Advancing US Wireless Excellence

The Case for Global Spectrum Harmonization

The United States has a gap in the amount of mid-band spectrum available for commercial wireless use that must be addressed to keep up with rising demand for wireless connectivity. By prioritizing the allocation of harmonized spectrum, the US can realize significant harmonization and leadership benefits that will maximize returns on clearing bands to meet growing demand. If the US ignores this opportunity however, it will leave significant value on the table and will risk limiting its influence and future leadership in the global wireless ecosystem.

accenture

Commissioned by CTIA

Executive Summary

Our previous paper, 'Spectrum Allocation in the United States', explored the shortfall of available mid-band spectrum for commercial wireless use. In this paper, we further examine the state of global spectrum harmonization in the lower mid-band, as well as the leadership opportunity this presents for the United States.

The role of spectrum has evolved with each wireless generation, and the growing demand for it is expected to continue in the coming years. This is particularly true in the lower mid-band (3-8.5 GHz), where bands that have a strong mix of coverage and capacity are vital to realize use cases from 5G and future generations.* Meeting this rising demand requires making a substantial amount of mid-band available in a way that balances various interests with broader economic and societal benefit.

Spectrum harmonization is one such strategic approach, which involves aligning spectrum regulation and commercial allocations with other countries. Allocating harmonized spectrum will not only ensure that the US avoids isolating itself from the international community, but it will enable it to maintain the wireless leadership it has demonstrated in 4G and early on in 5G.

Harmonization and wireless leadership offer incremental benefits beyond those associated with simply releasing more mid-band spectrum. These include unlocking economies of scale across the wireless value chain as well as fueling new sources of growth and innovation through wireless leadership, which are projected to generate approximately $23-$44B and $140B-$180B, respectively, in economic value over the next 10 years. These benefits will largely be felt by consumers and businesses in the form of cheaper devices and connectivity, improved service, and transformative new technology and use cases.

To realize and accelerate the benefits from spectrum harmonization, and ensure continued US wireless leadership, the US must license more spectrum, specifically in the 3.3-3.45 GHz, 4.4-4.94 GHz, and 7.125-8.5 GHz ranges. The US should also collaborate internationally to drive technical standards, support device and network ecosystem innovation, and encourage the rapid deployment of critical network infrastructure.

The US is developing implementation details for its National Spectrum Strategy, providing a key opportunity to catch up with other nations and lead the next wave of harmonization. Without swift action to license lower 3 GHz, 4 GHz, and the 7/8 GHz bands, the US could miss out on up to $200B in benefits.

US Benefits from Spectrum Harmonization

Spectrum Harmonization could lead to economic benefits of

$200B

over 10 years

These benefits consist of:

Wireless Technology Production Benefit of

$23B-$44B

over 10 years

Wireless Leadership Benefit of

$125B-$155B

over 10 years

*6G, for example, is expected to share many of the same spectrum needs as 5G

Executive Summary

The Global Need for Spectrum

Global mobile data traffic is forecasted to grow at a 21% CAGR through 2029,[1] driven by both increasing consumer demand and advancements in enterprise applications for 5G (and beyond), such as industrial IoT and smart cities. Past wireless generations show that timely allocation of spectrum for exclusive commercial wireless use – which is foundational to wireless networks - is critical to meet demand, drive innovation, and establish wireless leadership. Some countries, such as China, South Korea and the US have established themselves as leaders in the 5G era due to their wireless operators' access to critical spectrum early on.[2] This enabled them to be first-movers in 5G network deployments. Wireless dominance fluctuates over time, however, and sustained leadership depends on an ongoing commitment to proactively secure commercial spectrum in line with accelerating demand.

Some nations are taking bold action to bolster their leadership for the remainder of 5G and beyond, such as China's recent announcement of plans to designate most of the 6 GHz band for commercial use.[3]

Other countries are making significant progress in allocating additional mid-band and are increasingly taking a harmonized approach to managing their spectrum. It is critical that the US takes stock of its current wireless leadership and spectrum strategy, identifying opportunities to harmonize and avoid falling behind as a wireless leader.

The US Mid-Band Gap

The US has been successful in driving 5G coverage and adoption in recent years, supported by early commitment from operators to rapidly deploy networks.[4] However, the growing deficit in commercial mid-band spectrum puts the US' future wireless leadership at risk. This gap in mid-band allocation is clear from two angles:

US mid-band gap relative to **global counterparts**

As of September 2022, the US had 270 MHz of mid-band spectrum available for commercial wireless use, with an additional 180 MHz of C-Band allocated since then, bringing the US total mid-band to 450 MHz. Comparing this figure to its global counterparts (based on a September 2022 Analysys Mason report), the US lagged several countries in licensed mid-band spectrum for mobile use, with a 282 MHz* gap relative to five leading nations that were identified in the report. This gap is projected to nearly double by 2027 due to the lack of mid-band in the pipeline.

Today (2023)

Peer average:

652 MHz

Average availability of mid-band spectrum between five leading countries as of 2023[5]*

US deficit:

202 MHz

US Mid-band spectrum deficit relative to five leading countries*

Projected (2027)

Future peer average:

970 MHz

Forecasted average mid-band spectrum available between five leading countries **

Future US deficit:

520 MHz

US mid-band spectrum deficit relative to five leading countries, absent any new spectrum[6]**

The US mid-band gap relative to **meeting future data demand**

Mobile data traffic in North America is forecast to grow at a CAGR of 18% over the next six years,[7] absent any new allocations in spectrum, the US will have a significant mid-band gap, with a forecasted deficit of 400 MHz by 2027, and up to a 1,400 MHz by 2032.***

Projected (2027)

>250%

Forecasted US data traffic growth through 2027[8]

400 MHz

Forecasted deficit in US spectrum by 2027 absent any new allocations[10]***

Projected (2032)

>550%

Forecasted US data traffic growth through 2032[9]***

>1,400 MHz

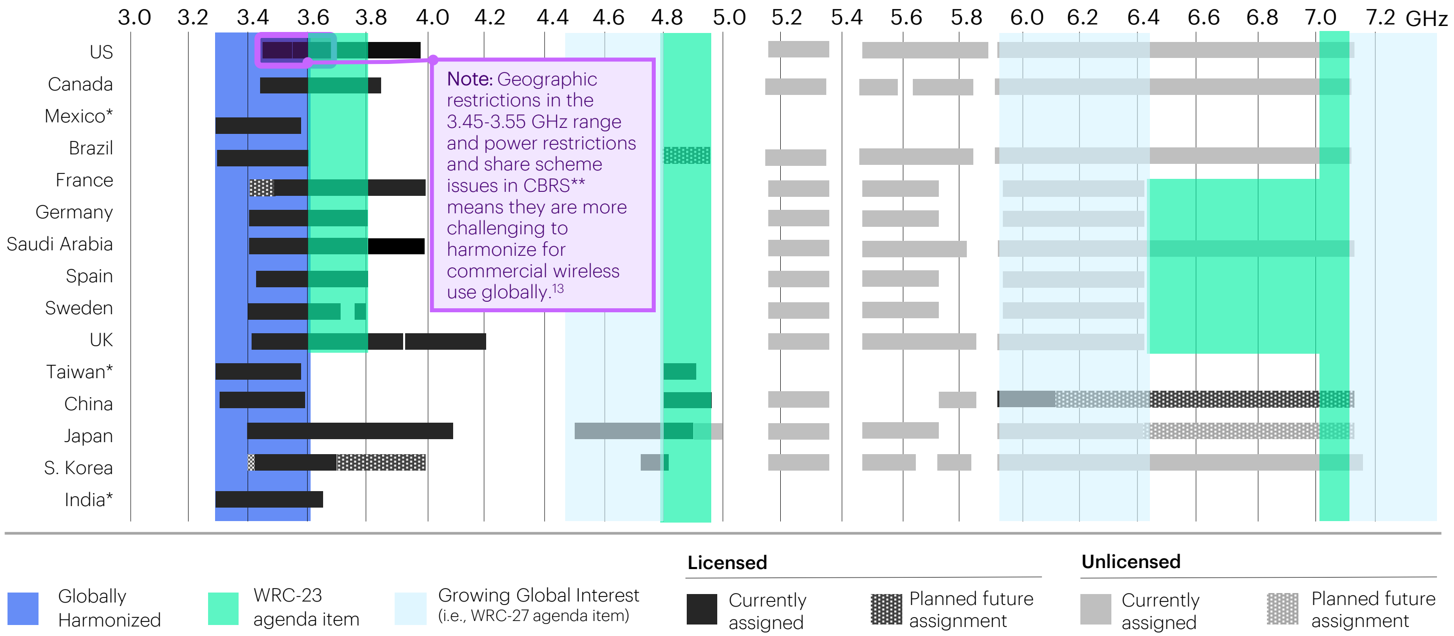
Forecasted US spectrum deficit by 2032 absent any new spectrum[11]***

Relative both to global peers and demand forecasts, the US gap in mid-band spectrum availability is clear. Failure to address this gap can exclude the US from realizing the full potential of 5G and may severely strain current networks that cannot meet the rising demand for connectivity, leaving US consumers and enterprises at a disadvantage. Furthermore, the US's reputation as a wireless leader is at risk, especially as other countries bolster their spectrum availability and further harmonize. If the US does not allocate more mid-band in a harmonized way, it risks falling behind other leaders or becoming siloed in the wireless ecosystem. The stakes are high for the US to remediate its mid-band deficit and thus secure its ongoing prosperity.

*Based on Analysys Mason's report issued in September 2022, several countries with more mid-band than the US included Japan (1100 MHz), the UK (790 MHz), France (510 MHz), China (460 MHz), and Saudi Arabia (400 MHz) ** By 2027, several countries with more mid-band spectrum than the US are projected to be China (1660 MHz), Japan (1100 MHz), the UK (790 MHz), South Korea (700 MHz) and Saudi Arabia (600 MHz), *** Forecasted spectrum deficit is normalized to a lower mid-band equivalent (exclusive use, with no power restrictions)

Global Spectrum Allocation and Harmonization Trends

Taking a harmonized approach to closing the US mid-band deficit requires assessing the global spectrum landscape and considering the trends around future spectrum allocations. As shown below, the 3.3-3.8 GHz band is widely harmonized for commercial wireless use, and the 3.3-3.4 GHz, 4.8-4.99 GHz, and 6.425-7.125 GHz ranges were under consideration for future harmonization as part of the World Radio Conference (WRC) 2023 agenda. Additional mid-band studies, including an extension in the 7-15 GHz range will be studied as part of the WRC study cycle leading up to the WRC 2027 event.[12] International spectrum allocation decisions from recent years show a trend of more harmonization in the mid-band, as countries align to allocation norms and follow the guidance of international forums such as ITU through its WRC conferences. This trend can be expected to continue and will be accelerated by the outcomes from WRC-23.



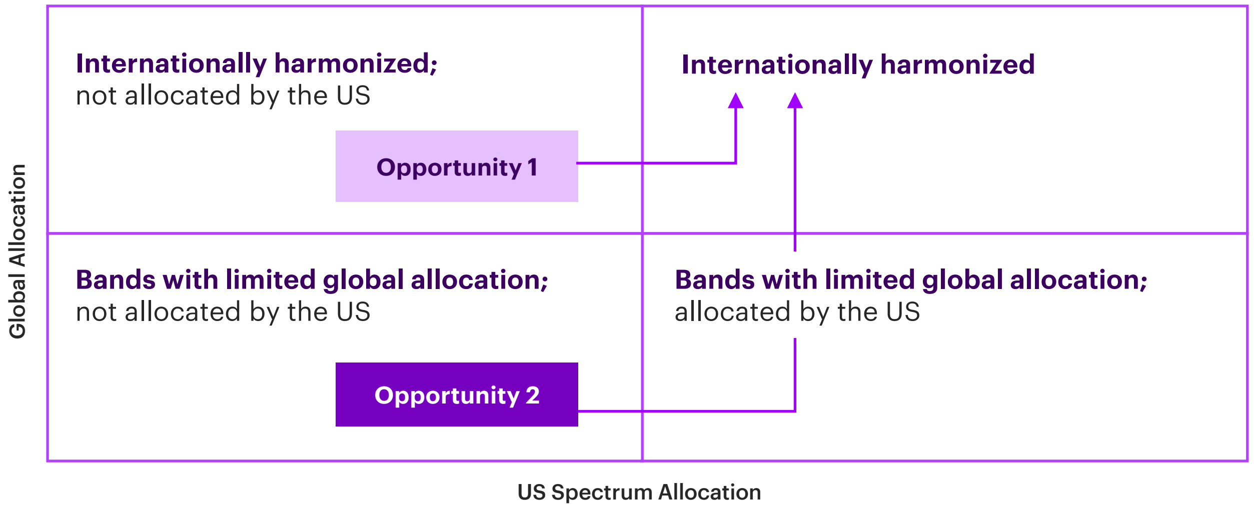
** The data source for spectrum allocation for these countries only indicated licensed 5G assignments*
*** The Citizens Broadband Radio Service is 150 MHz of spectrum in the 3.5 GHz band that is primarily used for private LTE and 5G networks*

While the US may appear harmonized at first glance, the fragmented approach and restrictions (e.g., power limits) on parts of the 3 GHz band have limited the full benefits of harmonization, which is typically based on exclusive-use licensing.[14] The global community is exploring new harmonization opportunities, some of which the US can participate in, and others, such as the consideration of the upper 6 GHz band, that are more difficult for the US to pursue given recent decisions to allocate the 6 GHz band for unlicensed use.[15]

With limited available options, it is critical that the US identifies and prioritizes the harmonization opportunities available to it to keep pace and stay synchronized with global counterparts, or risk falling behind and becoming further disconnected from the global wireless community.

Identifying Candidate Bands for Harmonization

To identify bands with harmonization and leadership potential, we considered the following criteria: Band characteristics, harmonization proximity, global traction, and domestic conditions. Based on these criteria, two types of harmonization opportunities emerge for the US. Both involve allocating spectrum where there is already significant harmonization, as well as leading by allocating bands that have significant potential but are not yet widely adopted.



Opportunity 1:
Allocate Currently Harmonized Bands

A 3.3-3.45 GHz Band

B 4.8-4.94 GHz Band

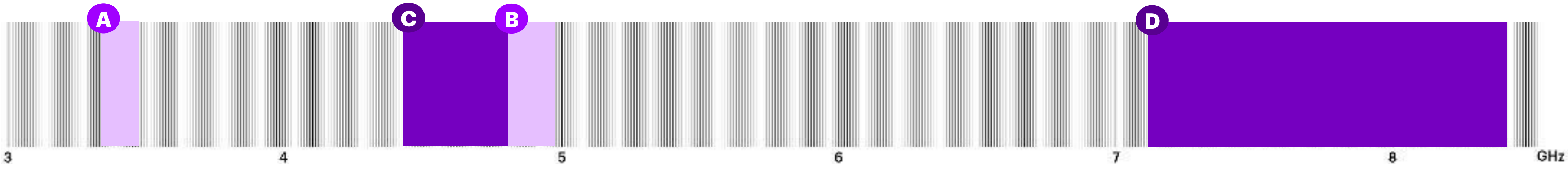
The entire 6 GHz band is currently allocated for unlicensed use in the United States. However, several other countries are harmonizing the upper portion of the band for licensed mobile use, potentially justifying reexamination of this band in the US.[16]

Opportunity 2:
Lead Harmonization on New Bands

C 4.4-4.8 GHz Band

D 7.125-8.5 GHz Band

Lower Mid-Band Spectrum



The Target Bands

Based on the key criteria for ideal harmonized spectrum (e.g., harmonization proximity, availability, etc.), there are three spectrum ranges that are ideal for the US to align to that enables it to harmonize with existing spectrum as well as lead harmonization on future spectrum.

