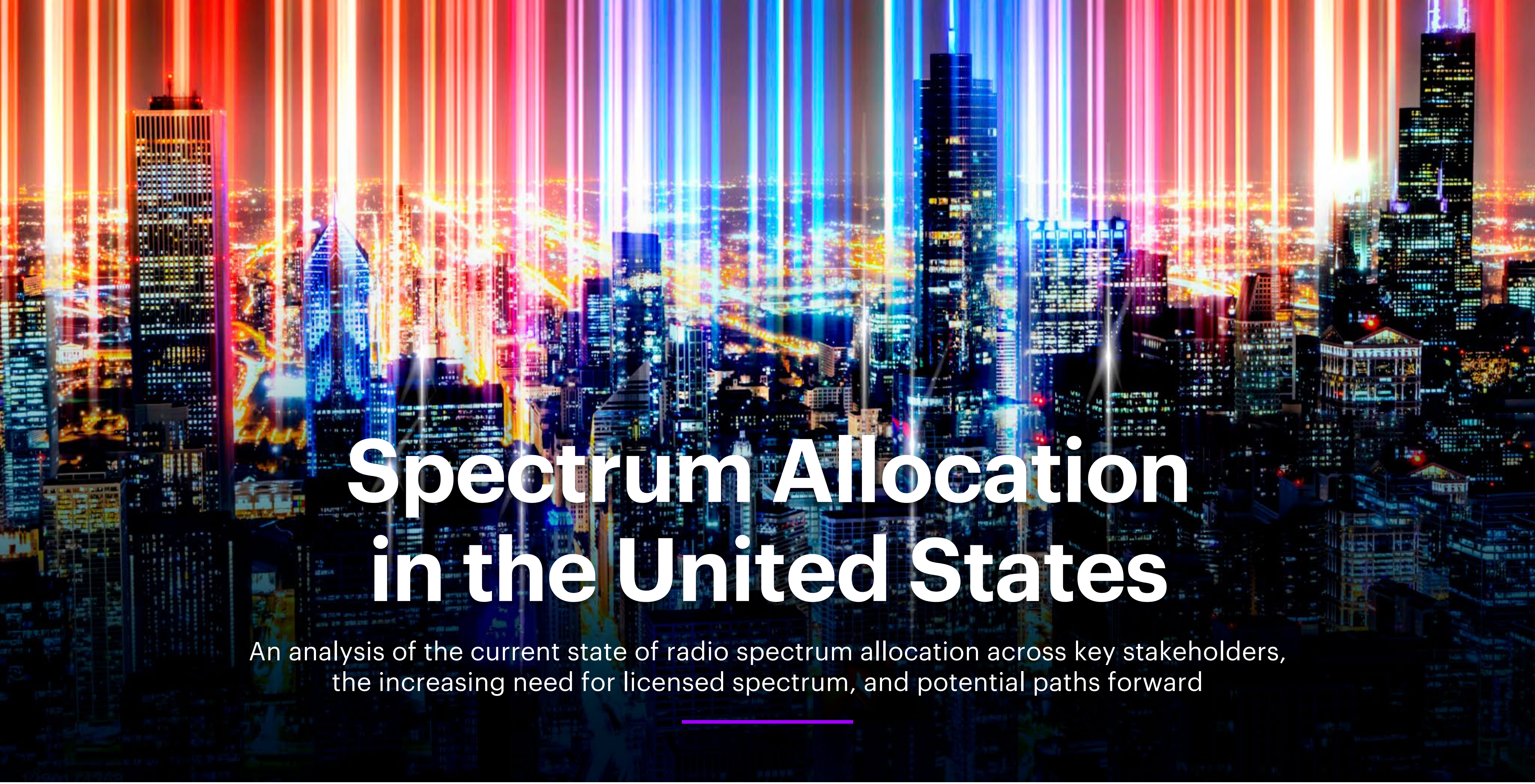


Spectrum Allocation in the United States

An analysis of the current state of radio spectrum allocation across key stakeholders, the increasing need for licensed spectrum, and potential paths forward

accenture

Commissioned by CTIA

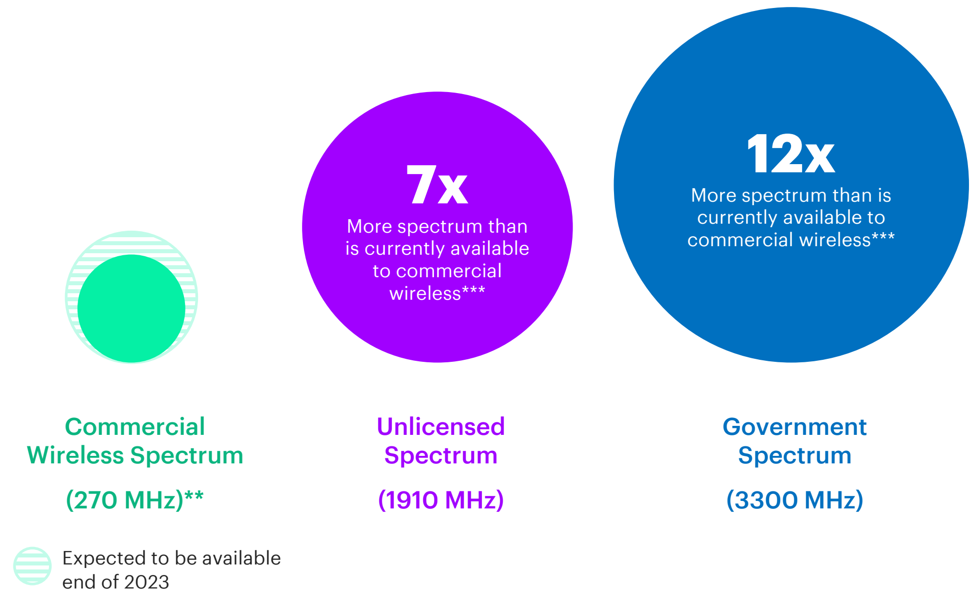
Executive Summary

This study explores the current state of radio spectrum (spectrum) allocation in the US and how additional licensed spectrum will enable wireless providers to continue expanding 5G connectivity and unlock 5G-enabled innovation.

5G brings new promises of greater capacity, lower latency and faster speeds. With 90% of all mobile subscriptions in North America forecasted to be using 5G networks by 2027, alongside the expected growth in industrial 5G connections,[1] the commercial wireless industry will need additional spectrum to bolster networks and ensure 5G connectivity reaches its full potential.

In assessing the current state of spectrum allocation in the US, it becomes clear that several imbalances could hinder the ability of wireless networks to keep up with projected growth and increased demand. In the lower mid-band, defined for the purposes of this study as the range of radio frequencies between 3 to 8.4 GHz*, the commercial wireless industry currently has access to only 5%** of spectrum. By comparison, unlicensed spectrum users have access to over 7x*** that amount (~36%), and government stakeholders have access to over 12x*** the amount of spectrum (~61%). This relative imbalance is particularly critical given that the lower mid-band is essential for supporting the type and amount of new data traffic associated with 5G services due to its ability to satisfy both coverage and capacity requirements.

Lower Mid-Band Spectrum Distribution (mid-2022 availability)



* 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).

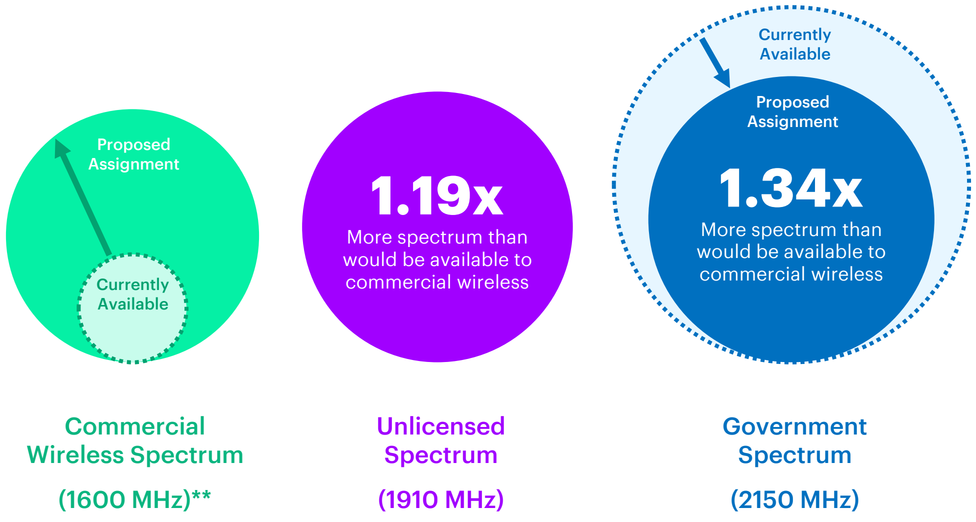
** Of the 450 MHz allocated to commercial wireless use, 270 MHz are currently available, and an additional 180 MHz are assumed to be made available by the end of 2023 pending clearing of the second tranche of C-Band. For the purposes of the analysis contained in this report, Commercial Wireless Spectrum refers to flexible and/or cellular point to multipoint licenses.
*** With an additional 180 MHz of spectrum made available to commercial wireless, unlicensed and government users will have 4x and 7x more spectrum than commercial wireless, respectively.

To date, the commercial wireless industry has delivered quality services to consumers by rapidly deploying the limited licensed mid-band spectrum available, being as spectrally efficient as possible, optimizing traffic, and repurposing bands (commonly known as "re-farming") to meet evolving demand.[2] However, if the relative imbalances in spectrum allocation are not addressed with more licensed spectrum made available to commercial wireless providers, consumers, businesses and public services will bear the burden of the expected network strain—through diminished quality and availability of services, and an inability to deliver on the full promise of 5G use cases which are poised to transform the economy and help tackle climate change.

Additional licensed spectrum has been made available to the commercial wireless industry over the past two years. For example, the 3.45 GHz band, the C-band, and the CBRS band* collectively made 270 MHz available to the commercial wireless industry, with an additional 180 MHz expected by the end of 2023. Despite this recent progress, further access to wide, contiguous spectrum is necessary to bring global harmonization, limit the costs to deploy infrastructure, and ensure continued efficient use of already allocated commercial wireless spectrum. In this study, we explore the **lower 3 GHz, mid 4 GHz**, and **7 to 8.4 GHz** bands as strong candidates to bolster networks and support 5G services. These bands, if allotted for licensed commercial wireless use, can enable Americans to reap the promised rewards of 5G, including improved economic outcomes, environmental benefits through carbon abatement, and technological advancement.

