Before the
U.S. DEPARTMENT OF COMMERCE
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
Washington, DC 20230

In the Matter of	)	
	)	
Development of a National Spectrum Strategy	)	Docket No. NTIA-2023-0003
	)	

COMMENTS OF CTIA

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CTIA[1] submits the following response to the Request for Comment ("RFC") issued by the National Information and Telecommunications Administration ("NTIA") on a National Spectrum Strategy.[2]

I. INTRODUCTION AND SUMMARY.

In 2010, just as the U.S. was launching the 4G revolution, President Obama issued a Memorandum directing the federal government to identify more commercial spectrum to unleash the wireless broadband revolution. It recognized that "America's future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum."[3] That leadership helped steer the repurposing of spectrum bands for full-power commercial wireless licensed use, resulting in massive U.S. private sector investment and innovation in 4G,

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[1] CTIA – The Wireless Association® ("CTIA") (www.ctia.org) represents the U.S. wireless communications industry and the companies throughout the mobile ecosystem that enable Americans to lead a 21st century connected life. The association's members include wireless carriers, device manufacturers, suppliers as well as apps and content companies. CTIA vigorously advocates at all levels of government for policies that foster continued wireless innovation and investment. The association also coordinates the industry's voluntary best practices, hosts educational events that promote the wireless industry and co-produces the industry's leading wireless tradeshow. CTIA was founded in 1984 and is based in Washington, D.C.

[2] Development of a National Spectrum Strategy, 88 Fed. Reg. 16244 (Mar. 16, 2023) ("RFC").

[3] The White House, *Presidential Memorandum: Unleashing the Wireless Broadband Revolution* (June 28, 2010) https://obamawhitehouse.archives.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution.

the launch of the app and sharing economy here in the U.S., millions of jobs, expansion of the U.S. GDP, and a decade of U.S. technological dominance on the global stage.[4]

The U.S. 5G story so far is one of impressive investment, deployment, and usage. 5G is being deployed nearly twice as fast as 4G, with 5G networks today covering more than 315 million Americans. The wide availability of 5G is the result of record-breaking investment—more than $35 billion in 2021 alone. In this, we lead the world: U.S. wireless investment accounted for 19 percent of the world's total mobile capital expenditures even though the U.S. has just four percent of the world's population. And while technological improvements have allowed wireless providers to do more with the spectrum they have, the industry's ability to innovate and lead is dependent on a reliable and known pipeline of new spectrum, on certainty of usage rights, and on deployment of cutting-edge networks at scale.

The challenge we face today is there are exponentially growing data demands, yet no additional spectrum bands in queue for commercial wireless use, especially in key mid-band spectrum between 3.1-8.4 GHz, and the statutory authority for the Federal Communications Commission ("FCC") to issue spectrum licenses by auction has lapsed. As a nation, our ability to lead the global wireless ecosystem—increasingly important to our economic interests and national security—starts with a sound spectrum strategy.

Continued American leadership in wireless is no sure thing. The U.S. is experiencing a deficit in full-power commercial licensed spectrum when compared to 5G allocations in other leading nations. And here in the U.S., federal agencies hold 12 times more mid-band spectrum than wireless licensees; unlicensed and shared use comprises seven times more mid-band

[4] *See The 4G Decade: Quantifying the Benefits*, Recon Analytics (2020) https://api.ctia.org/wp-content/uploads/2020/07/The-4G-Decade.pdf ("Recon Analytics 4G Decade Report").

spectrum than is available for licensed use. The licensed spectrum shortfall is expected to expand absent swift action to make additional licensed airwaves available for commercial use. According to the Brattle Group, the U.S. could face a spectrum deficit of 400 megahertz by 2027, and this deficit will have more than tripled to over 1,400 megahertz by 2032.[5]

Today, as the Biden-Harris Administration pursues a National Spectrum Strategy, the stakes are even higher than they were back in 2010:

1. Expanding access for commercial, full-power licensed spectrum use not only fuels millions of jobs, adds trillions to the U.S. economy, and enables U.S.-led innovation, but it is vital to maintaining U.S. global leadership in wireless, even as our adversaries seek to leverage their spectrum gains into technological advantage.

2. Absent U.S. leadership in the global spectrum ecosystem, we are at risk that China and other adversaries will disproportionately shape—and benefit from—global 5G developments, 6G, and technologies of the future.

3. A U.S. presence in future bands for 5G and beyond is a basic and necessary precursor to U.S. leadership in standards development and a supply chain of trusted vendors. At the World Radiocommunication Conference 2023 ("WRC-23"), China is supporting all five proposals for expanded or future 5G bands, and the U.S. government is currently supportive of only one.

Administration leadership is more important than ever in driving a spectrum strategy so that U.S. commercial wireless interests prevail in global spectrum debates and the wireless ecosystem writ large. The solution is to identify additional spectrum—mid-band spectrum, in particular—for either exclusive-use licensing or, if sharing is necessary, pre-defined sharing that provides the assured access and interference protection essential for network deployments at scale.

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[5] *See* Coleman Bazelon and Paroma Sanyal, *How Much Licensed Spectrum is Needed to Meet Future Demands for Network Capacity?*, The Brattle Group, at 3-4, 24 (Apr. 17, 2023) ("Brattle Group April 2023 Report"), https://www.ctia.org/news/how-much-licensed-spectrum-is-needed-to-meet-future-demands-for-network-capacity (attached as an appendix to this filing).

CTIA calls on NTIA to take the following steps as it develops the National Spectrum Strategy:

- Replenish the spectrum pipeline in the short- to medium-term by identifying and scheduling auctions for at least 1,500 megahertz of mid-band spectrum for licensed, full-power commercial wireless use, including in the Lower 3 GHz band (3.1-3.45 GHz), the Mid 4 GHz band (4.4-4.94 GHz), and the 7/8 GHz band (7.125-8.4 GHz);

- Embrace global band ranges identified for 5G to advance U.S. national security and economic interests;

- Adopt the RFC's definition of "Spectrum Sharing";

- Examine spectrum utilization and the efficiency of incumbent operations in candidate bands;

- Ensure the Spectrum Relocation Fund ("SRF") meets agencies' needs; and

- Recognize NTIA's role as the voice of the Executive Branch on federal spectrum and affirm the FCC's and NTIA's authority to adjudicate spectrum matters.

With these steps, the United States can make significant progress in advancing a National Spectrum Strategy that meets the needs of the nation for years to come.

II. THE UNITED STATES IS FACING A STEEP DEFICIT IN FULL-POWER COMMERCIAL WIRELESS LICENSED MID-BAND SPECTRUM.

A. U.S. Data Demands are Increasing at an Exponential Rate (Response to RFC Pillar #1, Questions 1, 2).

U.S. mobile data traffic expanded almost a hundredfold over the 4G decade, but low- and mid-band spectrum availability has increased by only about two times since 2012.[6] And in 2021, wireless providers carried more data than they did in 2010 through 2017 combined.[7] That trend

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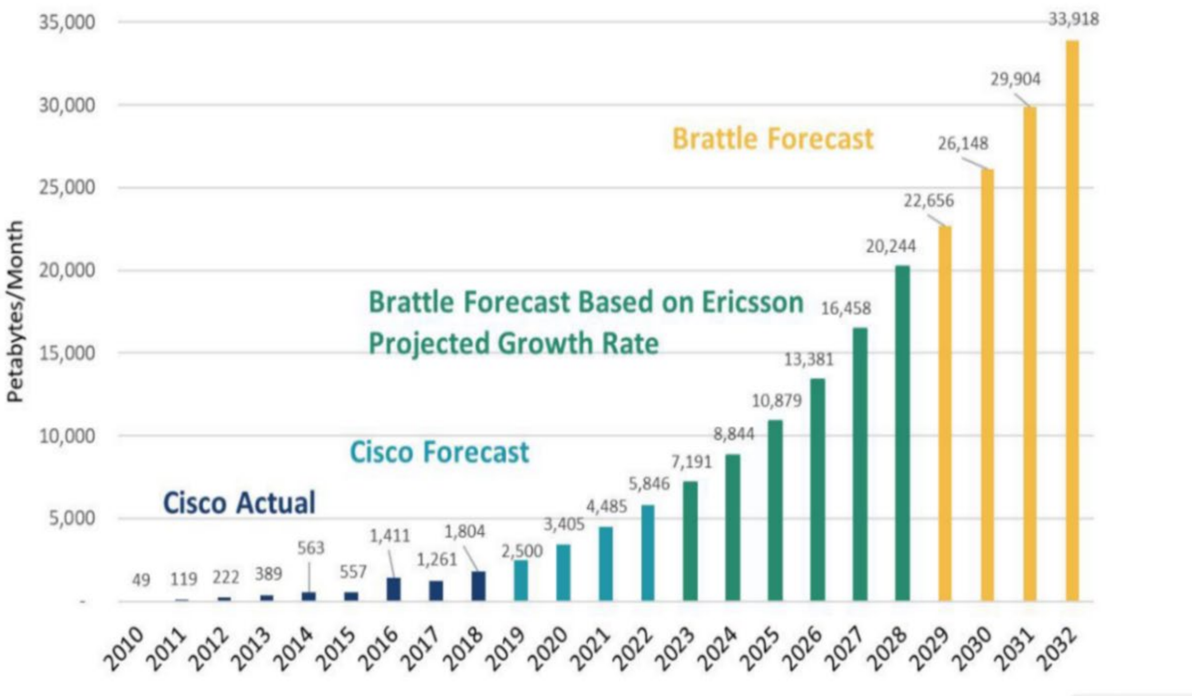
[6] *See* Val Elbert, et al., *Accelerating the 5G Economy in the US*, Boston Consulting Group, at 6 (Apr. 2023), https://www.bcg.com/publications/2023/accelerating-the-5g-economy-in-the-us ("BCG April 2023 Report") (attached as an appendix to this filing).

[7] CTIA, *2022 Annual Survey Highlights*, at 4 (Sep. 13, 2022), https://www.ctia.org/news/2022-annual-survey-highlights ("CTIA 2022 Annual Survey Highlights").

is expected to continue. By some estimates, North American mobile data traffic could grow nearly four-fold by 2028,[8] and potentially six-fold in the next ten years.[9]

North America Wireless Data Demand, 2010-2032



Source: Brattle Group April 2023 Report at 9, Figure 1.

Existing licensed spectrum allocations are not sufficient to meet this surging demand. In a new study, the Brattle Group projects that the U.S. could face a deficit of approximately 400 megahertz of mid-band spectrum by 2027—a deficit that could more than triple to 1,423 megahertz by 2032.[10] Others have made similar estimates, with Ericsson projecting a 1,500 to

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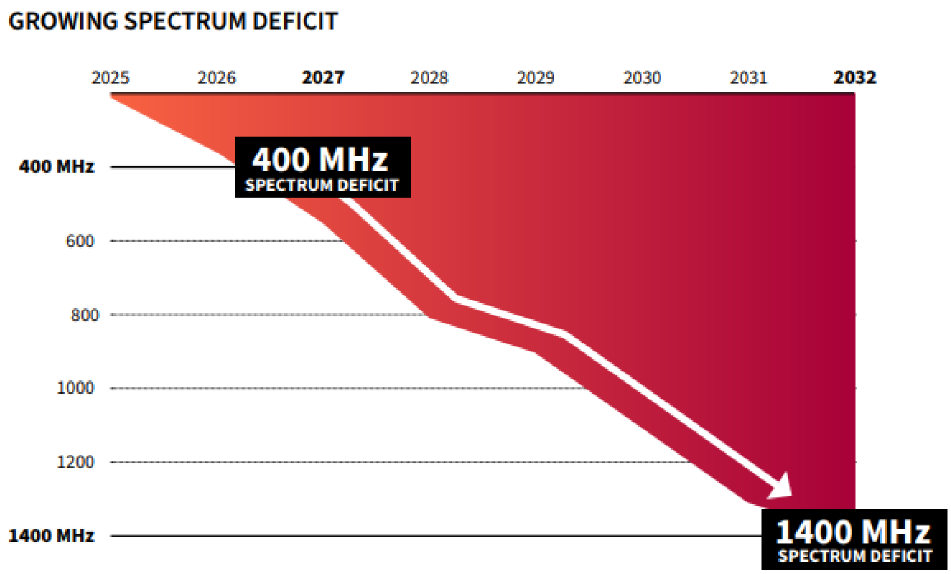
[8] Ericsson, *Ericsson Mobility Report*, at 39 (Nov. 2022), https://www.ericsson.com/4ae28d/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-november-2022.pdf. Ericsson also projects average monthly data usage per smartphone in North America is expected to grow from 17 GB in 2022 to 55 GB in 2028—the highest level anywhere in the world. *See id.*

[9] *See* Brattle Group April 2023 Report at 7-9.

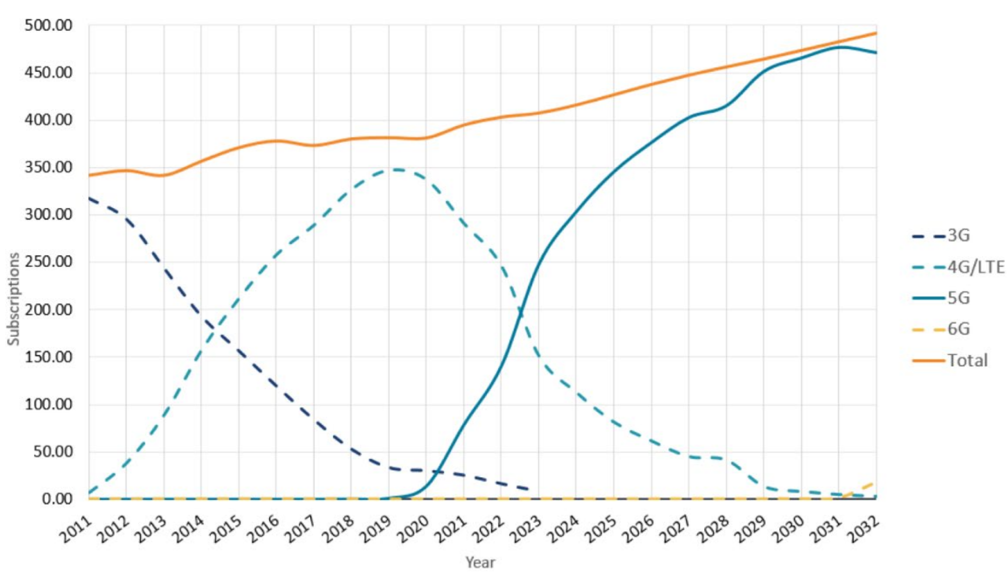
[10] *Id*. at 3-4, 24.

2,200 megahertz deficit in the availability of licensed, wide-area commercial spectrum by 2030.[11]



This deficit poses a significant threat to the ability of our nation's wireless networks to support the next phase of 5G deployments and further generations of use.

Subscriber Count by Technology



Source: Brattle Group April 2023 Report at 11, Figure 2.

[11] *See* Ericsson, *6G spectrum – enabling the future mobile life beyond 2030*, at 10 (Feb. 2023), https://www.ericsson.com/4953b8/assets/local/reports-papers/white-papers/6g-spectrum.pdf.

The dramatic increases in data traffic demands cannot be met through network efficiencies alone. When spectrum is a costly input, operators invest in technologies that squeeze more bytes out of every megahertz available. In fact, wireless service provider networks grew 42 times more efficient in their spectrum use over the 4G decade.[12] 5G technologies will further increase spectral efficiency by a factor of 52 percent in the mid-band range,[13] and wireless providers engage in "re-farming" existing bands to the extent possible, replacing older generations of wireless technologies with cutting-edge networks like 5G. Yet, while technological improvements have allowed wireless providers to do more with the spectrum they have, spectrum efficiency improvements are reaching their theoretical limit.[14] Moreover, Wi-Fi offloading is not expected to see significant increases to countervail the increasing demands on licensed wireless networks given the prevalence of unlimited wireless data plans and other changes that have reduced consumer incentives to leverage unlicensed access.[15]

As the Boston Consulting Group highlights, a shortage of licensed spectrum could "lead to congestion issues for existing mobile services, impeding companies' ability to scale [fixed wireless access] or other data-intensive applications, and discouraging innovators from taking full advantage of 5G's potential."[16] This is particularly detrimental to Americans living in rural areas, where fixed wireless services "appear[] to be the primary home broadband of choice,"

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[12] CTIA, *Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum*, at 3 (July 9, 2019), https://www.ctia.org/news/smarter-and-more-efficient-how-americas-wireless-industry-maximizes-its-spectrum.

[13] *Id*. at 7.

[14] *See* Brattle Group April 2023 Report at 20, n.53 (discussing Shannon's Law, which "sets an upper limit on the rate at which data can be transmitted over any communications channel, whether wired or wireless").

[15] *See id*. at 12.

[16] BCG April 2023 Report at 11.

with rural customers making up about 25 percent of the fixed wireless market while accounting for only 18 percent of the nation's population.[17]

Additional full-power, licensed spectrum is therefore needed to close the projected gap between demand and network capacity projections and to ensure wireless providers can support continued growth and new services and applications well into the next decade.

B. U.S. Wireless Providers Have Access to Fewer Megahertz of Mid-Band Spectrum Than Wireless Providers in Other Nations (Response to RFC Pillar #1, Question 9).

The U.S. is well behind key benchmark nations in the amount of mid-band spectrum, and lower mid-band spectrum in particular, that it has dedicated to commercial wireless licensing. A review of 15 leading markets confirmed that other nations are committing far more mid-band spectrum to licensed use.[18] Today, the U.S. trails its peers by an average of 378 megahertz in licensed mid-band access,[19] roughly the size of the 3.45 GHz and C-Band spectrum combined. U.S. wireless providers have been doing more with less for years, but we are at risk of surrendering economic opportunity and technological leadership.

Today's comparison is just a current snapshot; the U.S. licensed mid-band deficit as compared to other nations is expected to grow by nearly 40 percent in the next five years.[20]

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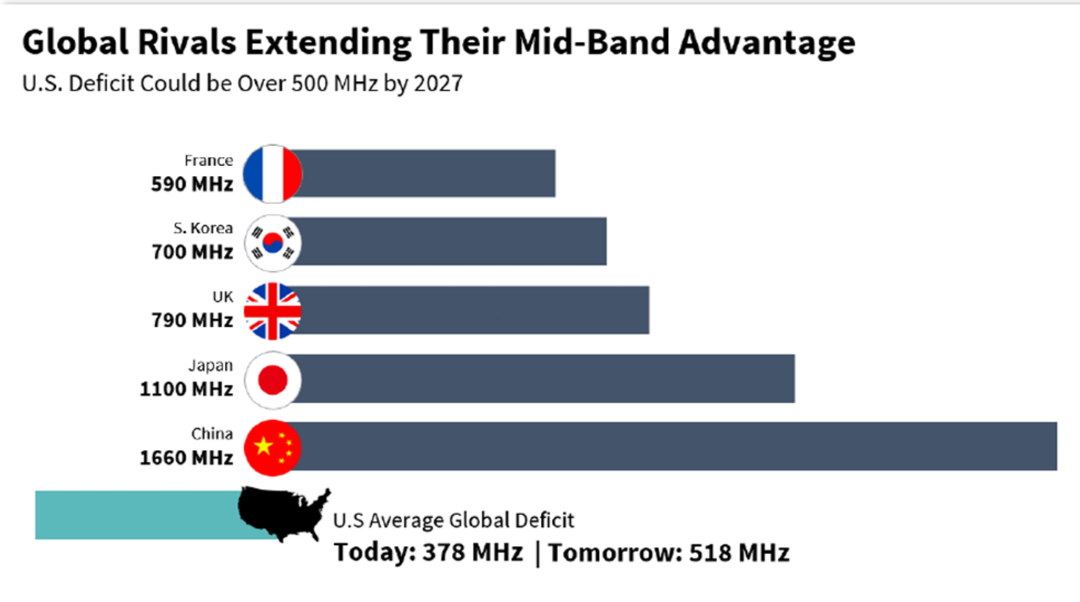
[17] BCG April 2023 Report at 8.

[18] *See* Janette Stewart, Chris Nickerson, & Juliette Welham, *Comparison of total mobile spectrum in different markets*, ANALYSYS MASON, at 3 (Sept. 2022), https://www.ctia.org/news/comparison-of-total-mobile-spectrum-in-different-markets ("Analysys Mason Sept. 2022 Report").

[19] *Id*. at 10-11 (showing the average amount of licensed mid-band spectrum currently assigned for mobile use in China, France, Japan, South Korea, and the United Kingdom (648 megahertz) as compared to the U.S. (270 megahertz)). This calculation includes the CBRS spectrum licensed through the PALs process, which has very different usage characteristics than other licensed mid-band spectrum. The nation is even further behind if we exclude the 70-megahertz of PALs and look solely at full-power licensed mid-band spectrum.

[20] *Id*.

Beyond the upcoming Phase II spectrum in C-Band, the U.S. is not expected to have any additional mid-band spectrum available by 2027.



Source: Analysys Mason Sept. 2022 Report.

Chinese wireless operators, meanwhile, already have greater access to mid-band spectrum than the U.S. wireless industry today, and they may soon have nearly four times the amount of commercial mid-band spectrum as the U.S. China is considering dedicating at least the upper half of the 1,200 megahertz in the 6 GHz band and perhaps the entire band for licensed use, whereas the U.S. dedicated the entire 1,200 megahertz for unlicensed operations.[21] If China follows through, it will have either 1,060 megahertz or 1,660 megahertz of licensed mid-band spectrum available, compared to 450 megahertz in the U.S.[22]

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[21] *See id*. at 11; *see also* Accenture, *Spectrum Allocation in the United States*, at 18, 32 (Sept. 28, 2022), https://www.ctia.org/news/spectrum-allocation-in-the-united-states ("Accenture Spectrum Allocation Report").

[22] *See* Analysys Mason Sept. 2022 Report at 11; *see also Balanced 6 GHz decisions continue as regional and global trend*, GSMA (Feb. 24, 2023), https://www.gsma.com/spectrum/balanced-6-ghz-decisions-continue-as-regional-and-global-trend/.

Swift government action for a comprehensive spectrum strategy that will refill our national licensed spectrum pipeline is needed to avoid falling further behind rival nations vying for global wireless leadership.

C. U.S. Wireless Providers Have Access to Far Fewer Megahertz of Mid-Band Spectrum than U.S. Government Systems or U.S. Unlicensed Operations (Response to RFC Pillar #1, Questions 1, 2).

It is worth highlighting as well that, here at home, the federal government occupies roughly two-thirds of mid-band spectrum. That's the equivalent of 12 times the amount of mid-band spectrum that is available for licensed commercial wireless networks.[23]

And on the commercial side, the amount of mid-band spectrum designated for unlicensed use eclipses licensed spectrum by seven to one. In recent years, U.S. policy has committed 1,350 megahertz of prime mid-band spectrum—the Citizens Broadband Radio Service ("CBRS") in 3 GHz and all of the 6 GHz band—to dynamic spectrum sharing access regimes deemed innovative, but those decisions have isolated the United States as nations devote mid-band spectrum resources to 5G and beyond.

Spectrum in the 3 GHz band in particular has become a hallmark of 5G deployments around the world, as dozens of countries (including NATO nations) are making the 3 GHz range available for wireless use and are evaluating upgrades to military radar technologies historically operated in those bands.[24] U.S. policymakers and lawmakers should identify spectrum in the Lower 3 GHz band for full-power commercial wireless use, while respecting the need to ensure federal systems continue to serve their missions. As discussed below, we have a playbook for

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[23] Accenture Spectrum Allocation Report at 18.