The Lower 3 GHz Band

The lower 3 GHz band, which shares characteristics with the C-band, has significant potential for future harmonization. It is ideal for commercial use cases like FWA, industrial IoT, smart manufacturing, and precision agriculture, as well as improved consumer network connectivity.[17]

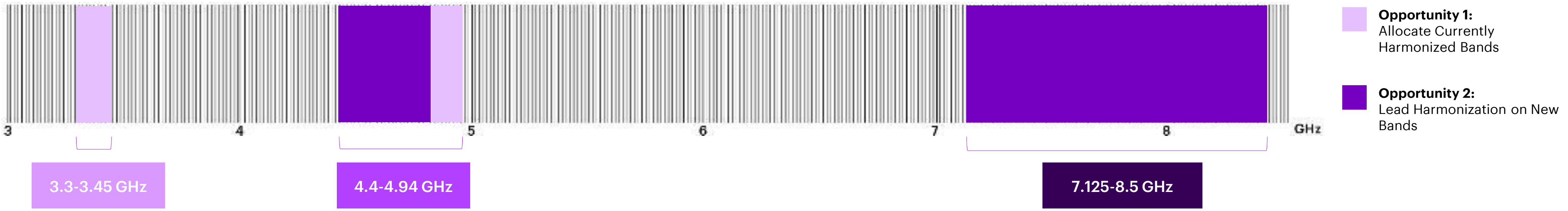
The mid-4 GHz range

The mid-4 GHz range is becoming increasingly harmonized, with parts of it allocated for IMT* use in Japan and South Korea and is being studied leading up to WRC-27.[18] The mid-4 band is suitable for various applications due to its broad coverage and high capacity, supporting techniques like beamforming and massive multiple-input, multiple-output (MIMO), which can reduce the need for large-scale fiber builds.[19]

The 7-8.5 GHz range

The 7.125-8.5 GHz band is currently being studied by the ITU leading up to WRC-27 for future harmonization.[20] The band's propagation characteristics and higher capacity make it ideal for emerging 5G (and potentially 6G) uses cases as well as for general consumer network connectivity (achieving similar coverage as C-Band) as antenna technology continues to evolve.

Lower Mid-Band Spectrum



*IMT stands for “International Mobile Telecommunications” and is used to designate broadband mobile systems globally

The Benefits of Harmonization and Leadership

By taking action to allocate the three identified bands for commercial wireless use and harmonize more of its spectrum, the US can unlock significant benefit for consumers and industry through cheaper wireless products and services, the acceleration of generational wireless use cases, and more economic growth. These benefits will be realized through the production of more cost-effective and higher quality technology as well as innovation from harmonization that originates domestically due to US wireless leadership. Additionally, the US stands to benefit in terms of national security in the long run, as US harmonization will bolster the market position of its trusted network equipment vendors.

Wireless Technology Cost and Performance Benefits

Spectrum harmonization can standardize network equipment and wireless device production, resulting in less market variation in radio requirements for these technologies. With more harmonization, fewer variations of network radios and wireless devices must be produced, and complex devices that support a wide range of frequencies can be simplified. These efficiencies result in cost savings for end users and drive additional downstream benefits (e.g., accelerated network deployment, earlier adoption of industry use cases, etc.) unlocking approximately **$23B-$44B in value for industry and consumers over the next 10 years.** Additionally, harmonization will improve network performance through minimized downtime, reduced interference, and better roaming.

Growth, Innovation, and Wireless Leadership

Spectrum harmonization will lead to more growth and innovation globally, with leading wireless nations driving and capturing a large share of the value. Through diligent network investment and proactive spectrum policy, the US can be a first-mover in advanced 5G and 6G, capturing the incremental economic benefit that results from wireless leadership in a more harmonized world. As was the case with 4G, a significant portion of the US' economic growth was due to its first-mover advantage and rapid deployment of new networks, which unlocked economic expansion in the form of job growth, cost savings, export competitiveness and net-new innovation (e.g., leadership in device manufacturing, app ecosystems, etc.). **The expected economic benefit attributable to leadership in 5G and beyond is estimated to reach up to $155B for the US over the next 10 years.**

Spectrum Harmonization could lead to economic benefits of

$200B

over 10 years

These benefits consist of:

$23B-$44B

over 10 years

The expected cost savings in higher-quality wireless technologies for US consumers and businesses, driven by production standardization for network equipment and wireless devices resulting from harmonization.

$125B-$155B

over 10 years

The expected economic benefit that is attributable to US wireless leadership in a more harmonized global wireless ecosystem, in the form of industry creation, job expansion, technology export strength, and increased domestic innovation.

The Path to Harmonization

Realizing the potential for harmonization and leadership is only possible if the US takes calculated and decisive action both at home and abroad. Domestically, the US will need to license the three target bands for commercial wireless use, while also facilitating rapid network deployment to meet growing connectivity needs and ensuring widespread coverage of 5G and future wireless generations. On the international stage, the US must advocate for more harmonization on the proposed bands both through international forums and direct engagement with other countries. Finally, the US has an opportunity to facilitate the expansion of device ecosystems by investing in R&D and engaging international stakeholders to collaborate on future innovations.

Harmonization and leadership represent a significant opportunity for the US and its economy. Swift action on each of these acceleration levers can position the US at the forefront of wireless innovation and lay the foundation for future growth.

Spectrum Licensing

Global Harmonization Advocacy

Wireless Innovation

Network Deployment

Content

Introduction 15

The Global Spectrum Landscape 27

The Benefits of Harmonization 41

Path to Harmonization & Leadership 61

Conclusion 69

Appendix 70

Section 01

Introduction

What is Spectrum? Why Does It Need to Be Allocated?

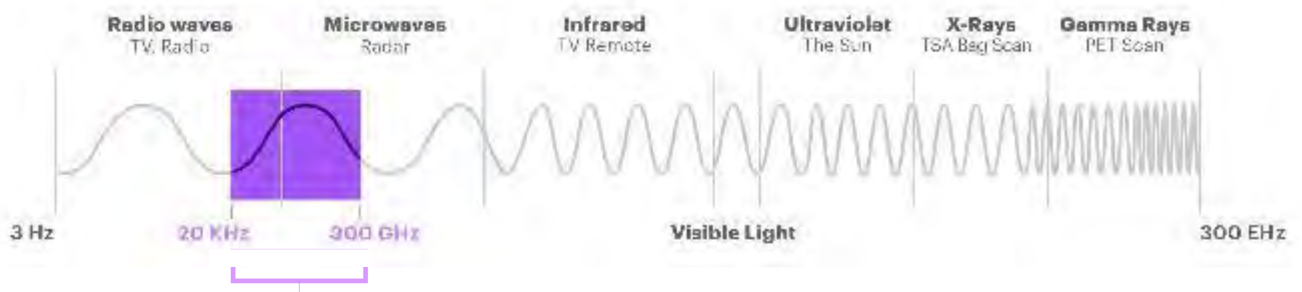
What is Radio Spectrum?

The invisible raw natural resource known as radio spectrum – or spectrum – supports wireless data transmission. It facilitates our contemporary way of life and connects our communities. Mobile internet, phone calls, email, and satellite communications would all be impossible without spectrum.[21]

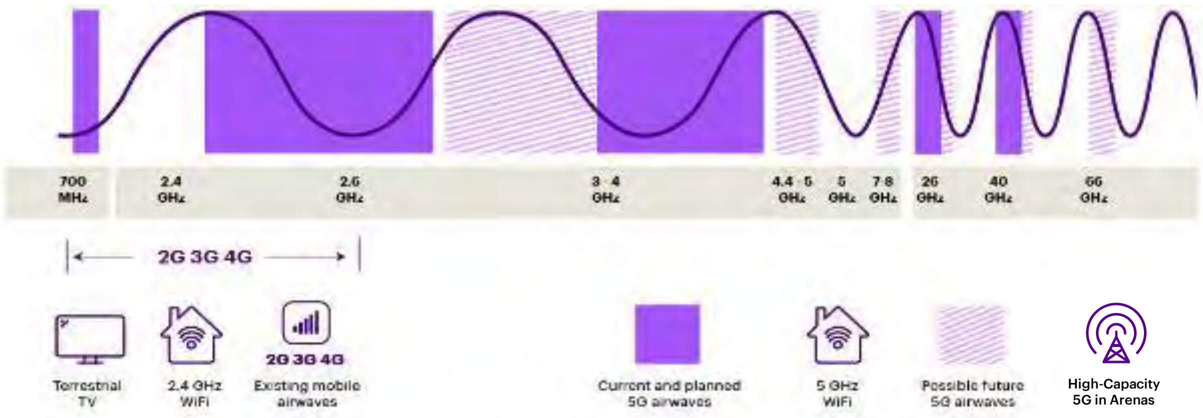
The electromagnetic spectrum includes the radio spectrum, which is made up of different frequencies (see Electromagnetic Spectrum and Radio Spectrum, right). These frequencies are divided into many bands and depending on the frequency's tendency for coverage and speed, each band has a distinct technical use. Three broad groupings are used to organize spectrum (see Low-, Mid- and High-Band Spectrum) – in this paper we will further divide mid-band into two categories, lower and upper mid-band.

For the purposes of this paper, we will primarily be focusing on lower mid-band spectrum, or the range between 3-8.5 GHz, because these bands offer the greatest potential for 5G (and potentially 6G) and are in short supply.

Electromagnetic Spectrum[22]



Radio Spectrum[23]



To Support Upcoming Wireless Generations, More Spectrum Needs to Be Released for Commercial Wireless Use

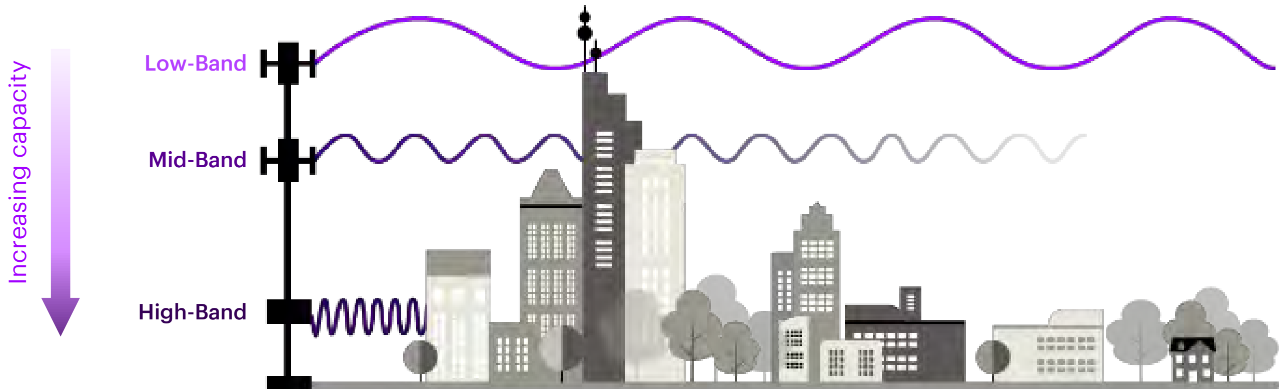
5G is expanding the role that mobile connectivity plays in society, opening doors to new use cases across industries, and driving the demand for spectrum to new levels. Exclusive-use spectrum is fundamental to expanding mobile network capabilities and ensuring that the required coverage, capacity, and latency demands of future wireless use cases can be met.[24]

As a result of the growing need for connectivity, the Global System for Mobile Communications Association (GSMA) forecasts that countries will need approximately 2 GHz of mid-band spectrum on average to accommodate this increase in traffic and to enable future generation wireless use cases like holographic communications and wide-scale digital twinning.[25]

A multi-layered spectrum approach will be essential to sustaining wireless growth, as traffic and use cases evolve for 5G and beyond. Low-band spectrum propagates over longer distances but transports less data, while high-band spectrum has less coverage and higher data transfer rates. Mid-band spectrum is most critical for future wireless growth, as it is the only spectrum range that provides a combination of capacity and coverage.

*an Exabyte is equivalent to 1B Gigabytes

Illustration: Low-, Mid- and High-Band Spectrum[26]



More Coverage ← → **Higher Capacity**

Low-Band 0.3-3 GHz	**Mid-Band** 3-24 GHz		**High-Band** 24-50 GHz
	Lower Mid-Band	**Upper Mid-Band**	
Required for its range and ability to propagate through obstacles, low-band is critical for ensuring that the benefits of 5G and future generations are accessible to all. Low-band helps maximize network coverage.	Lower mid-band balances coverage and capacity and is the band of choice globally for most 5G applications. The dominance of mid-band is expected to persist through to upcoming wireless generations.	Upper mid-band spectrum will be critical to meeting the network challenges associated with rapidly growing data traffic. It has higher capacity which can enable data-intense use cases and can help realize unfulfilled enterprise 5G applications. Additionally, bands closer to mid-band offer the greatest potential for synergies with existing wireless networks.[27]	Spectrum in the mmWave range (e.g., 26, 28 or 40 GHz) supports high-capacity throughput in crowded environments as well as delivering the low latencies and high reliability required by many future enterprise use cases.

***Note**: While there is no set rule for differentiating between low-,mid-, and high-band spectrum we've chosen to do so based on recent assignment decisions made by policymakers in relation to upcoming 5G service deployments.*

The Mid-band Gap and the Harmonization Opportunity

The importance of mid-band spectrum for 5G and beyond

Mid-band spectrum, particularly in the lower mid-band (frequencies 3-8.5 GHz), serves as a pivotal intermediary between low- and high-frequency bands. It is characterized by its balanced trade-off between coverage and capacity, providing the long range and high data rates needed for many 5G use cases. Mid-band also benefits from lower spectrum interference and attenuation, alongside enhanced penetration capabilities compared to higher frequencies that are above 24 GHz.

Mid-band spectrum must be allocated in a manner that maximizes efficiency and productivity, while also ensuring that wireless operators have exclusive access to spectrum to maximize the benefit from 5G network deployments. Approximately 65% of the projected global 5G GDP benefits expected by 2030 are dependent on mid-band spectrum, representing its criticality to sustaining 5G growth and value creation.[28] Mid-band spectrum will help realize transformational 5G use cases, such as digital twins, autonomous driving, connected industry, etc. because of its suitability for three defining characteristics of 5G – enhanced mobile broadband, ultra-reliable low-latency communications, and massive machine type communications. Mid-band spectrum for 5G will also be important for future generations like 6G, which is expected to leverage similar frequencies.[29]

Applications of 5G and Spectrum Requirements[30]

Enhanced Mobile Broadband (eMBB)

Enhanced mobile broadband supports use cases requiring high bandwidth and fast download speeds, such as high-resolution bi-directional video, extended reality, and Fixed Wireless Access (FWA). This type of traffic will be most used by consumers, and will support growth in demand for, and improved experiences with, mobile data usage.[31] 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 (e.g., remote surgery, autonomous driving, etc.). Delivery of URLLC service will require a mix of mid-band and high-band spectrum.[32] 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 industry and consumer uses cases (e.g., smart factories, smart cities, etc.). Supporting mMTC will require a mix of low-band and mid-band spectrum.[33] 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.

*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.

The Mid-band Gap and the Harmonization Opportunity

The gap in mid-band availability and the opportunity for harmonization

US mid-band gap relative to **global counterparts**

Today (2023)

Peer average:
652 MHz
Average availability of mid-band spectrum between five leading countries*

US deficit:
202 MHz
Gap between mid-band spectrum available in the US relative to five leading countries

Projected (2027)

Future peer average:
970 MHz
Forecasted average mid-band spectrum available between five leading countries**

Future US deficit:
520 MHz
Forecasted gap between mid-band spectrum available in the US relative to five leading countries, absent any new spectrum**

The mid-band gap relative to **meeting future data demand**

400 MHz
Forecasted deficit in US spectrum by 2027 absent any new allocations***

>1,400 MHz
Forecasted US spectrum deficit by 2032 absent any new spectrum***

Despite the importance of mid-band, the US has a significant and widening gap in this part of the spectrum relative to global counterparts. According to an Analysys Mason report from September 2022, at least five countries (studied in the report) have more mid-band spectrum assigned for commercial wireless use than the US, reflecting a gap between the US and the average of those nations of 202 MHz*. This gap is projected to widen to 520 MHz by 2027 unless the US makes more mid-band available**. Addressing this deficit is necessary to ensure that the US continues to be a wireless leader on the global stage, both for the remainder of the 5G era and for wireless generations to come.