* CBRS is included as Commercial Wireless Spectrum in this analysis as it is technically licensed, however it should be noted the lower power limits and government preemption in place in this experimental system, make the use of this band for Commercial Wireless more challenging.

Lower Mid-Band Spectrum Distribution with Candidate Bands Re-allocated



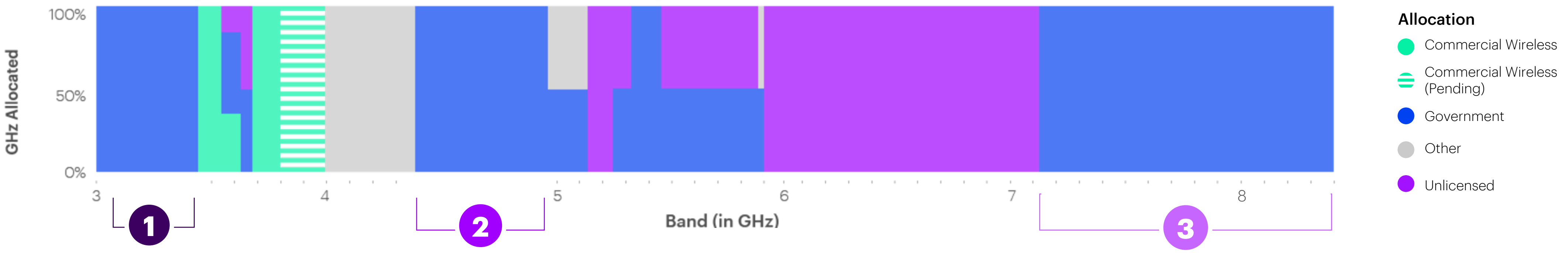
Candidate Bands in Focus

- 350 MHz in the **3.1 - 3.45 GHz band**
- 400 MHz in the **4.4 - 4.94 GHz band**
- 400 MHz in the **7.125 - 8.4 GHz band**

** This scenario reflects the inclusion of 180 MHz planned to be made available by the end of 2023 pending clearing of the second tranche of C-Band.

In our analysis, we identified three bands that offer the greatest potential for meeting the needs of additional 5G deployments by wireless operators: the **lower 3 GHz**, **mid 4 GHz**, and **7 to 8.4 GHz** bands. Below, we offer a brief preview into how these bands are positioned among existing allocations, and the unique benefits they may each present if allocated for Commercial Wireless use.

Current Lower Mid-Band Spectrum Allocation by Use Overlaid with Additional Candidate Bands



1 350 MHz between **3.1 to 3.45 GHz**

The lower 3 GHz band offers reliable coverage and adequate range of coverage, making it ideal for 5G data traffic. This band is adjacent to the recently auctioned 3.45 GHz band, which would help drive lower costs for device manufacturers when developing products for a wider contiguous band.

2 400 MHz in the **4.4 to 4.94 GHz** range

The mid 4 GHz band is a wide contiguous block of spectrum that provides high capacity for 5G networks. It has been allocated to wireless carriers in many other nations, meaning a similar allocation in the US would support international harmonization efforts yielding cost benefits.

3 400 MHz in the **7.125 to 8.4 GHz** range

The 7 to 8.4 GHz range is a significant block of higher frequency contiguous spectrum. The capacity characteristics of this range make it ideal for serving densely populated areas such as urban centers, where traffic requirements are greater.

Content

Section 01

Introduction

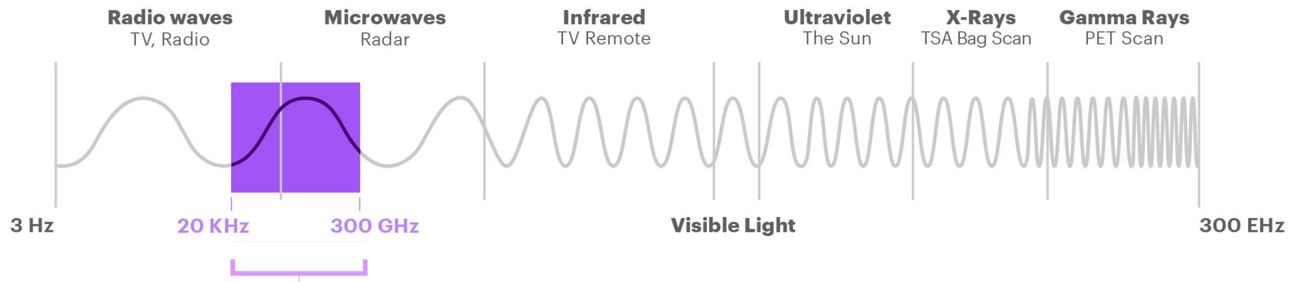
What is spectrum? Why does it matter how it is allocated?

Spectrum is a finite resource

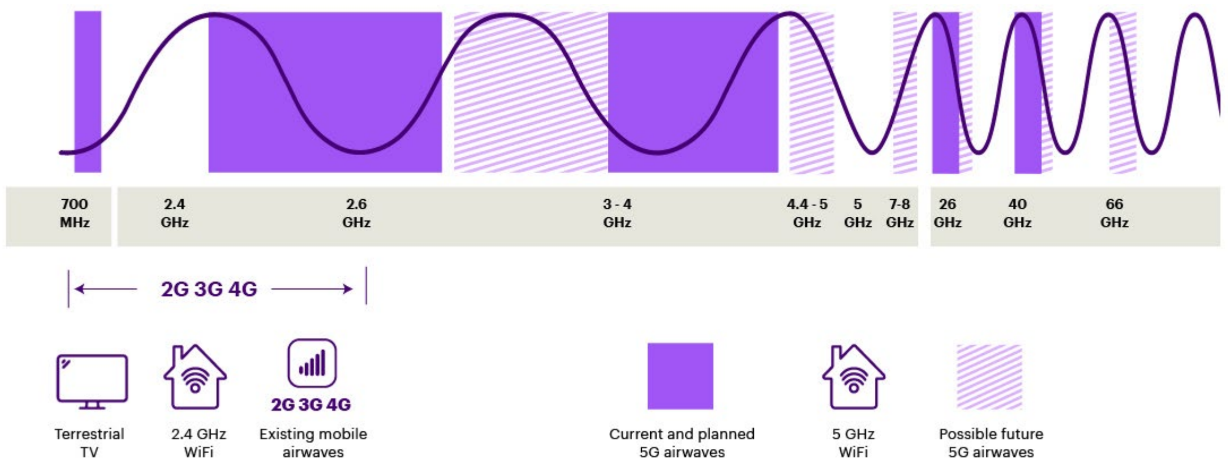
Radio spectrum (spectrum) is the unseen raw natural resource that underpins the wireless transmission of information. It connects our communities and enables our modern way of life. Without radio spectrum, there would be no mobile telephone calls, no emails on the go, and no satellite communications.

Radio spectrum is part of the electromagnetic spectrum and is composed of various frequencies (see Electromagnetic Spectrum and Radio Spectrum, right). These frequencies are organized into different bands, which each have different technological applications based on the frequency's propensity for coverage and speed.[3]

Electromagnetic Spectrum [4]



Radio Spectrum [5]



These broad groupings of bands are commonly referred to as: low-band, mid-band and high-band (see Low, Mid and High-Band Spectrum, right).

As a highly-coveted scarce resource, spectrum must be allocated in a manner that minimizes interference, maximizes efficient usage, and balances equities to benefit society.

Low, Mid and High-Band Spectrum [6]

Low-Band 0.3-3 GHz	Mid-Band 3-24 GHz		High-Band 24-50 GHz
	Lower Mid-Band 3-8.4 GHz	Upper Mid-Band 8.4-24 GHz	
Travels longer distances with minimal signal interruption. Today's 4G wireless networks are built primarily on low-band spectrum	Blends the characteristics of both low and high band spectrum, providing a mix of coverage and capacity		Travels much shorter distances (think feet, not miles) compared to low-band spectrum, but offers high capacity and ultra-fast speeds

The efficient use of spectrum impacts business, government, and everyday citizens. Commercial entities rely on spectrum to provide wireless connectivity (including 5G) and related services to customers. Government relies on spectrum for activities including conducting research, providing security, and operating satellites. Commercial spectrum allocation is carefully managed by the Federal Communications Commission (FCC) in coordination with the National Telecommunications & Information Association (NTIA). The FCC makes certain bands available to specific stakeholders, typically through an auction process.[7]

It is a balancing act to maximize the benefits of spectrum for each stakeholder.[8] For commercial entities, it is economic return through support of technological progress and innovation.

For government entities, it is support of broader national public interests. Because citizens have a vested interest in both public and commercial spectrum allocation, striking a balance between these interests is imperative to effectively serve their needs and maximize quality of life.

Spectrum allocation should follow demand and the potential to drive the greatest societal benefits

Demand for licensed spectrum is growing exponentially, in direct correlation to the increasing demand for wireless connectivity, as it becomes further engrained in how society communicates and functions.

Consumer mobile data usage continues to grow at a stunning rate; as of June 2022, the average monthly mobile data usage per smartphone in North America was around 15GB and is projected to hit 52GB in 2027—representing a compound annual growth rate (CAGR) of 24%.[9] This data usage will only continue to grow as 5G supports a wealth of new use cases for all users. 5G will enable a myriad of connected devices (up to 100x more than 4G) and technological applications (able to transmit data at up to 100x the speed of 4G), and it will rely heavily on the availability of spectrum.[10] It will require high-band spectrum to support more devices and high data throughput in dense urban areas and mid-band spectrum to provide a mix of geographic coverage and data throughput.[11, 12] Simultaneously, low-band spectrum will be required as a 5G coverage layer as well as to support and sustain existing wireless use cases and prior generations of technology (e.g., 4G), which currently provide coverage to 99.9% of Americans.[13]

This growing demand for 5G-enabling spectrum becomes increasingly complex when considering how spectrum can support sustainability, economic, social and geopolitical outcomes.

An Accenture study published earlier this year found that 5G has the potential to contribute approximately 20% toward US 2025 **climate change** goals through use cases the technology enables.[14] Beyond that—if spectrum were harmonized with global standards and allocated in contiguous blocks—operators and equipment manufacturers could be positioned to further reduce the carbon footprint of their supply chains (more on this shortly). This has the potential to drive more efficient equipment design and spectrum usage, while lowering power consumption.

