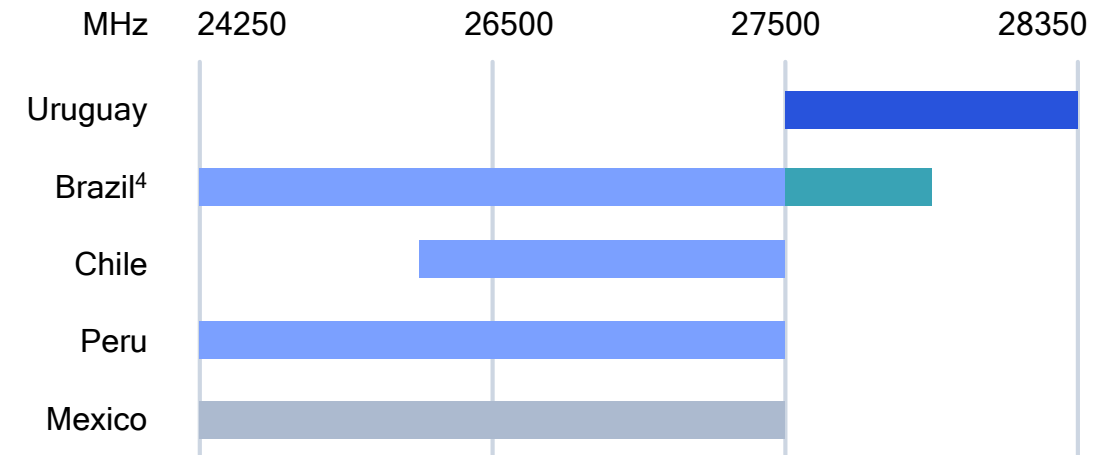


- High Level Forum submitted 5G recommendation in Aug'18
- 617-698 MHz in planning; 698-803 MHz auction in Q4'20
- 3.3-3.6 GHz and 24.25-27.5 GHz auction expected in Q3'21
- 24.25-27.5 GHz, 27.5-29.5 GHz preferred mmWave bands – two years free for trials; also looking at 37-43.5 GHz

3.5 GHz



26/28 GHz



* Nationwide or regional licenses for MNO's public networks

** Spectrum set aside for individual licensing on a local basis for 5G private networks

1 Set aside for individual licensing on a local basis for 5G private networks in the 3.7-3.8 GHz range under consultation

2 Spectrum re-farming desired

3 In Mexico, 3.3-3.35 GHz is assigned to the government (SCT). 3.3-3.4 GHz can be used for both mobile and fixed applications. 3.4-3.425 GHz is identified for FWA and to be auctioned in 2H21. 3.45-3.6 GHz range is assigned for FWA only

4 Brazil reserved the frequency range 27500-27900 MHz for private networks

5G update in LATAM



Brazil has auction of 3.3-3.7 GHz & 26 GHz planned for Q1 2021



Mexico is evaluating 3.3-3.3 GHz, 3.6-3.8 GHz, 26 GHz for 5G



Uruguay has very small 5G fixed/mobile deployments



Peru will carry out public consultation of 3.5 GHz and 26 GHz bands by end of 2020, and auction is expected to start in first semester of 2021



















Chile started the auction process, expecting licenses should be granted to operators by mid-2021 (3.3-3.4 GHz, 3.6-3.65 GHz, 25.9-27.5 GHz)



Dominican Republic is targeting to be the 2nd country in LATAM to auction 5G spectrum, which is planned for Jan. 2021



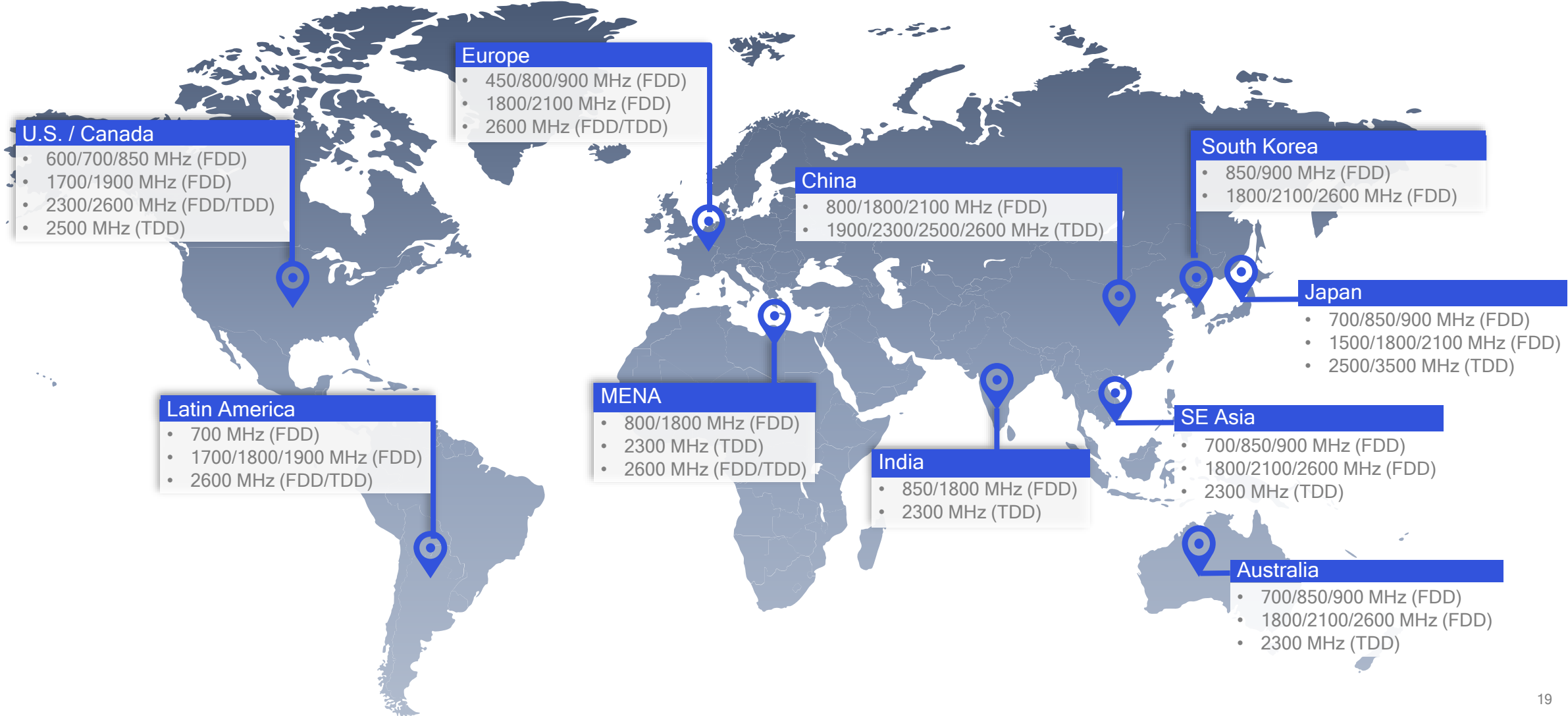
Colombia is still under consultation process. Spectrum allocation is being planned in 2021 for 700 MHz, 1.9 GHz, 2.5 GHz, and 3.5 GHz band