The mid-band gap will only increase as US demand for wireless network data accelerates, at a projected CAGR of ~20% from 2022 to 2028.[34] A lack of mid-band spectrum will result in network capacity issues and reduce service quality for end users. Absent any new spectrum, the gap between future needed and available mid-band will grow from 400 MHz in 2027 to more than 1,400 MHz by 2032.[35] Such a significant deficit will hinder the US' potential to realize the full benefits from 5G and beyond.

In attempting to address this mid-band gap, the US must look to allocate spectrum that is harmonized to that of its global peers, or risk falling behind as a wireless leader. Furthermore, as other nations increasingly harmonize their spectrum, the US must do the same to avoid becoming siloed in the wireless ecosystem and missing out on the economic benefits from harmonization.

*Based on Analysys Mason's report issued in September 2022, several countries with more mid-band than the US included Japan (1100 MHz), the UK (790 MHz), France (510 MHz), China (460 MHz), and Saudi Arabia (400 MHz) ** By 2027, several countries with more mid-band spectrum than the US are projected to be China (1660 MHz), Japan (1100 MHz), the UK (790 MHz), South Korea (700 MHz) and Saudi Arabia (600 MHz), *** Forecasted spectrum deficit is normalized to a lower mid-band equivalent (exclusive use, with no power restrictions)

How Spectrum Harmonization Works

Spectrum harmonization refers to the consistent distribution of radio frequency bands between countries, regionally and at a global level. Harmonized spectrum unlocks economies of scale and innovation and is a major factor when determining how to allocate new spectrum.

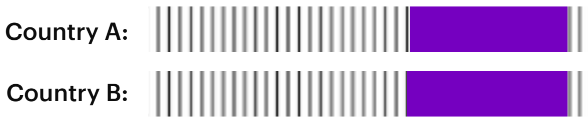
Harmonization is not a binary concept. Rather, it is a continuum influenced by the spectrum management decisions of various countries. This concept is demonstrated by the following scenarios, where country B is looking to allocate more spectrum for commercial use. While the extent of harmonization varies between scenarios 1 and 2, both are preferable to scenario 3, where no harmonization occurs and therefore no harmonization benefits are realized.

For the purposes of this paper, spectrum harmonization refers to the action taken by a national regulatory body to assign similar spectrum bands for similar use (e.g., for exclusive commercial wireless use) as other countries. Although spectrum harmonization is an international phenomenon, allocation decisions are made on a national level, and thus policymakers must weigh domestic priorities in the context of the broader international spectrum landscape.[36]

Furthermore, technical conditions (e.g., 3GPP*) associated with a spectrum band, such as its sharing system, out-of-band limits, etc. must be taken account to holistically consider bands to be harmonized. For example, the FCC had to work closely with 3GPP to establish special standards to accommodate CBRS.

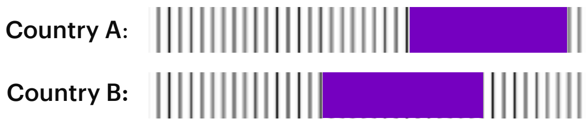
Scenario 1: Perfect Harmonization

Country B allocates its spectrum in full alignment to **Country A**'s allocation.



Scenario 2: Partial Harmonization

Country B allocates a range of spectrum that partially overlaps with **Country A**'s allocation.



Scenario 3: No Harmonization

Country B allocates a completely different spectrum range than **Country A**.

* The 3rd Generation Partnership Project (3GPP) is a technical standards-setting body for global wireless communications, which dictates the specifications for how new generations of wireless networks should be deployed and operated

Driving Global Harmonization through International Collaboration

The role of international forums in driving global spectrum harmonization

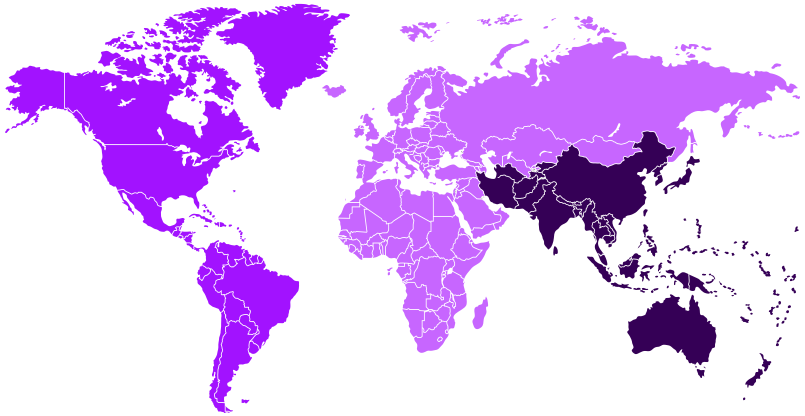
International forums such as the International Telecommunication Union (ITU), a United Nations agency, and 3GPP, a wireless technical standards-setting body, all play a role in spectrum harmonization. Manufacturers and industry players also influence harmonization and help shape regulatory decisions and international agreements that align with their interests and technology agendas.

ITU WRC – The ITU's World Radio communications Conference – is hosted every four years to review and revise the Radio Regulations, the international treaty that governs the use of radio-frequency spectrum. The ITU Council determines an agenda that considers recommendations previously made at other WRCs. WRC-23 was hosted from November 20 to December 15, 2023. Each ITU member state is represented at the WRC by a national delegation. At the conference, members discuss their national contributions and build consensus on ideas that could have an influence on other regional members. There are six regional groupings, which include the Americas, the Middle East, Europe, Africa, Asia, and the former Soviet Union. Considering that the Radio Regulations include three ITU primary regions, reaching consensus at the regional (and cross-regional) level is crucial. [37]

3GPP – The 3rd Generation Partnership Project is the most relevant standard setting organization in the field of mobile telecommunications. Formed in 1988, its purpose is to develop a common wireless system for Europe, Asia, and North America. 3GPP produces reports which aim to standardize cellular technologies, allowing them to operate effectively in licensed spectrum.[38]

Illustration: ITU Regions[39]

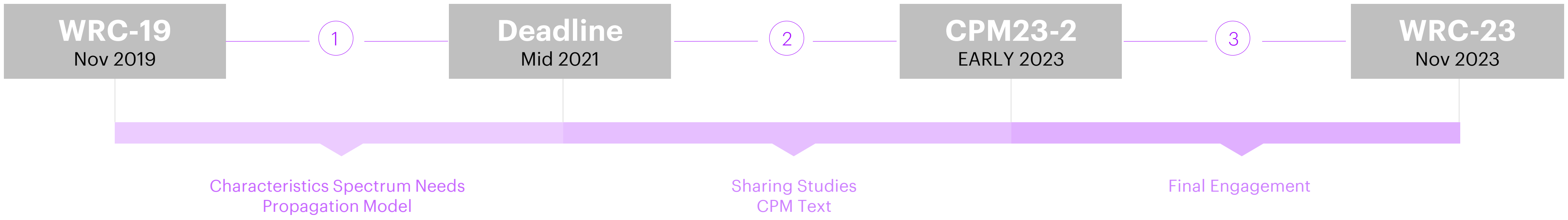
Spectrum harmonization can happen on a global or regional level, and given the extensive studies and consensus-building process, ITU decisions take time, effort, and leadership.



ITU Regions:

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

Illustration: ITU Study Cycle[40]



Why Spectrum Harmonization is a Pressing Concern

Spectrum harmonization drives broad economic and societal value

Spectrum harmonization generates benefits in addition to those that simply result from allocating more spectrum for commercial wireless.

Harmonization standardizes the use of spectrum globally, allowing network equipment and wireless device manufacturers to reduce duplication and streamline production across markets. These economies of scale provide consumers and industry with more affordable and higher-quality products and services, as well as faster and more widespread access to improved connectivity and new wireless technology. These efficiencies will drive broad value throughout the economy through realization of transformative 5G use cases, reduction in the digital divide, and more.

As spectrum harmonization delivers more growth and innovation globally, wireless leaders like the US stand to capture a larger share of the opportunity by establishing and maintaining a first-mover advantage. By making diligent investments in new generations of network infrastructure as well as proactively leading the conversation on policy and standards, the US can ensure that it captures the economic, societal, and national security benefits that come with wireless leadership.

A first-mover advantage in 5G and future generations can ensure that more innovation occurs domestically, through the creation of new industries and jobs as well as more economic growth overall.

The Burning Platform for Harmonization

While there has been incremental progress in driving alignment across countries to date, there are still significant gaps in harmonization, particularly for 5G and future wireless generations. With the increasing need for wireless connectivity over the coming years and as more countries look to align their spectrum allocations with established wireless leaders, it is more critical than ever for the US to play an active role in driving spectrum harmonization.

The US gap in commercial mid-band during an era of rapidly increasing wireless demand requires taking a harmonized approach to mid-band spectrum allocation. The opportunity for the US is to prioritize bands that offer clear harmonization benefits, thus maximizing the potential benefit from 5G and future generations of wireless.

If the US ignores this opportunity however, it will be leaving significant value on the table and risk limiting its influence and future leadership in the global wireless ecosystem. Therefore, it is more critical than ever for the US to play an active role in driving harmonization and wireless leadership.

In this paper, we first look at global approaches to spectrum allocation and lessons from historical wireless leadership across generations in order to identify the specific opportunity for the US.

We then examine and quantify the potential benefits from harmonized allocation and leadership, and finally, identify the actions and acceleration levers needed to realize these benefits.

Section 02

The Global Spectrum Landscape

Spectrum Harmonization and Wireless Leadership

Spectrum harmonization and wireless leadership demonstrate a persistent connection throughout the history of mobile networks. First-mover advantages obtained through wireless leadership provide notable benefits, especially when it leads to more harmonized spectrum globally.

2G → 3G → 4G → 5G

Europe Sets the Stage for 2G with GSM

The establishment of the GSM standards positioned Europe as a leader in the 2G wireless era. GSM accelerated the development and deployment of 2G technology across Europe, enabled spectrum harmonization, and helped set a global standard for mobile communication.[41] Initially, GSM was built for the 900 MHz band, but soon expanded to various frequency bands to provide a base framework for cellular and mobile use at a rapid rate. Germany, France, the UK, Italy, and Spain all reached 80%+ 2G adoption years before the US and other countries reached similar penetration levels.[42]

GSM became the leading 2G standard globally with over 1.266B subscribers. Europe's market dominance from its 2G leadership unlocked significant economic benefits and bolstered its wireless industry. Europe became a hub for wireless innovation, made European companies (e.g., Nokia) household names in mobile technology, and set the course for global 2G with GSM standards.

Spectrum harmonization and early allocation can empower leadership on standards development. Leading on standards creates a conducive environment for innovation and unlocks first-mover opportunities.

Fragmented 3G Landscape

Fragmentation and regulatory burdens in 3G derailed the EU's wireless leadership position. Regulatory restrictions limited leading EU operators from taking swift action on 3G. For example, one regulation prevented operators from repurposing 2G spectrum to deploy 3G in their respective countries – driving up licensing cost and delaying deployment timelines.[43,44] The first-mover advantage experienced by Europe and its original equipment manufacturers (OEMs) due to the widespread adoption of GSM for 2G led to a more complicated 3G landscape. Individual regions put their own standards forward with different allocations outlined for spectrum, such as WIMAX, W-CDMA, and CDMA200.[45] This resulted in international spectrum fragmentation, with some standards being more prominent in certain regions than others, with no clear leader or global spectrum standard to define the generation. The lack international alignment and collaboration led to uneven distribution of new wireless technologies, and a lack of global innovation overall.

Unsynchronized spectrum management and standards development leads to complexity and operating inefficiencies, limiting innovation in the global wireless ecosystem.

The US Leads 4G LTE as the EU Falls Behind

Overall, 4G was more harmonized than the prior generation. The US shifted from being a follower to a leader in 4G and established global dominance through investment in innovation and intelligent wireless policy-making.[46]

US regulatory bodies such as the FCC played a crucial role in driving US 4G leadership, auctioning spectrum assets (including 3000 PCS, AWS and 700 MHz) and implementing policies to expedite tower siting.[47] From 2007 to 2011, US mobile operators invested more than $117B in their networks.[48] This early availability and flexibility of spectrum allocation enabled a swift transition between technological generations, creating a conducive environment for 4G infrastructure development. This resulted in rapid adoption of 4G in the US, which had ripple effects throughout the wireless ecosystem (e.g., widespread adoption of American handsets, the rise of the app economy, etc.).

Conversely, many EU states were slow to allocate key 4G harmonized spectrum, namely the 800 MHz band.[49] These delays led to slower 4G rollouts, which contributed to a decline in EU OEM market dominance – especially for handsets – and reduced EU influence in the wireless ecosystem overall.

Early spectrum allocation and investment-friendly policies lead to ample and timely investments by mobile operators to build networks, which fosters innovation and enhances the nation's global influence.

Key Lessons on Leadership

In exploring the evolution of spectrum leadership and the actions that led to it, certain themes emerge that reflect the ties between a country's spectrum management approach and their wireless dominance. These include:

1. **Proactive allocation of strategic spectrum bands**
2. **Contribution toward a harmonized global spectrum landscape**
3. **Strong investment in next-generation network infrastructure**

Each wireless generation had specific ranges of spectrum that were in demand, and establishing wireless leadership required countries to make that resource available in a timely, consistent, and predictable manner. For 5G, allocation in the mid-band range, alongside effective harmonization, will ultimately determine which countries are able to establish and maintain wireless leadership.

Spotlight: The 5G Leaders

South Korea:

Early allocation of strategic bands leading to exceptional 5G network performance

South Korea licensed substantial C-band spectrum in contiguous blocks early in the 5G era, employing 280 MHz of spectrum fully harmonized with Europe's emerging plans for 5G. This proactive recognition of the strategic importance of the C-band has contributed to South Korea's success in its 5G rollout. South Korea was one of the first countries to launch a 5G network back in 2019 and has consistently been a top performer in terms of network speed, with a 496 Mbps download speed as of Q4 2022, second only to the UAE.[50,51] Additionally, South Korea was one of the first countries to achieve 90% population coverage within the first year of deploying 5G, partially due to its high population density.[52] By taking early action in securing highly coveted C-band and consequently being a leader on launching and scaling 5G networks, South Korea positioned its home-base network OEM to capture a first-mover advantage. On the back of this early domestic launch, Samsung was able to achieve significant global market share for network equipment, growing from 6.6% of 5G network equipment sales in 2018, to 36% in 2019. [53] Innovation and diligent technology policies by the Korean government were catalysts for Samsung's success in the smartphone market. Samsung was the first major enterprise to apply a structured framework for innovation, investing heavily in research and development. South Korea has been able to leverage this advantage to innovate on important 5G use cases such as smart cities, embedding connectivity into urban management in alignment with its national development strategy. Based on its early domestic success, South Korea has built a reputation as a connected industry leader and is partnering with other countries to help them revitalize their urban management practices.[54,55]

Spotlight: The 5G Leaders

China:

Early and ample allocation of mid-band spectrum enabled Chinese network equipment leadership.