From an economic perspective, the deployment and operation of 5G networks is expected to create up to 4.5 million jobs and generate $1.5 trillion in gross domestic product (GDP) for the US economy from 2021–2031.[15]

Social pressures are also driving the need for equitable access to the internet. 5G underpins fixed wireless access (FWA), which will be critical in bridging the digital divide and bringing high-speed internet to rural communities, improving quality of life and enabling essential services such as telemedicine and remote education.[16]

Last, **geopolitical pressures** are creating urgency to accelerate the rollout of 5G, so businesses can remain competitive in the global economy, and the US can retain its status as a 5G leader throughout the wireless ecosystem. This will further help maintain the influence of the US with international standard-setting organizations for wireless communications.

Efficient allocation of spectrum is critical to the evolution of wireless technology, and for enabling Americans to reap the multitude of benefits promised by 5G.[17]

How does spectrum get allocated, and who is involved?

The challenge

As demand for use cases requiring commercially allocated and licensed spectrum continues to grow at a rapid pace, how could the allocation of this finite resource evolve to strike a better balance across the ecosystem?

Primary stakeholders*

Spectrum stakeholders include those that manage spectrum, use spectrum, and design and manufacture devices which leverage that spectrum.

Stewards of spectrum

- Telecommunications companies that purchase spectrum licenses and use the frequencies to deploy services to businesses and consumers
- Government organizations that have rights to, and use spectrum for national interest use cases
- The FCC and NTIA, which manage spectrum allocation, whether licensed or unlicensed
- Other commercial entities that use spectrum to provide services (e.g., broadcasters, satellite operators)

Original Equipment Manufacturers

- Technology companies that engineer and build devices which transmit and receive information wirelessly using certain frequencies on the radio spectrum

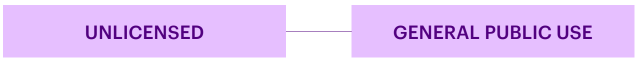
Users of spectrum

- Customers of telecommunications providers
- Users of government services (e.g., marine radar)
- General public users of unlicensed bands (e.g., Wi-Fi)

*List of stakeholders is not exhaustive.

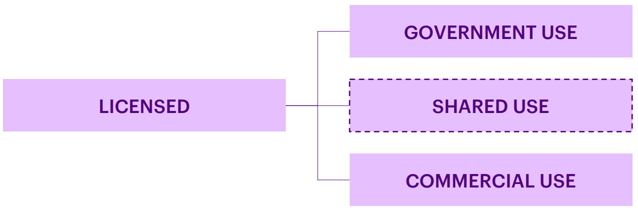
Spectrum allocation levers

In the process of spectrum allocation, several decisions must be made. Will the spectrum be allocated for exclusive licensed or general unlicensed use? Which types of entities may use the licensed spectrum? How is the spectrum managed? In the US, these questions are answered, and decisions coordinated, by the FCC and the NTIA.



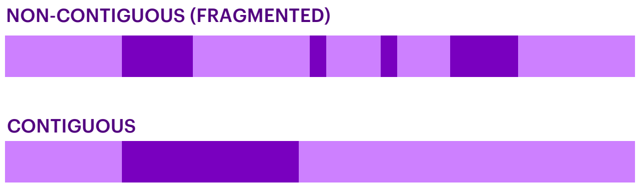
Licensed or Unlicensed

Spectrum licenses grant the spectrum license holder (which could be government, commercial, or individual) the sole right to use airwaves (for a particular use) within the defined frequency band(s), geographic reach, and duration.[18] Licensed spectrum enables the holder to manage against interference and control the level of service delivered, providing a benefit to users. Simultaneously, licensed spectrum allows operators to build mobile networks which are engineered with the latest global standards (e.g. 5G), bringing forward enhanced security benefits. By comparison, spectrum allocated for unlicensed use is available to the general public, but does not guarantee capacity due to possible interference and congestion. Common unlicensed uses include WiFi, Bluetooth, and amateur radio.



Licensed Right of Use

Once it is determined that the spectrum will be licensed out for exclusive use, which type of entity it should be made available to must be decided. The most common stakeholders that may own or lease a license include government entities (for federal or state use, research, security, and more) or commercial entities (telecommunications operators, broadcasters, or other private companies). Shared use refers to cases where simultaneous use of the same airwaves is possible between various entities (which may include unlicensed users). There are various mechanisms used, including geographic and temporal sharing, and various licensing formats, to govern the sharing of spectrum to ensure interference is avoided.[19]

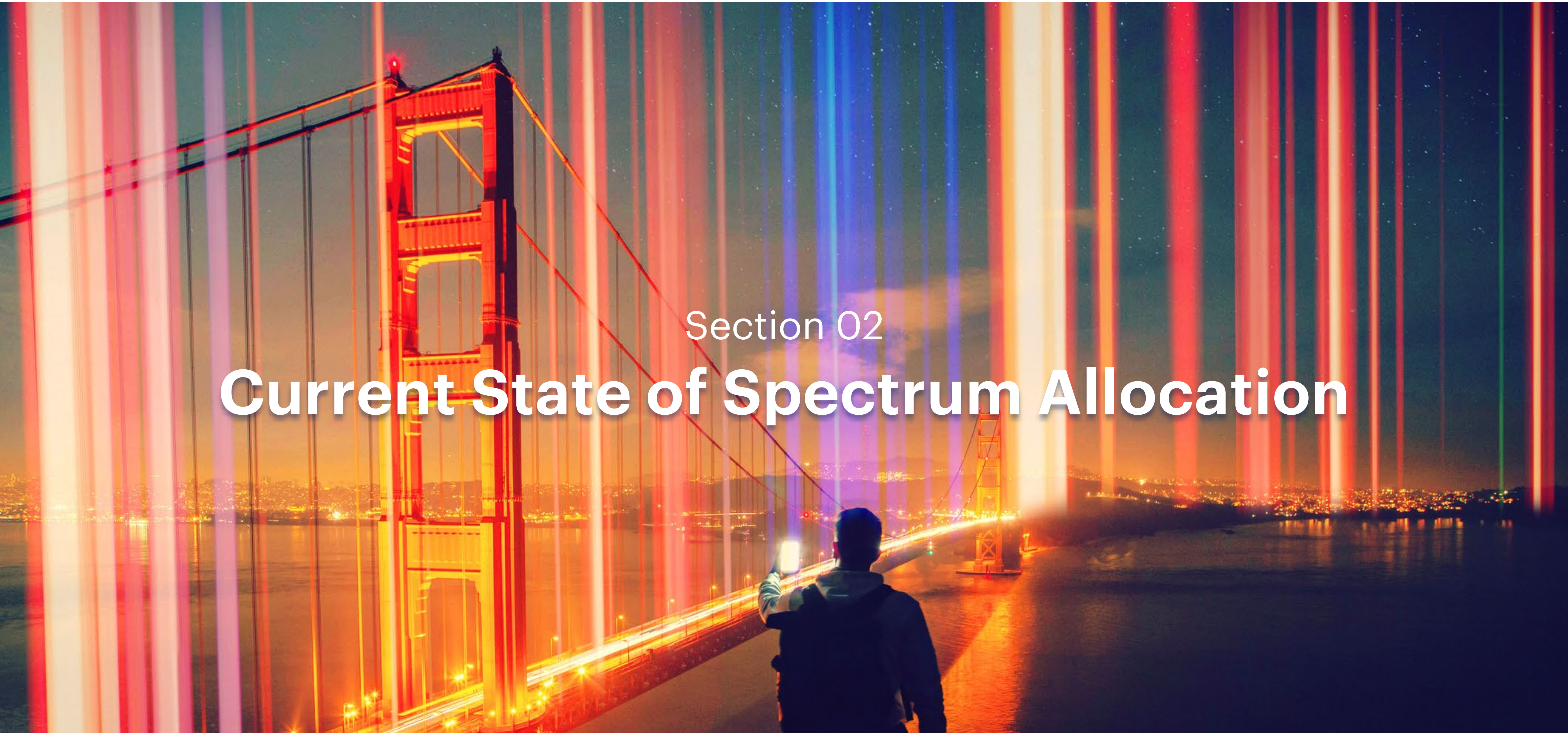


Contiguous vs Non-Contiguous (Fragmented)

A key consideration in the efficient use of allocated spectrum is the block size and arrangement. Contiguous spectrum refers to frequency blocks being allocated next to each other. A contiguous block enables the license-holder to use spectrum in the range more efficiently [20] and requires fewer antennas of device manufacturers, which significantly reduces the environmental impact of these electronics. In general, the wider the block (and therefore the more contiguous the spectrum), the greater the throughput and ability for devices to operate within the given range.

The current state of spectrum allocation is likely to inhibit the growth and innovation promised by 5G, resulting in negative impacts on the user experience. It could also lead to inefficiencies in network design that will impact multiple spectrum stakeholders (operators, OEMs, and consumers), by requiring more antennas, power, and physical infrastructure, driving up costs. This spectrum deficit in turn poses a risk of rising consumer prices which could perpetrate barriers to closing the digital divide.

To remedy this, more spectrum could be made available for licensed commercial use, particularly in the mid-band, where many of the key frequencies that enable modern 5G use cases reside.



Section 02

Current State of Spectrum Allocation

Current State of Spectrum Allocation

This section examines the current allocation of spectrum across four bands for different uses and purposes: licensed government use, licensed commercial wireless use, unlicensed use, and other uses. Analysis found a disparity in the amount of spectrum allocated to each entity type.

Forefront of Wireless Communication	5G Growth Engine	Future 5G & Next Generation of Wireless	Super High Capacity 5G
LOW-BAND	**LOWER MID-BAND**	**UPPER MID-BAND**	**HIGH-BAND**
300 MHz – 3 GHz	3 GHz – 8.4 GHz	8.4 GHz – 24 GHz	24 GHz – 50 GHz

300 MHz – 3 GHz

Low-Band Spectrum Allocation

Low-band spectrum has been at the core of 2G, 3G, and 4G/LTE deployments to date. The low-band is characterized by its ability to travel greater distances and require less infrastructure (such as towers and radio equipment) to operate, compared to higher frequency spectrum.