[24] *See, e.g.*, GSMA, *The WRC Series – 3.5 GHz in the 5G Era: Preparing for New Services in 3.3-4.2 GHz* (Oct. 2021), https://www.gsma.com/spectrum/wp-content/uploads/2021/10/3.5-GHz-for-5G.pdf.

static sharing in place that can and should be leveraged for the similar systems in the 3 GHz band.[25]

There is currently no licensed spectrum in the pipeline for wireless use, and the FCC's auction authority has lapsed for the first time in 30 years. It is in our national interest to address this shortfall promptly. CTIA supports a balanced spectrum policy that enables government agencies to meet their missions—including defense—while enhancing and expanding opportunities for commercial use, and for full-power commercial wireless use in particular. A forward-looking roadmap is needed to put the U.S. back on track and in a leadership role in global mid-band availability so that American policymakers can drive 5G adoption and promotion of trusted vendors—not China.

III. SPECTRUM AVAILABILITY FOR FULL-POWER COMMERCIAL WIRELESS LICENSED USE IS CRITICAL TO THE U.S. ECONOMY AND AMERICAN CONSUMERS, AND TO NATIONAL SECURITY.

A. Full-Power Commercial Wireless Licensed Spectrum is Vital to Our Nation's Economic Prosperity and Enhancing U.S. Connectivity (Response to RFC Pillar #1, Questions 1, 7).

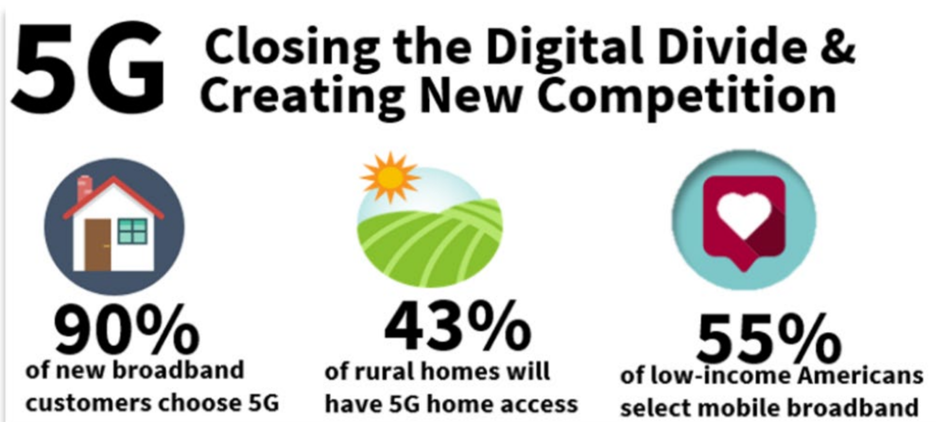
1. The U.S. Wireless Industry is at the Forefront of the Nation's Economic Success (Response to RFC Pillar #1, Questions 1, 7).

The wireless industry makes stunning direct and indirect impacts to the U.S. GDP and jobs outlook, with wireless connectivity delivering increasing capabilities for verticals that are serving consumer, enterprise, and government needs. These benefits are a result of comprehensive national policies that support access to licensed spectrum, which in turn promotes investment and innovation in next-generation technologies and networks deployed at scale.

[25] *See infra* Sec. IV.B.

Licensed, full-power spectrum has contributed more than $5 trillion to the U.S. economy in the last decade.[26] In 2020, the U.S. wireless industry, relying on full-power licensed spectrum, contributed $825 billion in GDP to America's economy.[27] Wireless-enabled jobs grew to 20.4 million by the end of the last decade—accounting for one out of every six U.S. jobs, making wireless the largest job contributor across all industries.[28]

Since 2018, the year 5G launched, U.S. wireless providers have invested more than $121 billion in growing and improving their networks.[29] The nationwide rollout of 5G happened nearly twice as fast as 4G, and 5G networks now cover more than 315 million Americans.[30] The 5G economy is projected to drive $1.4 trillion in GDP growth this decade and add 4.5 million new jobs.[31] And 5G is unlocking competition in the home broadband market as well, with 5G



[26] Aren Megerdichian, *The Importance of Licensed Spectrum and Wireless Telecommunications to the American Economy*, COMPASS LEXECON, at 3 (Dec. 7, 2022), https://www.ctia.org/news/the-importance-of-licensed-spectrum-and-wireless-telecommunications-to-the-american-economy.

[27] *Id*.

[28] Recon Analytics 4G Decade Report at 6.

[29] *See* CTIA 2022 Annual Survey Highlights at 3.

[30] *See id*. at 6.

[31] Enrique Duarte Melo et al., *5G Promises Massive Job and GDP Growth in the US*, BOSTON CONSULTING GROUP, at 3 (Feb. 2021), https://api.ctia.org/wp-content/uploads/2021/01/5G-Promises-Massive-Job-and-GDP-Growth-in-the-US_Feb-2021.pdf.

fixed wireless access offering affordable high-speed residential and business broadband services while providing more facilities-based competition to consumers.[32] In 2022, 90 percent of new broadband customers in the United States subscribed to fixed wireless service.[33]

This remarkable record is due in large part to the nationwide, light-touch wireless regulatory framework, driven by spectrum auctions for full-power, interference-protected licenses, that has prompted massive investment and innovation in the commercial wireless sector. Congress first authorized the FCC to conduct spectrum auctions back in 1993—the first-ever spectrum auctions anywhere—on the theory that auctions will result in the highest and best use of commercial wireless spectrum. U.S. academics were recognized with the Nobel Prize in Economics related to this decision to embrace auctions for allocating licensed spectrum.[34] Over the last three decades, the U.S. has led the world in spectrum policy, which has translated to economic success in the form of $635 billion invested in our nation's commercial wireless licensed networks and millions of good-paying American jobs.[35]

Spectrum auctions for licensed allocations have resulted, to date, in more than $200 billion in revenue being made available to the U.S. government in the form of auction proceeds. As discussed further below, Congress created the SRF to use revenue derived from auctions to help identify future federal bands for repurposing and sharing and for the upgrade of any affected

[32] *See, e.g.*, Accenture, *5G Fixed Wireless Broadband: Helping close the digital divide in rural America* (Nov. 18, 2021), https://www.ctia.org/news/5g-fixed-wireless-broadband.

[33] *See* Press Release, Leichtman Research Group, *About 3,500,000 Added Broadband From Top Providers in 2022* (Mar. 2, 2023), https://www.leichtmanresearch.com/about-3500000-added-broadband-from-top-providers-in-2022/.

[34] *See, e.g.*, Simon Johnson, *U.S. auction theory pioneers win Nobel economics prize*, Reuters (Oct. 12, 2020), https://www.reuters.com/article/us-nobel-prize-economics-idINKBN26X172.

[35] Press Release, CTIA, *U.S. Wireless Investment Hits Record High, CTIA Annual Survey Finds* (Sept. 13, 2022), https://www.ctia.org/news/u-s-wireless-investment-hits-record-high.

federal systems. This program is a powerful tool to make the most efficient use of limited airwaves while protecting or even enhancing the federal mission.

2. 5G Will Impact Nearly Every Industry Vertical, Aided by Network Slicing and Small-Scale Customization (Response to RFC Pillar #1, Question 1).

As the 5G transition continues, wireless will remain a catalyst for digital transformation across industries, including transportation, manufacturing, agriculture, education, healthcare, energy, and more. These include:

- Transportation. 5G is slated to alter almost every aspect of the transportation industry, including the vehicles we drive, the trucks that transport the products we depend on, and the roads that they traverse. Thanks to the low-latency and high-capacity features of 5G, cities can implement dynamic transportation planning, "potentially reducing traffic congestion or reallocating space for cyclists and pedestrians."[36] What's more, vehicle-to-everything communications enabled by wireless connectivity allow for increased road coordination and, ultimately, fewer accidents and safer roads. 5G will also further facilitate drones connectivity, which will impact other verticals such as the energy and utilities sectors, where drones could be utilized to capture real-time information for power substation and water tank inspections, as just some examples.

- Manufacturing. 5G is facilitating the growing use of smart equipment and the employment of real-time remote monitoring of operations in factories. Smart equipment in factories will enable manufacturers to collect, analyze, and make decisions based on massive amounts of data, bringing about efficiencies as factories automate and decide where to best deploy their human workforce. By 2028, manufacturing alone will account for nearly 25 percent of total revenue generated in 5G ultra low-latency use cases.[37]

- Agriculture. 5G-enabled agriculture will empower farmers to more efficiently manage their resources through a shift to precision agriculture. With 5G-powered equipment that will generate massive amounts of data about their agricultural operations, farmers can maximize resources and output, cut costs, optimize crop and livestock yields, and better preserve the environment. 5G can also increase efficiency in the agriculture sector via

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[36] Sarah Sultan & Adam Diehl, *5G and Transport—Envisioning Possibilities for a Better-Connected Tomorrow*, WORLD BANK BLOGS (Mar. 12, 2021), https://blogs.worldbank.org/transport/5g-and-transport-envisioning-possibilities-better-connected-tomorrow.

[37] *5G and the Factory Floor*, ABI Research, https://www.abiresearch.com/blogs/2019/12/13/5g-and-factory-floor/ (last visited Apr. 13, 2023).

precision farming, smart farm machinery, drone-based pesticide spraying, and weed and crop monitoring.[38]

- Education. As we continue integrating tele-education into the options available to students nationwide, 5G's capabilities will contribute to developing novel educational applications, with students and educators moving beyond the limitations of older technologies as they incorporate augmented reality and asynchronous instruction into their classes. Further, fixed wireless access is helping to close the homework gap by expanding affordable coverage in underserved and unserved communities.

- Healthcare. Next-generation connectivity will further the benefits of remote patient access to high-quality care. 5G-enabled healthcare can support not only the new telehealth wave for patients and healthcare providers, but also many improvements within the healthcare value chain, such as dynamically updating device inventories, hospital capacity, and inventory monitoring.[39]

- Energy and the Environment. 5G-enabled smart grids and smart buildings can prove invaluable in efforts to combat climate change. Through wireless monitoring and improved data collection and processing, 5G also enables operators to improve efficiency by optimizing the generation and transmission of energy as demand rises and falls. Among its many other use cases, 5G holds the potential to enhance the wireless industry's own energy efficiency and assist others' efforts to tackle the results of climate change. 5G-enabled use cases across five industry verticals are projected to make up to a 20 percent contribution toward the nation's carbon emission reduction targets by 2025.[40]

Network slicing enables enterprise users in these and other industries to access customized wireless network solutions to meet the performance characteristics their uses demand. Network slicing relies on the same physical network to provide virtual slices to meet different customer needs with tailored performance characteristics such as bandwidth, latency, and security. "[T]he development of network slicing allows providers and customers throughout the wireless ecosystem to continue to enjoy the efficiencies of flexible use licenses and larger

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[38] *See* Accenture, *5G Connectivity: A Key Enabling Technology to Meet America's Climate Change Goals*, at 50 (Jan. 26, 2022), https://www.ctia.org/news/5g-connectivity-a-key-enabling-technology-to-meet-americas-climate-change-goals ("*Accenture Climate Report*").

[39] PwC, *5G in healthcare*, PWC, at 5 (2020), https://www.pwc.com/gx/en/industries/tmt/5g/pwc-5g-in-healthcare.pdf.

[40] *See Accenture Climate Repor*t at 4 (highlighting projected emission reductions across the transportation and cities, manufacturing, energy and buildings, agriculture, and working, life, and health sectors).

geographic license sizes, while also benefitting from small-scale customization."[41] Network slicing on a general-use network is an underappreciated form of sharing. The opportunities available with network slicing should not be limited to the commercial sector—the federal government can utilize network slices for the secure connectivity many federal missions demand.

The universe of possibilities enhanced and enabled by 5G deployment will have significant economic impacts across the United States, but to achieve this promise access to more licensed spectrum will be necessary.

B. Spectrum Availability for Full-Power Commercial Wireless Licensed Use Is a National Security Imperative (Response to RFC Pillar #1, Questions 4, 5; Pillar #3, Question 3).

Spectrum allocation decisions directly implicate our national security interests. While spectrum supports the Department of Defense's ("DoD") domestic needs and warfighters overseas, leadership in the commercial wireless sphere has profound impacts for U.S. security interests as well. If the United States remains behind in identifying and making spectrum available for 5G and 6G, and if we are absent from global spectrum bands, China and other nations will fill the vacuum in standards-setting bodies and in the supply chain for next-generation wireless infrastructure. The stakes are high. As Secretary of Commerce Raimondo has observed, China's leaders "are accelerating their efforts to fuse their economic and technology policies with their military ambitions."[42]

A national campaign for U.S. technological superiority that is increasingly focused on the wireless ecosystem must incorporate a comprehensive spectrum roadmap that is consistent with

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[41] *Network Slicing Benefits and the Implications for Spectrum Licensing*, RECON ANALYTICS, at 1 (2021), https://reconanalytics.com/wp-content/uploads/2021/03/2021-5G-Network-Slicing.pdf.

[42] Gina Raimondo, U.S. Secretary of Commerce, Remarks on the U.S. Competitiveness and the China Challenge (Nov. 30, 2022).

and advances these efforts. The United States cannot lead in standards-setting bodies, and we cannot ensure a secure supply chain and bolster trusted suppliers for networks at home and across the globe, if we are not present in global bands for 5G and next-generation wireless services.

Successive Congresses and Administrations have correctly taken numerous steps to promote U.S. technological superiority. The National Defense Authorization Act, for instance, provides billions of dollars annually to support technology leadership, including more than $800 million over the last two fiscal years for DoD research, development, testing, and evaluation of 5G-enabled communications technologies.[43] Likewise, the CHIPS Act of 2022 provided nearly $53 billion for American semiconductor research, development, manufacturing, and workforce development, along with $1.5 billion for promoting U.S. leadership in advancing open, interoperable, and standards-based radio access networks, and creating a stronger supply chain.[44] The U.S. has also engaged in significant partnerships with allied nations to promote trusted communications suppliers and resilient communications networks.[45]

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[43] *See* National Defense Authorization Act for Fiscal Year 2023, H.R. 7776, 117th Cong., § 4201, Advanced Component Development and Prototypes, Line 093 (2022) (providing $329.59 million for research, development, testing, and evaluation of "Next Generation Information Communications Technology (5G)"); National Defense Authorization Act for Fiscal Year 2022, Pub. L. No. 117-81, § 4201, Line 097, 135 Stat. 1541, 2293 (2021) (providing $474.67 million for the same).

[44] The White House, *FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China* (Aug. 9, 2022), https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/; *see also* CHIPS Act of 2022, Pub. L. No. 117-167, 136 Stat. 1366 (2022).

[45] *See, e.g.*, Press Release, NTIA, *Joint statement between the United States of America, Australia, Canada and the United Kingdom on Telecommunications Supplier Diversity* (Dec. 8, 2022), https://www.ntia.gov/press-release/2022/joint-statement-between-united-states-america-australia-canada-and-united; The White House, *FACT SHEET: The U.S.-Japan Competitiveness and Resilience (CoRe) Partnership* (May 23, 2022), https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/23/fact-sheet-the-u-s-japan-competitiveness-and-resilience-core-partnership/; The White House, *Statement by NSC Spokesperson Emily Horne on U.S. Support for the Third Annual Prague 5G Security Conference* (Dec. 2, 2021), https://www.whitehouse.gov/briefing-room/statements-

China, meanwhile, is seeking to dominate various emerging technology sectors and is executing its comprehensive, multi-year Belt and Road Initiative to do so.[46] One component is the Digital Silk Road Policy, which assists recipient nations in improving their telecommunications networks and digital capabilities.[47] With more countries using Chinese-made technologies, China can attain allies in its effort to align global technology standards with its own interest, giving Chinese firms an advantage over trusted suppliers.[48] China is also seeking to lead in technology standards development through its China Standards 2035 initiative, which the National Institute of Standards and Technology has called "a blueprint for China's government and leading technology companies to set global standards for emerging technologies in areas such as artificial intelligence and advanced communications technology."[49]

Spectrum is a key aspect of China's initiative. China is using the international spectrum allocation process to advance its interests and undermine U.S. capabilities and leadership. Right now, China is moving aggressively to leverage the WRC-23 this fall to export its domestic 5G allocations globally, aiming to dominate standards-setting and build a global ecosystem based on its domestic 5G allocations. Here in the U.S., we have been setting our own course, often to the

releases/2021/12/02/statement-by-nsc-spokesperson-emily-horne-on-u-s-support-for-the-third-annual-prague-5g-security-conference/.

[46] *See* Office of the Director of National Intelligence, *Annual Threat Assessment of the US Intelligence Community*, at 7, 20 (Apr. 9, 2021), https://www.dni.gov/files/ODNI/documents/assessments/ATA-2021-Unclassified-Report.pdf.

[47] *See* Council on Foreign Relations, *Assessing China's Digital Silk Road Initiative*, https://www.cfr.org/china-digital-silk-road/ (last visited Apr. 12, 2023).

[48] Robert Greene & Paul Triolo, *Will China Control the Global Internet Via its Digital Silk Road?*, Carnegie Endowment for International Peace (May 8, 2020), https://carnegieendowment.org/2020/05/08/will-china-control-global-internet-via-its-digital-silk-road-pub-81857.

[49] Study on People's Republic of China (PRC) Policies and Influence in the Development of International Standards for Emerging Technologies, Request for Information, 86 Fed. Reg. 60801, 60802 (Nov. 4, 2021).

detriment of our strategic interests. The U.S. adopted a dynamic sharing unlicensed framework across the full 1,200 megahertz of 6 GHz spectrum (5.925-7.125 MHz), but China, along with Russia and some European countries, is seeking to gain licensed 5G access to at least the upper half of the band. There will be a significant debate on 6 GHz between unlicensed, led by the U.S., and licensed, led by China, at WRC-23. The 6 GHz issue follows the U.S. adoption of the low-power, preemptible dynamic sharing CBRS in the 3.55-3.7 GHz band. The United States is the only country that has provided shared or unlicensed use in these frequencies, which are located squarely in the key global 5G band.[50]

The implications for national security are clear: our spectrum decisions impact the U.S. ability to lead the global wireless ecosystem. And the consequences are significant: as FCC Chairwoman Rosenworcel pointed out, "the United States and authoritarian regimes have different views on how to use 5G technology" and "there is intense competition underway to shape what comes next."[51] The National Spectrum Strategy should account for these realities.

IV. TO MAINTAIN U.S. GLOBAL LEADERSHIP, THE NATIONAL SPECTRUM STRATEGY NEEDS TO IDENTIFY ADDITIONAL MID-BAND SPECTRUM FOR FULL-POWER COMMERCIAL USE, NOT MORE DYNAMIC SHARING.

A. Exclusive-Use Licensed Spectrum is the Backbone of Wireless Deployments at Scale (Response to RFC Pillar #1, Questions 3, 7).

While CTIA has long supported an approach to spectrum that enables both full-power commercial licensed use and unlicensed use, current U.S. mid-band allocations are out of balance and necessitate a focus on licensed spectrum. Exclusive-use spectrum access is the preferred course for wide-area network deployments.

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[50] *See* Analysys Mason Sept. 2022 Report at 12.

[51] Jessica Rosenworcel, Chairwoman, FCC, Remarks at the Center for Strategic and International Studies, at 1-2 (Jan. 17, 2023), https://www.fcc.gov/document/chairwoman-rosenworcel-center-strategic-international-studies.

Licensed spectrum with rights of assured access and interference protection against other operations allows the holder to manage interference to its network and provide a high and consistent level of service. This, in turn, provides sufficient certainty to inform auction participation and allow the holder to invest and build next-generation, secure networks at scale that can deliver the performance characteristics users want and expect in a competitive marketplace. Quality of service is fundamental as users "expect that their network of choice [will] be available at the performance characteristics they expect on a consistent basis."[52] No other framework for spectrum availability in the U.S. has enabled the combination of massive investment, ever-increasing capacity, sweeping reach, secure networks, and reliability that we have seen with interference-protected, licensed spectrum. The need for licensed spectrum with full power and wide channels is particularly acute for mid-band frequencies, which have propagation characteristics that lend themselves to efficient and effective coverage in rural and exurban areas. This puts licensed spectrum at the forefront of advancing consumer welfare, economic growth, and our national security. The proliferation of 5G use cases in transportation, manufacturing, agriculture, education, health care, energy, and other fields put a premium on reliability, quality of service, and security, underscoring the need for a full-licensed approach in many instances to meet future needs.

Unlicensed spectrum offers the benefits of Wi-Fi and Bluetooth, for example, but it cannot provide the same guarantee of access, wide-area coverage, security, or performance considering other operations on the same spectrum, possible interference, and low power levels. The same holds true for complex dynamic sharing like the three-tiered CBRS access regime in

[52] *CBRS: An Unproven Spectrum Sharing Framework*, RECON ANALYTICS, at 6 (Nov. 14, 2022), https://www.ctia.org/news/cbrs-an-unproven-spectrum-sharing-framework ("Recon Analytics CBRS Report").

the 3.55-3.7 GHz band. A wide-area deployment under the lower power CBRS regime, for example, would require five to seven times more base stations than traditional commercial licensed network deployments.[53] Full-power licensed regimes, like the C-Band and the 3.45 GHz band, are a better model for future mid-band access. Although the RFC places heavy emphasis on dynamic spectrum sharing, the reality is it is still nascent and has yet to be proven effective in its current form.

B. Pre-Defined or Static Sharing Can Successfully Advance the Interests of Incumbent Government Users and the Wireless Industry Without the Need for Complex Sharing (Response to RFC Pillar #1, Question 7; Pillar #3, Question 3).

As discussed above, full-power licensed spectrum is the linchpin of America's wireless leadership and remains an important tool in the wireless industry's continued efforts to expand broadband, bridge the digital divide, continue to drive U.S. prosperity, and advance U.S. technological superiority. Exclusive-use, licensed spectrum remains paramount, but with limited opportunities for greenfield spectrum in the mid-band range, it is necessary in many instances to develop a path for spectrum sharing among new and incumbent users, including DoD users that occupy a substantial majority of mid-band frequencies. Pre-defined sharing can provide sufficient certainty of access to warrant network investment and must be assessed on a band-by-band basis.

Fortunately, there is a long tradition of collaboration between federal agencies and the commercial wireless industry to make spectrum available for shared commercial use under a certain and workable framework—specifically, with reliance on geographic- and/or temporal-based sharing with a coordinated transition to protect federal missions while enabling nationwide

[53] Recon Analytics CBRS Report at 7 (citing to *5G Mid-Band Spectrum Deployment*, RYSAVY RESEARCH at 3 (Feb. 11, 2021), https://rysavyresearch.files.wordpress.com/2021/02/2021-02-5g-mid-band-spectrum-deployment.pdf ("Rysavy Research CBRS Report")).

commercial deployment, coupled with use of auction revenues to pay for relocation, repacking, or upgrading federal incumbent users as necessary. This sharing framework provides certainty to commercial wireless providers that the network will be scalable and available for secure connectivity that sustains a quality of service that consumers, enterprises, and government users have come to expect.

The Congressionally mandated Spectrum Relocation Fund is a key component of this success, serving as a resource since 2004 for directing spectrum auction proceeds to reimburse federal agencies for their relocation, repacking, or upgrades that make spectrum available for commercial use.[54] Repurposing or sharing government-held spectrum for full-power commercial wireless licensed services generates billions of dollars in auction revenues that can go back to federal agencies, allowing them to invest in modern, more efficient systems and technologies. This has helped DoD in the past and promises more benefits for the federal government in the future. We identify examples here.