China's proactive approach in making spectrum available for 5G solidified its initial success in 5G network rollout and wireless technology innovation. This early prioritization, especially in allocating harmonized mid-band for commercial use, continues to solidify its leadership position. According to GSMA, China is forecasted to be the first country to reach 1B 5G connections (by 2025).[56] A significant driver behind this success is China's spectrum policy, specifically with respect to allocations in the 2.6 GHz and 3.4 GHz ranges. China was one of the first countries to begin auctioning spectrum for 5G, having licensed 360 MHz of mid-band to operators by the end of 2019 as part of its broader strategy to use its wireless leadership to drive spectrum harmonization and advance its network equipment market leadership.[57,58] Chinese companies have also benefited from the country's early investment in 5G, with Chinese OEMs leading global telecom equipment revenues for the beginning of 2023, ahead in five out of six main network equipment categories.[59] This market dominance can be tracked back to early investment into R&D and contributions to standards development for 5G, with Chinese OEMs spending more than $600M on 5G research and innovation by 2013 prior to 5G technical specifications being established.[60] This leadership is also demonstrated by China's growing relevance in the 5G patent sphere. The proportion of 5G patent family share captured by Chinese companies grew from 19% in 2018 to 32% in 2023, trailed by South Korea and the US with shares of 24% and 19% respectively in 2023. As a result of prioritizing investment in innovation and R&D, Chinese companies have become global leaders in 5G relevant 3GPP contributions as well as 5G technology patent.[61]

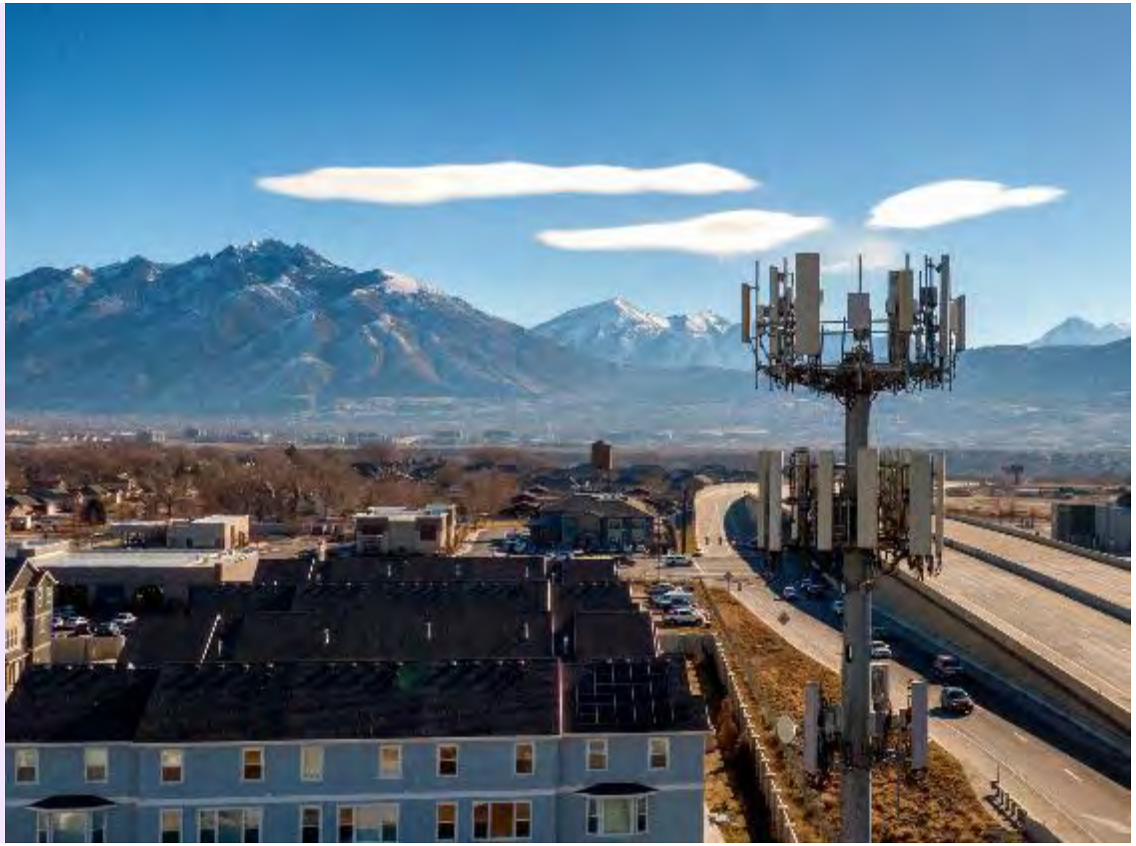
Spotlight: The 5G Leaders

The United States

Limited availability of spectrum necessitates wireless operator CAPEX to enable network excellence.

The US took an early lead in 5G as a result of significant investment in building and deploying network infrastructure. The nation is a global leader in terms of 5G adoption with 54% availability* as of mid-2023 which is largely due to the commitment by operators to rapidly deploy 5G networks.[62] This was demonstrated by the significant investments made in recent years, with approximately $186B invested in wireless networks between 2017 and 2022.[63]

However, 5G has yet to live up to it's full economic potential in the US, which is limited by a lack of mid-band spectrum, and it risks not being able to realize the full future potential of 5G without allocating additional spectrum for commercial use.



* "Availability" is measured as the number of 5G-enabled handsets that connect to a 5G network the majority of the time

The 5G Mid-band Landscape

A Recent History

Globally, countries have been making progress on allocating mid-band spectrum to support 5G networks. As of late 2022, five countries that lead the US in terms of mid-band availability have, on average, allocated 652 MHz of lower mid-band spectrum.[64] Furthermore, many countries are increasingly taking action to align their allocations with each other by focusing on distinctly harmonized bands as indicated by the 3.4-3.8 GHz band being almost universally harmonized. This trend of harmonized allocation is expected to continue. In particular, the 3.3 GHz and 4.8 GHz bands were on the agenda for WRC-23 and have already gained momentum with some countries proactively allocating these bands.

The 3 GHz Band

3.3-3.4 GHz

Globally, attention is turning to find opportunities to expand harmonization of the lower 3 GHz, with the WRC-23 agenda having included the 3.3-3.4 GHz band for IMT use in ITU regions 1 and 2, as well as 3GPP standardization of this band along with numerous deployments.[65]

3.4-3.8 GHz

The 3.5 GHz band, broadly considered the 5G launch band, has largely been harmonized, with over 60 countries having allocated at least some portion of the C-band. Furthermore, at least 20 countries have approximately 200 MHz of contiguous allocation exclusive for IMT use between the broader 3.3-4.0 GHz.[66]

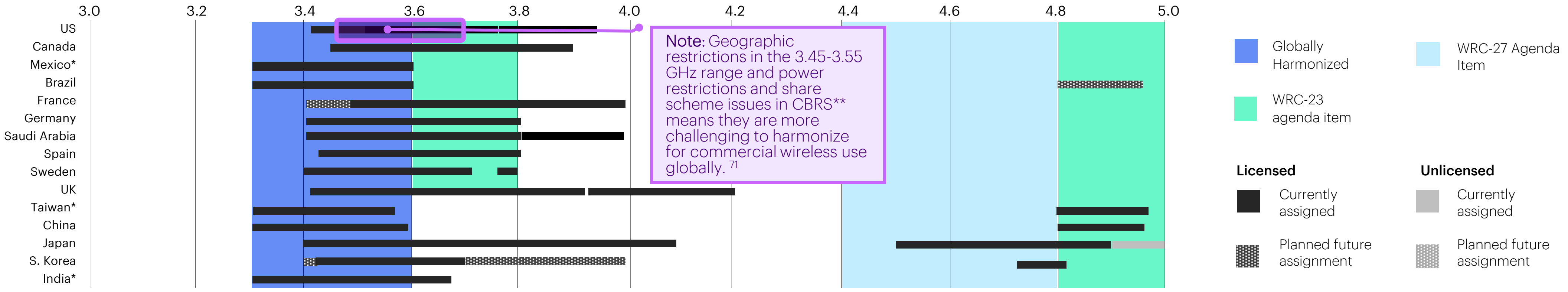
The 4 GHz Band

4.5-4.8 GHz

Japan has allocated this full block for commercial wireless use, whereas South Korea has allocated the upper portion of this segment.[67] 3GPP has also recognized the full 4.4-5.0 GHz band in its 5G NR band 79.[68]

4.8-4.99 GHz

Several countries have recently allocated portions of the upper 4 GHz band, namely China, Japan and South Korea.[69] The 4.8-4.99 GHz portion was on the WRC-23 agenda for all ITU regions.[70]



* The data source for spectrum allocation for these countries only indicated licensed 5G assignments

The 5G Mid-band Landscape

The 6 GHz Band

Lower 6 GHz: 5.925-6.425 GHz

China's recent decision to allocate most of the 6 GHz band for IMT use, contrasted with the US' decision to allocate it for unlicensed use to accelerate the growth of Wi-Fi 6, has sparked global debate on the intended use for this band moving forward. [72,73]

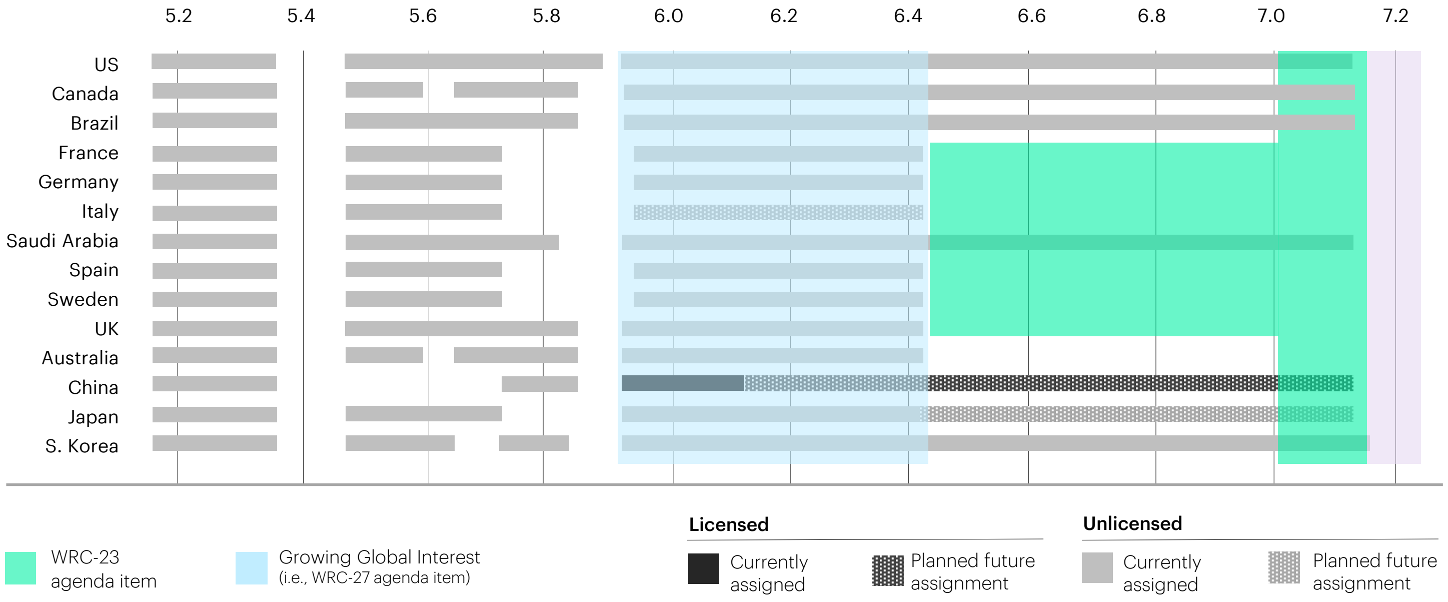
Upper 6 GHz: 6.425-7.125 GHz

The upper 6 GHz band was identified for IMT in Region 1 and several countries in Regions 2 and 3 at WRC-23, with the option for other countries to opt into the IMT footnote at WRC-27. In addition, all of Region 3 identified the top portion of the upper 6 GHz band for IMT at WRC-23.[74]

The 7-15 GHz Band

7.125-15 GHz

As focus shifts to future wireless generations, the global community is beginning to investigate the 7-15 GHz band and its potential commercial application. This band is being considered for study as part of the study cycle leading to WRC-27. The WRC-27 agenda will be pivotal in determining which bands will be harmonized beyond 5G, with a considerable amount likely to fall in this range.[75]



Many countries are expected to act in the coming years to increase their mid-band availability and do so in a harmonized way. Future planned assignments show that the average amount of mid-band spectrum available in five leading countries could grow to more than 970 MHz largely in bands that are increasingly harmonized. These allocations, however, are not going to be sufficient to meet rising demand. Wireless leaders can be expected to take action to reinforce spectrum availability, as has already been seen with China's announcement of plans to make the full 6 GHz band available for commercial wireless use.[76]

The US Mid-band Landscape

The US lacks available harmonized mid-band spectrum, risking significant economic benefit

The US has aimed to increasingly harmonize its spectrum in recent years, with allocations in the mid-3 GHz range through auctions across the 3.45 GHz band, the C-band, and the CBRS bands. However, such a fragmented approach has limited mobile operators' ability to capture the full benefits of the mid-3 GHz range. Specifically, the area and coordination restrictions over some of the 3.45 GHz band alongside the sharing scheme and associated low-power limits in place on the CBRS band constrains the utility of these bands.[77] Moreover, the CBRS technical rules were not aligned with the existing 3GPP standards, requiring costly changes to the specification for the new band class, custom software for equipment for the US market, and development of interworking requirements at standards bodies versus other countries operating 3 GHz networks.

While the US has been a leader in terms of 5G coverage and availability on the back of its early investment with 4G LTE, growing demand and limited/restricted access to mid-band spectrum have left the US with capacity challenges that have hindered 5G speeds domestically, with the US having a median 5G download speed of 133.47 Mbps as of the end of 2022, compared to the 496.63 Mbps and 280.85 Mbps speeds demonstrated by 5G leaders South Korea and China respectively.[78]

The US mid-band gap is apparent and is expected to only grow given the lack of planned future mid-band assignments combined with forecasted data traffic growth in the US. With the US deficit in spectrum relative to demand expected to reach 400 MHz by 2027, and over 1,400 MHz by 2032, wireless operators will be ill-equipped to realize the full value of 5G and estimates have indicated that $400B-$500B of economic value remains to be captured by the US from 5G, with approximately $250B-$330B of that value unlocked by mid-band spectrum.*[79,80,81]

The widening gap between the US and its global counterparts in terms of harmonized mid-band availability is putting the US' ability to sustain its wireless leadership at risk. As other countries continue to seek opportunities to harmonize their allocations, it is critical that the US takes advantage of opportunities to allocate more harmonized mid-band spectrum and avoid becoming siloed in the global wireless ecosystem.

*Based on applying the proportion of economic value attributable to mid-band spectrum (65% per GSMA) to the estimated remaining economic benefit in the US from 5G (Ericsson)

The US Mid-band Landscape

The US can allocate more harmonized mid-band spectrum to ensure its future wireless leadership

The Fork in the Road for the US – The Risk of Falling Behind

As other countries continue to harmonize and allocate more mid-band, the lack of a clear spectrum pipeline puts the US at risk of falling further behind. The lack of utility of US allocations in the 3.5 GHz band, alongside the decision to allocate the full 6 GHz band for Wi-Fi use leaves fewer options for addressing the existing mid-band deficit.[82] Closing this gap is imperative for the US to keep pace with competing wireless nations and bolster its 5G network performance.

As the US considers its options for closing this gap and looks to build a pipeline in the mid-band, it's important to consider the global spectrum landscape and stay ahead of harmonization trends.