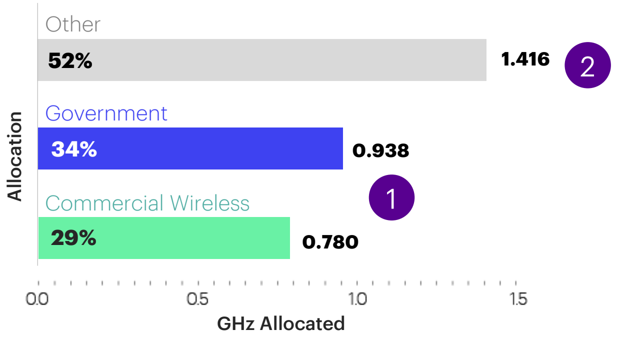
The current balanced allocation of spectrum in the low-band has allowed mobile connectivity to thrive in the United States over the past two decades, with recent auctions including the reverse-auction of the 600 MHz band to commercial wireless providers.[21] Additional auctions in this range are set to bring greater harmonization across networks in the near term (e.g., the recently concluded 2.5 GHz auction, which is reflected in the allocations illustrated below), providing more valuable low-band spectrum to commercial wireless providers. This emphasis means that while spectrum is balanced in this area, little room is left for future expansion of 5G networks and use cases. Stewards of low-band spectrum, particularly commercial players, have been "re-farming" this spectrum to transition its use from previous generations to 5G. However, even with these measures, low-band cannot provide enough spectrum for 5G on its own. Additionally, maintaining existing spectrum for earlier generations of wireless services will remain critical while 5G networks are rolled out.

Notable Findings

1. Currently, approximately 780 MHz of low-band spectrum are allocated for commercial wireless use compared to 938 MHz allocated to government. Government has access to spectrum in 34% of the low-band, other users have access to 52%, and commercial wireless has access to 29%.

2. 1416 MHz of spectrum are allocated for "other" uses, primarily composed of aeronautical and broadcast use cases.

Low-Band Spectrum Allocation Comparison in GHz



Current Low-Band Spectrum Allocation by Use

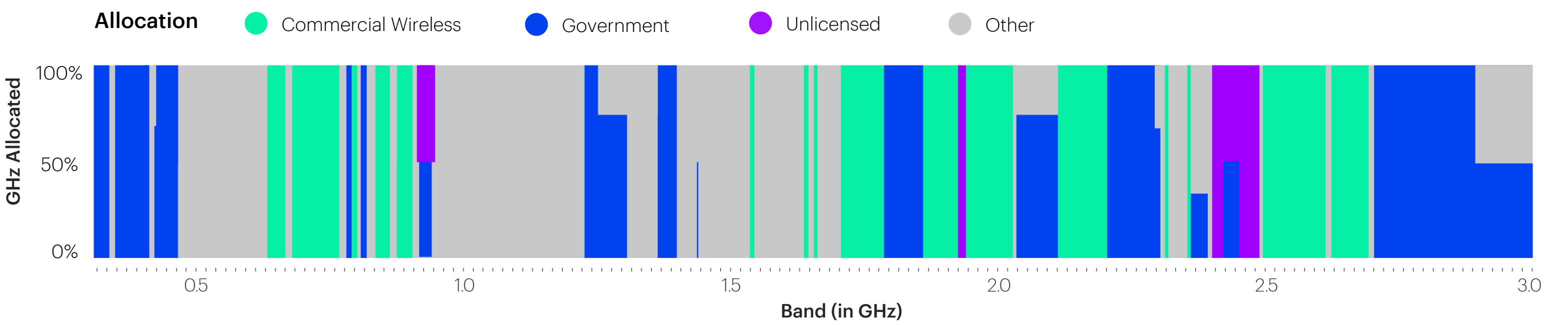


***Chart note**: GHz allocated indicates all spectrum bands in which these entities have **some** holdings – and are not necessarily exclusive holdings.*

3 GHz – 8.4 GHz

Lower Mid-Band Spectrum Allocation

Moving up in frequency, the lower mid-band begins to offer greater throughput per MHz, but travel radius begins to decrease slightly. Commercial wireless licenses in this range have largely been used to deploy 5G services to date due to this band's ability to support the required technological standards for 5G, including higher capacity.[22]

The US currently ranks 13th of 15 countries in amount of spectrum allocated to commercial wireless in the lower mid-band range with 270 MHz*, while leading countries – Japan, France and China– have 664 MHz available on average.[23] While on par in the upper 3 GHz band, the US lags in its commercial wireless allocation of the lower 3 GHz band and higher 4 GHz bands, with recent allocations of one or both of these bands to commercial wireless in China, UK and Japan. The US has some mid-band spectrum in the pipeline (180 MHz in the second tranche of the C-Band),[24] yet other countries have further planned allocations still. The UK and China, for example, are potentially planning to allocate over 1 GHz of lower mid-band spectrum for commercial wireless use.

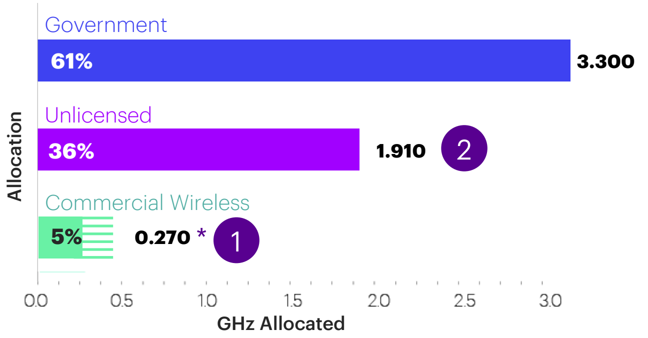
Given the potential for 5G use in this band alongside the growth in demand for 5G, there appears to be a relative deficit in spectrum allocation in the US for commercial wireless use.

Notable Findings

1. Currently, approximately 270 MHz of Lower Mid-Band spectrum is available for licensed commercial wireless use, compared to 1910 MHz+ for unlicensed and 3300 MHz for government use – equating to 7x and 12x the amount of spectrum that commercial wireless has access to, respectively. 180 MHz of spectrum within the second tranche of C-Band are planned to be made available to commercial wireless use by the end of 2023.[25]

2. Government has access to over 61% of lower mid-band spectrum. Use cases include radiolocation, space research, government satellite, aeronautical uses, and experimental uses.

Lower-Mid Band Spectrum Allocation Comparison in GHz



Current Lower-Mid Band Spectrum Allocation by Use

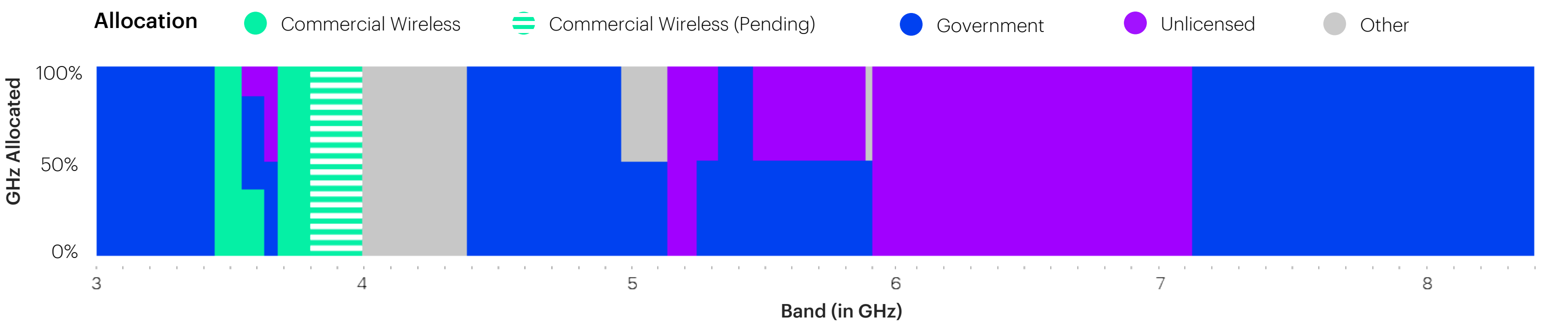


***Chart note**: GHz allocated indicates all spectrum bands in which these entities have **some** holdings – and are not necessarily exclusive holdings.*

***** Of the 450 MHz allocated to commercial wireless use, 270 MHz are currently available, and an additional 180 MHz are assumed to be available by the end of 2023 pending clearing of the second tranche of C-Band.

8.4 GHz – 24 GHz

Upper Mid-Band Spectrum Allocation

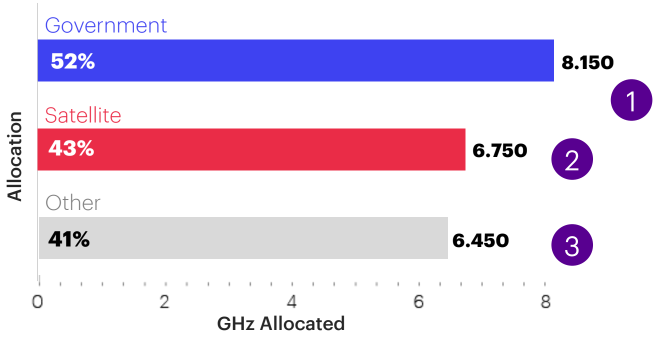
Upper mid-band spectrum continues to trade off a lower range of coverage with higher capacity. This range is increasingly coming into focus today as a potential spectrum source for commercial wireless 5G operations, and in the future may be further leveraged for future generations of wireless as standards are confirmed.[26]

In the upper mid-band, government and satellite use cases are dominant.

Notable Findings

1. The majority of spectrum in this range is held for government uses. Government has access to 8150 MHz which represents about 52% of spectrum in the upper mid-band.
2. Satellite occupies about 43% of the upper mid-band for uses such as satellite broadband and television distribution.
3. Other uses of this band include 4850 MHz of backhaul for fixed wireless services, representing 31% of spectrum in the upper mid-band. While fixed wireless backhaul may ultimately enable commercial wireless use cases, the nature of these licenses (fixed, point to point microwave) mean this spectrum cannot be use for mobile communications.