AWS-1. In 2006, the FCC conducted the AWS-1 auction, which included government-held spectrum in the 1710-1755 MHz band that had been identified for reallocation.[55] DoD had 16 military facilities classified as "protected facilities" in the AWS-1 band that included airborne telemetry and video systems, ground-based radio relay and fixed microwave systems, and

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[54] *See* Commercial Spectrum Enhancement Act, Pub. L. No. 108-494, § 202, 118 Stat. 3986, 3991-93 (2004).

[55] *See* Gerald F. Hurt et al., *Spectrum Reallocation Final Report, Response to Title VI – Omnibus Budget Reconciliation Act of 1993*, NTIA Special Publication 95-32, Sec. 4: Assessment of Reallocation Proposals (Feb. 1995), https://www.ntia.doc.gov/legacy/osmhome/EPS/openness/cover.html; *see also* NTIA Report, *An Assessment of the Viability of Accommodating Advanced Mobile Wireless (3G) Systems in the 1710-1770 MHz and 2110-2170 MHz Bands* (July 22, 2002), http://www.ntia.doc.gov/ntiahome/threeg/va7222002/3Gva072202web.htm; *Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, including Third Generation Wireless Systems*, Second Report and Order, 17 FCC Rcd 23193 ¶ 22 (2002) ("AWS Allocation Order").

precision guided munitions ("PGM") systems, among others.[56] Eleven other federal agencies had operations in the band as well.[57]

NTIA and the FCC determined through collaborative evaluation that the band could be made available for non-federal, commercial use subject to certain protection and coordination conditions.[58] The FCC and NTIA outlined detailed coordination procedures for this transition,[59] which provided potential commercial licensees the certainty they needed to bid $13.7 billion for licensed rights to these frequencies.[60] A total of $1.55 billion was made available from auction proceeds through the SRF to relocate and upgrade the federal systems.[61]

With the availability of SRF funds, DoD successfully relocated the aeronautical systems, converted the ground-based systems to mixed federal/non-federal use (with the exception of Yuma, Arizona and Cherry Point, North Carolina, which continue to operate on a primary basis indefinitely), and transitioned the PGM systems.[62] During the coordination period prior to the successful transition, new AWS-1 licensees coordinated with and protected these systems from interference until they were relocated to other spectrum.[63] New AWS-1 licensees also protected

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[56] *Service Rules for Advanced Wireless Services in the 1.7 GHz and 2.1 GHz Bands*, Report and Order, 18 FCC Rcd 25162 ¶ 118 (2003) ("AWS-1 2003 R&O").

[57] *See The Federal Communications Commission and the National Telecommunications and Information Administration – Coordination Procedures in the 1710-1755 MHz Band*, Public Notice, 21 FCC Rcd 4730, 4731 (2006) ("2006 AWS-1 Coordination Public Notice").

[58] *See* AWS Allocation Order ¶¶ 22-26.

[59] *See* 2006 AWS-1 Coordination Public Notice at 4732-34.

[60] *See* FCC, Auction 66: Advanced Wireless Services (AWS-1) Fact Sheet, https://www.fcc.gov/auction/66#tabpanel-factsheet (last visited Apr. 13, 2023).

[61] *Commercial Spectrum Enhancement Act, Annual Progress Report for 2021*, U.S. Department of Commerce – NTIA, at 1 (Oct. 2022), https://ntia.gov/sites/default/files/publications/2021_csea_report.final.pdf ("NTIA 2022 CSEA Report").

[62] *Id*. at 1 & n.1; *see also* AWS-1 2003 R&O ¶ 118.

[63] AWS-1 2003 R&O ¶¶ 119-123.

and coordinated with fixed systems operated by additional non-DoD agencies whose transitions have also largely been completed.[64] And coordination was required as well for non-federal systems in the paired band segment at 2110-2155 MHz.[65]

DoD and the 11 other federal agencies that received SRF funds have ceased operations in the 1710-1755 MHz band, and 11 agencies "have completed their relocation efforts and achieved comparable capability by relocating to new frequency assignments or by utilizing alternative technology."[66]

AWS-3. The AWS-3 auction, conducted in 2014 and 2015, is another example of a successful collaborative static sharing framework, with the auction of the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz bands.[67] Each of these band segments was specifically identified, or within the range of frequencies identified, for auction as part of the Middle Class Tax Relief and Job Creation Act of 2012,[68] with the NTIA-chartered Commerce Spectrum Management Advisory Committee and DoD proposing specific band segments and a coordination framework that NTIA endorsed.[69] Five federal agencies had systems in the 1695-1710 MHz band, including the Air Force, Army, and Navy, for space-to-Earth Meteorological

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[64] *Id.* ¶ 124.

[65] AWS Allocation Order ¶¶ 27-47.

[66] NTIA 2022 CSEA Report at 1. NTIA reports that the Department of Energy ("DOE") "is delayed beyond its previously planned date for achieving comparable capability" but that DOE "expects to complete the relocation effort and achieve comparable capability in 2023." *Id.*

[67] FCC, Auction 97: Advanced Wireless Services (AWS-3), https://www.fcc.gov/auction/97 (last visited Apr. 13, 2023).

[68] Pub. L. No. 112-96, § 6401(a)(2) (1675-1710 MHz), (b)(2)(C) (same), (b)(2)(D) (2155-2180 MHz), (b)(2)(E) (15 megahertz of contiguous spectrum to be identified by the FCC, which was interpreted by the FCC as the 1755-1780 MHz segment), 126 Stat. 156, 222-23 (2012).

[69] *See Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands*, Report and Order, 29 FCC Rcd 4610 ¶¶ 11-13 (2014) ("AWS-3 Report and Order").

Satellite ("MetSat") operations, among others.[70] These systems have been successfully transitioned and continue to use SRF funds to achieve comparable capability.[71] The 1755-1780 MHz band was allocated on a primary basis for federal fixed, mobile, and space operations (Earth-to-space) and was utilized by more than a dozen federal agencies, including DoD.[72] Eight of these agencies have completed their transitions and achieved comparable capability in the 1755-1780 MHz band; five agencies have transitioned their use of the 1755-1780 MHz band and are continuing to use SRF funds to achieve comparable capability; and the remainder of the agencies expect a full transition by 2025.[73]

Coordination for the federally allocated band segments—1695-1710 MHz and 1755-1780 MHz—required the affected agencies, including DoD, to provide information that included "the frequencies used, emission bandwidth, system use, geographic service area, authorized radius of operation, and estimated timelines and costs for relocation or sharing."[74]

The FCC also adopted rules establishing 27 Protection Zones encompassing 47 federal earth stations that would continue to operate in the 1695-1710 MHz band and 25 satellite earth stations that would continue to operate in the 1761-1780 MHz band, refined based on cooperative engagement between NTIA and the FCC.[75] The FCC and NTIA also developed

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[70] *Id*. ¶¶ 15, 198; *Transition Plans and Transition Data for the 1695 – 1710 MHz Band*, NTIA (Sept. 30, 2020), https://ntia.gov/other-publication/transition-plans-and-transition-data-1695-1710-mhz-band.

[71] NTIA 2022 CSEA Report at 9.

[72] AWS-3 Report and Order ¶ 206; NTIA, *Transition Plans and Transition Data for the 1755 – 1780 MHz Band* (Sept. 30, 2020), https://ntia.gov/other-publication/2020/transition-plans-and-transition-data-1755-1780-mhz-band.

[73] NTIA 2022 CSEA Report at 16.

[74] *The Federal Communications Commission and the National Telecommunications and Information Administration: Coordination Procedures in the 1695-1710 MHz and 1755-1780 MHz Bands*, Public Notice, 29 FCC Rcd 8527, 8528 (WTB/NTIA 2014) ("AWS-3 Coordination Public Notice"); *see also* NTIA, AWS-3 Transition, https://ntia.gov/category/aws-3-transition (last visited Apr. 13, 2023).

[75] AWS-3 Coordination Public Notice, 29 FCC Rcd at 8533-35, 8540-42.

both formal and informal coordination requirements, both for operations that would be transitioned out of the band and those that would remain.[76]

By leveraging proven processes for commercial access to globally harmonized band segments, the interagency process worked: the AWS-3 auction was, at its time, the highest-grossing spectrum auction in FCC history—raising $41.3 billion in net bids—and it resulted in more than $5 billion being made available from auction proceeds through the SRF to relocate and upgrade the federal systems, of which approximately $2.5 billion has been utilized as of last year.[77]

3.45 GHz. Another example of coordination with federal and commercial users is the 3.45-3.55 GHz band, which was just auctioned in 2021-2022.[78] For years, DoD, NTIA, the FCC, and the wireless industry have examined spectrum in the 3.1-3.55 GHz band for licensed wireless use in the U.S., just as frequencies in this band segment had been reallocated by many other nations for 5G.[79] As far back as 2010, NTIA identified the band as a potential candidate for repurposing.[80] Stakeholders later identified the top 100 megahertz at 3.45-3.55 GHz as the most promising path for near-term sharing.

In 2020, Congress adopted the Beat China by Harnessing Important, National Airwaves for 5G Act of 2020 ("Beat CHINA for 5G Act"), which required the FCC to begin an auction to

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[76] *See id*. at 8535-40.

[77] NTIA 2022 CSEA Report at 9, 16 (noting $254.3 million in cumulative outlays for the 1695-1710 MHz band and $2.27 billion in cumulative outlays for the 1755-1780 MHz band).

[78] FCC, Auction 110: 3.45 GHz Service, https://www.fcc.gov/auction/110 (last visited Apr. 13, 2023).

[79] *See Facilitating Shared Use in the 3100-3550 MHz Band*, Second Report and Order, Order on Reconsideration, and Order of Proposed Modification, 36 FCC Rcd 5987 ¶¶ 2-6, n.2 (2021) ("*3.45 GHz Second Order*").

[80] NTIA, *Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband* (Oct. 2010), http://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf.

grant new flexible-use licenses in the 3.45 GHz band by December 31, 2021.[81] At about the same time, the White House and DoD formed America's Mid-Band Initiative Team ("AMBIT") to explore making 100 megahertz of contiguous spectrum available in the 3.45 GHz band for commercial use.[82]

This shared-use exploration included elements of relocation and coordination for the myriad ground-based, airborne, and shipborne federal radionavigation services in the band,[83] utilizing the concept of protection zones through use of new federal Cooperative Planning Areas and Periodic Use areas. The 3.45 GHz band auction raised $22.5 billion in net auction revenue and far exceeded the reserve price to cover the estimated $13.4 billion in 3.45 GHz band transition costs.[84] While still in progress, the coordination process in some ways mimics the information sharing and coordination mechanisms that were successful in the AWS context.[85]

It is worth noting as well that DoD benefits from successful spectrum auctions not just through upgrades for its systems funded through auction proceeds, but as a result of successful collaboration with industry itself. DoD's negotiated use of commercial spectrum and networks supports many domestic military mission requirements.

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[81] Pub. L. No, 116-260, § 905, 134 Stat. 1182, 3215-16 (2020).

[82] *See 3.45 GHz Second Order* ¶ 6.

[83] *See id*. ¶ 9.

[84] NTIA 2022 CSEA Report at 34.

[85] *See 3450-3550 MHz*, NTIA, https://ntia.gov/category/3450-3550-mhz (last visited Apr. 13, 2023); *see also Portal Opens for AWS-3 Spectrum Sharing Coordination*, NTIA, https://ntia.gov/blog/portal-opens-aws-3-spectrum-sharing-coordination (last visited Apr. 13, 2023).

C. Dynamic Sharing Like CBRS Remains an Experiment and the U.S. Cannot Base the Future of Commercial Spectrum on a Yet-to-Be Proven Strategy (Response to RFC Pillar #1, Question 7; Pillar #3, Question 2).

Work is very much still nascent on dynamic spectrum sharing models, and the National Spectrum Strategy should not default to complex spectrum sharing regimes. To date, dynamic sharing bands have been underutilized and lacks robust investment.[86] It is premature to rely on these unproven solutions as the primary means of enabling sharing among federal and non-federal users.

As noted above, the dynamic sharing framework in the 3.55-3.7 GHz band, CBRS, is a low-power, preemptible service, and the vast majority of CBRS use today is as a localized supplement to wide area network capacity. With CBRS power levels up to 650 times lower than standard power levels used in commercial wireless networks in other spectrum bands, wireless providers would need to deploy five times the number of cells sites typically deployed in suburban areas and seven times as many in rural areas to compensate for coverage gaps, driving up costs, delaying deployments, and limiting spectrum efficiency and effectiveness.[87] As a result, CBRS use falls far short of what mid-3 GHz spectrum can deliver, as demonstrated in the 5G deployments in the same frequencies elsewhere across the globe.

Much of the existing use of CBRS is from traditional licensed spectrum users, including CTIA members. Of the top 20 auction winners of Priority Auction Licenses ("PALs"), 16 were traditional telecom providers[88] who are using CBRS to augment capacity in limited areas

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[86] *See, e.g.*, Recon Analytics CBRS Report (finding that real-world studies indicate low utilization of CBRS spectrum more than a decade after the framework was envisioned).

[87] *See id*. at 7; Rysavy Research CBRS Report at 3.

[88] *See* Mike Dano, *Verizon, Dish, Charter, Comcast: Here are the 20 biggest CBRS auction winners*, LIGHT READING (Sept. 2, 2020), https://www.lightreading.com/5g/verizon-dish-charter-comcast-here-are-20-biggest-cbrs-auction-winners/d/d-id/763633; *see also Auction of Priority Access Licenses in the 3550-*

surrounding the lower power CBRS cell. It seems likely that some of these users opted for PALs only because higher-power, exclusive-use licensed mid-band spectrum was unavailable.

While the cable industry touts its CBRS deployments as part of its wireless service offerings, it is important to recognize that cable companies engage in targeted CBRS deployments in high-traffic areas to offload customer traffic from their Mobile Virtual Network Operator ("MVNO") arrangements. The wireless service offerings that cable companies sell otherwise rely on the wide-area networks of the underlying mobile network operator, which in turn rely on full-power, commercial spectrum for deployments at scale.

While some CBRS proponents point to the number of CBRS access points, many of these access points are indoor-only and operate at Wi-Fi power levels with limited coverage. Much of the CBRS focus seems to discount the significant power restrictions built into CBRS that necessitate more inefficient and costly deployments than traditional licensed spectrum enables.

Further, the available CBRS metrics today also show an underutilized asset. CTIA commissioned a study of three cities—Atlanta, Kansas City, and Phoenix—to assess CBRS utilization. That study showed only partial buildout and coverage, limited CBRS transmissions, and an "ample supply of spectrum, particularly [General Authorized Access ("GAA")] access, which was unused in each of the three cities."[89] The measurements showed the most intensive use employing less than five percent of the available spectrum in those three cities.[90] And there

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3650 MHz Band Closes: Winning Bidders Announced for Auction 105, Public Notice, 35 FCC Rcd 9287 (2020).

[89] Recon Analytics CBRS Report at 3 (citing *CBRS Spectrum Occupancy Measurements*, CTIA (Jan. 28, 2022), https://www.ctia.org/news/cbrs-spectrum-occupancy-measurements).

[90] *See CBRS Spectrum Occupancy Measurements*, CTIA, at 3 (Jan. 28, 2022), https://www.ctia.org/news/cbrs-spectrum-occupancy-measurements.

are significant concerns regarding the effectiveness of the sensing technologies underlying that experiment and resulting inefficient spectrum use.[91]

Dynamic sharing has not yet proven to be a fix for spectrum scarcity. In addition to CBRS, the envisioned Automated Frequency Coordination system in the 6 GHz band and standard power access points have yet to be deployed.[92] As a nation, we cannot rely on low-power, preemptible service and massive exclusion zones to deliver the capabilities American consumers and enterprise expect or to compete in the global wireless ecosystem as other nations pursue full-power 5G network deployments.

V. THE ADMINISTRATION SHOULD TAKE SEVERAL ACTIONS TO LAUNCH THE NEW NATIONAL SPECTRUM STRATEGY.

A. Replenish the Spectrum Pipeline with At Least 1,500 Megahertz of Mid-Band Spectrum and Schedule Auctions for Full-Power Commercial Use (Response to RFC Pillar #1, Question 2).

As noted above, there are no spectrum bands teed up for auction today, so the first step for the National Spectrum Strategy is to identify spectrum to repurpose for full-power commercial licensed use. Given the assessment that the current U.S. mid-band spectrum deficit will grow to more than 1,400 megahertz or more within the decade,[93] and the economic and national security benefits that could be lost without closing that gap, CTIA supports repurposing

[91] *See, e.g.*, Letter from Megan Anne Stull, Counsel, Google, & Andrew W. Clegg, Spectrum Engineering Lead, Google, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 19-348 et al., at 1 (filed Dec. 17, 2020) (noting the CBRS Environmental Sensing Capability ("ESC"), which was designed to listen for federal operations and notify the CBRS Spectrum Access Administrator when those operations are detected, are "already constraining spectrum use in the CBRS band" because of the potential for interference to the ESC sensors).

[92] *See OET Announces Conditional Approval for 6 GHz Band Automated Frequency Coordination Systems*, Public Notice, DA 22-1146 (OET 2022).

[93] *See* Brattle Group April 2023 Report at 3-4, 24; *supra*, note 11 (citing Ericsson February 2023 report projecting a 1,500 to 2,200 megahertz deficit in the availability of licensed, wide-area commercial spectrum U.S. by 2030).

at least 1,500 megahertz of mid-band spectrum for full-power, licensed wireless use—not just the study of 1,500 megahertz. While spectrum studies will be needed to support that identification, NTIA should not stop at studies alone; clear identification of targeted bands for study and allocation is critical. The time it takes between identification of suitable spectrum and deployment is an impediment to competition on a domestic and global basis, underscoring the need for an established pipeline for licensed spectrum use. Section VI below identifies three frequency ranges in mid-band spectrum: Lower 3 GHz, Mid 4 GHz, and 7/8 GHz. Next, we need a schedule of future spectrum auctions to meet the significant demand for mobile and fixed wireless service. And we need to ensure the FCC has spectrum auction authority to secure U.S. international spectrum leadership.

B. Embrace Global Band Ranges Identified for 5G, as Other Nations Including China are Coalescing Around 5G Bands Without the U.S. (Response to RFC Pillar #1, Questions 4, 9).

As nations prepare for the upcoming WRC-23 this fall, China and other countries are identifying 5G-ready and beyond-5G mid-band spectrum, with plans to make large swaths of spectrum available for wide channels in full-power, wide-area networks. The United States is on a far different path.

China's global strategy—and the one it is ramping up in advance of WRC-23—is very 5G focused, aiming to build global ecosystems based on their domestic spectrum availability.[94] Presently, China supports all five bands at WRC-23 for future or expanded 5G mid-band use (in at least some global regions): 3.3-3.4 GHz, 3.6-3.8 GHz, 4.8-4.99 GHz, upper 6 GHz, and 10 GHz. The United States has yet to formalize its WRC-23 priorities, but it is actively opposing

[94] Michael Mullinix, *The U.S. Needs to Take Leadership Role in Global Spectrum Policy*, CTIA (Apr. 11, 2023), https://www.ctia.org/news/the-u-s-needs-to-take-leadership-role-in-global-spectrum-policy.

mobile service in the upper 6 GHz band and is only supportive thus far of proposals relating to the 3.6-3.8 GHz band.

The U.S. cannot afford to cede leadership to China in spectrum policy and technology standards development. To that end, a recent report on the U.S. national security interests in the wireless ecosystem recommends that the U.S. government "lead[] efforts toward globally harmonized licensing of spectrum bands that will enable the global scale necessary for trusted suppliers to design and market semiconductors and other related components."[95] Spectrum harmonization is the equalizer that will allow the U.S. and trusted allies to compete against China's state-backed champions that already have the benefit of scale—a captured market of one billion people. It is in the U.S. national interest to participate in global spectrum harmonization—rather than the U.S. on a spectrum island—to assure robust and secure connectivity here and abroad. U.S. development of more secure networks and trusted suppliers begins with a collaborative and comprehensive spectrum roadmap that ensures a strong U.S. presence in globally harmonized bands. Ensuring U.S. leadership globally in standards and emerging technologies will require concrete actions, including achieving advantageous results at WRC-23, especially as it applies to agenda items supporting future advanced wireless use. Harmonizing spectrum bands for substantially similar use worldwide helps minimize the threat from other countries to dominate strategic bands for 5G, 6G, and beyond.

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[95] Clete Johnson, *The Strategic Imperative of U.S. Leadership in Next-Generation Networks,* Center for Strategic and International Studies, at 10 (Jan. 2023), https://www.csis.org/analysis/strategic-imperative-us-leadership-next-generation-networks.

C. Adopt the RFC's Definition of "Spectrum Sharing" (Response to RFC Pillar #1, Question 6).

In the RFC, NTIA proposes to define "spectrum sharing" to include both pre-defined or static sharing and dynamic sharing. NTIA goes on to note that "[t]o implement the most effective sharing arrangement, in some situations incumbent users may need to vacate, compress or repack some portion of their systems or current use to enable optimum utilization while ensuring no harmful interference is caused among the spectrum users."[96] CTIA strongly supports this broad view of sharing, as it accounts for the successful static sharing repurposing approaches discussed above.

D. Examine Spectrum Utilization and the Efficiency of Incumbents in Candidate Bands (Response to RFC Pillar #2, Question 2; Pillar #3, Questions 3, 4).

As noted above, given the cost of acquiring spectrum by auction or in the secondary market, wireless providers have built-in incentives to make the efficient use of spectrum a key element of the wireless playbook. That is not the case, however, for many other spectrum users, including federal users. The National Spectrum Strategy should impose a data collection on spectrum utilization of federal operations in candidate bands for sharing and repurposing to commercial use.

[96] RFC at 16246, Pillar #1, Questions 6. DoD's recent Request for Information on a Spectrum Roadmap included an overly narrow definition of spectrum sharing that "does not involve reallocation or vacation of the band by incumbent users" and "does not involve compression above or below the band by incumbent users." DoD, *Next-Generation Electromagnetic Spectrum Strategic Roadmap*, Request for Information, Notice ID 632369514, at 3 (published Jan. 4, 2023; updated Jan. 17, 2023), https://sam.gov/opp/d0dcc926bb5c4d2f8dd9 c6bd51b3ce4a/view. NTIA should not adopt this overly narrow approach.

E. Ensure the Spectrum Relocation Fund Meets Agencies' Needs (Response to RFC Pillar #1, Question 8).

Federal agencies have benefitted from billions of dollars in technology upgrades funded through commercial spectrum auction revenues and the SRF.[97] The SRF facilitates reallocation or effective sharing of federal airwaves for full-power, commercial use, by using spectrum auction revenues to fund replacement federal systems that enable reallocation or sharing.

To further these efforts, CTIA supports modifications to the SRF to provide greater and more reliable funding to federal agencies for spectrum repacking, relocation, and sharing, as well as upgrades to modernized, more spectrum-efficient technologies. For example, CTIA supports expediting disbursements from the SRF to relevant agencies. CTIA also supports importing greater flexibility so SRF resources can be used for more efficient spectrum planning and to explore technology advancements that could facilitate the transition of federal spectrum for commercial use.

While the RFC seeks comment on federal agency access to "new spectrum access opportunities in non-federal bands, including on an 'as-needed' or opportunistic basis,"[98] there are significant roadblocks to any such approach. Rather, federal agencies should consider how commercial arrangements with wireless providers can advance the federal mission.[99] 5G network slicing referenced above, with customized performance characteristics for individual enterprise or government agency needs, is one such option.

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[97] 47 U.S.C. § 928.

[98] RFC at 16246, Pillar #1, Question 8.