The Opportunity for Harmonization

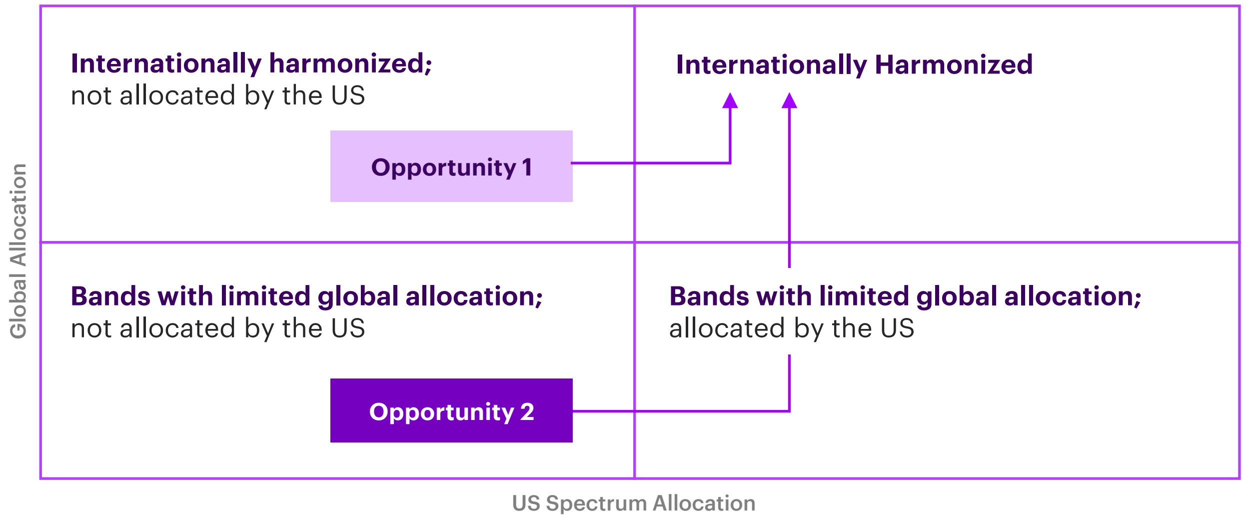
Fortunately, the gap in mid-band availability gives rise to opportunity. There are several bands that offer clear harmonization and leadership benefits that would maximize the return on investment from having to clear bands.

However, if the US ignores this opportunity, it will leave significant value on the table and will risk limiting its influence and future leadership in the global wireless ecosystem.

Spectrum Harmonization Opportunities

Seizing the Harmonization Opportunity: Identifying and Selecting Optimal Bands

There are two opportunities for the US to address its mid-band gap while becoming more harmonized: Allocating bands that are already widely harmonized and playing a leadership role to allocate bands that are not currently harmonized but are strong candidates for future-generation use cases.



Opportunity 1: Allocate Currently Harmonized Spectrum

Considers bands that are currently harmonized, or are gaining global traction for harmonization, both of which the US lacks. By allocating these bands, the US can capture immediate harmonization benefits.

Opportunity 2: Lead Harmonization on New Bands

Bands with high potential to be harmonized due to their favorable characteristics and proximity to existing harmonized bands. By allocating these bands domestically while advocating for other countries to follow suit, the US can capture the immediate benefits from harmonization and strengthen its wireless leadership position.

We can apply the following criteria to identify the specific, high-priority spectrum bands that best position the US to realize harmonization benefits for both opportunities above:

Performance Characteristics

The utility of a band for specific wireless use cases, such as its propagation qualities, coverage, throughput, etc.

Proximity to Harmonized Bands

The extent to which a band is adjacent or near ranges that are already globally harmonized (i.e. a band's potential for harmonization expansion).

Global Traction

The extent of current or planned allocation by other countries, acknowledgement by ITU for WRC, inclusion in 3GPP specifications, etc.

Domestic Conditions

The extent to which the US has already made the band available or if it can be made readily available.

Prioritized Spectrum Bands

The US Spectrum Harmonization Opportunities

In evaluating bands for US allocation based on performance characteristics, proximity to harmonized spectrum, global traction, and domestic availability, there are several that are ideal candidates for closing the mid-band gap in a way that drives more spectrum harmonization between the US and its international counterparts.

Opportunity 1
Align to Existing Harmonized Bands

(Globally harmonized bands that the US has not yet allocated for commercial wireless use)

These bands have been identified due to their widespread international adoption as indicated by their status on the WRC-23 agenda. Additionally, these bands are ideal for 5G use cases due to their high coverage and capacity characteristics.

A 3.3-3.45 GHz Band

B 4.8-4.94 GHz Band

The entire 6 GHz band is currently allocated for unlicensed use in the United States. However, several other countries are harmonizing the upper portion of the band for licensed mobile use, potentially justifying reexamination of this band in the US.[83]

Opportunity 2
Lead Harmonization on New Bands

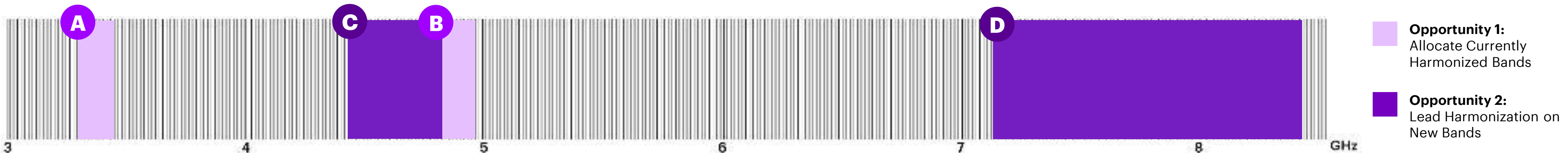
(High-potential bands that meet harmonization criteria, but are not widely licensed for commercial use in other countries)

These bands have been identified based on their capability to support higher throughputs while maintaining broad coverage, making them ideal for 5G (and potentially 6G) uses cases. They are also contiguous with current and potential harmonized bands and thus are attractive expansion opportunities, especially as it pertains to US wireless leadership. Because 6G is likely to leverage similar or adjacent spectrum to that of 5G, allocating these bands is critical for the US' future wireless leadership.

C 4.4-4.8 GHz Band

D 7.125-8.5 GHz Band

Lower Mid-Band Spectrum

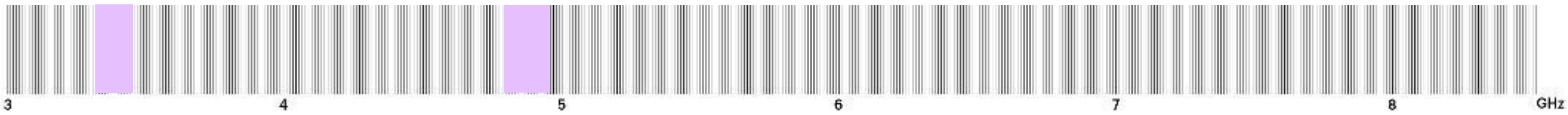


Opportunity 1

Align to Currently Harmonized Bands

Two high-potential bands have widespread global adoption and have been identified for broader harmonization by standard-setting bodies, such as the ITU and 3GPP. The US has an opportunity to follow suit and allocate these bands for commercial wireless use in alignment with the global community. In doing so, the US would unlock the near-term benefits from harmonization, such as the potential for economies of scale and process efficiencies for network OEMs and device manufacturers, faster deployment of wireless networks, and improvements in network performance.

Lower Mid-Band Spectrum



The 3.3-3.45 GHz

The 3.3-3.45 GHz band is growing in global relevance; and was on the WRC-23 agenda for ITU Regions 1 and 2 and is already part of the 3GPP's 5G NR specifications, namely the n77 and n78 bands.[84] Many countries have already made this band available for commercial use, including but not limited to Brazil, China, Chile, India, Mexico, the Philippines and the UAE.[85] The band's proximity to the C-band and favorable performance qualities have contributed to its global adoption, especially as countries seek to bolster 5G adoption through 2030.

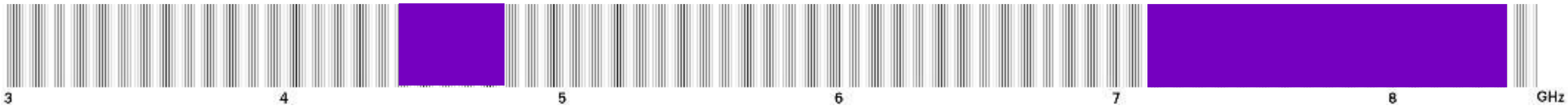
The 4.8-4.94 GHz

The upper 4 GHz band is adjacent to the upper portion of the C-band and boasts similar properties, making it ideal for 5G use. Some countries have allocated portions of this range for IMT use, such as China, Japan and South Korea, and many other countries are considering harmonizing to this band.[86] The 4.8-4.99 GHz range was on the WRC-23 agenda across all three ITU regions and 3GPP has recognized the full band in its 5G NR specifications, with the n79 band covering the 4.4-5.0 GHz range.[87,88]

Opportunity 2
Lead Harmonization on New Bands

Another opportunity for harmonization arises from frequency ranges that have not been widely adopted for commercial wireless use globally. These are valuable as they create potential first-mover advantages, including for next-generation wireless technology. The full extent of potential benefits from these opportunities are contingent on the US' ability to successfully advocate for the widespread adoption of these bands, which can be done both through direct engagement and via standard-setting bodies.

Lower Mid-Band Spectrum



4.4-4.8 GHz

The mid-4 GHz range is becoming increasingly harmonized, with both Japan and South Korea allocating parts of the 4.4-4.8 GHz band for IMT use.[89] With further harmonization of the adjacent 4.8-4.99 GHz frequency band at WRC-23, and the full 4.4-5.0 GHz range recognized in 3GPP's 5G NR specifications as band n79, it is reasonable to expect that the mid-4 GHz band could be more widely harmonized.[90,91,92] This band is suitable for a variety of applications due to its broad coverage and high capacity. It can support techniques like beamforming and massive multiple-input, multiple-output (MIMO). It is also critical for filling the mid-band capacity gap needed to address increasing mobile traffic, which is particularly impactful in regions with cost or geographical barriers to laying fiber.[93]

7.125-8.5 GHz

Future wireless generations are expected to be launched on the 7-15 GHz range, with manufacturers stating that there are benefits to prioritizing the lower end, such as the 7.125-8.5 GHz range, that are adjacent to the lower mid-band.[94] WRC-23 agreed to focus studies on global harmonization of IMT in this range for WRC-27 decision.[95]

The 7 GHz band's blend of coverage and capacity also make it suitable for future generations of mobile broadband as well as transformational use cases like smart cities, connected factories, etc.[96]

Section 03

The Benefits of Harmonization

WIP – subject to change

The Benefits of Spectrum Harmonization

Spectrum harmonization and wireless leadership offer broad benefits globally and for the United States, such as reducing the cost of wireless devices for end users, accelerating the realization of transformational 5G uses, and powering economic growth.

Spectrum harmonization will make network equipment and wireless devices more affordable for consumers and industry, due to the resulting standardization and economies of scale in production. These cost savings will come in the form of cheaper devices (e.g., smartphones, IoT sensors, wearables, etc.) and more accessible and scalable network equipment. Consumer savings on smartphones is critical in an era when US smartphone prices have steadily increased over the last decade.[97] Also, more cost-effective equipment and devices will provide more scale and velocity for network deployments, which, in turn, can unlock new industry use cases, help keep up with the rapid growth of wireless demand, and reduce the digital divide. Harmonization will also improve the quality and reliability of network infrastructure by reducing interference between neighboring regions and improving global roaming for end-users.

As was the case from 3G to 4G, more harmonized spectrum can unlock incremental growth and innovation globally. A more cohesive global wireless market generates more economic activity in terms of new industries, jobs, and dominant domestic technology companies. Countries that lead the charge on 5G and beyond stand to capture a disproportionate amount of these long-term benefits.

Cost-Savings for Consumers and Industry

Acceleration of Use Cases from 5G and Beyond

Economic Expansion (e.g., new industries, job creation, etc.)

The Benefits of Spectrum Harmonization

How Spectrum Harmonization Drives Value

Wireless technology production efficiencies and global growth and innovation will drive most of the benefits from spectrum harmonization. Although all harmonized nations will benefit, wireless leaders can capture a larger share of the overall value.

Cost efficiencies from spectrum harmonization are primarily driven by standardization of network equipment and mobile device production across geographies. Consistency in spectrum allocation across markets drives economies of scale in manufacturing processes and simplifies needed radio capabilities. These efficiencies flow through the entire wireless value chain, which includes original equipment manufacturers (OEMs), device manufacturers, and mobile network operators (MNOs). Network OEMs and device manufacturers can consolidate overhead (e.g., R&D) and simplify their technology, enabling MNOs to deploy network infrastructure more quickly due to improved investment economics. Harmonization also allows operators in different countries to collaborate more easily and provide better service to end users.

Additionally, spectrum harmonization unlocks growth and innovation globally, as countries can work together to develop new wireless standards and collaborate on new technology that has global appeal. In addition to the global advantages of spectrum harmonization, countries that establish early leadership (particularly on new generations of wireless technology) can benefit disproportionately – both from an economic and national security perspective. This first-mover advantage accelerates the growth and innovation that comes with having robust and widely adopted wireless infrastructure and technical standards, as was the case with 4G and the resulting mobile app ecosystems that originated in the US. Taking a leadership position in 5G and beyond will allow the US to capture more of the global value that spectrum harmonization can generate. It will also ensure that the US' ecosystem of trusted technology vendors can benefit from economies of scale, which, in turn, will bolster US national security in the face of global technological and geo-political threats.

1 Wireless Technology Cost and Performance

1.1 Network Equipment Efficiencies

- Economies of Scale
- Network Deployment Efficiencies
- Operational Performance and Reliability (e.g., equipment maintenance, interference, roaming)

1.2 Wireless Device Efficiencies

- Economies of Scale
- Radio Component Simplification

2 Growth, Innovation, and US Leadership

2.1 Growth and Innovation

- Global Growth and Innovation (i.e., new technology, more use cases)

2.2 US Leadership

- Incremental Economic Benefit
- National Security

The Mobile Wireless Technology Value Chain

The Wireless Value Chain

Each stakeholder in the wireless technology value chain is impacted by how spectrum is allocated, as it is the fundamental mechanism that facilitates connectivity for all wireless technology.

Chipset and network OEMs produce the components (e.g., chipsets, antennas, batteries, etc.) that are inputs into connected devices (IoT sensors, smartphones, etc.) and wireless network infrastructure (e.g., base stations).

Device manufacturers produce end user wireless devices used by consumers and industry, such as smartphones, IoT sensors, wearables, and more.

MNOs deploy and operate the cellular networks that connect wireless devices. Device Manufacturers develop the final products used by MNOs, consumers, and industry such as network equipment, smartphones, and IoT sensors, respectively.

Spectrum harmonization benefits each of these entities, and ultimately consumers and businesses in the form of cheaper products, better connectivity, and new applications. Spectrum is a critical resource for connected technology, and global alignment on how that resource is deployed is imperative for realizing the full economic value from 5G and future generations.