Upper Mid-Band Spectrum Allocation Comparison in GHz



Current Upper-Mid Band Spectrum Allocation by Use

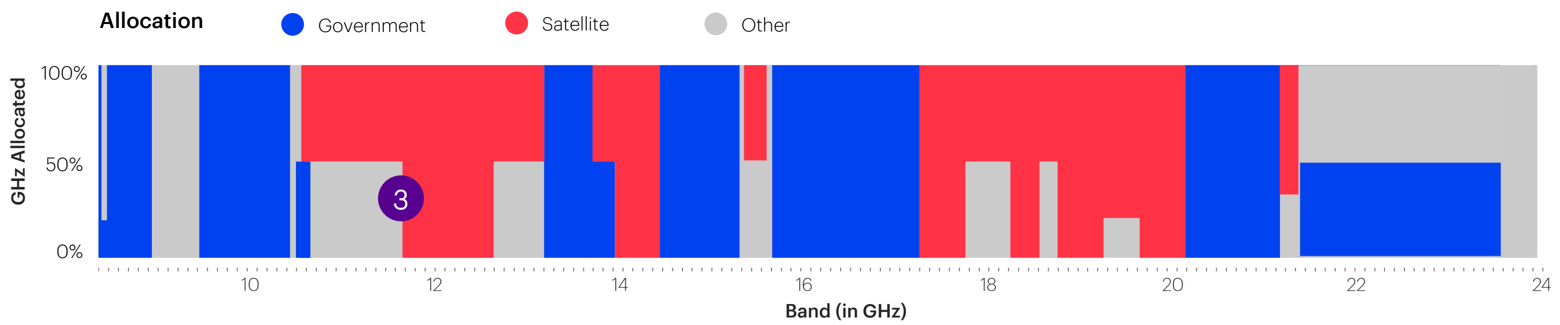


***Chart note**: GHz allocated indicates all spectrum bands in which these entities have **some** holdings – and are not necessarily exclusive holdings.*

24 GHz – 50 GHz

High-Band Spectrum Allocation

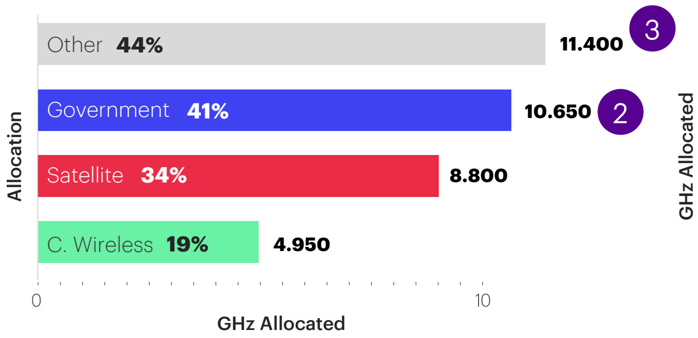
High-band spectrum offers the greatest capacity (in the ranges examined here) balanced with a shorter range of coverage. While it was not traditionally in focus for most non-government uses, with the advent of mmWave technology used in 5G, this band has become more critical for commercial wireless use.[27] The increased interest has spurred several recent auctions of mmWave bands in the past several years, rendering 5.4 GHz of high-band spectrum available for commercial wireless use cases.[28]

The high-band is still predominantly allocated to government, satellites, and "other" uses, such as experimental services.

Notable Findings

1. Recent "Spectrum Frontiers" auctions have made bands available for commercial wireless use in the 24 GHz, 28 GHz, 37 GHz, 39 GHz and 47 GHz ranges, accounting for about 19% of spectrum in the high-band range.[29]
2. Government remains the majority spectrum holder in the high-band with over 2x as much spectrum as commercial wireless in this band, primarily using these ranges for satellite, radiolocation and radionavigation, and experimental uses.
3. Beyond Satellite, which has access to over one third of the high band, "Other" uses include experimental, space and exploration, and broadcast.

High-Band Spectrum Allocation Comparison in GHz



Current High-Band Spectrum Allocation by Use

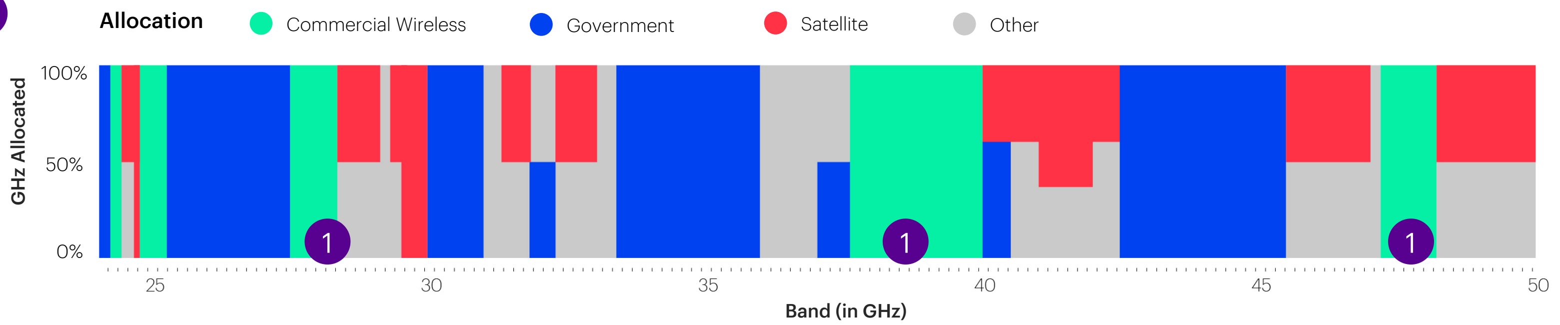


***Chart note**: GHz allocated indicates all spectrum bands in which these entities have **some** holdings – and are not necessarily exclusive holdings.*

Section 03

Evolution of Demand for Licensed Spectrum

What is putting pressure on existing spectrum use?

Demand for connectivity continues to rise, new applications are emerging, and wireless mobile networks are becoming more critical than ever.

Demand for more connectivity is driven by consumers, public services, and businesses alike. Consumers will accelerate demand by using more data in their daily lives—a trend that was amplified by COVID-19 and will continue as data usage patterns shift to a new post-pandemic normal. To help bridge the digital divide and ensure equitable access to high-speed internet and the services it empowers, bringing connectivity to unserved and underserved communities, particularly in rural areas, will continue to be a priority. Public services will explore how connectivity can spark innovative solutions to new and evolving societal and environmental challenges. Finally, the next wave of industrial advances will see more ubiquitous wirelessly-connected devices to improve efficiency and safety of operations.

Increasing Consumer Data Usage

Closing the Digital Divide with FWA

Improving Public Services with Connectivity

Growing Industrial Connectivity

Cellular connectivity is at the heart of nearly everything we do today—it powers simple tasks like navigation, enables the American workforce, and ensures connection between families. Connectivity is instrumental to modern American society, and society has reaped benefits from its ubiquity.

The critical nature of connectivity, coupled with a rapid pace of innovation in the US, is prompting consumers to use more data. In 2021, the average smartphone in North America consumed 15 GB of data per month. This is forecasted to grow to 52 GB per month by 2027, at a CAGR of 24%.[30]

This growth in data usage will be driven in part by the adoption of innovative new use cases like augmented reality (AR), virtual reality (VR), and wearable technology. It will also come with improvements to services consumers currently enjoy, such as the move from 4K to 8K video streaming. As time passes and digital natives increasingly embrace new technology trends, the need to transmit more and more data quickly, reliably, and from/to anywhere will continue to grow.

108X

Growth in mobile data demand between 2010 to 2020 [31]

3.6X

Growth in mobile data traffic per smartphone in North America by 2027 [32]

Increasing Consumer Data Usage | **Closing the Digital Divide with FWA** | Improving Public Services with Connectivity | Growing Industrial Connectivity

The digital divide—a term often used to describe the inequity in access to digital services—can be seen across the US and affects consumers living in both rural and urban areas.

In rural areas, one of the primary barriers to providing reliable access to high-speed internet is the economic and operational feasibility of deploying fixed solutions (e.g., fiber) to households in sparsely populated regions.

Fixed wireless access (FWA) offers a solution for connecting rural Americans. It enables wireless carriers to provide high-speed internet through mobile networks at an economically viable build cost—as much as 40% less than the cost of fiber-to-the-home last mile connectivity.[33] 5G-enabled FWA will have 10 to 100x more capacity than 4G and promises significant improvements to the quality of life of currently-disconnected citizens.[34]

14.5M

Americans living without access to reliable high-speed internet (as of 2019) [35]

8.4M

Rural American households could be served by at least one new 5G FWA provider [36]

Increasing Consumer Data Usage | Closing the Digital Divide with FWA | Improving Public Services with Connectivity | Growing Industrial Connectivity

Improving Public Services with Connectivity

Connectivity is being leveraged to significantly improve public services and tackle evolving challenges, such as those arising from increased density in urban centers and the growing threat of natural disasters spurred by climate-change.

In metro areas, connectivity will underpin the shift toward smart cities, whereby a network of connected sensors could enable a host of improvements, such as intelligent traffic systems used to reduce congestion on roadways and lower response times for emergency vehicles.[37, 38]

Outside of urban centers, connectivity has the potential to reshape emergency management and response systems. In the case of natural disasters, early detection of forest fires and flooding will be improved by sensors and monitors that will alert response teams as soon as a situation arises.[39]

Drones will also play a role both with high-risk rescue operations, as well as containment of fires (e.g., dropping retardant to control spread).[40] As natural disasters become more prevalent and severe, connectivity will play a critical role in supporting emergency management processes.

$41T

Forecasted investment by U.S. city governments to implement IoT solutions from 2017-2037 [41]

24.2%

Forecasted CAGR of the global smart cities market from 2022 to 2030 [42]

Increasing Consumer Data Usage | Closing the Digital Divide with FWA | Improving Public Services with Connectivity | **Growing Industrial Connectivity**

Growing Industrial Connectivity

Virtually all industries are experiencing an operational shift, as commercial entities look to artificial intelligence (AI), internet of things (IoT), and extended reality (XR) to gain a competitive edge through capturing and processing more data faster and using it to inform decision-making.

The benefits of wireless connectivity have long been felt by consumers and businesses, as physical barriers to exchanging information are reduced. Wireless connectivity is at the heart of powering Industry 4.0.[43]

Examples of industries being transformed with wireless connectivity include renewable energy, manufacturing and agriculture. AI, IoT, and edge computing have the potential to improve predictive maintenance and grid management, making renewable energy more reliable. Smart manufacturing, underpinned by IoT capabilities, could yield efficiency and productivity gains. Precision agriculture, which uses AI and IoT to optimize farming operations, could drive greater crop yields and more sustainable farming practices.

16%

CAGR of the Industrial IoT industry between 2022 to 2029 [44]

~300K

Forecasted new jobs in the manufacturing sector by 2035 [45]

Meeting this demand will require greater capacity, lower latency, and faster speeds than have historically been possible from wireless networks. Innovation in wireless communication technology (namely the 5G standard) is focused on supporting the type of traffic enhancements required. Further scaling and operationalizing this innovation will only be possible if wireless carriers are afforded the opportunity to secure more spectrum to expand their networks. Without more spectrum, the potential downstream benefits could be limited.

How is 5G answering the call?

5G offers unique technological advantages, depending on the type of traffic handled.

5G is bringing new levels of efficiency, speed, latency, and capacity to meet societal demands. The 5G standards outline the ability to support three types of data traffic that are essential to modern wireless connectivity use cases: enhanced mobile broadband (eMBB), ultra reliable and low latency communications (URLLC), and massive machine type communications (mMTC). These different types of wireless traffic generally all require some level of additional mid-band spectrum to operate efficiently.