[99] *See, e.g.*, *DOD Announces $600 Million for 5G Experimentation and Testing at Five Installations*, DoD (Oct. 8, 2020), https://www.defense.gov/News/Releases/Release/Article/2376743/dod-announces-600-million-for-5g-experimentation-and-testing-at-five-installati/; *DOD Establishes 5G and Future Generation Wireless Cross-Functional Team*, DoD (Mar. 9, 2022), https://www.defense.gov/News/Releases/Release/Article/2960806/dod-establishes-5g-and-future-generation-wireless-cross-functional-team/.

F. Recognize NTIA's Role as the Voice of the Executive Branch on Federal Spectrum and Affirm the FCC and NTIA Authority to Adjudicate Spectrum Matters (Response to RFC Pillar #1, Question 5; Pillar #2, Questions 3, 5).

Nearly 90 years ago, Congress granted to the FCC, as an independent agency, the authority to determine the non-federal allocation and use of radio spectrum across the nation, with the goal of expanding the use of radio and other communications facilities "by centralizing authority heretofore granted by law to several agencies" in the FCC.[100] NTIA, meanwhile, was established as the twin authority tasked with managing spectrum use by federal agencies, including DoD.[101] As the voice of federal agency spectrum users, NTIA assesses the nation's broader strategic needs, including balancing the economic and security implications for Executive Branch agencies of any spectrum policy decisions.[102]

The foundation for success in this engagement is that the Executive Branch speaks with one voice. The FCC and NTIA have worked in partnership toward these missions for decades, with recent reaffirmation of cooperative government engagement ratified in an updated Memorandum of Understanding between the two agencies.[103] The National Spectrum Strategy should reinforce this understanding for all.

[100] 47 U.S.C. § 151.

[101] *Id*. § 901(b)(6).

[102] *See* NTIA, Organizational Chart, https://www.ntia.doc.gov/book-page/national-telecommunications-and-information-administration (last visited Apr. 13, 2023).

[103] FCC & NTIA, *Memorandum of Understanding Between the FCC and NTIA on Spectrum Coordination* (Aug. 2, 2022), https://www.fcc.gov/document/mou-between-fcc-and-ntia-spectrum-coordination.

VI. THE NATIONAL SPECTRUM STRATEGY SHOULD REPURPOSE THE LOWER 3 GHz BAND, THE MID-4 GHz BAND, AND THE 7/8 GHz BAND (Response to RFC Pillar #1, Question 3).

A recent analysis commissioned by CTIA identifies three large swaths of spectrum within the lower mid-band range that offer the greatest potential for meeting the needs of additional 5G deployments by wireless operators.[104] As described in further detail below, mid-band spectrum from 3 GHz to 8.4 GHz includes three frequency ranges that are critical to support full-power, commercial licensed spectrum in the short- to medium-term: (1) the Lower 3 GHz band (3.1-3.45 GHz); (2) the Mid 4 GHz band (4.4-4.94 GHz); and (3) the 7/8 GHz band (7.125-8.4 GHz).

The **Lower 3 GHz band** is well-situated as part of the broader launch band for 5G services across the globe, with portions of this band identified for 5G services in more than two dozen countries.[105] The 3.3-3.4 GHz frequencies are subject to consideration at WRC-23.[106]

Because the Lower 3 GHz band is adjacent to the recently auctioned 3.45 GHz band, repurposing this band for commercial use and creating a large block of contiguous spectrum would benefit consumers, as it would drive lower costs for device manufacturers and enhance 5G performance. The large bandwidth and range of coverage offered by this band also make it ideal for supporting fixed wireless access in rural areas.

The Lower 3 GHz is currently a federal-only band used by DoD. As part of the Infrastructure Investment and Jobs Act ("IIJA"), Congress directed DoD to study this band and identify spectrum that could be made available for shared use by non-federal users.[107] Section

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[104] *See* Accenture Spectrum Allocation Report at 18.

[105] *See, supra*, Section III.C.

[106] *See* ITU, *ITU-R Conference Preparatory Meeting (CPM): Preparatory Studies for WRC-23*, Agenda Item 1.2, https://www.itu.int/wrc-23/status-of-studies/ (last visited Apr. 13, 2023).

[107] *See* Congressional Research Service, *Repurposing 3.1-3.55 GHz Spectrum: Issues for Congress* (Mar. 16, 2023), https://crsreports.congress.gov/product/pdf/download/IF/IF12351/IF12351.pdf/.

90008 of the IIJA funded DoD with $50 million to study the 3.1-3.45 GHz band "to improve efficiency and effectiveness" of DoD spectrum use in order to make spectrum in this band available for shared use and auction of commercial wireless licenses.[108] Congress dictated that the funding be used for specific purposes—research and development, engineering studies, economic analysis, activities with respect to systems, or other planning activities—to improve DoD spectrum efficiency and effectiveness to enable commercial sharing in the band.

DoD has launched a collaborative initiative with industry, Partnering to Advance Trusted and Holistic Spectrum Solutions ("PATHSS"), to provide a forum to exchange information on the Lower 3 GHz band. In contrast to the RFC's inclusive definition of sharing, however, DoD has thus far taken a narrower view of sharing, defining it in a way that does not include vacating the band or repacking incumbent operations for more efficient use. This approach restricts consideration of proven and available options and risks limiting the types of use cases that can be supported. CTIA believes it is critical that DoD consider how to make its use more efficient, consistent with Congress's directive, and examine multiple paths in making its assessment regarding whether spectrum in the Lower 3 GHz band can made available for sharing with non-federal users.

The **Mid 4 GHz band** is a contiguous block of spectrum that already provides high capacity for 5G networks and use cases in many other countries. Although this band is currently licensed for federal use, reallocating approximately 400 megahertz for non-federal uses would make a large, contiguous block of mid-band spectrum available to support 5G deployment and

[108] Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, § 90008(b)(1)(A), 135 Stat. 429, 1349 (2021).

use cases. The National Spectrum Strategy should include this band in its inventory of frequencies for study for licensed, commercial use.

The **7/8 GHz band** is a large block of contiguous spectrum that is ideal for serving densely populated areas with high-capacity demands. NTIA previously examined this federal-only band and determined it was underutilized,[109] making it similarly well suited for further investigation for potential repurposing for commercial use.

Finally, separate from the goal of identifying at least 1,500 megahertz of spectrum for licensed wireless use, NTIA should also consider the long-term benefits of access to spectrum across frequency ranges, as wireless providers continue to need a mix of low-, mid-, and high-band spectrum to meet escalating demands for wireless capacity across all population densities.[110] This includes bands that can support advanced wireless use cases in the upper mid-band frequency range through 15 GHz. Among other things, the Administration should support investigation of the 7-15 GHz band for IMT at WRC-27. NTIA should also support the FCC's investigation of the 12.7-13.25 GHz band for flexible, high-power commercial use by 5G and beyond technologies. Reallocation of the 12.7-13.25 GHz band and other spectrum in the upper mid-band frequencies can complement, but not substitute, necessary efforts to free up the critical tranches of mid-band spectrum in the 3 GHz, Mid 4 GHz, and 7/8 GHz bands that are necessary to maintain U.S. competitiveness in the wireless marketplace.

[109] *See* Comments of CTIA, ET Docket No. 18-295, GN Docket No. 17-183, at 15 (filed Feb. 15, 2019).
[110] *See, e.g.*, BCG April 2023 Report at 2-3.

VII. CONCLUSION.

CTIA appreciates the opportunity to provide this input to the National Spectrum Strategy. The Administration should recognize the U.S. economic and national security aspects of commercial wireless spectrum and identify ways to rectify the imbalance in U.S. mid-band allocations that currently favor federal, unlicensed, and shared use while U.S. commercial wireless licensed allocations increasingly fall behind rival nations and other countries. By developing a National Spectrum Strategy that keeps the U.S. competitive in the global wireless ecosystem, NTIA and the Administration can better position the nation's wireless industry to continue to support our nation's top economic and national security priorities.

Respectfully submitted,

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How Much Licensed Spectrum is Needed to Meet Future Demands for Network Capacity?

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APRIL 17, 2023

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CONTENTS

Executive Summary

Mobile data demand is exploding, with aggregate data downloaded quadrupling in the last seven years. New and innovative uses enabled by 5G, as well as the prospect of 6G applications, point towards further increases in expected demand for mobile network capacity. Unfortunately, the U.S. spectrum landscape appears to be stalled, with no clear prospects for significant spectrum reallocations this year and insufficient bands under consideration for reallocation in the coming years. This lack of a spectrum pipeline, coupled with the lapse of the Federal Communications Commission (FCC) auction authority, has raised the prospect of significant capacity constraints in the terrestrial wireless space, and concern that this may limit the U.S.'s ability to be a leader in this area. This paper investigates this capacity constraint and estimates the likely spectrum deficit the U.S. will face over the next decade absent policymakers allocating additional full-power, licensed spectrum.

We examine several potential mechanisms to ease the gap between projected demand for mobile data and estimated future capacity of mobile networks. Obviously one way to align supply and demand is simply through reducing network usage. Restricted offerings or higher prices could limit demand to maintain network performance in the face of inadequate supply of capacity. This approach would reduce the growth of innovative applications, ultimately restraining economic growth and potential U.S. leadership without any real benefit to users. We assume policymakers would seek to avoid this outcome.

Two historically effective avenues for increasing mobile network capacity include improvements in spectral efficiency and adding more physical infrastructure such as base stations or cell towers. Unfortunately, both of these options are approaching serious limitations, as we analyze below. Even under optimistic projected improvements in the areas of spectral efficiency and infrastructure deployment, the U.S. will still face a significant capacity deficit—leaving additional new mobile spectrum allocations as essential to meet projected future demand.

> In 5 years, by the end of 2027, the U.S. is expected to have a capacity deficit of over 10 exabytes/month. In ten years, by 2032, this deficit could grow to approximately 17 exabytes/month.

Extrapolating from historical trends, we project that data traffic on the macro network is expected to increase by over 250% in the next 5 years and by over 500% in the next 10 years. If no new spectrum bands are allocated for wireless use in the next 5-10 years, we estimate that by 2027, the U.S. could face a spectrum deficit of approximately 400 megahertz, and by 2032, this deficit will have more than tripled to over 1,400 megahertz, normalized to lower mid-band equivalent spectrum, licensed at full power.[1] To avoid this deficit, work needs to begin now on filling the spectrum pipeline.[2]

Absent any new spectrum, in 5 years, by 2027, the U.S. is expected to have a spectrum deficit of nearly 400 megahertz. In ten years, by 2032, this deficit could more than triple to approximately 1,400 megahertz.

[1] The report analyzes the spectrum deficit in terms of a normalized band of spectrum with propagation characteristics of 1-2 GHz frequency, average power limits, and free of encumbrances—bands with other characteristics will vary in the amount needed to cover the capacity deficit.

[2] The authors recognize that a lot can change over the studied time period, so we also calculated potential spectrum deficits using other demand projections. We found that under all plausible scenarios we examined, the United States will have a substantial spectrum deficit in 2027 and an even larger deficit in 2032.

I. Introduction

The global COVID pandemic moved a large part of the workforce and academia from physical to virtual work and learning spaces, leading to an explosion of demand for data in both wired and wireless networks.[3] Consumers and businesses large and small used mobile broadband networks at an unprecedented pace for a variety of uses, including schoolwork, shopping, entertainment, and telemedicine.[4] The trend continues with hybrid work options and people using more data-intensive applications on their mobile phones.

In seven years, from 2015 to 2022, global mobile traffic increased from five exabytes per month to 93 exabytes per month – a more than 18-fold increase.[5] Over that period, aggregate data demand in North America has more than quadrupled.[6] In 5 years, from 2021 to 2027, the average monthly data usage per smartphone in North America is expected to grow from 15 GB to 52 GB – more than tripling per device data consumption.[7] New and innovative uses enabled by 5G, the proliferation of Internet of Things (IoT) devices, enhanced mobile broadband, augmented and virtual reality applications, are dramatically increasing demand for mobile network capacity.[8] These trends have raised the specter of significant capacity constraints and spectrum shortfalls

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3 Bruce Duysen, "5G and the age of pandemic: A look at the US," April 27, 2020, last accessed December 15, 2022, RCR Wireless News, https://www.rcrwireless.com/20200427/opinion/readerforum/5g-and-the-age-of-pandemic-reader-forum.

4 Karthikeyan Iyengar, Gaurav K. Upadhyaya, Raju Vaishya, and Vijay Jain, "COVID-19 and Applications of Smartphone Technology in the Current Pandemic," Diabetes & Metabolic Syndrome: Clinical Research & Reviews, Vol. 14(5), September - October, 2020, https://www.sciencedirect.com/science/article/abs/pii/S1871402120301521?via%3Dihub.

5 Ericsson, "Mobility Report," Ericsson, June, 2022, last accessed August 16, 2022, at p. 15, available at https://www.ericsson.com/49d3a0/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-june-2022.pdf ("Ericsson Mobility Report, June 2022"). Note: One exabyte equals one billion gigabytes. *See*, Alexander S. Gillis, "What is an Exabyte?" TechTarget, last accessed August 21, 2022, https://www.techtarget.com/searchstorage/definition/exabyte.

6 *See,* Ericsson Mobility Report, June 2022, at pp. 17-19. Note that Ericsson reports the mobile traffic number for North America and not just the US. However the vast majority of the traffic is US-based.

7 *See,* Ericsson Mobility Report, June 2022, at pp. 17-19. Note that Ericsson reports the mobile traffic number for North America and not just the US. However the vast majority of the traffic is US-based. *See also*, GSMA, "The Mobile Economy – North America 2022," accessed December 25, 2022, p. 13, https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/09/290922-Mobile-Economy-North-America-2022.pdf.

8 Ericsson, "Ericsson Mobility Report," November 2022, last accessed December 19, 2022, at p. 22, https://www.ericsson.com/4ae28d/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-november-2022.pdf ("Ericsson Mobility Report, November 2022"). *See also*, Noman M. Alam, Mark Racek, and Kumar Balachandran, "Mid-Band Spectrum – Laying a strong foundation for 5G," Ericsson, July 4, 2022, last accessed December 15, 2022, https://www.ericsson.com/en/blog/6/2022/mid-band-spectrum-in-the-us-a-strong-foundation-for-5g, ("Mid-Band spectrum – Laying a strong foundation for 5G").

in mobile networks and concern that this may constrain the U.S.'s ability to be a leader in data-intensive 5G applications.[9]

Engineers remind us that there are several ways to avoid capacity constraints on wireless networks, such as through installing more equipment or infusing more spectrum into the network.[10] In this paper we account for the interrelated and complementary tools that can help solve the gap between the demand for and supply of capacity in the mobile network, estimating how to what extent non-spectrum inputs can go toward meeting demand. We find non-spectrum avenues lacking even under highly optimistic scenarios, leaving more full-power, licensed spectrum as the most effective way to meet projected wireless demand.

This paper aims to identify how much additional full-power, licensed spectrum is needed to close the projected gap between demand for wireless services and network capacity projections. Section II discusses the demand for data and the expected growth in data demand for the next five to 10 years. Section III presents the available inventory of spectrum today, as well as briefly discussing various supply-side factors used to help meet demand. Section IV discusses the spectrum deficit estimation, concluding that even under optimistic scenarios the United States would face a deficit of approximately 400 megahertz in five years, growing to over 1,423 megahertz in ten years.[11]

This analysis indicates that additional mobile spectrum allocations are necessary if U.S. wireless networks are to be able to supply enough capacity to meet growing demand. It is infeasible to expect non-spectrum inputs to cover the capacity deficit, even using conservative inputs and under the most optimistic scenarios. With aggressive investment in infrastructure and reasonably expected improvements to spectral efficiency, we estimate that in order to meet demand in five years industry will still require approximately 400 megahertz of spectrum in the next 5 years, and over 1,400 megahertz in ten years. This estimate is normalized to exclusively licensed, wide-area, full-power spectrum, with propagation characteristics of 1-2 GHz. Spectrum with other characteristics would change the analysis—for example, if spectrum were only made available with lower power levels, much more would be required to meet demand.

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9 Roger Entner, "The U.S. is Hamstrung by Spectrum Constraints," Fierce Wireless, April 22, 2022, Fierce Wireless, https://www.fiercewireless.com/wireless/us-hamstrung-spectrum-constraints-entner.

10 Richard N Clark, "Expanding Mobile Wireless Capacity: The challenges presented by technology and economics," Telecommunications Policy 38(8-9) (September 2014): 693-708, pp. 694-695, https://www.sciencedirect.com/science/article/pii/S0308596113001900 ("Expanding Mobile Wireless Capacity"). *See also*, Ericsson Mobility Report, November 2022.

11 We normalized these figures to the equivalence of lower mid-band spectrum licensed for full power, flexible mobile use.

II. Demand for Capacity

Analyzing historical growth in wireless traffic allows us to predict future trends. We estimate both the growth in traffic as well as its composition in terms of different generations of wireless technologies, which is important in analyzing expected efficiency gains over time, as well as the potential trends in network offloading.

A. Growth in Wireless Traffic

Today, the ubiquity of mobile devices, increasing per-user data consumption, and more data-hungry applications have led to an explosion of mobile traffic and, consequently, a demand for greater capacity of the mobile networks to accommodate such increases in traffic. According to Ericsson, the growth in mobile data traffic per smartphone can be attributed to three main drivers: "improved device capabilities, an increase in data-intensive content and growth in data consumption due to continued improvements in the performance of deployed networks."[12] In North America, mobile data demand is expected to increase significantly, driven by new services such as "unlimited data plans and improved 5G network coverage and capacity" that will attract new 5G subscribers.[13]

To project the demand for capacity on the U.S. macro network of facilities-based operators, or the "on-network traffic," we turn to Cisco's Visual Networking Index (VNI) data to review historical data demand and use these to ground our estimates of mobile data demand going forward.[14] The VNI reports provide a geographic breakdown of Internet users, mobile users,

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[12] *See* Ericsson Mobility Report, November 2022, p. 22. This paper seeks to quantify the deficit in licensed spectrum from the mobile perspective, notwithstanding the explosive growth of fixed wireless access among home broadband subscribers. We exclude demand for fixed wireless for present purposes, as we understand fixed wireless services currently rely primarily on excess mobile capacity. Ultimately, however, the growing popularity of fixed wireless among consumers will cause the spectrum deficit to likewise grow.

[13] *See* Ericsson Mobility Report, November 2022, p. 22.

[14] Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017-2022," White Paper, Appendix A, Table 4, February 2019, last accessed December 18, 2022, http://media.mediapost.com/uploads/CiscoForecast.pdf, ("Cisco VNI: Global Mobile Data Traffic Forecast Update, 2017-2022"). *See also*, Cisco, "Cisco Annual Internet Report (2018–2023)," March 9, 2020, https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html, ("Cisco Annual Internet Report (2018–2023)"). *See also*, Sources and Notes for

We are interested in understanding long-term trends in traffic growth (2022 – 2032). However, the VNI data includes only five-year projections. For predicting traffic growth from 2023 – 2032, we use a combination of a projected CAGR and a regression analysis. We use the 2010-2022 Cisco mobile traffic data, which is comprised of actual data traffic forming the basis of each report from 2010 – 2018, as well as Cisco's 2018 forecasts for

Continued on next page

networked devices, speeds, and traffic for actual and forecasted traffic data from 2010 – 2022 for North America.[15]

The blue and teal bars in Figure 1 show that North American traffic has grown from 49 petabytes per month in 2010 to 1,804 petabytes in 2018 and is projected to reach over 5,800 petabytes per month in 2022.[16] The Ericsson numbers are slightly higher at around 6,000 petabytes in 2022.[17] Our data forecasts are shown in green and yellow and they project a roughly 2.5-fold increase in mobile traffic in the next 5 years and an almost six-fold increase in the next 10 years.[18]

2019 – 2022 North America traffic, as our baseline traffic numbers. For the years 2023 – 2028, we use Ericsson's predicted 2022 – 2028 CAGR (23%) to generate forecasted traffic. We then use the actual and predicted traffic data from 2010 – 2028 as the dependent variable in a regression analysis, predicting data traffic for 2029 – 2032 based on a quadratic time trend, a COVID indicator, and the previous year's population as covariates. The results are presented in Table A1.

Table A1. Note that we could have used the Ericsson traffic forecasts, which are in general higher than the Cisco forecasts, although the data availability for earlier years is better for Cisco. However, to be conservative, we use the Cisco forecasts in the base model for 2023, and then use a 23% CAGR from the Ericsson data forecasts. Also note, that the mobile traffic forecasts by Cisco and Ericsson are for the mobile traffic on the macro network of wireless operators. Facilities-based carriers are those with a nation-wide or regional cell site infrastructure that use licensed spectrum.

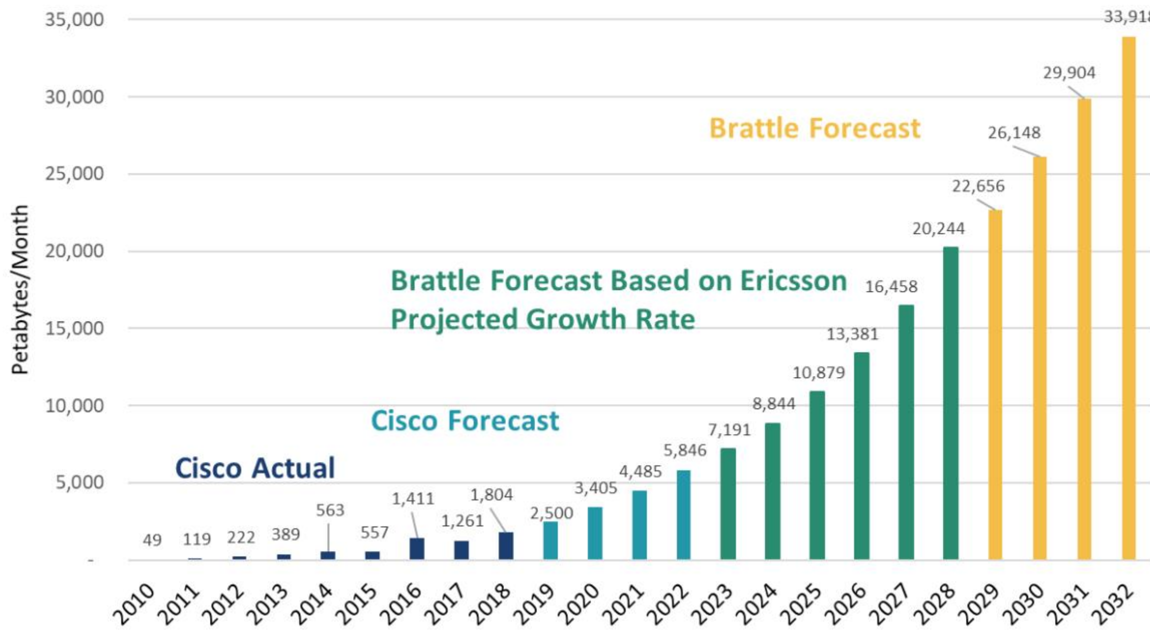
15 *See* Cisco Annual Internet Report (2018–2023). *See also* Cisco VNI: Global Mobile Data Traffic Forecast Update, 2017-2022.

16 See Figure 1. Note that the traffic forecasts are for North America which includes the U.S. and Canada. We use this as the aggregate U.S. forecasts and the Canadian data traffic is a very small fraction of the North American traffic volume.

17 Ericsson Mobility Report, November 2022, p. 39. The monthly data traffic for North America is reported in EB/month or exabytes/month. We have converted these to PB (petabytes) using 1EB=1000 PB. See https://www.coolstuffshub.com/data-storage/convert/exabytes-to-petabytes/.