The Wireless Technology Value Chain

	Original Equipment Manufacturers (OEMs)	Device Manufacturers	Mobile Network Operators (MNOs)	Consumers and Businesses
Description	OEMs produce the components that are used in devices and within cellular network infrastructure. Chipset OEMs produce a variety of mobile, network processing, and radio equipment (e.g., CPUs, GPUs, etc.). Network OEMs develop the computing and radio components that are built into network infrastructure such as radio units, antennas, and core networking hardware.	Device Manufacturers produce consumer devices such as smartphones, VR headsets, wearable devices, and smart thermostats, as well as industry technologies, like IoT sensors, drones, and Point-of-Sale systems. Many of these devices are built with radio functionality to enable connectivity and are rapidly becoming more intelligent as they capture increasing amounts of data and are processing that data in real time (i.e. edge computing).	MNOs serve as the primary channel for wireless communications for consumers and businesses. They deploy and run networks using the equipment developed by OEMs. Consumers and businesses then utilize these networks for wireless communications via the technologies developed by device manufacturers.	Consumers are the true demand drivers for spectrum. Through everyday activities such as using their smartphones, streaming media, and working, they transmit data over networks underpinned by spectrum. Enterprises rely on a wide range of wireless technologies to operate, from private wireless networks for secure and functional connectivity to Machine-to-Machine IoT for data exchange and automation.
Potential Benefits of Harmonization	• Economies of scale in the production of network equipment and wireless devices due to a reduction in frequency variants across global markets • Reduced cost and overall need for complex multi-band capability, allowing for resources and device functionality to be allocated to developing additional computing capabilities and new form factors		• Improved capital efficiency and accelerated deployment of network infrastructure • Operational efficiencies from reduced network downtime and interference, and improved roaming	• Cost savings on wireless technologies • Improved quality, coverage, security, and capacity of networks • Realization of additional 5G (and potentially 6G) use cases

1.1 Network Benefits

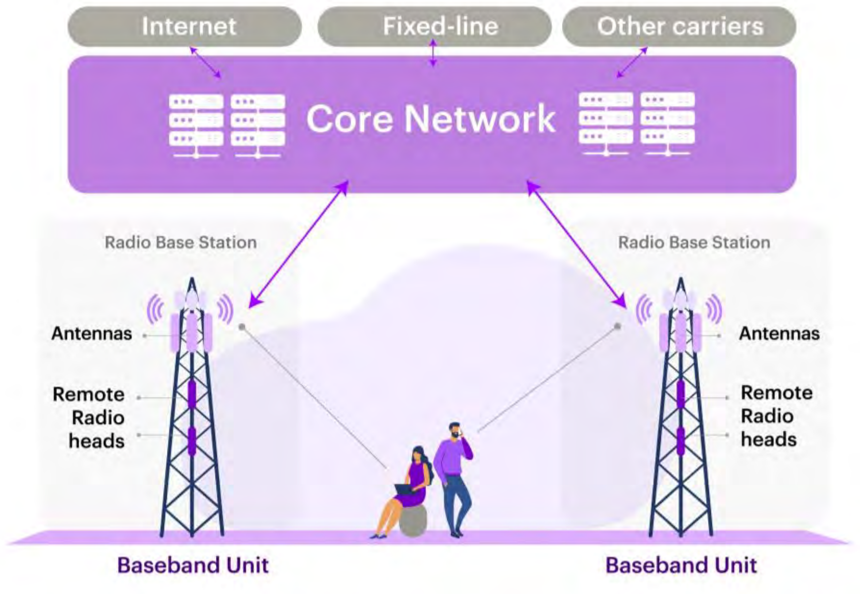
How Radio Networking Equipment Interacts with Spectrum

Radio Access Networks

The Radio Access Network (RAN) is a critical component of telecommunications network infrastructure that connects end-user devices to the core network, relying on spectrum to facilitate that connectivity. The Remote Radio Head or Radio Unit (RU) is responsible for transmitting and receiving radio signals, and its design and functionality are dependent on the frequencies it supports. Despite innovations in digitizing some of the RAN's functionalities*, the RU remains tightly coupled to hardware and typically operates on a limited number of frequency ranges.

The RU is equipped with specific hardware components (e.g., amplifiers, filters, etc.) that are subject to various modifications based on the frequency bands they are intended to support. For example, antennas that are designed for lower frequency bands tend to be larger in size, which has implications on equipment performance and form factor. Therefore, the variation in commercially licensed spectrum across geographies creates inefficiencies in radio equipment production and leads to higher costs.

Illustration: Network Architecture



RAN architecture is comprised of three main components: The Centralized Unit (CU), Distributed Unit (DU), and Radio Unit (RU). Base stations are the towers that house many of these components, in addition to the backhaul cables, antennas, etc.

The **Centralized Unit (CU)** is responsible for the overall management and coordination of multiple base stations, such as handling network capacity, computing, etc.

The **Distributed Unit (DU)** handles radio-related functions specific to a cell site, enabling communication between the three main RAN components.

The **Radio Unit (RU)** is responsible for receiving and transmitting wireless signals, which uses spectrum to communicate and operate. The RU manages the process of converting electrical signals into radio waves for transmission, and radio waves into electrical signals for further processing by the CU.

*Innovation in Software-Defined Networking (SDN) such as Cloud-RAN, has enabled RAN components like the Centralized Unit (CU), which is responsible for core network management, to become more software defined

1.1 Network Equipment Efficiencies

Challenges in Network Equipment Production

Economies of Scale from Spectrum Harmonization

Spectrum harmonization drives economies of scale in equipment production (specifically for radio units) primarily by standardizing hardware across geographies, allowing products to get to market faster and cheaper. Because network radios are modified substantially based on the spectrum they are intended to support, having more of the same hardware applicable to more markets enables consolidation of R&D, Testing & Certification, and Production, which can drive approximately $2B-$3.5B in annual savings (to industry and end users) in the US over the next 10 years.

To handle different spectrum bands, network OEMs design and produce different stock-keeping units (SKUs) of the same type of radio units for different geographic markets, inflating costs and go-to-market timelines. Modified radios (or "frequency variants") require separate technical configurations, performance specifications, and testing requirements, which present unique engineering challenges and significant duplication of costly development activities.[98]

1.1 Network Equipment Efficiencies

Challenges in Network Equipment Production

01

R&D

New frequency variants are expensive to develop and require an entire end-to-end R&D cycle that can cost close to $1M per variant.[99] With each new variant and its supported bands, engineers must understand what type of filtering is required, whether antennas need to be added, reduced, or modified, and what power amplification levels are permitted on that slice of spectrum[100] .For example, they must assess which other frequencies are fielded around a given band to manage potential interference issues associated with other uses of that spectrum.[101] Furthermore, requiring different types of radio components for different variants results in more time spent identifying and working with a broader supplier base to source components. With more harmonization, many aspects of these activities can be consolidated across fewer radio SKUs, significantly reducing the cost to bring new generations of equipment to market.

02

Testing and Certification

Because RAN components rely on spectrum, they are highly regulated by government bodies. Certifying a radio unit that is modified for a specific market can take months and sometimes years, costing tens of thousands of dollars.[102] In the US, the Federal Communications Commission (FCC) must approve all devices that transmit radio signals – down to the component level. Every country has its own certification processes, in large part because they vary in terms of the bands that are licensed for commercial use. Regulations also dictate performance parameters for each band, such as ensuring that power levels do not interfere with other nearby technologies that operate on similar or adjacent bands (e.g., in 2021 the FAA expressed concern with C-band allocation due to potential interference with aircraft safety equipment).

When multiple regions use harmonized commercial bands as well as align on band plans (such as the capacity, coverage, and power levels of those bands) network OEMs can streamline many of the testing and certification processes that are redundant across markets. For example, the FCC accepts some testing requirements that are conducted outside of the US if there is alignment with the international governing body on the standards and practices that apply to those tests. Harmonizing spectrum would create opportunities to scale up this shared testing infrastructure across other governing bodies as more bands are harmonized internationally.

03

Economies of Scale in Production

RAN component production requires sourcing and assembling hundreds of unique inputs and parts. Producing radios for smaller markets as well as markets with many MNOs can be even more complicated and costly for network users. For example, smaller markets can experience anywhere from 15%-30% in additional costs due to radio modifications, and experience additional lag time of up to 12 months for equipment to be deployed. With harmonization, the time spent on these modifications can be reduced by almost half.[103, 104] While the US does not face this challenge to the same extent as smaller markets, it is still impacted by the widespread production and supply chain inefficiencies due to a lack of harmonized spectrum. With more harmonization and a reduction in required frequency variants, RAN components can be standardized, streamlining equipment costs and time-to-market for all geographies.

1.1 Network Equipment Efficiencies

Network Deployment Efficiencies

Wireless Network Capital Intensity

Building out network infrastructure is capital intensive, with global spend expected to total $137.7B in 2023 and expected to grow at a 6.10% CAGR through 2028.[105]

A large portion of that investment occurs in the US, where operators consistently invest anywhere from $30B-$40B per year to build their networks with increasing focus on deploying 5G base stations.[106] There is significant complexity in deploying and operating wireless networks: Infrastructure investment thresholds are high and service operations are complex. Equipment failures, interference, and roaming issues all affect the quality and reliability of service and are impacted by fragmented commercial spectrum allocation.

Network Deployment Challenges

Of US operators' overall investment in building out network infrastructure, as much as $12B is dedicated annually to expanding capacity to meet the accelerating demand for connectivity.[107] A significant part of this network infrastructure cost is from the RAN components. Operators purchase radios, antennas, and other components from network OEMs.

In addition to the cost of procuring radio equipment, which can cost tens of thousands of dollars per macro cell*, deploying these base stations is a capital and time-intensive process.[108] For example, deploying a new macro cell site in the form of a new cell tower costs $250K on average in the US.[109] The process typically involves upfront research to decide where to position the site, and whether to build, buy, or rent the tower. MNOs must then purchase, install, and set up the hardware, which includes mounting the radio units and antennas on the tower. Backhaul is then connected to link the base station to the core network, either through fiber-optic cables or micro-wave links depending on the spectrum needed, rights of way, etc.

The high upfront investment required to deploy wireless networks acts as a rate limiter, slowing down the breadth and deployment speed for new generations of network infrastructure. This contributes to overall lack of wireless capacity and leaves underserved populations with reduced access to high-performing connectivity.

Standardized Network Equipment Accelerates Deployments

With capital investment and implementation time being major hurdles for 5G network deployment, MNOs must ensure that their returns substantiate their investments. This is particularly a challenge in the face of increasing demand for wireless connectivity.

Therefore, equipment cost savings from economies of scale in production will improve network investment returns for MNOs, and in turn accelerate network deployments. Earlier network activation accelerates the broad set of economic benefits that are linked to 5G. For example, even a 2%-3% reduction in network deployment time would contribute approximately $660M-$1B in economic benefit which is largely due to the earlier realization of use cases from 5G and future generations.[110]

Faster deployment of new network infrastructure will help meet the rising demand for data capacity and enable 5G use cases that will give way to new industries, job growth, and innovation. Furthermore, with more cost-effective network deployment, more favorable return profiles for building networks in remote areas will help to reduce the digital divide. As of 2021, only 72% of American rural communities had broadband connections at home, compared with over 80% for urban centers.[111] Improved economics to deploy network infrastructure as well as innovations like Fixed Wireless Access (FWA) will contribute to improving broadband access for all Americans.

**A macro cell is a base stations (usually in the form of a large cell tower) that provides connectivity over longer distances*

Harmonization Benefits Throughout the Network Equipment Value-Chain

1.1 Network Equipment Efficiencies

Network Performance and Operational Efficiencies

Network Operations Background

Fragmented spectrum has significant performance and user experience implications. In the US, operators spend tens of billions of dollars annually in OPEX, which includes site leases, energy, equipment maintenance, interference management, transportation, etc.[112] Efficiencies or improvements in these areas not only translate into downstream cost savings for consumers, but also more consistent and reliable coverage and roaming experiences.

Equipment Maintenance

Maintenance costs constitute up to 15% of network OPEX, and a significant portion involves replacing equipment. With reduced equipment costs due to the production efficiencies that spectrum harmonization enables, maintenance costs can be optimized as well. Furthermore, as network OEMs increasingly standardize their equipment, MNOs will be able to maintain their networks more easily through faster access to standardized replacement parts. For example, radio units that are more standardized across markets and geographies allow OEMs to get replacement parts to operators soon, reducing total network downtime in the event of equipment failure.

Network Interference

Radio interference occurs when a signal from an unwanted source disrupts the communication of another on a portion of spectrum. This problem is amplified when base stations (or devices) are in proximity and operating on similar frequency bands at varying power levels, band plans, etc. For example, both the US and Mexico use similar portions of the 700 MHz band in different ways, with Mexico using it for uplink and the US using it for downlink. US base stations close to the border have a high chance of experiencing interference, which can amount to 5%-10% in network overhead cost for the impacted area.[113] This was a significant problem in Europe as 4G was being deployed. Border countries had varying allocations for similar bands, which resulted in constant interference on bands critical for 4G deployment. This ultimately limited the rollout of 4G for affected regions and the availability of next-generation devices.[114]

With more alignment on how bands are used in adjacent regions, end-users stand to benefit from improved network quality at more affordable pricing. For example, if operators can maximize power amplification on their spectrum without worrying about interference, they can maximize the average coverage per cell and avoid having additional base stations at lower power levels for the same amount of coverage. These efficiencies would drive more reliable and affordable coverage for consumers over time.

Roaming Quality

Harmonization results in significant roaming efficiencies. Consumers benefit from having more coverage and consistent connectivity as they travel across regions while industries can benefit from applications that require devices to remain connected when moving across regions (e.g., IoT trackers on shipping containers). MNOs also benefit from the revenue gained in providing the improved roaming service (i.e., better coverage, service quality, etc.) and through more equitable bilateral agreements with each other due to more comparable service which results in less complexity when negotiating roaming terms.

1.2 Wireless Device Efficiencies

Challenges in Device Manufacturing

Inefficiencies in Wireless Device Production

Like network equipment, wireless devices, such as smartphones, wearables, and IoT sensors, are dependent on spectrum, and thus are impacted by harmonization. Similar to RAN components, the radio components in mobile devices are designed to operate on specific frequency bands. For example, many devices are intended to support a limited set of frequencies, and like radio units, must be modified to operate in different geographies. Higher-end devices such as newer iPhones can support a wide range of bands, enabling operability across regions. However, producing these devices comes at a higher cost and can limit performance in other areas as well as restrict form factors. For example, millimeter wave capabilities added approximately $30 in Bill of Material (BoM) costs to the iPhone 12, and additional 5G radio requirements have continued to add complexity and cost to more recent iPhone models.[115]

Both types of devices lead to additional costs for end users and limit potential capabilities and performance in other aspects of the device. As is the case with network equipment, spectrum harmonization can drive economies of scale in wireless device production, due to standardization across global markets and the reduced need for multiple frequency variants. Harmonization can also decrease the cost of multi-band devices, since more of the advanced radio functionality can be simplified.

1

Multiple Frequency Variants

2

Complex Multi-Band Devices

1.2 Wireless Device Efficiencies

Device Frequency Variants

A lack of spectrum harmonization drives significant incremental costs in device manufacturing due to the duplication of R&D, testing/certification, and production to develop SKUs that would otherwise be identical outside of the frequency ranges they support. Historically, devices were designed to be used on a limited number of bands, localized to a specific country or portion of spectrum. Despite the increase in multi-band devices, which can support hundreds of bands across several regions, most connected devices have several frequency variants to accommodate different markets. This is particularly the case for IoT devices and wearables, for which form factors are highly constrained and are developed to work on specific frequencies that best support their intended use cases (e.g., NB-IoT, CAT-M, etc.).

Spectrum harmonization can standardize wireless device production, enabling economies of scale, thus reducing the cost of devices for end users. Having fewer frequency variants can also accelerate the development of connected industry and consumer uses cases, as wireless device producers can allocate more of their resources toward innovation.

1.2 Wireless Device Efficiencies

Device Frequency Variants

Streamlined R&D and Testing & Certification

Because of how intricate and interconnected the components and functions within a wireless device are, modifying radio components impacts the entire development process, much like it does for network equipment. Each frequency variant has its own end-to-end R&D cycle, including sourcing for different components, unique software and hardware configurations, and testing/certification criteria. Like network equipment, with more harmonized spectrum, similar duplicative R&D activities can be rationalized across more SKUs, bringing device costs down, and allowing R&D resources to be spent on innovation.

The testing and certification process for a new smartphone can take anywhere from one to three months before getting to market and require up to 30 different certifications depending on the region.[116] These tests evaluate a range of specifications, including power consumption, material toxicity, radio transmission, etc. With five common radio frequency (RF) standards (WFA, PTCRP, 3GPP, Bluetooth, and IEEE), significant time and resources are spent on ensuring that radio capabilities are compliant, which can cost anywhere from $40K-$100K per frequency variant.[117] Harmonized spectrum can streamline radio testing across regions, as requirements in one country could be more easily applied to other harmonized regions, thus minimizing the need for additional cycles. Such efficiencies could reduce the pre-release testing/certification cycle by up to 30% and allow new devices to reach end users faster.[118]

Production Efficiency

The standardization of devices allows manufacturers to use similar radio components (e.g., antennas, transceivers, power amps, etc.) across more production units. The type, amount, and quality of a given radio component can vary based on the frequency band the device must support. For example, different frequency bands have different power amplification requirements, and different amplifiers have different costs and configurations, which increase overall costs and can alter the performance and form factor of the device. The consolidation of radio components provides economies of scale in production, driving lower device unit costs and improving device performance.