Enhanced Mobile Broadband (eMBB)

Enhanced mobile broadband supports use cases requiring high bandwidth and fast download speeds. This type of traffic will be most used by consumers, and will support growth in demand for, and improved experiences with, mobile data usage.[46] eMBB networks will primarily require mid-band spectrum due to this range's ability to balance speed, capacity, and coverage.

Ultra Reliable Low Latency Communications (URLLC)

Ultra reliable low latency communications will support mission critical applications where reliable real-time processing is required to avoid high-risk outcomes. Delivery of URLLC service will require a mix of mid-band and high-band spectrum.[47] The combination of these two ranges provides unparalleled speed (from the high-band) while ensuring reliability (with wider-coverage from the mid-band spectrum).

Massive Machine Type Communications (mMTC)

Massive machine type communications is defined by high connection density (more devices on the network) to support a vast quantity of low data/low energy devices across various industries. Supporting mMTC will require a mix of low-band and mid-band spectrum.[48] The combination of these two frequency ranges offers wider coverage (through the low-band) and device density (through both the low- and mid-band) with the ability to support up to one million devices per square kilometer.

Translating traffic into key 5G Applications – What's at stake?

The features of eMBB, URLLC, and MMTC are critical to key wireless connectivity use cases, many of which will rely on a combination of the three to be successful (e.g., AI and edge computing are enabled by both mMTC and URLLC). The applications described below are therefore not linearly related to any one of the three different types of 5G data traffic but offer insight into how 5G is positioned to drive innovation.

Internet of Things (IoT)

Connecting physical objects to the internet, using sensors or software to enable monitoring and remote control. This will impact various industries (e.g., healthcare, manufacturing, utilities) improving data and analytics capabilities and driving operational efficiencies.

Applications include connected appliances, precision agriculture, smart manufacturing, etc.

In practice: AT&T and Cisco have launched a 5G service for IoT devices, enabling enterprises, such as automotive, manufacturing and entertainment, to take advantage of 5G's improved speed and capacity.[49]

Extended Reality (XR)

Experiences across a range of devices (e.g., laptop, VR headset, etc.) whereby participants are immersed, to varying degrees, in physical and virtual realms. This will impact industries by making products and services more easily accessible from remote locations.

Applications include VR gaming, AR retail shopping, digital twins, simulation training for high-risk activities, etc.

In practice: Accenture recently partnered with ESPN's Edge Innovation Center to explore ways to use 5G, AR, and edge computing to enable new fan experiences.[50]

Fixed Wireless Access (FWA)

Providing high-speed internet access over a mobile wireless network, bypassing the need to wire individual properties with fiber-optic or cable lines.

Applications include high-speed internet access to rural communities; enabling remote healthcare and education, and greater opportunities for economic participation.

In practice: US wireless service providers are investing in FWA to make high-speed internet available to more homes across the country. For example, T-Mobile's 5G network expansions have made 10 million additional homes eligible for 5G Home Internet nationwide.[51]

Edge & Artificial Intelligence (AI)

Combining AI with edge computing to allow the complex computations and processing of large datasets required for AI-based decisions to occur closer to devices.[52]

Applications include smart cities, autonomous vehicles and operations, safety of life services, security, etc.

In practice: Ice Mobility leverages Verizon's 5G Edge Technology to reduce its product packing errors, providing opportunity for a 15% to 30% savings in processing time.[53]

Section 04

Solutions to Meet Spectrum Demand

How would more spectrum help?

To deliver on the promise of 5G, wireless operators need more spectrum allocated for licensed commercial use

The impending unprecedented growth in data traffic will heavily strain current cellular networks. By 2027, 5G is projected to account for 90% of all mobile subscriptions in North America, compared to 20% in 2021.[54] Without action to fortify their capacity, networks will not be able to meet future demand while maintaining the quality consumers have come to expect.

Improvements in network technology efficiency and network densification are important levers that have been and will continue to be explored to meet demand increases. However, additional dedicated spectrum, particularly in the mid-band, will be critical for enabling 5G networks throughout the country and ensuring the promised benefits of 5G are widely felt by American consumers.

This will enable commercial wireless providers to meet the full, significant demand increase while also ensuring a low cost to consumers.

> In recent years, there has been progress in making more spectrum available for licensed commercial use. In these instances, we see a necessary prioritization of modern technology over previous uses of spectrum.

A clear example of this was the 2017 auction covering the 600 MHz band.[55] In this auction, operators gained access to a significant amount of low-band spectrum, which was critical for bolstering their nationwide service levels. The 600 MHz band had previously been used for ultra high frequency (UHF) television broadcast purposes, but with the shift to digital television broadcasting, it was possible to reallocate this band to wireless providers with relatively minimal impact on consumers.[56] The movement of this spectrum between holders over time, funneling toward modern use cases, is of unquestionable net benefit to US society.

As previously discussed, mid-band spectrum is of primary interest for operators operationalizing 5G due to its mix of coverage and capacity. Deploying on mid-band spectrum enables operators to roll out 5G with lower densification compared to high-band (mmWave) rollouts, which results in a faster, lower-cost deployment. Allocating more mid-band is also critical for maintaining global competitiveness. Nations investing the most in commercial mid-band allocation are seen as leaders in 5G performance.

China, for example, has made approximately three times more mid-band spectrum available to wireless carriers than the US, which is directly reflected in the global performance rankings of 5G networks.[57]

Despite being ranked first for 5G availability by country, the US ranked 11th for 5G download performance in early launch markets, with a download speed of 94Mbps.[58] Ookla highlights that the lagging performance was explainable by the difference in access to spectrum bands suitable for 5G services between the US and leading countries.

Even with some recent progress toward more equitable spectrum allocation, to continue to meet the growing demand, more licensed spectrum is required.

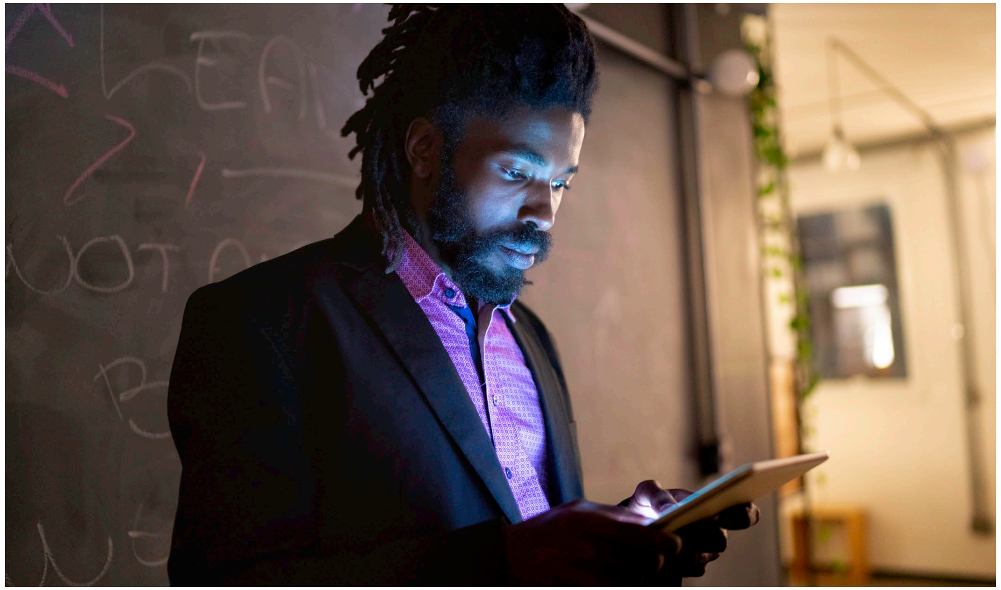
The following bands could be considered strong candidates for commercial wireless use:

- the full 3.1 to 3.45 GHz band
- 400 MHz in the 4.4 to 4.94 GHz range
- 400 MHz within the 7.125 to 8.4 GHz range

Auction revenue from making these ranges available could fund the clearing of spectrum and upgrading of technology and infrastructure for incumbent users. Examples of this include the recent C-band auction, wherein satellite incumbent users were compensated $9.7 billion in accelerated reallocation payments to clear the spectrum in a timely manner, and to procure and launch new satellites and other equipment and services.[59]

History has shown that funding and collaboration such as this are paramount to an efficient reallocation effort, including with government agencies.

In addition to the specific bands and frequencies of spectrum, contiguous blocks are a critical consideration for spectral efficiency. Contiguous blocks allow carriers to be more spectrally efficient, drive benefits such as lower latency, faster data transmission, and deploy capital-efficient and eco-friendly 5G networks.[60] We explore these bands and their benefits in the following pages.



Three bands that offer the greatest potential for 5G expansion

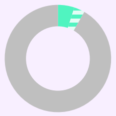
Our analysis identified three bands within the broader mid-band range that offer the greatest potential for meeting the needs of additional 5G deployments by wireless operators: the **lower 3 GHz**, **mid 4 GHz**, and **7 to 8.4 GHz** bands.

These three bands would help operators contribute to international harmonization efforts of 5G services and equipment, as well as more efficiently deploy and run standalone 5G networks optimized to unlock the promised societal, economic and environmental benefits of 5G.

Current Allocation

270 MHz*

MHz currently available for commercial wireless use, representing



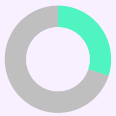
5%*
of Lower Mid-Band Spectrum

* Of the 450 MHz allocated to commercial wireless use, 270 MHz are currently available, and an additional 180 MHz (indicated in striped green) are assumed to be available by the end of 2023 pending the clearing of the second tranche of C-Band.