18 The detailed methodology and data sources are described in 0 and the regression estimates are shown in Table 1.

FIGURE 1: NORTH AMERICA WIRELESS DATA DEMAND, 2010-2032



Sources and Notes: *See*, Appendix

We are interested in understanding long-term trends in traffic growth (2022 – 2032). However, the VNI data includes only five-year projections. For predicting traffic growth from 2023 – 2032, we use a combination of a projected CAGR and a regression analysis. We use the 2010-2022 Cisco mobile traffic data, which is comprised of actual data traffic forming the basis of each report from 2010 – 2018, as well as Cisco's 2018 forecasts for 2019 – 2022 North America traffic, as our baseline traffic numbers. For the years 2023 – 2028, we use Ericsson's predicted 2022 – 2028 CAGR (23%) to generate forecasted traffic. We then use the actual and predicted traffic data from 2010 – 2028 as the dependent variable in a regression analysis, predicting data traffic for 2029 – 2032 based on a quadratic time trend, a COVID indicator, and the previous year's population as covariates. The results are presented in Table A1.

Table A1.

This aggregate trend masks the changing composition of traffic on a network – that is, it does not show how the traffic moves between generations of cellular technology, from 2G to 3G, 4G, 5G and beyond. As technology progresses, traffic will decline on the older generations of technology, through consumers upgrading to newer technology and operators shutting down older generation networks, while traffic on the newer technology increases. The next sub-section discusses how the traffic composition has changed.

B. Mobile Traffic Composition

The changing composition of traffic has implications for how efficiently a network is used, as described later in Section III, and for understanding the relationship between technology evolution and data demand.

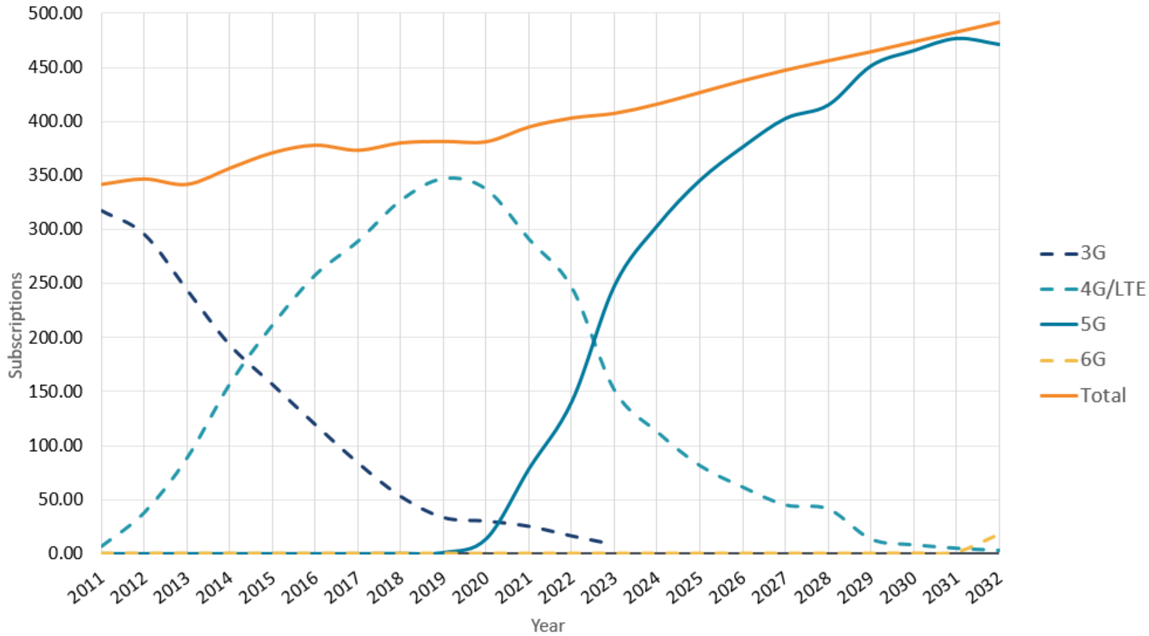
We use subscriber data from the Ericsson Mobility Visualizer to analyze how data traffic patterns change as a cellular technology moves from its nascent form to maturity and then to obsolescence.[19] This dataset lists the number of mobile subscriptions for each technology generation through 2028.[20] Figure 2 below shows the composition of traffic over the years. From Figure 2, we see that the inflection point for LTE and 5G almost mirror each other, with LTE declining from its peak and 5G subscriptions increasing after 2019, and 5G subscriptions expected to be greater than 4G subscriptions after 2023.[21]

19 Ericsson, "Ericsson Mobility Visualizer," Mobile Subscriptions, last accessed December 9, 2022, https://www.ericsson.com/en/reports-and-papers/mobility-report/mobility-visualizer?f=1&ft=2&r=2,3,4,5,6,7,8,9&t=1,2,3,4,5,6,7&s=4&u=1&y=2022,2028&c=3.

20 Ericsson reports the following technology categories for North America – CDMA, WCDMA/HSPA, GSM/EDGE, LTE, 5G and Other. We classify CDMA and GSM/EDGE under 3G and WCDMA/HSPA under 4G. The 'Other" category is classified as 2G.

21 *See* Figure 2.

FIGURE 2: SUBSCRIBER COUNT BY TECHNOLOGY



Sources and Notes: *Ericsson, "Ericsson Mobility Visualizer," last accessed December 14, 2022, https://www.ericsson.com/en/reports-and-papers/mobility-report/mobility-visualizer?f=1&ft=2&r=2,3,4,5,6,7,8,9&t=1,2,3,4,5,6,7&s=4&u=1&y=2021,2027&c=3.*

To complete the data composition patterns from 2022 – 2032, we generate predictions for 2029 – 2032, using the historical data. We construct subscriber shares by technology, and use these to predict subscriber shares for LTE and 5G, using a linear time trend to project the total number of future subscriptions in each category through 2032.[22] However, since we are projecting for a period 10 years from now, we have to factor in the evolution of 6G. The Ericsson data does not include any 6G subscription predictions. Therefore, we assume that 6G subscriptions will likely take off later and we predict the 6G trend in 2030 – 2032 using historical 5G customer patterns. Thus, for 6G we apply the same share of traffic that 5G experienced when it was in its infancy. We then apply these shares by technology to the total subscribers to obtain the number of customers by technology. Our projections show that for 2029 – 2032, LTE subscriptions are almost zero, 5G subscriptions have reached their peak, and 6G starts gaining market share.

Next, we discuss another factor affecting demand trend – traffic off-loading.[23]

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22 We assume that 4G (HSPA) will be phased out by 2024 so the subsequent years have 0% traffic share. Note, that we rescale the shares after prediction to ensure that the shares add up to one.

23 Rashmi Bharadwaj, "What is Wi-Fi Offload? An Overview," last accessed December 20, 2022, !https://ipwithease.com/what-is-wi-fi-offload-an-overview/, ("What is Wi-Fi Offload? An Overview").

C. Traffic Offloading

Offloading traffic generally refers to the situation when a mobile subscriber elects to connect using Wi-Fi over unlicensed spectrum rather than rely on the mobile network. Trends in Wi-Fi offloading featured prominently in our earlier analysis, which was done before the popularity of unlimited mobile broadband plans. In 2017 Cisco reported that 54% of total data traffic on mobile devices was over Wi-Fi, and estimated that in 2022, this figure would rise to 59%.[24] Unfortunately, Cisco no longer provides these statistics, making analysis of recent offloading trends difficult. The historic level of offloading is incorporated into the base for our demand projection, thus the important question for our analysis is whether offloading will change dramatically from prior years.

Recent trends indicate it is unlikely we will see a significant increase in Wi-Fi offloading. Improvements in mobile network capacity and latency mean consumers often do not see a material gain in network performance when switching to Wi-Fi. Furthermore, with the widespread prevalence of unlimited plans, users do not face the same cost incentive to seek out Wi-Fi access.[25] Finally, recent growth in popularity of fixed wireless access, which provides home broadband over licensed mobile spectrum, will increase the capacity load on licensed networks.[26] Again, our demand projections maintain historic rates of traffic offloading, so our estimated deficit is likely conservative in this regard.

In the next section, we turn to the supply side of the network capacity issue and explore how technological solutions (increasing spectral efficiency), infrastructure deployments (deploying more cell sites), and increased spectrum availability can ease capacity constraints.

24 Cisco, "Cisco: Global Mobile Networks Will Support More Than 12 Billion Mobile Devices and IoT Connections by 2022; Mobile Traffic Approaching The Zettabyte Milestone," February 19, 2019, last accessed December 13, 2022, https://newsroom.cisco.com/c/r/newsroom/en/us/a/y2019/m02/cisco-global-mobile-networks-will-support-more-than-12-billion-mobile-devices-and-iot-connections-by-2022-mobile-traffic-approaching-the-zettabyte-mil.html.

25 Unlimited plans gained popularity after Cisco's most recent offloading data, complicating analysis. *See* e.g., Chaim Gartenberg, "Why every US carrier has a new unlimited plan," *The Verge* (Feb 2017), https://www.theverge.com/2017/2/17/14647870/us-carrier-unlimited-plans-competition-tmobile-verizon-att-sprint.

26 Furthermore, fixed wireless home broadband access will complicate future offloading measurements, as analytics captured from devices may show them connected to a Wi-Fi network, when nevertheless licensed spectrum is ultimately carrying the traffic.

III. The Supply Side Inputs

A. Spectrum Availability

When it comes to spectrum, there are two broad types of regulatory constructs – licensed spectrum and unlicensed spectrum. Licensed spectrum is a part of the frequency assigned for terrestrial wireless use to an array of nationwide and regional cellular operators, cable companies, and others who pay a licensing fee for the "right to transmit on an assigned frequency within a certain geographic area so that nothing interferes with transmissions."[27] Unlicensed spectrum are frequencies that the FCC assigns for non-exclusive usage without the need for a license, *i.e.*, any entity can use it, subject to some regulatory restrictions.[28] Wi-Fi is one of the prime examples of the use of unlicensed spectrum. In this section, we discuss the availability of the licensed spectrum that is used for the traffic of cellular operators.[29]

1. Current Spectrum Inventory

The composition of the U.S. spectrum inventory grew slowly but steadily until 2019, with spectrum bands mostly below 3 GHz available for use for mobile terrestrial networks. However, with the advent of 5G, for the first time, carriers could utilize low, medium, and high frequencies in the same integrated, optimized network. In particular, with this "multi-layered" network, 5G is able to utilize the mmW spectrum, which has extremely short coverage capabilities and was previously not viable for use, along with mid- and low-band spectrum.[30] This resulted in a dramatic increase in the total stock of spectrum available for wireless networks, a development that coincides with a new focus on capacity by carriers. Importantly, much of this spectrum is licensed for full-power exclusive use, with larger geographic license sizes, all of which enhances the efficiency of network deployments.

27 Christopher Trick, "Licensed vs. Unlicensed Spectrum: Key Differences and 5G Use Cases," November 7, 2022, last accessed December 29, 2022, https://www.trentonsystems.com/blog/licensed-vs-unlicensed-spectrum, ("Licensed vs. Unlicensed Spectrum: Key Differences and 5G Use Cases").

28 *See* Licensed vs. Unlicensed Spectrum: Key Differences and 5G Use Cases.

29 It is beyond the scope of the current analysis to evaluate any needs for additional unlicensed spectrum.

30 OmniSci "5G's Data Science Challenge," at p. 4, 2021, last accessed August 1, 2022, https://www2.omnisci.com/resources/whitepaper/5g-data-science-challenge/lp.

The spectrum inventory table (Table 1) lists the frequencies that are available to be integrated into mobile broadband networks.[31]

- *3 GHz and Below (Low Band)*: Currently, the licensed sub-1 GHz frequencies – 600 MHz, 700 MHz and 800 MHz (cellular and SMR) Bands – have a total of 204 megahertz licensed. Between 1-3 GHz, the AWS-1, AWS-3, AWS-4, PCS, and H-Block, in total, comprise 335 megahertz of licensed spectrum.[32] The licensed frequencies in the 2 - 3 GHz range are WCS and BRS/EBS. In aggregate, these comprise 743 megahertz of low and low mid-band spectrum.[33]

- *Between 3 GHz and 8.4 GHz (Mid Band)*: The licensed frequencies in these bands are CBRS, C-Band, and the 3.45 GHz Band, which total 450 megahertz of licensed spectrum, although 180 MHz of the C-Band spectrum will not be available for use until later this year.[34] These bands were added to the inventory in the past three years.

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[31] "While there is no set rule for dividing between low-, mid-, and high-band spectrum, we have chosen dividing lines that best reflect recent allocation decisions made by policymakers with knowledge of forthcoming 5G service deployments. To further expand on one such delineation we made: while we selected 3 GHz as the dividing line between low- and the lower mid-band, the 2.5 GHz band - first allocated about two decades ago shares many of the same characteristics of the identified lower mid-band spectrum (e.g., large bandwidth, use of time division duplexing, and propagation ability.)" *See* Accenture, "Spectrum Allocation in the United States," CTIA, September 28, 2022, https://api.ctia.org/wp-content/uploads/2022/09/Spectrum-Allocation-in-the-United-States-2022.09.pdf. Note that the table lists all spectrum made available by the FCC for terrestrial mobile use and is different from the spectrum screen.

[32] There is one possible addition to this band expected in the near-term: 10 megahertz of spectrum from the NOAA/Ligado Band (1670 MHz – 1680 MHz band).

[33] We use 156.5 megahertz for the BRS/EBS spectrum to match the bands excluded from the FCC's updated spectrum screen. *See*, "Policies Regarding Mobile Spectrum Holdings," Federal Communications Commission, WT Docket No. 12-269, June 2, 2014, at ¶¶ 107-125, available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-63A1.pdf. *See also*, "Mobile Broadband Spectrum," at p. 7. *See also*, "FCC Establishes Procedures for 3.5 GHz Band Auction," Federal Communications Commission, FCC-20-18, 35 FCC Rcd 2140 (3), March 2, 2020, available at https://www.fcc.gov/document/fcc-establishes-procedures-35-ghz-band-auction-0. *See also*, "FCC Acts To Free Up C-band Spectrum For 5G Services," Federal Communications Commission, GN Docket # 18-122, February 28, 2020, available at https://www.fcc.gov/document/fcc-expands-flexible-use-C-band-5g. *See also*, Coleman Bazelon and Paroma Sanyal, "Mobile Broadband Spectrum: A Revaluation in a 5G World," CTIA, May 20, 2019, ("Mobile Broadband Spectrum: A Revaluation in a 5G World").

[34] Although wireless providers have obtained licenses to use CBRS spectrum, the low power levels and a new spectrum sharing regime made CBRS spectrum less valuable at auction than other licensed spectrum bands. We have accounted for this through adjustments made to how much CBRS spectrum to count as usable, as discussed below.

TABLE 1: SPECTRUM INVENTORY 2022

	Band Name	Location	Potential Spectrum Supply (Megahertz)
	[a]	[b]	[c]
	3 GHz and Under		**1,193**
[1]	600 MHz	600 MHz	70
[2]	700 MHz		
[3]	Paired	700 MHz	58
[4]	Unpaired	700 MHz	12
[5]	Cellular	800 MHz	50
[6]	SMR	800 MHz / 900 MHz	14
[7]	AWS-1	1.7 GHz / 2.1 GHz	90
[8]	PCS	1.9 GHz	120
[9]	G-Block	1.9 GHz	10
[10]	H-Block	1.9 GHz /2.0 GHz	10
[11]	AWS-3		
[12]	Paired	1.7 GHz / 2.1 GHz	50
[13]	Unpaired	1.7 GHz	15
[14]	AWS-4	2.0 GHz / 2.2 GHz	40
[15]	WCS	2.3 GHz	20
[16]	BRS/EBS	2.5 GHz	160.5
[17]	EBS New	2.5 GHz	23.5
[18]	CBRS	3.5 GHz	70
[19]	3.45 GHz	3.45 - 3.55 GHz	100
[20]	C-Band	3.7 GHz / 4.2 GHz	280
	Millimeter Wave		**4,950**
[21]	24 GHz	24 GHz	700
[22]	28 GHz	28 GHz	850
[23]	37 GHz	37 GHz	1,000
[24]	39 GHz	39 GHz	1,400
[25]	47 GHz	47 GHz	1,000
[26]	**Total**		**6,143**

Sources and Notes: FCC's 2022 Communications Marketplace Report.[35]

- *Above 24 GHz (mmW Bands)*: The total millimeter wave (mmW) spectrum licensed for use through Auctions 101 – 103 is 4,950 megahertz, which includes 850 megahertz of the 28

[35] FCC, "2022 Communications Marketplace Report," DA/FCC #: FCC-22-103, adopted December 30, 2022, https://www.fcc.gov/document/2022-communications-marketplace-report.

GHz Band, 700 megahertz of the 24 GHz Band, along with 2,400 megahertz in the Upper 37 GHz and 39 GHz spectrum bands, and 1,000 megahertz in the 47 GHz Band.[36]

2. Spectrum Used and Relative Effectiveness

While there are several spectrum allocations available for licensed use, not all frequencies are of equal usefulness, given different propagation characteristics, power levels, geographic license sizes, or sharing obligations. For example, over 80 percent of the total 6143 megahertz licensed spectrum inventory is mmW spectrum with highly limited propagation. We adjust to account for the estimated relative usefulness of bands. Furthermore, some of frequencies are not yet actually deployed, so we estimate when they will come into service and contribute to supporting network capacity. In the end, these adjustments allow us to represent network capacity and needs relative to full-power, mid-band spectrum because it is the prime workhorse used in networks today. For example, the coverage and capacity characteristics, and hence value, of 1 megahertz of low-mid band spectrum is not the same as 1 megahertz of say, 3.45 GHz spectrum. We use the 1 – 2 GHz frequencies as the base band and determine the other frequency bands' equivalent amount of spectrum to this base.[37] Additionally, the year that some spectrum bands would become available is uncertain. Therefore, in our base model of spectrum availability, we only include the quantity of frequencies in use, *i.e.,* the bands outlined in Table 2. There are several adjustments we make to the spectrum inventory to reflect availability and the coverage characteristics of higher bands to create low-band equivalents.

Available for Use

- *2.5 GHz*: 23.5 megahertz of 2.5 GHz is considered available and usable immediately after the auction in 2022.
- *28 GHz and 24 GHz*: Auction 101 and 102 ended in 2019.[38] We assume that it takes around 1 year to 18 months to start integrating this new mmW spectrum into the network.

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[36] The FCC allocated the 37.0 to 37.6 GHz mmW frequency band (the "Lower 37 GHz band") as a shared licensed band in July 2016. *See*, FCC, "In the Matter of Use of Spectrum Bands Above 24 GHz For Mobile Radio Services," GN Docket No. 14-177, adopted April 12, 2019, ¶¶ 2, 5, https://docs.fcc.gov/public/attachments/FCC-19-30A1.pdf.

[37] We use the term mid-band equivalent when converting the higher frequencies to be comparable to this range.

[38] FCC, "Auction 101: Spectrum Frontiers – 28 GHz," https://www.fcc.gov/auction/101/factsheet; FCC, "Auction 102: Spectrum Frontiers – 24 GHz," https://www.fcc.gov/auction/102/factsheet.

Therefore, 25% is available for use in 2021, 50% will be in 2022-2023, and 75% in 2024-2027. All the spectrum would become fully integrated in 2032.[39]

- *Upper 37, 39 and 47 GHz*: Auction 103 ended in early 2020.[40] We assume that 25% is available for use in 2021-2022, 50% will be available for use in 2023-2024, and 75% in 2025-2027. All the spectrum would become fully integrated in 2032.
- *CBRS (3.5 GHz):* Auction 105 ended in late 2020.[41] We assume that 25%, 50%, and 75% of the band is available in 2021, 2022 and 2023, respectively.
- *C-Band (3.7 GHz)*: Auction 107 ended in early 2021.[42] We assume that 25% , 50%, and 75% of the band is used or will be available for use in 2022, 2023, and 2024 respectively, and the band will be fully available for use from 2025.
- *3.45 GHz*: Auction 110 concluded in late 2021.[43] Given the coordination requirement with the Department of Defense, we assume that 25% of the band is used in 2022, 50% and 75% of 3.45 GHz will be available for use in 2023 and 2024 respectively, and that the band becomes fully available for use in 2025.

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39 The 10-year roll out of mmW spectrum reflects the uncertainty around its use cases.

40 FCC, "Auction 103: Spectrum Frontiers – Upper 37 GHz, 39 GHz, and 47 GHz," https://www.fcc.gov/auction/103/factsheet.

41 FCC, "Auction 105: 3.5 GHz Band," https://www.fcc.gov/auction/105/factsheet.

42 FCC, "Auction 107: 3.7 GHz Service," https://www.fcc.gov/auction/107/factsheet.

43 FCC, "Auction 110: 3.45 GHz Service," https://www.fcc.gov/auction/110/factsheet.

TABLE 2: SPECTRUM BANDS AND USABLE MEGAHERTZ WITH NO NEW SPECTRUM ALLOCATION

	2022	2027	2032
Spectrum Band		**In Use**	
Cellular	50.0	50.0	50.0
SMR	14.0	14.0	14.0
Broadband PCS	130.0	130.0	130.0
H Block	10.0	10.0	10.0
AWS-1	90.0	90.0	90.0
700 MHz	70.0	70.0	70.0
AWS-3	65.0	65.0	65.0
AWS-4	40.0	40.0	40.0
WCS	20.0	20.0	20.0
BRS	54.0	54.0	54.0
EBS	93.2	93.2	93.2
600 MHz	70.0	70.0	70.0
24 GHz	350	525	700
28 GHz	425	638	850
Upper 37 GHz	250	750	1,000
39 GHz	350	1,050	1,400
47 GHz	250	750	1,000
CBRS	7	14	14
C-Band	52.5	210	210
3.45 GHz	0	50	50
Low / Mid-Band Pre-2020	706	706	706
Adjusted for EBS	687	706	706
Mid-Band 2020-2022	60	274	274
mmWave	1,625	3,713	4,950
mmWave Equivalent (at 5%)	81	186	248
Spectrum Usable	862	1,166	1,228

Sources and Notes: *See* Brattle calculations.

Coverage Adjustment

- To compare like-to-like, we estimate the amount of spectrum in each band that should be counted in the usable inventory by creating a "mid-band" equivalent by calibrating the greater than 2 GHz bands to the 1-2 GHz frequency bands.
- Based on prior work, the relative band value of 2.5 GHz band vis-a-vis the 1-2 GHz bands is 80%, *i.e.*, it has a 20% discount due to coverage and hence value characteristics.
- We estimate the C-Band is similar in coverage to other lower mid-band spectrum. In prior work, we have shown that the C-Band covers approximately 75% of the population of the

U.S. compared to near 100% coverage by 1 – 2 GHz bands; thus, we use a relative band value of 75% vis-a-vis the 1 – 2 GHz bands.[44]

- The 3.45 GHz band, although similar to the C-Band, has a higher discount due to the encumbrances that are present in this band.[45] We use a relative band value of 50%.[46]
- The CBRS band (3.5 GHz) has a discount of 80% compared to the 1 - 2 GHz bands due to their lower coverage characteristics and lower power limits.
- Only 5% of the mmW spectrum is counted in the effective 1-2 GHz equivalent inventory due to propagation characteristics.[47]

The subset of licensed spectrum bands and megahertz that are being used today are shown in terms of their mid-band equivalents in Table 2.