<p>USA</p> 	<ul style="list-style-type: none"> • 3.5 GHz CBRS, exclusive & shared licenses, deployments in 2H19 • 37 - 37.6 GHz shared spectrum/local licenses, under evaluation 	<p>Brazil</p> 	<ul style="list-style-type: none"> • 3.7 - 3.8 GHz, under consideration • 27.5 - 27.9 GHz, allocation completed
<p>Germany</p> 	<ul style="list-style-type: none"> • 3.7 - 3.8 GHz • 24.25 - 27.5 GHz, local licenses, expected Q4 2020 • Local licenses. Assignment complete; available 2H 2019 	<p>Chile</p> 	<ul style="list-style-type: none"> • 3.75 - 3.8 GHz, allocation completed at end of 2019
<p>U.K.</p> 	<ul style="list-style-type: none"> • 3.8 - 4.2 GHz • 24.25 - 26.5 GHz, local licenses, applications open since end of 2019 • Local licenses (50 meters square); regulator database; decision formalized; applications invited from end 2019 	<p>Australia</p> 	<ul style="list-style-type: none"> • 24.25 - 27.5 GHz and 27.5 - 29.5 GHz for local licensing in 1Q21 • 3.7 - 4.2 GHz under consultation for local licensing
<p>Sweden</p> 	<ul style="list-style-type: none"> • 3.72 - 3.8 GHz, in consultations 	<p>New Zealand</p> 	<ul style="list-style-type: none"> • Licenses in 2575 - 2620 MHz may be assigned for localized use
<p>Finland</p> 	<ul style="list-style-type: none"> • Sub-licensing of 3.4 - 3.8 GHz • Local permission via operator lease; assignment complete 	<p>Malaysia</p> 	<ul style="list-style-type: none"> • 26.5 - 28.1 GHz will be assigned for the deployment of local/private networks
<p>Netherlands</p> 	<ul style="list-style-type: none"> • 3.5 GHz for local industrial use; 3.7 - 3.8 GHz (in consultations); 2.3 - 2.4 GHz (licensed shared access online booking system) • 3.5 GHz for local industrial use; however users may need to move to 3.7 - 3.8 GHz, if allocated; 2.3 GHz approved for PMSE 	<p>Singapore</p> 	<ul style="list-style-type: none"> • Each operator has acquired 800 MHz of 26/28 GHz spectrum to deploy local networks
<p>France</p> 	<ul style="list-style-type: none"> • 2.6 GHz, regulator database & approval. Up to 40 MHz approved for Professional Mobile Radio 	<p>Hong Kong</p> 	<ul style="list-style-type: none"> • 24.25 - 28.35 (400 MHz) available for local licenses
<p>Czech Republic</p> 	<ul style="list-style-type: none"> • 3.4 - 3.44 GHz for private networks 	<p>Japan</p> 	<ul style="list-style-type: none"> • Phase 1: 2,575 - 2,595 MHz (NSA anchor) and 28.2 - 28.3 GHz; local licenses, legislated in December 2019 • Phase 2: 1888.5 - 1916.6 MHz (NSA anchor), 4.6 - 4.9 GHz (4.6 - 4.8 GHz indoor only, 4.8 - 4.9 GHz outdoor possible) & 28.3 - 29.1 GHz (150 MHz outdoor use; total 250 MHz range 28.2 - 28.45 MHz); local license. Legislation in 4Q20. Uplink heavy TDD config. using semi-sync is allowed in sub-6 & 28 GHz

Global snapshot of spectrum optimized for industrial IoT / vertical / private network use – local licensing or sharing




Global 4G LTE spectrum landscape

Over 1,000 band combinations now supported for LTE





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