As is the case for network equipment, spectrum harmonization unlocks significant economies of scale and innovation benefits in wireless device production. Streamlining R&D, Testing/Certification, and Production translates into more affordable devices, ranging from approximately $1.5B-$3B in potential annual savings for end users in the US. For handsets specifically, US consumers account for approximately 10% of global consumption and thus stand to capture an estimated $500M-$1B in savings per year, which amounts to $5-$10 off the cost of each unit. [119]

The US also accounts for approximately 20% of the world's connected devices with an estimated 2.6B IoT connections in 2022.[120] Because connectivity and radio components make up a larger portion of IoT device functionality and cost, savings for IoT devices and sensors can be significant, reaching up to 20% per unit.[121] These cost efficiencies can reduce the barriers to transforming industry with IoT and unlock more connected use cases across industries (e.g., agriculture, mining, retail, etc.).[122]

1.2 Wireless Device Efficiencies

Simplification of Multi-Band Devices

Higher Ongoing Production Costs for Multi-Band Devices

In recent years, manufacturers have developed devices that can support increasingly more spectrum bands, providing reliable connectivity across regions and networks. For example, higher-end devices like iPhones are designed to operate on multiple bands and can work across many networks. Over several generations of the iPhone, engineers have built multi-band operability into the device, with versions of the iPhone 15 Pro supporting frequencies in up to 192 countries.[123]

Packing such robust and complex radio capabilities into devices comes at an expense, however; the components and engineering constraints required can drive up device cost, and limit potential functionality and form factor. As RF requirements for 5G and future generations continue to evolve and more countries allocate additional commercial spectrum, supporting an increasing number of bands within a device will only become more complex and expensive.[124]

1.2 Wireless Device Efficiencies

Simplification of Multi-Band Devices

Reduced Costs

Due to 5G, the cost and complexity involved in developing RF capabilities are growing at a faster rate than the innovation being made around those components.[125] As more commercial spectrum is deployed globally, more advanced components will be required (e.g., more capable RFFEs*, longer-lasting batteries), higher quantities of certain components needed (e.g., more RF filters needed to attenuate more unwanted frequencies) and added complexity will be involved in device assembly.

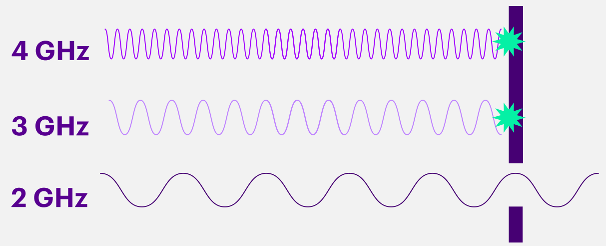
Spectrum harmonization will be increasingly critical to solve this problem. As more countries align on bands for IMT use, future devices won't need to support as many bands, and will be able to achieve the same coverage and reliability across regions without having as much complex RF capability. This simplification has the potential to reduce device costs through a reduction in the concentration of radio components (e.g., less RF filters and antennas) as well as in radio complexity and alleviating engineering constraints. These benefits will translate into more affordable devices over time for end users.

Enhanced Performance

Next-generation RF requirements have also started to increase the amount of physical space that RF capabilities need to have on device circuit boards which will limit the potential for other features and restrict form factors that are critical for the advanced use cases supported by 5G and future generations. Spectrum harmonization, however, can reverse this trend. With less space and functionality dedicated to RF components, other aspects of the device can be enhanced, such as battery life, processing power, and form factor. This is especially beneficial for many industrial IoT sensors and edge computing applications, where a large portion of the device space and functionality is dedicated to RF capabilities. For example, IoT sensors are often used for tracking and monitoring assets that are in hard-to-reach places and must operate on a battery without needing to be recharged for several years.[126] With more available space in a device, a larger and denser battery can be used. For agricultural use cases like crop monitoring, miniature sensors are used to continuously capture and process soil quality data (e.g., moisture levels) at the edge and are buried in the ground at different depths and spread across large areas. With less radio functionality required in these types of sensors, more resources and space can be dedicated to improving processing power for analyzing data at the edge and in real time.

Example: Radio Component Simplification

RF filters are an example of a type of component that can be reduced as the number of bands a device must support decreases. As the name suggests, RF filters are responsible for filtering out unwanted signals to devices. Each filter is designed to allow or attenuate (i.e., weaken) certain frequency ranges. The number of filters that must be built into a device's RFFE* is directly proportional to the number of frequency bands that the device is intended to support. The iPhone 11 had approximately 100 filters, in line with each frequency band it supported.[127]



*The Radio Frequency Front-End (RFFE) consists of all the circuitry and hardware that receives, transmits, and manages radio signals (it includes components like RF filters, signal amplifiers, etc.)

2.1 Growth & Innovation

Growth and Innovation from Spectrum Harmonization

Global Innovation and Growth

Spectrum harmonization will accelerate innovation on a global scale

Spectrum harmonization and international coordination on spectrum policy can accelerate the innovation driven by the global wireless ecosystem. According to the GSMA, innovations in wireless technology contributed $4.5T total global economic value in 2021.[128] Furthermore, harmonization is critical to ensuring that the future benefits promised in 5G and beyond are realized.

More harmonized spectrum provides wireless technology companies with enhanced access to global markets and more revenue potential. Because the cost to deploy new generations of wireless technology are so high, the increase in scale allows innovators to deploy in more cost-effective ways, which improves the business case for making high-risk investments in generational technologies. International alignment on wireless standards also simplifies global collaboration for innovation and creates opportunities for cross-border digital ecosystems and partnership.

In contrast, countries that do not harmonize run the risk of falling behind in terms of growth and innovation. Lessons learned from the lack of harmonization for 4G in the EU prove that countries that don’t align to how critical commercial bands are used risk delaying or deterring innovations from being introduced to and developed in their markets.

How spectrum harmonization accelerates technical standards development

The 3GPP plays a pivotal role in setting spectrum usage standards for mobile telecommunications. Spectrum harmonization is a crucial catalyst in the efficient and timely development of these standards.

As more countries align on the commercial use of similar bands, the development of technical specifications for those bands can be achieved more rapidly. Widespread adoption of specific spectrum bands helps incentivize these standards bodies to define requirements and focuses more stakeholders on driving a cohesive agenda forward. The speed and applicability of these specifications promotes interoperability and paves the path for standardization in technology development worldwide, accelerating innovation and encouraging new product development.

With a lack of harmonized spectrum in the US, there is a risk that future wireless standards will not be optimized for the US market. This could inflate the cost for end users in the US to acquire new technology, as there would be more customization involved due to the country’s unique standards. These higher costs would make it less attractive for equipment and device OEMs to invest in developing and improving technologies specifically for the US market.

2.2 Leadership Benefits

Growth and Innovation from Spectrum Harmonization

The Case for US Leadership in 5G and Beyond

Beyond the shared global benefits for harmonized nations, being a wireless leader can provide additional technological growth and favorable economic positioning for decades to come. As the US demonstrated with 4G, early action and investment can allow more innovation and downstream benefits to emerge domestically. For example, an entire ecosystem of mobile applications valued in the hundreds of billions of dollars, from Uber to Airbnb, was built in the US, in large part because of a first-mover advantage in 4G.

Capturing a first-mover advantage for new generations of wireless drives hardware and software ecosystems to gear their initial R&D for new technologies toward domestic markets. As a result, more of the follow-on economic growth, in terms of job creation, export dominance and competitiveness, etc. will occur domestically. This is critical for the US due to its market scale, as innovators would prefer to bring new technologies to the US first, tapping into large markets. Subsequently, as new wireless generations are tested and deployed in the US first, the conversation on technical standards begins to shape in favorable ways for use cases that disproportionately benefit American consumers.

The upside of leadership is further amplified as other countries look to harmonize their spectrum to that of wireless leaders. For example, for past generations of wireless, Sub-Saharan Africa looked to license more commercial spectrum that was already harmonized internationally to provide more connectivity to its population.[129] As smaller and developing nations look to license widely harmonized bands for their commercial use, leading nations stand to benefit even further. Falling behind as a wireless leader can mean that these smaller countries will harmonize their spectrum more closely with other nations competing to lead, like China, allowing them to shape technical standards and regulations instead.

Through diligent investment in wireless infrastructure and proactive spectrum policy, the US can ensure that it realizes the economic benefit associated with wireless leadership in 5G and beyond. The economic value at stake is estimated at approximately $125B-$155B over the next decade*, in the form of industry creation, job expansion, technology export dominance, and increased domestic innovation. This would outpace the growth that the US experienced as a leader in the 4G era.

*See “Methods” section in Appendix for explanation of US growth, innovation and leadership benefit

2.2 Leadership Benefits

Spectrum Harmonization & Leadership Benefits

Trusted Vendor and National Security Benefits of Spectrum Harmonization

As China has risen economically and technologically over the last few decades, US policymakers have expressed concerns with the increasing market dominance of Chinese telecom giants.[130] Many experts have labelled their dominance as a national security issue, since telecommunications infrastructure has increasingly become a focal point for technological innovation and a critical dimension in deterrence and defense.[131] For example, a 2022 analysis from a GMF roundtable discussion details the concerns around the relationship between Chinese cybersecurity threats and 5G network infrastructure. The report outlines that under Chinese law, the government can request and be granted access to data from any private company in China, which has raised concerns as networks everywhere become more digitized and process richer and higher volumes of critical data.[132]

National security concerns around the so-called "back doors" inserted into telecoms equipment by the Chinese government has led many countries to ban the use of Chinese equipment in their network infrastructure.[133] In the US, the FCC launched the "rip and replace" program to remove all existing Chinese equipment from American networks. As a result, the US will solely rely on select trusted vendors for network equipment in future wireless generations.

Mid-band spectrum is critical for powering use cases in 5G and beyond and will be central to new innovations in network equipment. China is currently outpacing the US in terms of mid-band spectrum allocation, with 1,160 MHz allocated compared to 450 MHz for the US.[134] China's current allocation is also more harmonized with other countries, which helps its positioning in becoming an emerging 5G leader.[135] As China leads in allocating mid-band for commercial use, Chinese telecom companies can benefit from a first-mover advantage and economies of scale in developing equipment for other markets. These companies already dominate the networking equipment market, with over a third of global market share and according to experts, increasing global reliance on Chinese telecom equipment poses a national security risk to the US as more network infrastructure, especially that of its NATO allies, is potentially vulnerable to Chinese government access.[136,137]

By accelerating the allocation of harmonized mid-band spectrum, the US can enable its trusted vendors to benefit from economies of scale driven by the US and nations that follow, which will help those vendors compete more effectively in the global market and ensure that global network infrastructure for 5G and future generations uses trusted and secure equipment.

Spotlight:
"Rip and replace" program

The "rip and replace" program, which was launched in 2020 in the United States by the FCC, was intended to retroactively remove all telecoms equipment made by Chinese companies from US wireless network infrastructure. The government allocated $1.9B in funding to reimburse network operators for replacing their equipment. The program was in response to the US suspicion that Chinese authorities were using the equipment for espionage, escalating geopolitical tensions between China and the US.[138]

Spectrum Harmonization & Leadership Benefits

Summary of the Benefits of Harmonization and Leadership

Spectrum harmonization will further standardize wireless technology production, enabling economies of scale for network equipment and mobile devices which will result in more cost-effective technology for end users, faster network deployments, and more reliable and widespread wireless service.

As was the case with 4G, a significant amount of economic value that the US can capture from 5G will be due to wireless leadership in a more harmonized wireless ecosystem. Harmonization will accelerate global innovation for generational wireless use cases, and taking a leadership position through strategic spectrum policy and proactive infrastructure deployment will help ensure that the US maximizes the economic benefits from 5G and beyond.

The economic impact of spectrum harmonization and US leadership in 5G and future generations is significant and will be achieved incrementally as the US looks to allocate more harmonized spectrum and work with its international partners to drive more growth and innovation.

US Benefits from Spectrum Harmonization and Leadership

1 $23B-$44B over 10 years

Wireless Technology Production Benefits in the form of consumer and business value from more cost effective and productive wireless technology, as well as accelerated deployment of network infrastructure.

$8B-$13B

Economies of scale from network equipment production and improved network deployment

$15B-$31B

Economies of scale and simplification of wireless device development

2 $125B-$155B over 10 years

Economic value attributable to US wireless leadership in 5G, and the increased growth and innovation globally that results from harmonization. These benefits come in the form of more domestic innovation, industry expansion, and export dominance in wireless technology (e.g., app ecosystems, smartphones, etc.).

Note: See "Methods" section in Appendix for explanation for the harmonization benefits quantification

Section 04

Path to Harmonization & Leadership

The Opportunities for Harmonization in the US

The US' Spectrum Harmonization Opportunities

As previously highlighted, there are two types of opportunities available for the US to capitalize on the potential benefits from harmonization. By pursuing both, the US can secure not only the baseline benefits from allocating more mid-band, but also up to $44B in wireless technology production efficiencies and up to $155B in leadership benefits over the next decade.

Opportunity 1
US Alignment to Existing Harmonization

(Bands where the US has not yet aligned with existing international allocation for commercial wireless use)

These bands have been identified due to their global traction, as indicated by their status on the agenda for WRC-23 – as well as countries that have already taken action to allocate these bands for commercial use. Additionally, these bands have characteristics that make them highly suitable for wireless use, such as a good mix of coverage and capacity.

A 3.3-3.45 GHz Band

B 4.8-4.94 GHz Band

Opportunity 2
US Leadership on Harmonization

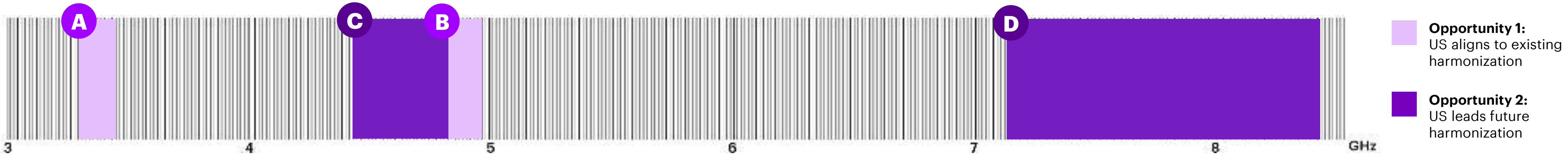
(High-potential bands with strong spectrum characteristics, but limited current global allocation for commercial wireless use)

These bands have been identified due to their band characteristics such as their ability to support higher capacities while still offering broad coverage, which make them highly beneficial for current and emerging wireless use cases. Additionally, these bands are adjacent to current or upcoming harmonized bands indicating that they are attractive expansion opportunities. This potential makes these bands ideal prospects for the US to lead on further global harmonization.

C 4.4-4.8 GHz Band

D 7.125-8.5 GHz Band

Lower Mid-Band Spectrum



Closing the Mid-Band Gap by Allocating Key Harmonized Bands

Combining the two types of harmonization opportunities yields three broader bands (i.e. the lower 3 GHz, upper 4 GHz and full 7 GHz/lower 8 GHz bands) that the US should allocate for exclusive commercial use. These three bands will help the US further harmonize its existing spectrum with that of its international counterparts, as well as position it as a first-mover on higher frequency bands (e.g., above 7 GHz) that are projected to be critical for future generations of wireless.

Closing the mid-band gap in a way that maximizes the potential benefits from harmonization

The 3.3-3.45 GHz Band

The lower 3 GHz band is an especially important opportunity for closing the mid-band gap in a harmonized manner. The US has taken a fragmented approach to lower mid-band to date, with power limitations and complex sharing hampering the use of 3.55-3.7 GHz, and a piecemeal approach to spectrum below that. This has left the US with C-band (3.7-3.98 GHz) as the core 5G workhorse. Making an additional 150 megahertz from 3.3-3.45 GHz available as a contiguous, full-power block will bolster both coverage and capacity in the US, while also driving immediate harmonization benefits with other countries that have already allocated spectrum in that range. This band should be allocated as soon as possible to realize untapped 5G potential in the US.