B. Spectral Efficiency

Historically, technological improvements allowed wireless operators to do more with a given quantity of spectrum. Spectral efficiency is a measure of how much data can be transmitted over a given amount of spectrum, and as such, is an important factor in meeting growing demand. For the purposes of communications networks, efficiency is measured as a ratio of "the amount (or bits) of information transmitted" and "the amount of spectrum (or Hertz) impacted or made unavailable for use."[48] It is usually expressed as "bits per second per hertz," or bps/Hz, *i.e.*, the

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44 Coleman Bazelon and Paroma Sanyal, "Valuing the 12 GHz Spectrum Band with Flexible Use Rights," Prepared for RS Access, filed on the docket "In the Matter of Expanding Flexible Use of the 12.2-12.7 GHz Band," WTB 20-443, GN 17-183, filed May 7, 2021, p. 18, Table 1,https://www.fcc.gov/ecfs/document/10508241713847/3; ZTE, "APT 700 MHz: Best Choice for Nationwide Coverage," June 2013, https://www.gsma.com/spectrum/wp-content/uploads/2013/07/ZTE-LTE-APT-700MHz-Network-White-Paper-ZTE-June-2013.pdf

45 FCC, "Correction of Select Inventory Announced for the Auction of Flexible-Use Service Licenses in the in the 3.45–3.55 GHz Band for Next-Generation Wireless Services (Auction 110)," DA/FCC #: DA-21-1132, issued on September 10, 2021, https://www.fcc.gov/document/correction-auction-110-inventory.

46 The C-Band is 80% of the 1 – 2 GHz bands. At $0.74 MHz/Pop, the 3.45 GHz band was valued at approximately 70% of the C-Band values ($1.10/ MHZ-pops). This the 3.45 GHz band is 50% of the 1 – 2 GHz band ((0.51 = 0.74/1.10)*0.75). For auction prices, see Sasha Javid, "Post Auction Analysis for Auction 110," accessed January 11, 2023, https://www.sashajavid.com/FCC_Auction110.php. See also, Sasha Javid, "Post Auction Analysis for Auction 107," accessed January 11, 2023, https://www.sashajavid.com/FCC_Auction107.php.

47 This is done to adjust for the limited coverage property of mmW compared to low and mid-band spectrum.

48 Richard Engelman et. al., "Federal Communications Commission Spectrum Policy Task Force," Federal Communications Commission, November 15, 2002, last accessed December 13, 2022, https://transition.fcc.gov/sptf/files/SEWGFinalReport_1.pdf.

"net data rate in bits per second (bps) divided by the bandwidth in hertz."[49] Increasing spectral efficiency allows the same amount of spectrum and same number of cell sites to provide greater overall capacity.[50] Unfortunately improvements in spectral efficiency are approaching their theoretical limit.

To estimate rates of spectral efficiency for the aggregate U.S. mobile data traffic through 2032 we use the spectral efficiency rates for different technologies predicted by analysts as discussed earlier. To implement this we make some assumptions about the applicability of rates to various technologies and the composition of mobile traffic over the next 10 years as estimated earlier in Section II.B. We understand that peak efficiency numbers can only be met when there is a confluence of several ideal conditions, and is not feasible across the entire network.[51] Thus in a very real sense, any projections we make to account for efficiencies are purely theoretical and may overstate the ability of efficiencies to decrease spectrum demand.[52]

As the demand for data continues to grow, any increase in the throughput of data over spectrum that allows for faster, less costly and ubiquitous deployment of 5G services is of significant value. Despite the fact wireless technology has seen great advancements in the last 50 years, there is a hard mathematical limit to how much spectral efficiency can improve.[53] Furthermore, future gains in spectral efficiency will increasingly depend on costly deployments of additional physical infrastructure.

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[49] "Spectral Efficiency," Techplayon, last accessed December 12, 2022, https://www.techplayon.com/spectral-efficiency-5g-nr-and-4g-lte/, ("Spectral Efficiency").

[50] *See,* Spectral Efficiency. *See also*, Mike Eddy, "Overcoming a Spectrum Deficit in a 5G World," Electronic Design, April 3, 2021, last accessed December 13, 2022, https://www.electronicdesign.com/industrial-automation/article/21159765/resonant-overcoming-a-spectrum-deficit-in-a-5g-world.

[51] To achieve peak efficiency the device must be directly in front of the base station under perfect RF, the base station is transmitting all resources and power to the device, it is using the most efficient data transfer method, for example.

[52] For 3G we use 2.6 bps/MHz, for 4G we use 3.5 bps/MHz, for 5G we use 6 bps/MHz, and for 6G we use 10 bps/MHz.

[53] Shannon's Law: This theorem "sets an upper limit on the rate at which data can be transmitted over any communications channel, whether wired or wireless." Shannon's law measures channel capacity as a function of the radio frequency of spectrum used, the number of antennas on uncorrelated signal paths, and the signal-to-noise ratio on the channel. *See* Larry Hardesty, "Explained: The Shannon Limit," MIT News, January 19, 2010, available at https://news.mit.edu/2010/explained-shannon-0115. *See also*, Waveform, "5G's Faster Data Rates and Shannon's Law," April 27, 2022, last accessed December 14, 2022, https://www.waveform.com/a/b/guides/5g-and-shannons-law, ("5G's Faster Data Rates and Shannon's Law").

C. Building Cell Sites

Deploying more cell sites, including small cells, is another way to increase the capacity of a wireless network. Increasing the number of cell sites increases the capacity of a given network by dividing or splitting cells to reduce cell size. This functionally allows for the reuse of existing spectrum, thereby increasing the overall capacity. Ideally, each cell would continue to deploy the full set of frequencies available for the market area, but this is only feasible up to a certain point.[54] Unfortunately, this approach also has natural limitations, as discussed below.

After successive deployments of macro cells throughout earlier network generations, macro coverage is beginning to reach maturation, with small cells anticipated to play a key complementary role to macro cells in the deployment of 5G.[55] As such, we anticipate the growth of macro cells over the next decade to occur at a lower rate than when the rollouts of 3G and 4G occurred. This is shown in Appendix Table B1.

When 4G/LTE subscriptions started accelerating around 2013-2014, and the industry had positioned itself to service the increased traffic by deploying more cell sites, the YoY average growth rate of macro sites was approximately 3.5% (2011-2015).[56] Given not all 5G site growth will be on macro towers, we assume that 5G sites will grow at half that rate, 1.75%, and use this to forecast the macro cell sites from 2022 – 2032. We estimate that by 2032 there will be approximately 354,000 macro sites, or a total additional deployment of approximately 61,000 sites between 2022 – 2032. This can be seen in Figure 3.

Next, we turn to the growth in small cells. While the macro cell infrastructure is mature, small cells are still at their nascent stage. Industry analysts report upwards of 80% of all future

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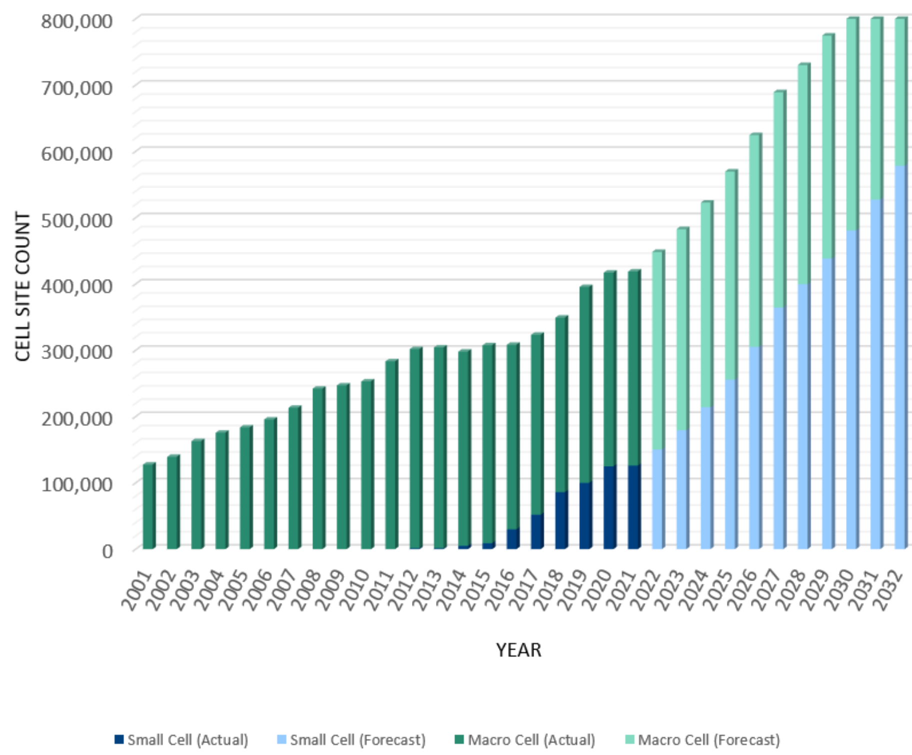
54 This ideal scenario is not realistically achievable after cells are shrunk to a certain size, as self-interference concerns limit the ability to re-use the same bands in directly adjacent cells. Additional infrastructure in the form of small cells typically use a limited sub-set of spectrum bands licensed to an operator.

55 *See*, Scott Bergmann, "A Year of Accelerated Wireless Infrastructure Investment," CTIA, March 22, 2019, last accessed December 6, 2022, https://www.ctia.org/news/a-year-of-accelerated-wireless-infrastructure-investment, ("CTIA: Accelerated Wireless Infrastructure"). *See also*, "Smart Cities: How 5G Can Help Municipalities Become Vibrant Smart Cities," Accenture, 2017, https://api.ctia.org/docs/default-source/default-document-library/how-5g-can-help-municipalities-become-vibrant-smart-cities-accenture.pdf. *See also*, "Impact of Federal Regulatory Reviews on Small Cell Deployment," Accenture, March 12, 2018, https://api.ctia.org/docs/default-source/default-document-library/small-cell-deployment-regulatory-review-costs_3-12-2018.pdf ("Accenture: 2018 Small Cell Report").

56 CTIA data on macro cell sites.

deployments will be small cells.[57] Our forecast suggests that by 2027, the United States will have around 365,000 small cells deployed and this will increase to about 580,000 by 2032. Keeping in mind initial over-estimates of small cell deployment, we believe our ten-year forecast is a reasonable one, expecting an optimistic level of small cell deployment. Figure 3 shows a composite chart of macro and small cell sites till 2032.

FIGURE 3: ACTUAL AND FORECASTED CELL SITES 2001-2032: SMALL VERSUS MACRO CELL



Sources and Notes: *See*, Appendix Table B1
2001-2021 data based upon CTIA data.
Macro cells: 2022 onwards based on Brattle forecast using 1.75% YoY growth rate.
Small cell forecast: 2022-2027 based on Brattle forecast using a 19.4% annual growth rate and 2028-2032 based on half of that rate.

While additional infrastructure may be desirable to provide additional capacity, deploying new sites is expensive, time consuming, and has a natural limit, "requiring the construction of extra

[57] FCC, "FCC Facilitates Wireless Infrastructure Deployment for 5G," FCC-18-133, 33 FCC Rcd 9088 (14), September 27, 2018, https://www.fcc.gov/document/fcc-facilitates-wireless-infrastructure-deployment-5g. "From a regulatory perspective, these raise different issues than the construction of large, 200-foot towers that marked the 3G and 4G deployments of the past. Indeed, estimates predict that upwards of 80 percent of all new deployments will be small cells going forward. To support advanced 4G or 5G offerings, providers must build out small cells at a faster pace and at a far greater density of deployment than before" (at p. 2).

towers/antennas, deploying more radios and base station equipment; as well as extending additional backhaul links to link new towers back into the mobile operator's core network."[58] Investments in additional macro cell sites include capital expenditures, such as the cost of the land, towers, radios and backhaul, and operating expenditures, such as electricity, maintenance, security, etc. These capital and operating expenditures cost billions of dollars in capex.[59]

In sum, keeping up the pace of new cell site construction comes with practical challenges including site acquisition, acquiring fiber backhaul and reliable power, and a shortage of trained work force talent. Site acquisition gets more challenging in urban and even suburban areas, as providers seek to find the right site locations to provide capacity relief, while minimizing interference from surrounding sites and navigating the state and local approval processes. Operators work to obtain the best site locations while balancing the costs of leasing new space for towers and sites in order to provide quality service for their customers. Regardless, there are real limits about the ability for operators to rely on additional infrastructure to meet capacity demand. Regulators functionally limit the number and location of sites, so the needed sites might not be available regardless of the carrier's willingness to invest. This and other natural limits on the number of available sites is compounded by the fact that multiple carriers are all competing for ideal locations, particularly for small cell deployments. Therefore, if historical technology trends hold and forecasted traffic patterns are realized, these solutions are unlikely to be sufficient to meet rapidly growing traffic demand.

Controlling for advancements in technology and deployments, we estimate that there will be an almost four-fold increase in traffic per site in the next 10 years, putting continued strain on existing networks and adding pressure for mobile operators to find new spectrum to ease capacity constraints. To meet the growing demands of wireless networks, additional frequencies will be a necessary part of the solution.

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[58] *See* Expanding Mobile Wireless Capacity, at p. 695.

[59] One analyst source estimates that "between 2022 and 2025, mobile operators will need to invest more than USD 600 billion in capex." *See* Mordor Intelligence, "United States Telecom Towers Market – Growth, Trends, COVID-19 Impact, and Forecasts (2023-2028)," accessed January 6, 2023, https://www.mordorintelligence.com/industry-reports/united-states-telecom-towers-market

IV. Absent Capacity from More Full-Powered, Licensed Spectrum Macro Networks Will Likely Be Constrained

A. Capacity Constraint and Spectrum Deficit if No New Spectrum is Made Available

To estimate the spectrum deficit, we use a model of supply and demand for macro network data capacity. Our data projections already exclude Wi-Fi offload.[60] To project macro network demand, we estimate the amount of traffic that will be carried by small cells, and remove that from our demand projections. We then calibrate the model assuming that network capacity will just meet demand in 2025. This assumption recognizes that, with several auctions in the past few years, there is, or shortly will be, more spectrum licensed than will be needed to meet near-term demand. That this current inventory of licensed spectrum will be exhausted by 2025 is based in part on judgement, but is informed by the recognition that 2025 provides the carriers two years to fully deploy the complete set of their licensed C-Band frequencies.

We use our calibrated model to project network capacity. This project takes into account improvements in spectrum efficiency, growth of cell sites, and the integration of licensed, but not yet deployed, spectrum into mobile networks. By comparing projected network capacity and demand, we can estimate any shortfalls in the ability of capacity to meet demand.[61] We then estimate how much additional spectrum is needed to make up that capacity shortfall.

We find that if no new spectrum bands are allocated for terrestrial mobile use in the next 5 years, then the U.S. is expected to have a capacity deficit of roughly 10 exabytes per month and a spectrum deficit of roughly 400 megahertz. In ten years, without new mobile spectrum, the capacity deficit will increase to almost 17 exabytes per month and the spectrum deficit will more than triple to approximately 1,400 megahertz. See Table 3 and Appendix C, Table C1.

[60] As noted above in Section II.C, we assume that MVNO non-WiFi offload is carried via licensed spectrum and this does not reduce demand for that spectrum.

[61] Any projected network capacity surpluses do not cause any significant policy concerns.

B. The Effect of Demand Shock and New Spectrum Availability on Capacity Constraint and Spectrum Deficit

To understand the sensitivity of our model to various uncertainties, we calculate the spectrum deficit under alternative demand assumptions. Many factors can influence the spectrum deficit. Variations in macro network demand can come from many sources, such as analysts' expectations about the mobile traffic not being realized and the share of realized offload being higher or lower than expected. Similarly, supply expectations also contain uncertainty. For example, spectral efficiency could be higher or lower than predictions; technology transitions might not happen according to expectations, and macro and small cell growth could fall short or exceed our forecasts. Rather than modeling all these variations separately, we incorporate the uncertainties they represent into four broad scenarios – a ±10% and ±20% change in demand. A summary of the results is presented below in Table 3, and details are in presented in Appendix C Tables C1-C5.

TABLE 3: SPECTRUM DEFICIT AND SENSITIVITY TO DEMAND CHANGES

Year		2027 [1]	2032 [2]
Base Traffic Forecast			
Spectrum Deficit (Megahertz)	[a]	401	1,423
Spectrum Deficit %	[b]	47%	165%
Traffic Increase 10%			
Spectrum Deficit (Megahertz)	[c]	558	1,688
Spectrum Deficit %	[d]	65%	196%
Traffic Increase 20%			
Spectrum Deficit (Megahertz)	[e]	715	1,953
Spectrum Deficit %	[f]	83%	227%
Traffic Decrease 10%			
Spectrum Deficit (Megahertz)	[g]	245	1,158
Spectrum Deficit %	[h]	28%	134%
Traffic Decrease 20%			
Spectrum Deficit (Megahertz)	[i]	88	893
Spectrum Deficit %	[j]	10%	104%

Notes and Sources:
[a]-[b]: Table C1: Capacity and Spectrum Deficit in 5 and 10 years if no new Spectrum is Available in 2027 and 2032.
[c]-[d]: Table C2: Demand Increase 10%.
[e]-[f]: Table C3: Demand Increase 20%.
[g]-[h]: Table C4: Demand Decrease 10%.
[i]-[j]: Table C5: Demand Decrease 20%.

We conclude that even with a significant decrease in demand (or, equivalently, unexpected increase in supply), the current spectrum availability is not adequate. Even with a 20% decrease in demand, which all else being equal is highly unlikely, there is going to be a spectrum deficit in 2032 if no new spectrum is allocated to mobile uses. By contrast, a 20% *increase* in demand would obviously exacerbate the deficit and the follow-on, downstream negative effects. Given the possibility of accelerating data-intensive 5G applications such as fixed wireless home broadband access, AR/VR, aggregate IoT connections, or other unforeseen popular use cases, a 20% increase in demand is not an unreasonable possibility (particularly over the projected 10-year window).

V. Conclusion

Our analysis indicates that, given the pace of the demand growth, technological solutions and deploying more cell sites are insufficient to ease the capacity constraint currently facing the U.S. cellular networks. Spectrum availability is the key to solving the capacity shortfall and Congress, the FCC, and other policymakers should work to allocate more spectrum for licensed mobile uses in a timely manner. Otherwise, the U.S. may run the risk of losing leadership in the international wireless space due to unavailability of licensed spectrum.[62]

A lack of additional high-power licensed spectrum would have several effects throughout the wireless ecosystem. Wireless service is a highly competitive industry, with firms making massive investments to compete in providing as much value to consumers as possible. Without cost-effective means to increase capacity—additional spectrum—operators would have to effectively limit use of their network. Given the dynamic nature of wireless competition, it is difficult to anticipate exactly what form these limitations would take, but certainly consumers would face a less reliable, robust, or consistently improving experience than they have from mobile wireless networks today.

Fixed wireless access would likely be the first service to be impacted—already today home broadband over 5G is only offered in locations where operators have available capacity in the network to provide sufficient quality of service for a home connection. Without additional

[62] *See, e.g.* for example: Janette Stewart, Chris Nickerson, Juliette Welham, “Comparison of Total Mobile Spectrum in Different Markets,” Analysis Mason, CTIA, September, 2022, https://api.ctia.org/wp-content/uploads/2022/09/Comparison-of-total-mobile-spectrum-28-09-22.pdf. See also, “Data Demand is Causing Spectrum Deficit; What Can Operators Do?” RCR Wireless, May 5, 2021, last accessed December 9, 2022, https://www.rcrwireless.com/20210505/5g/data-demand-is-causing-spectrum-deficit-what-can-operators-do.

spectrum, fixed wireless access will not be able to reach its potential scale, limiting the opportunity for additional competition to be injected into the home broadband market.

Operators may also look to continue or further limit the data-intensity of specific applications, such as streaming video, or otherwise manage their networks to ration limited capacity. The long trend of declining prices for unlimited wireless service may slow or stall as operator turn to more expensive options to increase supply. In short, the progress toward wireless connectivity abundance would slow, with knock-on effects throughout the economy. Spectrum repurposing is a difficult and time-consuming process, and unfortunately there is not an adequate pipeline of spectrum anticipated to meet mobile demand today. Our analysis gives a glimpse of the stunted wireless future if policymakers do not act.

In five years, the U.S. is expected to have a spectrum deficit of about 400 megahertz, which could more than triple to approximately 1,400 megahertz over another five years, even accounting for optimistic improvements in spectral efficiency and new infrastructure deployment. Additional spectrum is the only realistic option for meeting this gap.

Appendices

Appendix A: Demand and Traffic Growth

We are interested in understanding long-term trends in traffic growth (2022 – 2032). However, the VNI data includes only five-year projections. For predicting traffic growth from 2023 – 2032, we use a combination of a projected CAGR and a regression analysis. We use the 2010-2022 Cisco mobile traffic data, which is comprised of actual data traffic forming the basis of each report from 2010 – 2018, as well as Cisco's 2018 forecasts for 2019 – 2022 North America traffic, as our baseline traffic numbers.[63] For the years 2023 – 2028, we use Ericsson's predicted 2022 – 2028 CAGR (23%) to generate forecasted traffic.[64] We then use the actual and predicted traffic data from 2010 – 2028 as the dependent variable in a regression analysis, predicting data traffic for 2029 – 2032 based on a quadratic time trend, a COVID indicator, and the previous year's population as covariates. The results are presented in Table A1.

[63] See Cisco Annual Internet Report (2018–2023). *See also* Cisco VNI: Global Mobile Data Traffic Forecast Update.

[64] *See* Ericsson Mobility Report, November 2022, p. 39. The Cisco data is a little more conservative than the Ericsson data so we use it for our baseline of actual data usage. The Ericsson data have projections longer into the future, so we use the growth rates from those projections.

TABLE A1: NORTH AMERICAN MOBILE DATA TRAFFIC (ACTUALS AND FORECAST)

Year [1]	North America Mobile Data Traffic (PB/month) [2]
2010	49
2011	119
2012	222
2013	389
2014	563
2015	557
2016	1,411
2017	1,261
2018	1,804
2019	2,500
2020	3,405
2021	4,485
2022	5,846
2023	7,191
2024	8,844
2025	10,879
2026	13,381
2027	16,458
2028	20,244
2029	22,656
2030	26,148
2031	29,904
2032	33,918

Sources and Notes:
[B]: For 2010 data, *see,* "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010-2015," Cisco, February 1, 2011, Table 9. For 2011 data, *see,* "Cisco Visual Networking Index: Forecast and Methodology, 2011-2016," Cisco, May 30, 2012, Table 16. For 2012 data, *see*, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017," February 6, 2013, Table 6. For 2013 data, *see,* "Cisco Visual Networking Index: Forecast and Methodology, 2013-2018," Cisco, June 10, 2014, Table 16. For 2014 data, *see,* "Cisco Visual Networking Index: Forecast and Methodology, 2014-2019," Cisco, May 27, 2015, Table 16. For 2015 data, *see*, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015-2020," Cisco, February 3, 2016, Table 5. For 2016 data, *see*, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021," Cisco, February 7, 2017, Table 4. For 2017-2022 data, *see*, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017-2022," Cisco, February 2019, Table 3. Note that values for 2019-2022 are Cisco forecasts. Also, note that for years 2010, 2012, 2015, and 2016, values in source are given in TB per month, so they have been multiplied by .001 to convert to PB. Data for 2023-2032 were predicted using the regression methodology outlines in Appendix A.