Allocation Including Three Candidate Bands

1600 MHz**

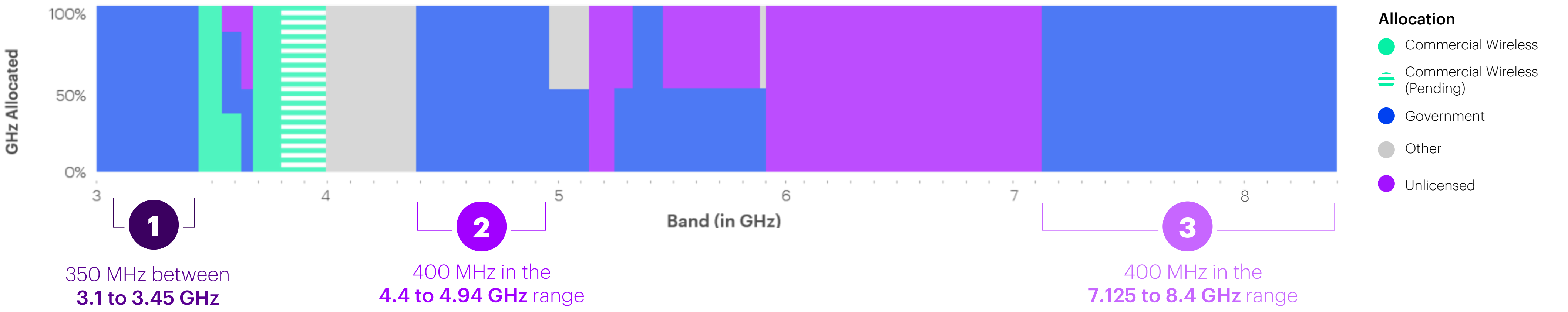
MHz would be available for licensed commercial wireless use based on proposed reallocation, representing



30%
of Lower Mid-Band Spectrum

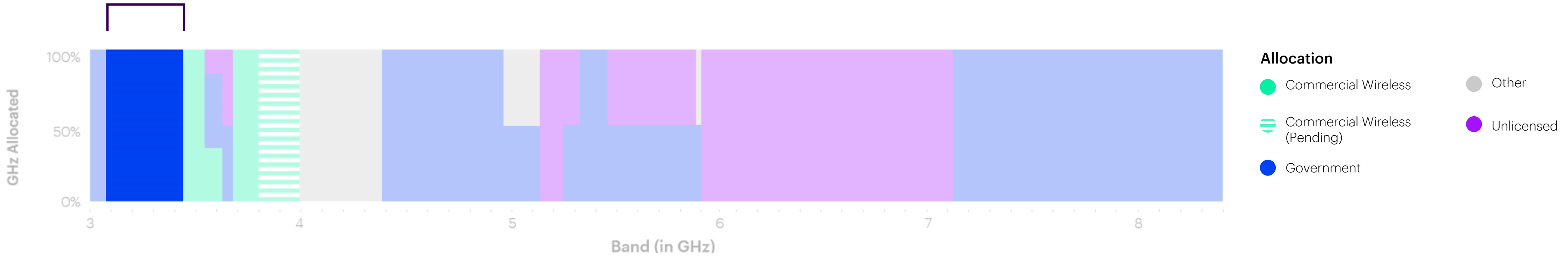
** This scenario reflects the inclusion of an additional 180 MHz planned to be made available by the end of 2023 pending the clearing of the second tranche of C-Band.

Current Lower Mid-Band Spectrum Allocation by Use Overlaid with Additional Candidate Bands



Three bands that offer the greatest potential for 5G expansion

1 350 MHz between 3.1 to 3.45 GHz



The 3 GHz band is regarded and prioritized as the launch band for 5G services, with portions of this band identified for 5G in more than 25 countries around the world, making it a clear candidate for allocation to commercial wireless in the US.[61] Putting this band up for auction would create a large block of contiguous available spectrum, providing wireless carriers the opportunity to acquire contiguous bands that will enhance 5G performance for a better consumer experience and more energy efficient networks.[62] This band's adjacency to the recently-auctioned 3.45 GHz band enables greater simplicity and lower costs for device manufacturers when developing products for this broader range of bands.

Current Allocation

This band is currently licensed exclusively for US Department of Defense (DoD) use. Uses include maritime radionavigation, radiolocation, aeronautical mobile, space research, broadcasting, and mobile. The DoD was recently directed to study this band and to identify spectrum that could be cleared for reallocation or sharing.[63]

Potential Licensed Wireless Uses

The large bandwidth and adequate range of coverage offered by this band make it ideal for supporting 5G, including FWA in rural areas, by enabling similar speeds to broadband to deliver high-speed internet at an affordable cost.

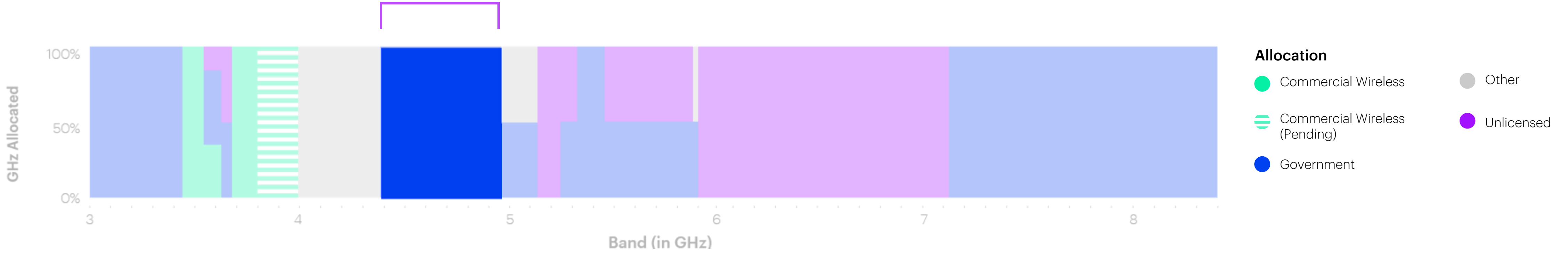
These characteristics also enable the 3 GHz band to support a vast number of devices with reliable coverage, making it ideal for supporting commercial use cases such as industrial IoT, smart manufacturing, and precision agriculture.

International Harmonization Considerations

Making this band available for commercial wireless use would support efforts for international harmonization, while also allowing for standard hardware to be used, which would drive down costs for both operators and consumers.[64]

Three bands that offer the greatest potential for 5G expansion

2 400 MHz in the 4.4 to 4.94 GHz range



The 4 GHz band has been a topic of discussion on a global scale as an avenue for enabling novel 5G use cases. Allocating approximately 400 MHz in this band to commercial wireless use would make a large contiguous block of valuable mid-band spectrum available to support 5G deployment.

Current Allocation

This band is currently licensed exclusively for Federal use, supporting applications including Point-to-Point (P2P), Microwave, drone control, telemetry, Navy, Satellite, DoD aeronautical use, radiolocation, broadcasting, and other fixed and mobile uses.

Potential Licensed Wireless Uses

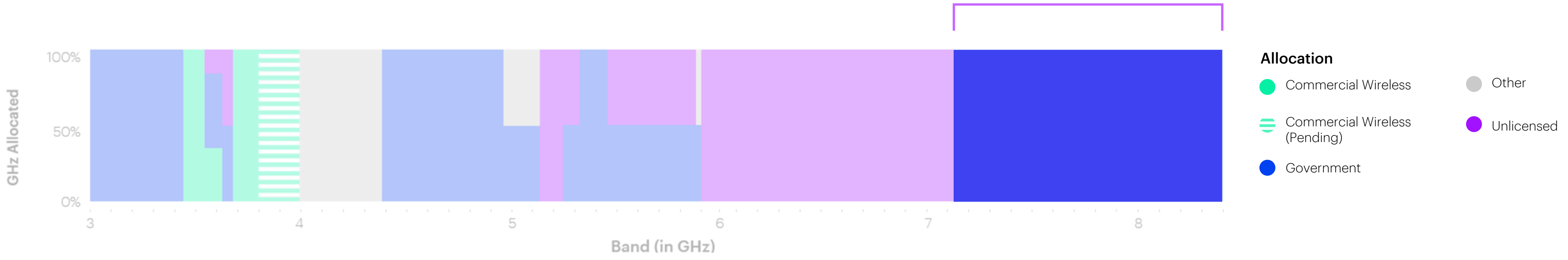
The width of this band would provide enough capacity for 5G networks and a multitude of 5G use cases. These could include broadcasting, autonomous vehicles, and other uses which require this unique mix of coverage and capacity. Techniques like beamforming and massive multiple-input, multiple-output (MIMO) can be leveraged in this band to enable point-to-point communications, including backhaul to enable consumer data traffic and at times reduce the need for massive fiber builds.

International Harmonization Considerations

The FCC has acknowledged that part of this band is a priority given the number of other nations which have already allocated it for wireless carrier use to support 5G services.[65,66] Auctioning this band would support international harmonization, yielding cost benefits.[67]

Three bands that offer the greatest potential for 5G expansion

3 400 MHz in the 7.125 to 8.4 GHz range



The 7 GHz band represents an opportunity for a well-positioned, contiguous 400 MHz block of commercial wireless spectrum within the mid-band. Allocating a contiguous block of this size is ideal for 5G standards to support deployment. FCC Chairwoman Jessica Rosenworcel recently called out spectrum in the 7 to 15 GHz range for its ability to support faster speeds and wide coverage.[68] The FCC also acknowledged that it would be well-positioned to reallocate blocks within this band to support 5G services.[69]

Current Allocation

This band is currently licensed exclusively for various federal applications. These include fixed and mobile connectivity, satellite (fixed, mobile, meteorological, and earth exploration), broadcasting, amateur, international broadcast, and maritime mobile.

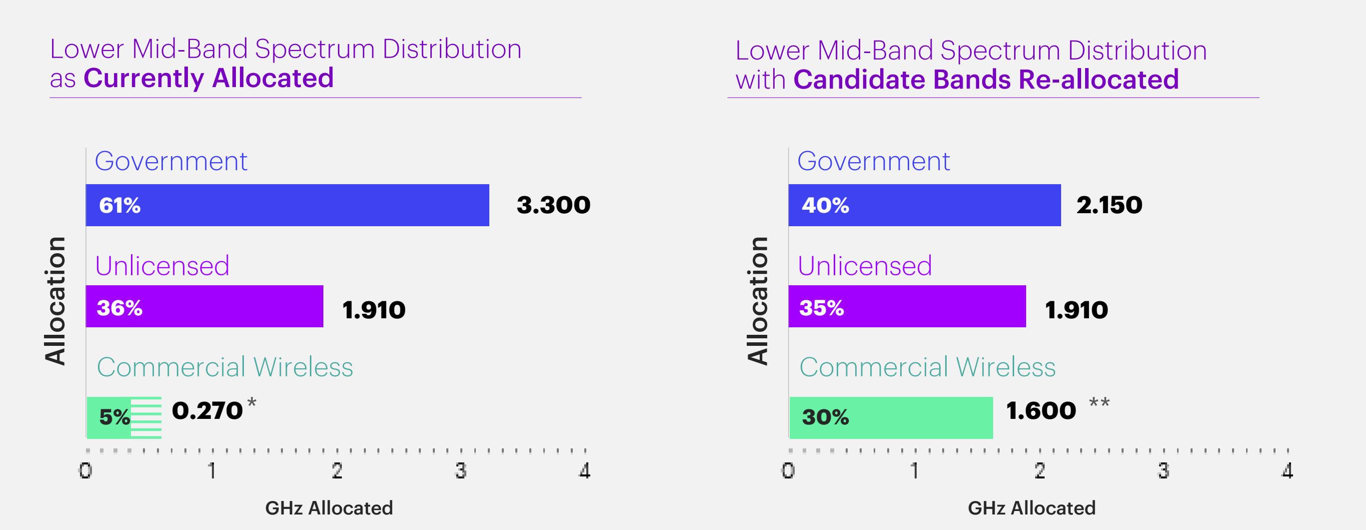
Potential Licensed Wireless Uses

The higher capacity of the 7 GHz band makes it ideal for using 5G networks to serve densely populated areas such as urban centers. The higher frequency also means this band can propagate to dense areas, making it useful for supporting use cases such as smart cities, and as a suitable alternative to wired local networks in indoor environments, such as campuses or office buildings.