The 4.4-4.94 GHz Band

The full 4.4-4.94 GHz range is critical for commercial wireless allocation due to both the various harmonization advantages it offers as well as for the natural characteristics of the band that make it an ideal candidate for closing the mid-band gap. There is strong international alignment to harmonize on the upper 4.8-4.94 GHz range, and early movement on the 4.4-4.8 GHz range, indicating that further harmonization in this band is likely.[139,140] There is increasing global momentum in the 4 GHz band due to its capacity to handle higher data traffic rates, mixed with the coverage it offers, which is becoming increasingly important as mobile data traffic grows.[141] The US should seize the opportunity to allocate a contiguous portion of this band for commercial wireless use to capture harmonization benefits in addition to supporting continued 5G growth.

The 7.125-8.5 GHz Band

Allocating a significant block of contiguous spectrum in the 7.125-8.5 GHz band would be a bold act of leadership, especially as the global community is just starting to weigh potential harmonization options for commercial wireless use above the 7 GHz band, seeking a C-band equivalent 'launch' band for future wireless generations.[142] Early allocation would present US companies and the broader economy with significant first-mover advantages, given the lack of action on this band by other countries. The higher capacity offered by this band makes it beneficial for the emerging wireless use cases of 5G and beyond. This band is also important for the US given the recent momentum toward harmonized IMT usage of the upper 6 GHz band. Licensing 7 GHz could keep the US allocation within the tuning range of equipment intended for the upper 6 GHz band, enabling some economies of scale. The US should allocate this band to full-power, licensed mobile use to set the direction for future harmonization above 7 GHz, while securing the additional capacity to close the mid-band gap and bolster 5G growth.

The Harmonization Acceleration Levers

Even with high-potential bands for harmonization identified, capturing the benefits of harmonization requires the US to act both at home and abroad. The US must facilitate ways to allocate more commercial spectrum, as well as coordinate with countries and international bodies to drive alignment on the selected harmonization bands. Additionally, the US must work with stakeholders throughout the spectrum value chain to ensure that they are able to take advantage of the opportunities created by harmonization: Equipment and devices must be standardized, networks deployed, and innovation and growth opportunities pursued. This process is required for all selected bands. However, additional focus on global advocacy will be crucial for bands where the US is looking to lead the direction for future harmonization, as some of the benefits such as first-mover advantages are only possible if other countries act in alignment with the US and allocate the bands for the same purpose.

Spectrum Licensing	Global Harmonization Advocacy	Wireless Innovation	Network Deployment
The US must allocate the selected bands for commercial wireless use, auctioning them to MNOs in a timely manner.	The US will need to engage other countries, both directly and through forums such as the ITU's WRC events, to encourage international alignment on selected bands and build momentum.	Devices need to be standardized, and core processes optimized across the value chain to build economies of scale and accelerate GTM capabilities. The US should also cultivate device ecosystems to foster innovation and build leadership.	MNOs must put the newly allocated spectrum to use in short order by rapidly building and deploying networks, unlocking the utility of the opportunity bands for 5G wireless use cases and beyond.

Licensing Spectrum – Harmonization Acceleration Levers

Spectrum Licensing | Global Harmonization Advocacy | Wireless Innovation | Network Deployment

The Critical Path to Harmonization

A key milestone for progressing harmonization is to license the relevant spectrum bands for commercial wireless use. This will require domestic coordination to ensure all government agencies and users of spectrum are given adequate time to prepare and plan for clearing critical spectrum in the opportunity bands. Additionally, auctions will need to be planned and held to determine the license recipients. This process depends on congress' renewal of the FCC's auction authority, which should be a top priority for enabling spectral planning and licensing.

Early consultation and coordination with incumbents will be key to timely allocation and maximizing the potential benefits of harmonization across the wireless value chain. The US should act early on domestic coordination to prevent licensing delays that could exacerbate the spectrum shortage for operators. In particular, the NTIA, FCC, and federal government should coordinate with existing federal and non-federal spectrum users to understand their spectrum requirements and assess the most optimal deployment of critical bands. They should also ensure timely and transparent transition and repurposing of the harmonized bands that have been identified for study (from both WRC-23 and the National Spectrum Strategy released in November of 2023).

Incremental Enablers of Harmonization

The US' delay in releasing an actionable national spectrum strategy has resulted in fragmented allocation and a lack of synchronization among several globally harmonized bands. With the release of the 2023 National Spectrum Strategy, the US has an opportunity to proactively prepare for future wireless generations and to get ahead of the spectrum required for them. The spectrum pipeline will provide a clear roadmap to meeting future demand, while also sending clear intentions to the global community and standard-setting bodies, thus showing leadership and paving the path forward for wireless innovation and growth.

The US' spectrum strategy and associated pipeline should be continuously refined through both public and private sector coordination, weighing both domestic and international needs to ensure that it maximizes the benefits from harmonization as well as the overall benefit of deploying more spectrum for 5G and future generations.

Global Harmonization Advocacy – Harmonization Acceleration Levers

Spectrum Licensing | Global Harmonization Advocacy | Wireless Innovation | Network Deployment

The Critical Path to Harmonization

While taking action at home is a prerequisite to realizing value from spectrum harmonization, it will also be critical for the US to expand its role on the global stage. Central to spectrum harmonization is global coordination, with the objective of aligning domestic spectrum management approaches around common frequencies. In practice, this requires a great deal of international cooperation, which occurs both through direct channels such as country-to-country organizations, as well as multi-party forums, such as standard-setting organizations. To maximize the benefits of harmonization, the US should leverage all available channels to advocate for the bands it has identified and licensed, with the objective of influencing other countries to align to those same bands.

In terms of direct channels, the US should engage with countries to make the case for the benefits of harmonization and the suitability of target bands for wireless use. The US has engaged in bilateral dialogues and agreements with many regions, such as Canada, the EU, Japan, etc., many of which are specifically centered around Information Communication Technology Services (ICTS).[143,144,145] These can be leveraged by the US to highlight the benefits of its supported bands for commercial wireless use, and to encourage other regions align to them.

In the case of standard-setting organizations, the US should focus on expanding existing harmonization of its target bands, as well as proposing harmonization on the bands that have yet to be formally considered for harmonization, as a step to lead others to align to them. The US should make the most of opportunities at WRC events and through the interim study cycles to advocate for preferred bands and to promote harmonization. In the near term, this should include support for the 3.3-3.4 GHz and 4.8-4.9 GHz WRC-23 agenda items, alongside supporting the 7.125-8.5 GHz band as a specific agenda item for WRC-27. Additionally, the US should support the 4.4-4.8 GHz band as a study item for harmonization as part of the WRC study cycle. While opportunities for US leadership on harmonization (e.g., when the US will seek to drive harmonization on a band that has not yet been allocated by other countries) will require significant advocacy to raise awareness and promote the bands internationally, the US also has a role to play in encouraging further alignment on bands that are broadly harmonized to maximize the potential economic benefit.

Incremental Enablers of Harmonization

Ongoing coordination with neighboring countries, such as Mexico and Canada, will continue to be important to reduce cross-border interference. This includes engaging with neighboring countries with the objective of aligning on specific band plans, which describe how specific bands are used by the network.

Alignment between border-sharing countries on the band plans used for harmonized frequencies will reduce cross-border interference, which would minimize the effort needed for interference mitigation planning and ongoing coordination with neighboring countries.

Device Innovation – Harmonization Acceleration Levers

Spectrum Licensing | Global Harmonization Advocacy | **Wireless Innovation** | Network Deployment

The Critical Path to Harmonization

Much of the economic growth that harmonization promises is attached to transformative use cases from 5G and beyond. For example, more widespread 5G connectivity can enable connected factories and smart cities, which can improve production and societal benefit overall, and drive more economic output in the form of more jobs, new industries, etc.

Through the standardization of wireless technology production, spectrum harmonization plays a pivotal role in driving innovation and economic benefit. Network and device OEMs are at the forefront of this standardization and must streamline core processes including R&D, testing, and production to drive down costs and improve time to market for new and innovative products. For example, current device testing processes can be duplicative and time consuming due to band differentiation. Harmonization unlocks the possibility for reducing redundant testing and certification across countries, streamlining costs and accelerating product launches. The US should collaborate with other countries to understand where testing and certification processes can be rationalized.

Furthermore, the US should look to foster innovation and growth in the wireless technology development ecosystem. One way to do this is to build influence with standard-setting bodies, such as 3GPP. The US should use this channel to promote technology development for its harmonized target bands, thus increasing their value and integration into the global wireless ecosystem. Typically, member companies can submit contributions but require the support of four other members to have a contribution studied as a work item on its path to becoming a specification.[146] Therefore, securing a broad base of international support for a contribution helps accelerate the specifications-setting process with 3GPP, as well as other standards bodies. The US should actively engage with trusted manufacturers to advocate for R&D on preferred target bands and collaborate with allied nations to foster support for key contributions.

Incremental Enablers of Harmonization

The US has an opportunity to drive harmonization by promoting and investing in device and innovation ecosystems, especially for upcoming wireless generations. These ecosystems should include stakeholders and partners from different backgrounds, including government and regulatory bodies, equipment and device manufacturers, academic specialists, MNOs, etc. These ecosystems can foster collaboration in R&D and co-solutioning on key industry challenges. The US should incentivize research and development to build its reputation as an innovation driver and should play an organizing role in developing partnerships with key stakeholders. These actions would make it easier to be a market leader and to influence the direction of future harmonization opportunities. Furthermore, these ecosystems should be cross-border in nature, with the US partnering with ally countries (as was recently announced between Finland and the US) to foster innovation in technology development. This will ensure that the benefits of harmonization are captured by trusted ecosystem partners, which, in turn, will serve the geopolitical and national security interests of the US.[147]

Network Deployment – Harmonization Acceleration Levers

Spectrum Licensing | Global Harmonization Advocacy | Wireless Innovation | **Network Deployment**

The Critical Path to Harmonization

Upon licensing spectrum for exclusive commercial wireless use, MNOs will be responsible for building and deploying networks on the newly assigned bands. The economic benefits from harmonization can only be realized once 5G and future-generation networks are widely deployed. Although network deployment is capital intensive, rapid expansion is critical for realizing these benefits and ensuring broad societal access to advanced broadband connections.

The US has an opportunity to remove obstacles in the way of accelerated network rollouts. Regulatory requirements and talent availability are major challenges for network deployment. Permitting for network builds can take up to a decade due to outdated systems that lead to frequent and burdensome delays.[148] Progress can be made by streamlining the tower siting and permitting processes and by enforcing federal permit review deadlines (e.g., 270 days as established in the 2018 MOBILE Now Act).[149] These actions can accelerate the ability for MNOs to get approvals to initiate new builds.

US should also look to incentivize and invest in more talent development programs geared toward network engineering, network technicians, etc., to address labor shortages that have limited network build capacity. For example, the US Government Accountability Office (GAO) published a study in 2022 that revealed that thousands of additional network workers were needed to build out 5G infrastructure.[150] Ensuring that there is enough talent to meet the increasingly rapid demand for network infrastructure is critical for the US to realize the full potential of 5G, and eventually 6G.

Incremental Enablers of Harmonization

Innovations like Open-RAN (O-RAN), which enables modularity and interchangeability among the various RAN components, can amplify the cost savings from harmonization. Harmonization drives down costs by standardizing network components, and O-RAN allows more OEMs to compete to produce a given component, further reducing their costs. As network equipment becomes cheaper, deployments will happen faster, and consumers and industry will reap the benefits.

Additionally, MNOs can accelerate the benefits of harmonization by sharing learnings and best practices around network design and deployment with other MNOs in different markets. Sharing insights on how to maximize the utility of the opportunity bands would reduce duplicative efforts and would ultimately benefit consumers by streamlining network deployments.

Conclusion

A Call to Action:
Empowering the US to Lead the World in 5G and Beyond

Despite the US' success in deploying 5G so far, a lack of harmonized spectrum – specifically in the mid-band – has put its wireless leadership at risk. Mid-band spectrum is critical for realizing the full potential of 5G and future generations of wireless (e.g., 6G). With exploding demand for data and the need to accelerate 5G deployments, the US is projected to have a mid-band deficit of over 1,400 MHz by 2032*.

The US is trailing several countries in terms of available mid-band. Wireless competitors like China are taking aggressive action to allocate more harmonized spectrum to bolster their own leadership positions. To bridge its projected mid-band gap and further harmonize its spectrum, the US should look to allocate the 3.3-3.45 GHz, 4.4-4.94 GHz, and 7.125-8.5 GHz frequency bands due to their favorable capacity and coverage characteristics.

Spectrum harmonization and wireless leadership can drive significant economic value globally and for the US in the form of cheaper technology, faster realization of transformational wireless use cases, and more economic growth. Approximately $23B-$44B of value can be realized over the next decade through cost savings and higher quality wireless technologies for consumers and businesses, largely due to economies of scale and simplification in network equipment and device production. The US can also ensure that it captures the $125B-$155B in economic output that results from being a wireless leader in a more harmonized world. More harmonization will drive more growth and innovation globally and US leadership in 5G and beyond will enable more of the economic activity, such as industry creation, job expansion, and ecosystem development, to originate domestically.

*Lower mid-band equivalent of total spectrum

A Call to Action:
Empowering the US to Lead the World in 5G and Beyond

To realize and accelerate the benefits from spectrum harmonization, the US needs to act in four key areas:

1. License more spectrum, specifically in the 3.3-3.45 GHz, 4.4-4.94 GHz, and 7.125-8.5 GHz ranges, as well as coordinate with internal regulatory bodies to refine spectrum policy to meet future wireless demand.
2. Collaborate with international partners and standard-setting bodies to drive alignment and conditions for use on the proposed bands, especially those that have strong wireless potential but are not currently broadly allocated.
3. Support device and network OEMs to realize R&D and production efficiencies (e.g., in testing and certification) that lead to more innovation.
4. Encourage rapid network deployment by implementing policies that remove regulatory hurdles and improve access to specialized labor.

Ultimately, a harmonized approach to filling the growing mid-band spectrum gap represents a game-changing opportunity for the US economy and consumers. If this opportunity is seized, the US can secure its leadership for both 5G and future generations and realize the full potential of wireless connectivity to transform everyday life.

Appendix

Harmonization Benefits Methodology

As part of broader research to examine the opportunity presented by spectrum harmonization and leadership in the US, Accenture consulted a broad range of industry stakeholders across the spectrum value chain, as well as existing literature, to quantify and validate the impact harmonization can have on different aspects of the global and US economies. This impact is driven by two main components: Efficiencies across the wireless technology value chain from harmonization, and further economic growth as a result of harmonization and early wireless leadership.

Wireless Technology Production Efficiencies

To estimate the potential cost-savings for wireless technology due to harmonization, we examined different stages of the global wireless value chain (e.g., device R&D) for both network equipment and wireless devices. Within each stage, we identified process steps and components that are highly influenced by spectrum (e.g., RF components, developing frequency variants, etc.), and estimated the reduction/efficiency that could be realized if countries shared common, harmonized spectrum.

We then determined what portion of those global savings would benefit the US economy (and consumers) specifically, based on relative contribution.

Growth, Innovation, and US Leadership

To estimate the benefit from growth, innovation and US wireless leadership, we first examined the baseline economic uplift expected from 5G. This was derived from a range of previously published figures (incl. GSMA and Nokia) and was normalized over a 10-year period (accounting for, in part, future wireless generations beyond 5G). We then estimated the proportion of that uplift that is dependent on early US wireless leadership, based on the relationship observed in previous generations of wireless technology.

In particular, we applied a factor (identified in a previous study commissioned by CTIA), representing the difference between expected 4G GDP based on 3G trends, with the actual GDP generated from 4G from 2010 to 2020, largely attributable to US 4G leadership (in the form of industry creation, job expansion, technology export dominance, and increased domestic innovation), and also the relative increase in harmonization during the 4G era.

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