Appendix B: Infrastructure

TABLE B1: FORECASTED AND ACTUAL CELL SITE GROWTH IN THE UNITED STATES 2022-2032

Year [1]	Total Cell Sites [2]	Macro Sites [3]	Small Cell [4]
2001	127,540	127,540	
2002	139,338	139,338	
2003	162,986	162,986	
2004	175,725	175,725	
2005	183,689	183,689	
2006	195,613	195,613	
2007	213,299	213,299	
2008	242,130	242,130	
2009	247,081	247,081	
2010	253,086	253,086	
2011	283,385	283,385	
2012	301,779	300,479	1,300
2013	304,360	302,960	1,400
2014	298,055	293,055	5,000
2015	307,626	298,626	9,000
2016	308,334	278,334	30,000
2017	323,448	271,448	52,000
2018	349,344	263,344	86,000
2019	395,562	295,562	100,000
2020	417,215	292,215	125,000
2021	418,887	292,887	126,000
2022		298,001	150,399
2023		303,205	179,522
2024		308,499	214,285
2025		313,886	255,779
2026		319,366	305,308
2027		324,943	364,428
2028		330,617	399,711
2029		336,390	438,412
2030		342,264	480,859
2031		348,240	527,415
2032		354,321	578,480

Sources and Notes:

[1]-[2]: CTIA 2022 Survey provides actuals for all cells from 2001-2021. For 2022 onwards, assume macro cells grow yearly at 20% of the 5-year CAGR, where the CAGR is 6.68%.

Appendix C: Calculating Spectrum Deficit Under Alternative Scenarios

TABLE CI: CAPACITY AND SPECTRUM DEFICIT IN 5 AND 10 YEARS IF NO NEW SPECTRUM IS AVAILABLE IN 2027 AND 2032

Year		**2022**	**2027**	**2032**
		[1]	[2]	[3]
Aggregate Demand For Capacity				
Data Traffic Forecast (PB/month)	[a]	5,846	16,458	33,918
Traffic Growth	[b]		282%	580%
Adjustments in Demand for Capacity				
Adjustment for Traffic on Small Cells				
Number of Small cell	[c]	150,399	364,428	578,480
Macro Cell Equivalent Small Cell Sites	[d]	15,040	36,443	57,848
Total Macro Cell Sites	[e]	298,001	324,943	354,321
Macro Cell + Macro Cell Equivalent Sites	[f]	313,041	361,386	412,169
Traffic on Small Cells (PB/month)	[g]	280.87	1,660	4,760
Small Cell & Wi-Fi Adjusted Traffic on Macro Cells (PB/month)	[h]	5,565	14,799	29,157
Adjusted Traffic Growth on Macro Cells	[i]		266%	524%
Supply Side Adjustments				
Spectral Efficiency				
Average Spectral Efficiency (bps/Hz)	[j]	4.28	5.74	6.13
Spectral Efficiency Growth	[k]	111%	134%	143%
Cell Sites				
Total Macro Cell Sites	[l]	298,001	324,943	354,321
Total Cell Site Growth	[m]		109%	119%
Spectrum				
Spectrum Licensed	[n]	1,081	1,840	2,010
Spectrum Available/ Usable	[o]	862	1,166	1,228
Deficit				
Traffic per Site Growth	[p]		244%	441%
Tech Adjusted Traffic/Site Growth	[q]		182%	308%
Excess Traffic After Technology & Infrastructure Adjustment (PB/month)	[r]		10,123	17,123
Total Spectrum Required	[s]		1,567	2,651
Spectrum Deficit	[t]		401	1,423
% Deficit	[u]		47%	165%

Sources and Notes:
[a]: North American Mobile Traffic (PB/month)
[b]: 2027: [a][2] / [a][1]; 2032: [a][3] / [a][1].
[c]: Forecasted and Actual Cell site Growth in the United States 2022-2032
[d]: [c] / 10; Note, we assume there are roughly 10 small cells per macro cell, hence the adjusted value.
[e]: Total Actual and Forecasted Macro Cell Sites.
[f]: [d] + [l].
[g]: ([a] / [f]) *[d].
[h]: [a] - [g].
[i]: 2027: [h][2] / [h][1]; 2032: [h][3] / [h][1].
[j]: Spectral Efficiency Table.
[k]: 2022: [j][1] / 3.87 (average spectral efficiency in 2021); 2027: [j][2] / [j][1]; 2032: [j][3] / [j][1].
[l]: Total Actual and Forecasted Macro Cell Sites.
[m]: 2027: [l][2] / [l][1]; 2032: [l][3] / [l][1].
[n]: Megahertz of Spectrum by Year Table.
[o]: Spectrum Deficit Model Table.
[p]: [i] / [m].
[q]: [p] / [k].
[r]: [q] * [h][1].
[s]: [o][1] * [q].
[t]: [s] - [o].
[u]:[t] / [o].

TABLE C2: DEMAND INCREASE 10%

Year		2022	2027	2032
		[1]	[2]	[3]
Aggregate Demand For Capacity				
Data Traffic Forecast (PB/month)	[a]	5,846	18,104	37,310
Traffic Growth	[b]		310%	638%
Adjustments in Demand for Capacity				
Adjustment for Traffic on Small Cells				
Number of Small cell	[c]	150,399	364,428	578,480
Macro Cell Equivalent Small Cell Sites	[d]	15,040	36,443	57,848
Total Macro Cell Sites	[e]	298,001	324,943	354,321
Macro Cell + Macro Cell Equivalent Sites	[f]	313,041	361,386	412,169
Traffic on Small Cells (PB/month)	[g]	280.87	1,826	5,236
Small Cell & Wi-Fi Adjusted Traffic on Macro Cells (PB/month)	[h]	5,565	16,278	32,073
Adjusted Traffic Growth on Macro Cells	[i]		293%	576%
Supply Side Adjustments				
Spectral Efficiency				
Average Spectral Efficiency (bps/Hz)	[j]	4.28	5.74	6.13
Spectral Efficiency Growth	[k]	111%	134%	143%
Cell Sites				
Total Macro Cell Sites	[l]	298,001	324,943	354,321
Total Cell Site Growth	[m]		109%	119%
Spectrum				
Spectrum Licensed	[n]	1,081	1,840	2,010
Spectrum Available/ Usable	[o]	862	1,166	1,228
Deficit				
Traffic per Site Growth	[p]		268%	485%
Tech Adjusted Traffic/Site Growth	[q]		200%	338%
Excess Traffic After Technology & Infrastructure Adjustment (PB/month)	[r]		11,135	18,835
Total Spectrum Required	[s]		1,724	2,916
Spectrum Deficit	[t]		558	1,688
% Deficit	[u]		65%	196%

Sources and Notes:
See Table C1

TABLE C3: DEMAND INCREASE 20%

Year		2022	2027	2032
		[1]	[2]	[3]
Aggregate Demand For Capacity				
Data Traffic Forecast (PB/month)	[a]	5,846	19,750	40,701
Traffic Growth	[b]		338%	696%
Adjustments in Demand for Capacity				
Adjustment for Traffic on Small Cells				
Number of Small cell	[c]	150,399	364,428	578,480
Macro Cell Equivalent Small Cell Sites	[d]	15,040	36,443	57,848
Total Macro Cell Sites	[e]	298,001	324,943	354,321
Macro Cell + Macro Cell Equivalent Sites	[f]	313,041	361,386	412,169
Traffic on Small Cells (PB/month)	[g]	280.87	1,992	5,712
Small Cell & Wi-Fi Adjusted Traffic on Macro Cells (PB/month)	[h]	5,565	17,758	34,989
Adjusted Traffic Growth on Macro Cells	[i]		319%	629%
Supply Side Adjustments				
Spectral Efficiency				
Average Spectral Efficiency (bps/Hz)	[j]	4.28	5.74	6.13
Spectral Efficiency Growth	[k]	111%	134%	143%
Cell Sites				
Total Macro Cell Sites	[l]	298,001	324,943	354,321
Total Cell Site Growth	[m]		109%	119%
Spectrum				
Spectrum Licensed	[n]	1,081	1,840	2,010
Spectrum Available/ Usable	[o]	862	1,166	1,228
Deficit				
Traffic per Site Growth	[p]		293%	529%
Tech Adjusted Traffic/Site Growth	[q]		218%	369%
Excess Traffic After Technology & Infrastructure Adjustment (PB/month)	[r]		12,148	20,547
Total Spectrum Required	[s]		1,881	3,181
Spectrum Deficit	[t]		715	1,953
% Deficit	[u]		83%	227%

Sources and Notes:
See Table C1

TABLE C4: DEMAND DECREASE 10%

Year		2022	2027	2032
		[1]	[2]	[3]
Aggregate Demand For Capacity				
Data Traffic Forecast (PB/month)	[a]	5,846	14,812	30,526
Traffic Growth	[b]		253%	522%
Adjustments in Demand for Capacity				
Adjustment for Traffic on Small Cells				
Number of Small cell	[c]	150,399	364,428	578,480
Macro Cell Equivalent Small Cell Sites	[d]	15,040	36,443	57,848
Total Macro Cell Sites	[e]	298,001	324,943	354,321
Macro Cell + Macro Cell Equivalent Sites	[f]	313,041	361,386	412,169
Traffic on Small Cells (PB/month)	[g]	280.87	1,494	4,284
Small Cell & Wi-Fi Adjusted Traffic on Macro Cells (PB/month)	[h]	5,565	13,319	26,242
Adjusted Traffic Growth on Macro Cells	[i]		239%	472%
Supply Side Adjustments				
Spectral Efficiency				
Average Spectral Efficiency (bps/Hz)	[j]	4.28	5.74	6.13
Spectral Efficiency Growth	[k]	111%	134%	143%
Cell Sites				
Total Macro Cell Sites	[l]	298,001	324,943	354,321
Total Cell Site Growth	[m]		109%	119%
Spectrum				
Spectrum Licensed	[n]	1,081	1,840	2,010
Spectrum Available/ Usable	[o]	862	1,166	1,228
Deficit				
Traffic per Site Growth	[p]		219%	397%
Tech Adjusted Traffic/Site Growth	[q]		164%	277%
Excess Traffic After Technology & Infrastructure Adjustment (PB/month)	[r]		9,111	15,410
Total Spectrum Required	[s]		1,410	2,386
Spectrum Deficit	[t]		245	1,158
% Deficit	[u]		28%	134%

Sources and Notes:
See Table C1

TABLE C5: DEMAND DECREASE 20%

Year		2022	2027	2032
		[1]	[2]	[3]
Aggregate Demand For Capacity				
Data Traffic Forecast (PB/month)	[a]	5,846	13,167	27,134
Traffic Growth	[b]		225%	464%
Adjustments in Demand for Capacity				
Adjustment for Traffic on Small Cells				
Number of Small cell	[c]	150,399	364,428	578,480
Macro Cell Equivalent Small Cell Sites	[d]	15,040	36,443	57,848
Total Macro Cell Sites	[e]	298,001	324,943	354,321
Macro Cell + Macro Cell Equivalent Sites	[f]	313,041	361,386	412,169
Traffic on Small Cells (PB/month)	[g]	280.87	1,328	3,808
Small Cell & Wi-Fi Adjusted Traffic on Macro Cells (PB/month)	[h]	5,565	11,839	23,326
Adjusted Traffic Growth on Macro Cells	[i]		213%	419%
Supply Side Adjustments				
Spectral Efficiency				
Average Spectral Efficiency (bps/Hz)	[j]	4.28	5.74	6.13
Spectral Efficiency Growth	[k]	111%	134%	143%
Cell Sites				
Total Macro Cell Sites	[l]	298,001	324,943	354,321
Total Cell Site Growth	[m]		109%	119%
Spectrum				
Spectrum Licensed	[n]	1,081	1,840	2,010
Spectrum Available/ Usable	[o]	862	1,166	1,228
Deficit				
Traffic per Site Growth	[p]		195%	353%
Tech Adjusted Traffic/Site Growth	[q]		146%	246%
Excess Traffic After Technology & Infrastructure Adjustment (PB/month)	[r]		8,098	13,698
Total Spectrum Required	[s]		1,254	2,121
Spectrum Deficit	[t]		88	893
% Deficit	[u]		10%	104%

Sources and Notes:
See Table C1

Accelerating the 5G Economy in the US

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Introduction

The US leads the world in mobile communications. It is the country with the most sustained and intensive investment in both networks and radiofrequency spectrum. The US mobile industry's investments have been particularly effective in deploying the initial wave of 5G networks and providing a platform for further 5G innovations that will continue through the 2020s.

Although the nation's commercial mobile networks are expanding, they could soon face capacity constraints – unless they receive an infusion of additional transmission power, through additional licensed spectrum. Additional spectrum—particularly licensed mid-band spectrum, which provides the performance necessary to support large-scale wireless networks—is essential if the US is to continue to lead and grow the 5G economy.

The 5G economy is the US economy as powered by wireless high-speed connectivity. On the basis of BCG's ongoing research, we estimate that by 2030, the 5G economy will have contributed from $1.4 trillion to $1.7 trillion in US economic growth. Deployment of this wireless system will have created from 3.8 million to 4.6 million jobs and will have driven innovation throughout the country.

The first phase of this growth, which began in 2019 with the introduction of 5G, has affected the economy directly through network infrastructure development and deployment. A second phase is now underway, as 5G networks continue to roll out and improve. The new wave of economic potential derives from advanced applications that 5G makes possible, such as augmented reality (AR), precision robotics and manufacturing, and the Internet of Things (IoT) at a massive scale. As these applications become integrated into the country's economic and social systems, they expand opportunity and raise productivity across the country.

In an earlier article evaluating the economic relevance of 5G networks, "Building the US 5G Economy," we identified five key success factors that would enable the 5G economy to thrive over the next decade. The conventional narrative of a race among nations for technological dominance in the 5G arena often focuses on narrow metrics, such as the number of subscribers or cell towers. Although such measurements may be relatively easy to gather, they tell an incomplete story of the potential performance of wireless networks and the integration of 5G capabilities into economic production. In this article, we examine five factors that we believe serve as more accurate, holistic indicators of 5G's ongoing positive impact on business innovation and activity:

- **Spectrum Availability.** The lifeblood of wireless networks, spectrum is responsible for sending calls, texts, and data from device to device. To meet escalating demand for wireless capacity, providers need a sufficient mix of low-, mid-, and high-band spectrum to provide the right combination of coverage and capacity for delivering services over the range of population densities from rural to suburban to urban. Spectrum should be made available through a transparent, market-based set of forward-looking auctions, and should be licensed to deliver performance characteristics that support reliable, robust wireless service nationwide. (See the sidebar "High-Band, Low-Band, and Mid-Band.")

HIGH-BAND, LOW-BAND, AND MID-BAND

A confluence of technological advancements makes possible the higher performance of 5G compared to earlier cellular technology, but the most important and constraining input for mobile networks is radio spectrum. 5G transmissions can leverage numerous bands of spectrum, but the properties of these bands generally fall into three different categories: low-band, mid-band, and high-band spectrum. Ideally, 5G networks will have access to enough bandwidth of each spectrum type to provide a reliable, high-quality experience for mobile subscribers. The three spectrum categories have the following characteristics:

- **High-Band Spectrum.** This spectrum category, also called millimeter wave (mmWave), can achieve the highest speeds because it uses large amounts of spectrum, generally above 10 GHz. These frequencies, which were not previously considered useful for communications, are available in relative abundance. Furthermore, these high-frequency waves' short wavelength allows them to better leverage recent advances in antenna technology. Unfortunately, these signals generally travel only a short distance—about one city block—and are easily obstructed by buildings or objects.
- **Low-Band Spectrum.** This region of the spectrum is historically the range used for most cellular transmission. Low-band spectrum provides blanket network coverage for mobile operators. Low-band signals can travel many miles and penetrate buildings. On the other hand, not much of it is available, and it offers the slowest data throughput capacity and speeds of the three types of spectrum bands, making it inadequate for the most data-intensive applications.
- **Mid-Band Spectrum.** This part of the spectrum sits between high-band and low-band. It can take advantage of improvements in antenna technology and, if made available in sufficient quantities, can offer high data throughput capacity and wide coverage (up to about half a mile). C-Band spectrum, between 3.7 GHz and 4.2 GHz, is a good example of mid-band spectrum used for mobile communications in the US today.

Mid-band spectrum plays an important role in such popular 5G use cases as high-definition video streaming, responsive gaming applications, and high-speed internet or FWA—and it will play an increasingly important role in supporting future 5G applications at scale. It offers a cost-effective way to consistently deliver good speed and latency performance to consumers. The rollout of mid-band spectrum was made possible by the introduction of massive multiple input multiple output (MIMO) technology, which facilitates relatively low-cost transmission of a wider spectrum range on existing wireless tower infrastructure. Mid-band can be a game-changing technology in rural areas, where it can provide connectivity that would otherwise be unavailable, helping to bridge the digital divide, attract telecommuting professionals, and support economic growth.

- **Networks.** Capital investments in network infrastructure are critical to building strong 5G telecommunications infrastructure. Such investments cover cell towers, 5G base stations, security systems, and more. Local policies on rights-of-way, streetlights, and other public assets can play an important role in facilitating network deployment.
- **Innovation Ecosystem.** A virtuous cycle of innovation and development—funded by private-sector R&D spending, aligned with government policies, and backed by strong intellectual property protection—is essential for 5G's evolution, as well as for the development of products and services that ride on the networks.
- **Business Climate.** A commercial culture that is conducive to technological innovation will help 5G-enabled technologies thrive and will encourage the continued rollout of 5G networks. It flourishes when enabled by access to funding, openness to risk, and business-friendly government policies.
- **Talent.** Widespread availability of tech-related training and certification is important to ensure that the US workforce has the skills needed for future technological changes in 5G and beyond.

In the years since our initial research in this area, the opportunities associated with 5G have grown stronger. Companies have built initial 5G networks throughout the US, and consumers and businesses are taking advantage of the improved speed and performance that 5G provides. Wireless service providers are building and scaling early use cases that capture the potential of 5G, such as enhanced mobile broadband (eMBB) and fixed wireless access (FWA). (See the sidebar "Four Categories of 5G Service.")

FOUR CATEGORIES OF 5G SERVICE

Four categories of wireless technology service take advantage of 5G's faster speeds and higher bandwidth. Developed independently of one another, each has gradually gained scale over time and has been deployed in an ever-expanding variety of use cases. As 5G evolves, these four service categories are advancing along with it:

- **Enhanced Mobile Broadband (eMBB).** Companies in this category provide fast, reliable broadband service for mobile subscribers. Enhanced mobile broadband offers peak download speeds of 10 Gbps (tripling previous offerings) and can be used for videoconferencing and high-resolution (4K) video streaming. Phones can connect reliably even in challenging locations such as high-rise neighborhoods, airports, moving transit, and stadiums.
- **Fixed Wireless Access (FWA).** FWA delivers high-speed, high-capacity stationary broadband to homes and businesses, transmitting through radio frequency towers. It can reach clusters of homes and businesses in rural and suburban areas at a lower initial cost than fiber optic.
- **Massive Internet of Things (IoT).** The IoT offers efficient, low-cost, broad internet coverage to enable the interconnection of many smart devices and processes. Applications include smart manufacturing, logistics and tracking innovations, data-driven agriculture, wearable devices, and AI-enabled utilities and smart-city projects.
- **Ultra-Low-Latency, High-Reliability Communications.** Services in this category provide high-performance broadband access for connected devices that perform mission-critical vital functions such as the IoT, self-driving vehicles, telemedicine, government applications, and AR. During the remainder of the 2020s, advanced IoT use cases will continue to mature, enabling a broader array of 5G capabilities.

It's a start. But building out the full US 5G economy will require the entire decade. Each year, more progress will be made toward the envisioned end state.

In this report, we review the current state of the US 5G economy, assessed in terms of each of the five success factors noted above. We then examine the question of what to expect with regard to those factors during the second half of this decade.

The report concludes with five recommendations for US policymakers: increase the availability of licensed full-power mid-band spectrum for mobile use; create a future pipeline for licensed spectrum auctions; provide further incentives for 5G innovation; develop a 5G partnership function in governments; and promote and support the development of large-scale IoT deployment. Adopting these measures can help secure the future of the 5G economy with targeted efforts related to spectrum availability and overall support to help 5G networks reach their potential and yield all of the benefits that attend them.

The US 5G Economy Today

Since 2020, the 5G economy has made significant technological and institutional progress in the US on each of our key success factors. Collectively, spectrum availability, networks, innovation ecosystems, business climate, and talent serve as an index of 5G growth and influence.

Spectrum Availability. In the 2010s, US mobile data traffic grew considerably. It expanded almost a hundredfold over the decade. By contrast, since 2012, low- and mid-band spectrum availability increased by only about two times. Today, as 5G networks roll out, demand for US data traffic will continue to grow. BCG's analysis of Omdia's 2022 data suggests that by 2027 the amount of annual 5G data traffic will expand to seven to nine times the level of annual data traffic before 5G.

Recent research by The Brattle Group projects that mobile traffic will increase in the next five years by roughly 2.5 times, and almost sixfold increase in the next ten years. But if no new spectrum bands are allocated for commercial wireless use, the study estimates that the US could face a spectrum deficit of approximately 400 megahertz by 2027—a deficit that could more than triple to 1,423 megahertz by 2032.

These estimates represent the projected demand curve for 5G data traffic. However, doubts are growing about whether US wireless operators will be able to meet that demand. Capacity is directly related to spectrum availability, but the future availability of high-performance 5G spectrum to enable carriers to meet this demand is by no means guaranteed.

The US has not yet developed a current national spectrum strategy and has not identified any specific mid-band spectrum to make commercially available in the next five to ten years. Given the time required to make more spectrum available in the future, the lack of a pipeline of licensed full-power spectrum for 5G is an increasing concern.

Networks. Wireless network capital expenditure per capita in the US has increased by about 12% since 2019. By year's end in 2022, about 95% of the US population had access to a 5G network, and about 80% of the population had access to networks capable of download speeds of 200 Mbps, up to ten times faster than 4G. To achieve this expansion, the major wireless operators invested about $35 billion in wireless networks in 2021, or about $105 per capita, compared to $95 per capita in 2019.

5G networks deliver higher speeds and lower latencies. Wireless networks provide enough speed to support current enhanced mobile broadband, as well as new 5G FWA that rivals average speeds over cable today.

However, 5G does have limitations. First, performance depends on how many users are sharing limited spectrum resources in a given area. For example, network capacity can struggle to keep up with demand in dense urban areas with many simultaneous users. Second, rising data use as broadband service categories grow will intensify customer demand further. Accommodating this growth in wireless broadband use will require additional spectrum, particularly in the mid-band range. Third, the ability of network operators to increase the density of their networks and integrate new spectrum bands will depend, in part, on land use and right-of-way policies at the federal, state, and local levels. Although stakeholders have made some progress in this area, providers still face opaque permit approval processes and other challenges to optimizing the location of network infrastructure.

Innovative Ecosystems. The US remains a center for wireless innovation and continues to add new 5G research labs as the demand for advanced 5G applications increases. Wireless companies and their network and technology suppliers are offering simpler and more effective broadband solutions to their customers, and companies are developing advanced applications that leverage 5G capabilities.