What would this re-allocation mean for the lower mid band?

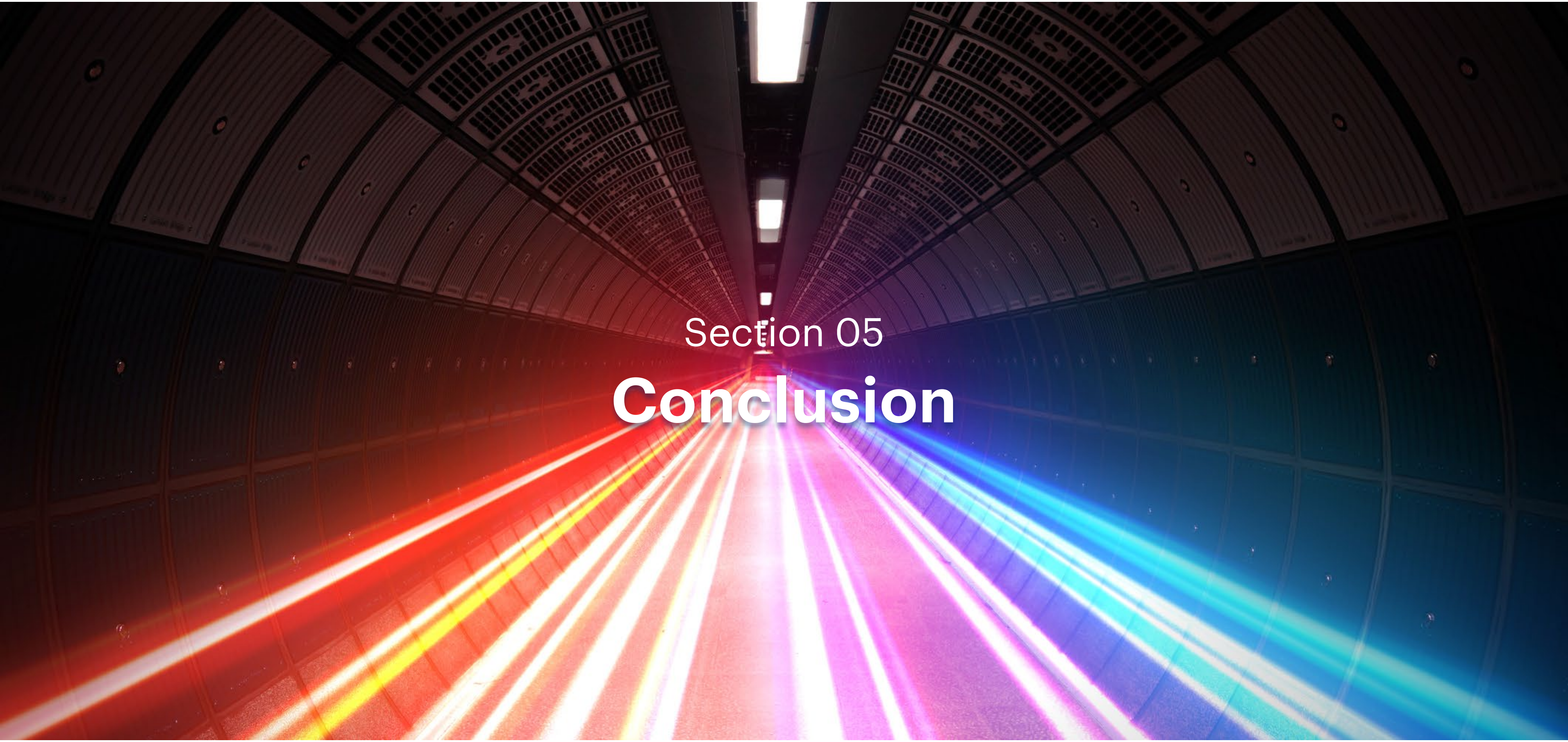
As the growth engine for 5G, the lower mid-band spectrum is critical for the continued development of the US commercial wireless industry, which is currently heavily outweighed in spectrum holdings in this band by unlicensed and government users.

We have explored three target bands that could be re-allocated through public auction to the commercial wireless industry to solve for this imbalance. If all three candidate bands are re-allocated as outlined, the commercial wireless industry would move from holding 5% to 30% of spectrum in this range—a move that could enable the industry to further deliver on the promises of 5G technology. Although this would mean a vast increase in the holdings of the commercial wireless industry, there would still be close to equal allocation between all three major interest groups, with government continuing to hold 40% of the spectrum in this range and 35% still allocated to unlicensed use. The goal of this reallocation would be to increase the total value delivered for the United States from the scarce natural resource that is spectrum—by bringing commercial wireless onto an equal footing with other major spectrum holders.



- The 3.030 GHz gap between the highest group of spectrum holders and the lowest closes to 550 MHz** in the re-allocated state.
- This brings the US close to achieving parity between spectrum stakeholders in the lower mid-band.

*Of the 450 MHz allocated to commercial wireless use, 270 MHz are currently available, and an additional 180 MHz (indicated in striped green) are assumed to be made available by the end of 2023 pending clearing of the second tranche of C-Band.
** This scenario reflects the inclusion of an additional 180 MHz planned to be made available by the end of 2023 pending the clearing of the second tranche of C-Band.



Section 05

Conclusion

Striking a spectrum allocation balance; empowering the US to lead the world in 5G

The role of connectivity in society is growing and expanding, reshaping the fundamentals of how communities in the US function. As wireless technology evolves, and innovations driven by 5G continue to scale, the strain on cellular networks will only increase.

New types of data traffic enabled by 5G are making new use cases possible for consumers and industry alike. Further, the number of connections are growing, and amount of data transmitted through networks is bringing the industry to an inflection point. As we have outlined, spectrum is the fuel that powers all wireless connectivity.

To enable international competitiveness and propel the US economy forward, wireless carriers will require additional spectrum—particularly in the lower mid-band—if they are to sustain and fortify networks so they can meet demand and ensure minimal disruption or impact to the quality of service they offer. Striking the right balance of uses for this spectrum is paramount.

In the highly coveted lower mid-band (i.e., 3 GHz to 8.4 GHz), wireless carriers currently have access to 270 MHz, which represents just 5% of the spectrum in this range of frequencies. At the same time, government and unlicensed stakeholders have access to approximately 61% and 36% of the spectrum in this range, respectively.

This lower mid-band is universally regarded as being central to the delivery of 5G services, due to the balanced mix of high capacity and wide coverage it can support.[70] While recent steps have been taken to make more spectrum available for licensed wireless use (e.g., the CBRS, C-band, and 3.45 GHz auctions), more action is needed to ensure wireless operators have exclusive access to larger contiguous blocks of mid-band spectrum to support the continued deployment of 5G.

Continued limitations on the amount of spectrum in the lower mid-band may have detrimental effects for consumers, businesses, and public services across the country, inhibiting the scaling of innovative applications and negatively impacting quality of service. Also, from a global competitiveness perspective, the relatively limited availability to wireless operators of the lower mid-band spectrum that is essential for 5G services is putting the US's position as a 5G leader at risk.

Conversely, resourced with adequate spectrum to support 5G services, the nation's wireless networks will have the power to digitally transform all aspects of American society. The US economy could reap unprecedented economic benefits from being a leader in 5G, in the form of increased jobs in domestic manufacturing and industry, GDP uplift, improved trade deficits, and more.

Beyond economics, the effective delivery of 5G services is expected to have profound social and environmental impacts, from connecting millions of rural Americans through FWA, to providing improved monitoring and response systems for natural disasters to prevent the devastating loss of life and livelihoods from catastrophic flooding and fires. And addressing spectrum imbalances between commercial wireless and other allocation uses could bolster cellular networks and guarantee that connectivity will continue to advance American prosperity.

Making additional lower mid-band spectrum available for exclusive commercial wireless use—particularly in the lower 3 GHz, mid 4 GHz, and 7 to 8.4 GHz bands—while balancing against other national interests is crucial for the continued excellence of the United States wireless industry.

Appendix

Spectrum Allocation Analysis Process

To analyze spectrum allocation, we split relevant spectrum bands into four individual sections based on their use cases, and collected allocation from a number of varied sources to improve accuracy and completeness

Methodology

1. Examined NTIA Spectrum Allocation Chart[71] to identify whether usage was Federal, Non-Federal or Shared; and beyond this, any other specific uses to further categorize the spectrum.

2. Overlaid all Spectrum Auctions[72] since 1994 (when FCC first started auctioning bands) as well as public information on who these bands were auctioned to, to both validate 2016 NTIA data and update it in areas where it was not current.

3. Identified all unlicensed spectrum using the Title 47, Part 15 of the FCC's Code of Federal Regulations.[73]

4. For areas with remaining unknowns, we completed searches of the FCC ULS Database,[74] and other FCC documentation and band plans,[75-88] for current licensing data to understand use cases and ownership within the band .

Assumptions

Analysis:

- NTIA Data assumption: spectrum bands with a "primary use" and "secondary use" indicated were allocated to the primary user.
- NTIA Data assumption: where spectrum is shared approximate delineations were made around sharing percentages based on the NTIA chart. If there was not enough information available to determine the exact breakdown of sharing between government and commercial entities, a 50/50 rule was applied.
- NTIA Data assumption: in areas where spectrum is shared e.g., between federal/unlicensed and federal/satellite, we provide the total number of GHz/bandwidth taken up by the entity, even if shared with another entity.

Categorization:

- The "Commercial Wireless" category includes flexible and/or cellular point to multipoint licenses, and excludes LMDS and other fixed point to point licenses
- The "Government" category includes uses such as safety of life
- The "Other" category includes uses such as aeronautical, broadcast, experimental, guard bands, radio navigation, satellite, space research, etc. (Not exhaustive)

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