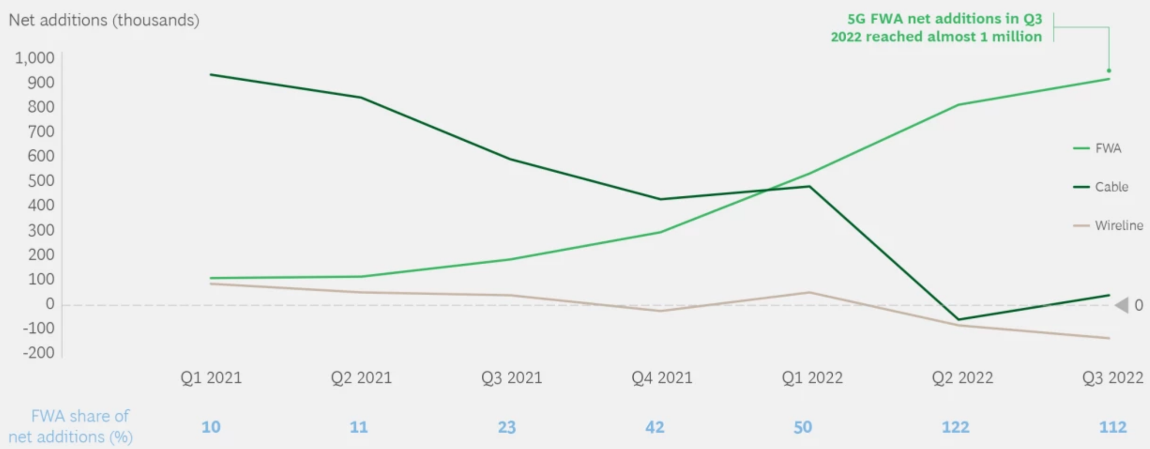
Several innovative use cases are gaining traction in the market. In cooperation with basketball and hockey leagues, Verizon has used 5G to establish immersive virtual reality (VR) and AR fan experiences in more than 60 stadiums and sports venues. These systems process and present data about players in real time and make predictions about each game as it is being played.

FWA usage in the US is growing rapidly, too, bringing a new dynamic to the US broadband market. This 5G service category grew by more than 70% in 2022, and mobile service operators now compete with cable TV providers in offering home internet connections in many locales. T-Mobile and Verizon are expected to reach 11 million to 13 million FWA customers by 2025. (See the sidebar “The Great FWA Rollout.”)

THE GREAT FWA ROLLOUT

Starting in the spring of 2022, all network-added broadband in the US has been fixed wireless access (FWA), compared to 10% to 20% in 2021. About half of all new customers are switching from cable TV connections. In other words, FWA has become a mainstream alternative to satellite and fiber, drawing market share from both. (See the exhibit.)

As FWA Usage Rises, Cable and Wireline Lose Momentum



Sources: FWA net additions (new subscribers) for 2021 from Ericsson FWA reports; companies and Leichtman Research Group, Inc.; BCG analysis.

Note: FWA = fixed wireless access.

Subscriptions have expanded rapidly as FWA broadband service becomes available. In the third quarter of 2022, the number of subscribers grew at a rate 450% above that of the year before, to 3 million in the US. It is now on track to reach 11 million or more by 2025.

FWA is transforming the geography of internet access. Its speed and versatile reliability appeal to businesses in densely populated areas, and yet urban users constitute only about 30% of the total subscriber base. In the US, suburbs lead in FWA 5G market share, with about 45% of all subscribers. Here, FWA brings new competition to markets that have had limited broadband options. In rural areas, FWA appears to be the primary home broadband of choice. Rural customers make up about 25% of the FWA market—a relatively high share, considering that the rural share of the country's population is about 18%.

The rural story is a triumph of persistent innovation and implementation, leading over time to a step-change in national connectivity, with a do-it-yourself component that adds to the technology's appeal. Before FWA was introduced in the early 2000s, most broadband connections in small towns required cumbersome antennas, typically installed by a specialist on a roof or tower in a town.

In contrast, FWA provides a MIMO-based platform, enabling directional antennas that make more efficient use of the available spectrum. Hardware manufacturers can more easily develop indoor, compact, and portable antennas. The new platform has revolutionized the scale of local loop wireless internet access, enabling local ISPs to provide enhanced access for their communities and allowing some individuals to set up their own connection points out of the box. The single 5G standard fosters collaboration among wireless service providers and alignment across customer and business needs.

Innovative 5G enterprise initiatives—ranging from smart-city urban deployments to remote locations such as oilfields and mining operations, which need connectivity for reliability and performance—are taking advantage of 5G capabilities. Other areas such as industrial IoT and cellular vehicle-to-everything (C-V2X) applications are still in development and early testing stages. These and other emerging areas, including health care and agriculture, will require time to solve challenges related to scale, cost, and ecosystem management. Nonetheless, they hint at the great potential impact of this technology.

For example, the Ford Motor Company and AT&T are outfitting Ford's Rouge Electric Vehicle Center in Dearborn, Michigan, with 5G connectivity and autonomous assembly line technology. This massive IoT project will automate production of the 2022 Ford F-150 Lightning, the first electric F-Series truck. Working with sensors and interconnected controls, these lines will improve the efficiency, safety, and design of the F-150 fleet.

An example of mission-critical IoT is taking place in Peachtree Corners, a smart city in Georgia. T-Mobile has partnered with the community to launch a fleet of self-driving vehicles that the city has dubbed Piloting Autonomous Use Locally (PAUL). The shuttles are equipped with gateways to the city-owned 5G network. They navigate by picking up signals from sensors on traffic lights, crosswalks, buildings, and roadside fixtures, as well as law enforcement messaging systems, input from pedestrians, and sensors on the vehicles themselves.

In the health care arena, Emory Healthcare is collaborating with Verizon to provide a 5G platform for accelerating a host of smart-hospital innovations related to remote patient monitoring, medical imaging, pre-surgical planning, and more. The platform provides integrated access to mobile edge computing, IoT devices, artificial intelligence/machine learning, and artificial reality tools to drive innovation across a wide variety of health-care use cases.

Business Climate. As a global center of digital technology, the US is a magnet for telecommunications innovation. According to Startup Genome's 2022 report, the US is home to 12 of the top 30 startup ecosystems in the world; it also hosts four of the top six cities for startups. That makes the US the highest-ranked country for both number of startups and quality of startups, in terms of the factors that make them likely to succeed.

Awareness of the value of 5G is growing in the digital sphere, with increased investment and noteworthy publicly funded innovation projects. The US Department of Defense is prototyping a 5G-to-Next-G smart warehouse system, the first in a series of DoD 5G investments that will total more than $500 million. Idaho National Laboratory has opened its 5G-based Wireless Test Range for exploring security risks and military capabilities. The National Science Foundation supports the Platforms for Advanced Wireless Research program, providing test platforms for a wide array of use cases and enabling research into cutting-edge technology to solve business challenges. All of this and more will contribute to rising demand.

Private company R&D will do the same. Many major wireless and tech businesses—including Verizon, AT&T, and T-Mobile—as well as startups such as the AR company Taqtile are investing in 5G research. For its part, Warner Media has incorporated 5G research into its work on virtual reality storytelling.

Talent. There is reason to be concerned about the staffing requirements associated with a 5G rollout, particularly the engineers, technicians, installers, equipment operators, and other professionals needed to install and maintain service. Talent levels have adequately kept pace with growth so far—but as early as the late 2010s, HR experts were warning industry leaders that more needed to be done to address the impending talent gap. Now, some stakeholders are taking action to address the issue.

The FCC released an interagency group report in January 2023 to propose methods for maintaining the telecommunications workforce. The report's recommendations include new recruitment efforts (for example, with veterans), new apprenticeship programs, a greater emphasis on diversity and inclusion, the use of Pell grants and other funding sources, and guidelines for emphasizing safety in the field.

Since 2020, for example, the US government has allocated about $80 billion in federal funding for technical training in wireless and broadband. The 2021 Infrastructure Investment and Jobs Act (IIJA) includes another $2.75 billion for workforce deployment grants. The number of apprenticeships has grown by about 16% annually since 2018. Telecommunications providers and technical schools have established new partnerships to upskill the workforce.

The Future of the 5G Economy

As the US continues to build out its 5G economy, it must maintain progress along all five key success factors: spectrum availability, networks, innovative ecosystems, business climate, and talent. Bringing the technology to scale and managing the barriers and risks that hold back full deployment will take time.

Planners must also manage the risks inherent in any new technology. For example:

- **Unpredictability in the spectrum pipeline represents a risk.** Areas of concern include unpredictability in the future supply of full power, the licensed spectrum for 5G (particularly mid-band spectrum), and the risk of falling behind global peers in enabling future 5G use cases.
- **Orchestrating the many ecosystem players for advanced 5G use cases is an ongoing challenge.** Planners must explore ways to overcome orchestration challenges among players in the innovative ecosystem in light of the complexity of B2B integration owing to the number of players involved and the transformative changes often required within businesses.
- **Digital talent will play an increasingly important role in the 5G economy going forward.** The US needs to develop the requisite digital talent domestically and continue to upskill its workforce to meet the needs of the 5G economy.

All of these risks are manageable. In this section, as we look at the future of success factors, we'll also consider ways to manage and mitigate risk.

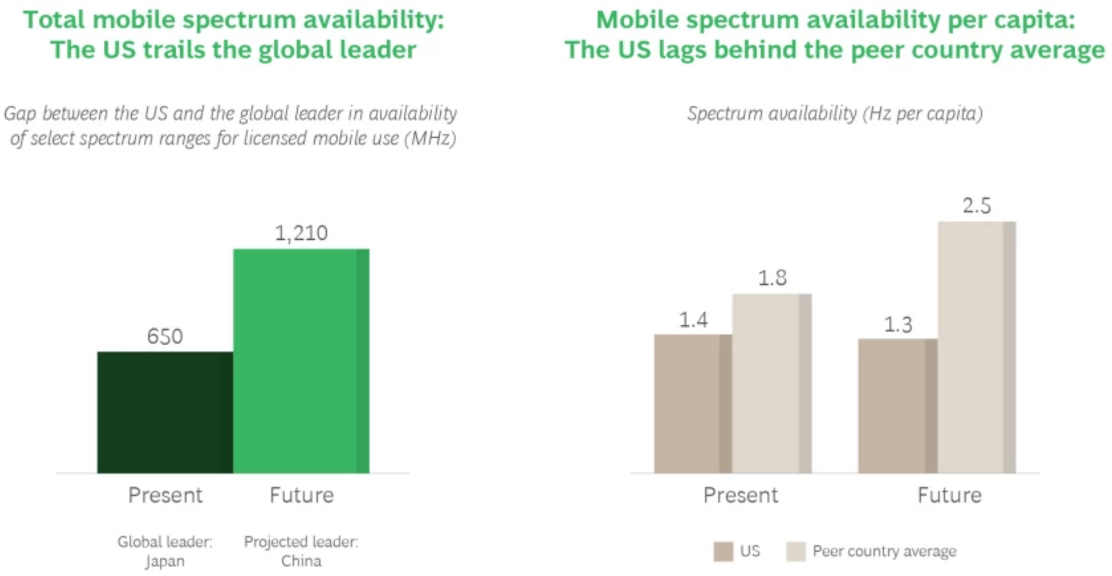
Spectrum Availability. Congressional authorization for the FCC to conduct spectrum auctions expired in March 2023. In the meantime, policymakers have not developed long-term plans for future auctions or spectrum reallocations.

The primary way for policymakers to fuel the supply side of the 5G ecosystem is by making more licensed full-power spectrum available for mobile use. This will ensure that the US is fully equipped to foster and respond to new 5G use cases. Future applications, whatever form they take, will likely demand more capacity, speed, and reliability from 5G networks.

On the other hand, spectrum shortages may lead to congestion issues for existing mobile services, impeding companies' ability to scale FWA or other data-intensive applications, and discouraging innovators from taking full advantage of 5G's potential. Establishing a clear plan for allocating the 5G spectrum is also important to give wireless service providers the certainty they need for long-term capacity and capital expenditure planning.

Today, the US trails a number of other countries—including Brazil, China, France, Germany, Italy, Japan, and the UK—in 5G spectrum availability. This gap will probably grow wider over the coming years if the US government does not hold further spectrum auctions.

Exhibit 1 - Projected US Gap in 3- to 7.2-GHz Spectrum Availability

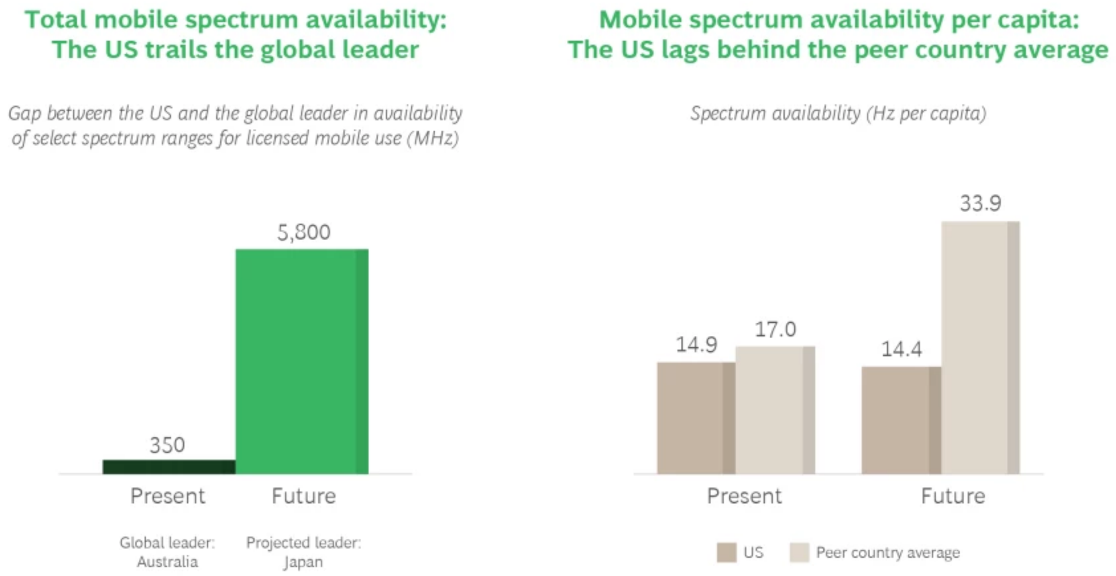


Sources: Analysys Mason 2; World Bank population projections; BCG analysis.

Note: US and peer country figures represent the average spectrum per capita, weighted by population. Peer countries include Brazil, China, France, Germany, Italy, Japan, and the UK. 2027 figures are estimates. Data in this exhibit reflects the radio frequency spectrum range from 3 to 7.2 GHz.

Exhibit 1 shows the gap in spectrum availability for the 3- to 7.2-GHz range if there are no further FCC auctions. Spectrum in this range is especially important for adding capacity to high-performing, wide-area networks. Exhibit 2 shows spectrum availability in the range above 24 GHz in the absence of further FCC auctions.

Exhibit 2 - Projected US Gap in Spectrum Availability Above 24 GHz



Sources: Analysys Mason 2; World Bank population projections; BCG analysis.

Note: US and peer country figures represent the average spectrum per capita, weighted by population. Peer countries include Brazil, China, France, Germany, Italy, Japan, and the UK. 2027 figures are estimates. Data in this exhibit reflects the radio frequency spectrum range above 24 GHz.

The potential impact on the 5G ecosystem of a stronger international alignment on spectrum allocations for such services is quite large. If the US steps out of the global debates on spectrum allocations for 5G—whether because it lacks of a plan, lacks auction authority, or opts out for some other reason—peer countries are ready to fill that void and identify their own suitable bands for 5G development. The US may then lose its first-mover advantage in identifying globally harmonized spectrum for 5G, and be left with a more insular approach to spectrum allocation outside the international consensus. That eventuality would have negative downstream effects on equipment, handsets, and services, and would limit the economic growth associated with 5G.

Networks. After years of building out 5G networks, the US is likely to see expanding use of its networks. Projected momentum will move penetration among US subscribers from 15% of the population in 2021 to 68% by 2025. Only South Korea is expected to have a greater proportion of 5G subscribers, at 73%. Network density will increase, too, with more towers and cells installed. Although the pace of increased network density is difficult to predict, it will not outstrip the need for additional spectrum investments.

This expansion will catalyze the innovation of more applications, requiring better network performance and higher speeds. Wireless service providers will bring mmWave to more parts of the network and will continue to upgrade in other ways—migrating to standalone 5G core networks, for example, to enable greater speed and less latency.

In 2022, the Creating Helpful Incentives to Produce Semiconductors and Science (CHIPS) Act authorized more than $1.5 billion in federal funding for wireless supply chain innovation. Industry and regulators may form partnerships to use that money more effectively. Collaboration with international providers, trade mechanisms that encourage the collaboration, and new sourcing relationships will probably help diversify the manufacturing base. Telecommunications manufacturers will learn to source from friendly and near-shore suppliers, especially for components that the US is unlikely to produce.

Innovative Ecosystems. As 5G use proliferates, wireless providers and their hardware suppliers will play a critical role in deploying private 5G networks as a catalyst for more general innovation. Companies in many different fields—health care, financial services, transportation, and urban planning, among others—will use 5G to accelerate their efforts and coordinate their offerings. For example, the Japanese telecom company Docomo has established collaborative innovation partnerships with more than 5,200 companies and 100 local governments. (See the sidebar "Learning from Docomo's Open-Partner Program.")

LEARNING FROM DOCOMO'S 5G OPEN-PARTNER PROGRAM

NTT Docomo, the largest wireless carrier in Japan, was an early mover in developing an innovative ecosystem for the Japanese 5G economy. It launched its open-partner program in 2018 with 600 partner companies, a number that has subsequently grown to 5,200 companies and 100 local governments. Docomo developed its own 5G and cloud research labs to create services exclusively for its partners. It offers them seminars, workshops, training camps, and other facilities to encourage co-creation and collaboration.

The results have included many 5G-related applications. In a partnership with BMW, for example, Docomo produced an eSIM that permits enhanced navigation and voice recognition, along with connections to up to ten smartphones or tablets. Another joint project produced smart glasses for factory and construction workers. These devices can exchange text, audio, and video with offsite advisors, enabling employees to raise issues and receive guidance instantaneously. Docomo's Virtual Design Atelier supports remote collaboration on visual and architectural design. Its Temi system is a hospital guided robot system that uses the IoT to navigate. It reduces staff burdens and manages communication in situations where human contact is not feasible.

Docomo cites a number of key lessons from its experience with its open partner program:

- Invest in 5G use cases before a demonstrated product demand exists.
- Build general solutions that are applicable to multiple companies across different industries.
- Emphasize co-creation, with R&D and testing facilities accessible to members of the partner network.
- Set up digital exchanges where businesses can post their technical needs and others can answer with solutions.
- Monetize use cases by selling solutions to incoming members.

Advances such as the IoT and automated vehicles will involve 5G development in leading-edge technologies. Health care is another example. Wearable devices can now monitor arrhythmias and EKG data as well as basic heart rates, and many benefit from 5G transmission of data.

As innovative uses roll out, cities with high levels of digital activity will need to increase their supply of mid-band 5G service. GSMA estimates that these cities will require 1,300 to 3,700 megahertz by 2025 to 2030. To meet this demand, the US would need to add 30% to 250% more mid-band spectrum for mobile use than it currently allocates.

Adding full-power spectrum availability will ensure a higher-quality user experience and better 5G coverage. It will support greater mobile traffic demands and will permit scaling of data-intensive applications in an economically feasible manner.

Business Climate. Regardless of how the economy unfolds, the US appears to be in a relatively strong position to continue building out its 5G networks over the coming decade. The US government remains a thought leader in adopting 5G applications, with the DoD and the Department of Veterans Affairs among the most advanced users of 5G innovations.

Current macroeconomic trends—including tight labor markets, positive wage gains, and high operating margins—suggest that markets and supply chains could be more resilient than many people expect. There are structural issues to contend with, however, such as the continuing effect of the COVID-19 pandemic and the war in Ukraine, and these may lead to further supply constraints and price shocks. Tax policy changes, especially if they are related to the expensing of network infrastructure and R&D, could also impact wireless investment strategies. Even so, the basic upward growth curve of the 5G economy seems unlikely to change soon.

Talent. In the future, talent will be even more of a differentiator for business than it is today. As the 5G innovative ecosystem develops new use cases—for example, in IoT, AR, VR, wearables, real-time analytics, and other consumer and industrial technologies—the requisite design and software engineering skills will be increasingly in demand. Already, several US states (Hawaii, North Carolina, North Dakota, Oklahoma, and Pennsylvania) are applying some of their IIJA funding to foster digital skill development in K-12 and adult education.

BCG's analysis of job-related data has found that talent disruption is at least as strong today as it has ever been, spurred in large part by the upskilling that is continually needed for proficiency in digital technology. Public and private education efforts will become increasingly important in 5G development, and schools will most likely use 5G-based tools and platforms to convene and instruct students.

The US has always demonstrated an unparalleled ability to attract digital talent from around the world. Today, foreign-born talent represents almost a quarter of the US STEM workforce, compared to about 16% in 2000. With the advent of remote work as a standard employment option, participation in the US workforce by people from around the world will grow even more rapidly. This will help fuel the growth of the 5G economy.

Recommendations for Policymakers

The future of the 5G economy in the US will depend to a large extent on decisions made by government. Policymakers can help this essential technology expand by focusing on spectrum availability and the innovation ecosystem. We propose five key initiatives:

- **Increase the availability of licensed full-power mid-band spectrum for mobile use.** Doing so will enable the US 5G economy to better support innovative use cases and further scale existing successes. As noted earlier, mid-band spectrum is in short supply, and more of it is sorely needed. Adding capacity in this range will provide the greatest benefit for users in urban, suburban, and rural locales. With additional exclusive-use licensed spectrum, telecom companies can provide a consistent, reliable, and robust experience for consumers and businesses through 5G connectivity.
- **Create a pipeline of licensed full-power spectrum.** To provide predictability in this pipeline, policymakers should aim for clear visibility with regard to the future spectrum bands to be auctioned, the auction dates, and the availability dates. Predictability is essential to wireless service providers as they undertake their capex planning. It enables informed participation in spectrum auctions, efficient spectrum planning, and effective sequencing of network

improvements to deliver the best experience for end users. It also will position the US to lead international spectrum allocation discussions, facilitating the nation's ability to build international scale for the wireless ecosystem. This was extremely important in the development of 4G. Finally, spectrum predictability will give innovators the security they need to advance the US domestic tech ecosystem, cementing the US's economic and national security.

- **Provide incentives for 5G innovation.** Give businesses and organizations reasons to build and operate robust 5G innovation hubs and testing facilities to develop broad use cases. The expanded footprint would benefit wireless companies in several ways. It would centralize solutions, collocating innovation hubs and testing facilities. It would cultivate supply-side innovation before demand overtook capacity. It would encourage the co-creation of 5G solutions across industries. And it would leverage the next wave of solutions to productize and monetize new offerings with subsequent partners.
- **Develop a 5G partnership role for governments.** At the federal, state, and local levels, specifically appointed officials should promote 5G development, coordinate collaborative efforts, and mitigate roadblocks. This would encourage collaborations, particularly on complex projects like smart-city initiatives. Using 5G connectivity to revamp traffic control patterns, for example, could benefit from an in-depth partnership between government and businesses from several sectors.
- **Promote and support the deployment of the IoT.** This technology represents one of the highest-leverage ways to advance the 5G economy. Like many large-scale innovations, the IoT may need extra support when introduced in a city, before it achieves economies of scale or has been integrated into local operations.

US competitiveness depends on the nation's ability to provide leading wireless communications networks and innovative applications and uses that enhance consumers' lives and improve business efficiencies. With the rollout of the 5G economy, the US is poised not just to catch up with other countries, but also to establish a body of activity that promotes innovation and growth throughout the coming decade, and in the years that follow.

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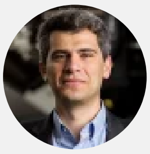

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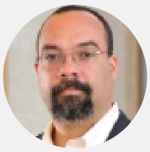

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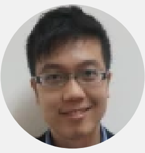

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