National Telecommunications and Information Administration

Docket No. NTIA-2023-0003

Development of a National Spectrum Strategy

Request for Comment

Comments of Intel Corporation

April 17, 2023

Intel Corporation ("Intel") appreciates this opportunity to comment on the National Telecommunications and Information Administration's ("NTIA") Request for Comments ("RFC") to develop and implement a national spectrum strategy in collaboration with the Federal Communications Commission ("FCC"). Intel is a leading global semiconductor supplier; our processors, memory, storage, and other products power much of the world's computing capability. Intel is also a leading silicon provider for 5G infrastructure and Wi-Fi products. Intel employees hold leadership positions in 3GPP, IEEE, and ATIS Next G Alliance, as well as Working Groups in the ITU, including WRC preparatory efforts. In the context of a national spectrum strategy for the United States, Intel has long supported sound spectrum policy to facilitate spectrum availably to meet increasing demand for wireless applications and services. Thus, we have a strong interest in any actions stemming from this RFC that could affect future spectrum availability. We provide solutions for businesses, consumers, and industries, and we enable customers in both the private and public sectors.[1] We are therefore motivated to seek

[1] See Intel's product portfolio and solutions portfolio at: https://www.intel.com/content/www/us/en/homepage.html

spectrum policy solutions which broadly and expeditiously create an ongoing pipeline of spectrum opportunities considering the needs of both the private and public sectors.

Intel supports the goal of identifying at least 1500 MHz of spectrum to be studied towards potential repurposing for more intensive use. Below, Intel provides responses to select questions within the three pillars. Since certain questions in pillars two and three overlap with questions in pillar one, we address such questions in our response to pillar one.

I) Pillar #1 – A Spectrum Pipeline to Ensure U.S. Leadership in Spectrum-Based Technologies

A) Implications of Spectrum Pipeline on U.S. Leadership

The dynamics of international spectrum policy decision-making processes are increasingly interconnected to U.S. domestic processes. For example, the FCC's decision to open the 6 GHz band for unlicensed use has been transformative to Wi-Fi technology around the world. In the first two years following the FCC decision, over 60 countries have followed FCC's lead to open 6 GHz spectrum to Wi-Fi. At the 2015 WRC ("WRC-15"), the U.S. was able to secure an allocation to the Mobile Service in ~600 MHz (low band), which was crucial to enabling the FCC's successful $20 billion incentive auction to repurpose broadcast spectrum for mobile broadband use. Similarly, WRC-15 also adopted provisions for the Americas region to enable the 3.4-3.6 GHz (mid-band) to be utilized for mobile broadband. During WRC-19, deliberations included topics such as unlicensed (e.g., Wi-Fi) and licensed (e.g., 5G) broadband technologies; in addition to changes in 5 GHz regulations, much of the U.S. high-band spectrum was also identified for harmonized use by mobile broadband technologies. WRC-23 will also address key frequency bands for broadband technologies.

Technical work has already begun on the next generation of technologies including “Advanced 5G”, “6G”, “Wi-Fi 7” and “Wi-Fi 8”. Innovation in radiocommunication technologies goes through a well-known development and investment cycle, from research to prototypes, trials, and finally commercialization of products, which could take up to several years. Research and development of new generations of technologies in turn relies on the availability of associated components such as radios, filters, etc. Technology developers need to know which frequency ranges to design for; therefore, early indications of which spectrum bands might be available, followed by early availability of spectrum, facilitates technology leadership. It is important that regulations are put in place in a timely manner, so spectrum availability intercepts the product cycle at the appropriate time.

In summary, given the lengthy process involved in making spectrum available for commercial use, consideration of spectrum bands which could be studied is urgently needed if the U.S. wants to ensure it has a leadership position on next generation deployments. For example, now is the time to make progress on which low, mid (e.g., within 7-15 GHz), and high bands (e.g., including new spectrum ranges above 95 GHz) might be available for use by both early 6G deployments as well as the next generations of unlicensed technologies. Alternately, if the U.S. does not make timely progress of identifying potential spectrum bands and subsequently making spectrum available, then the U.S. will not be in a position to take a leadership role in helping define which spectrum ranges will be utilized; it is crucial to intercept the development and investment cycles to ensure timely commercialization of products for the U.S. market.

B) Spectrum requirements for next-generation networks, emerging technologies and standards

Assessing spectrum requirements relies on, among other things, an evaluation of anticipated usage scenarios and their associated spectrum utilization. Usage scenarios of next generation cellular and Wi-Fi are still under discussion in various research and development projects around the world including NextG Alliance in North America, Wi-Fi Alliance and IEEE 802; our response addresses the factors used to determine numeric requirements rather than a specific numeric value. Based on our current understanding, the envisaged usage scenarios are quite diverse and span a large set of potential deployment environments and models from wide area to local area to very short-range scenarios. The great diversity of use cases and applications envisaged for 6G points to the need for frequency bands with propagation characteristics that optimally match the applications and the environment they operate in (i.e., there is also need for the right type of spectrum). Both the amount and type of spectrum needed are influenced by technical capabilities of 6G and Wi-Fi as well as band-specific regulatory conditions of operation.

The technical capabilities of any radio interface are generally characterized by Key Performance Indicators (KPIs) such as peak data rate, spectral efficiency, over-the-air latency, minimum SINR, etc. Some of these KPIs can impact the amount of spectrum needed while others affect the type of spectrum. The amount of spectrum needed is generally impacted by capacity and interference environment considerations and characterized by certain KPIs including peak data rates, spectral efficiency (including the effect of multi-antenna techniques), and over-the-air packet/burst latency. The type of spectrum is generally impacted by the deployment model in conjunction with propagation and wireless channel model considerations and characterized by certain KPIs including wide-area outdoor and outdoor-to-indoor acceptable coverage levels, short range LOS/near-LOS requirements, operation in cluttered environments, and degree of mobility. Once next generation's KPIs and deployment scenarios are established spectrum requirements can be derived accordingly.

C) Use cases and anticipated high-level technical specifications driving requirements

There are a few trends in use cases already apparent from discussions in various academic research and standardization bodies regarding next generation protocols. These could be generally categorized as follows:

1) Evolution of mobile broadband use cases – higher throughout, faster connections.
2) Evolution of mobile technology for support of vertical industries – lower latencies, larger number of devices, private and enterprise networks with geographically-constrained emissions (i.e., local area coverage).
3) Emergence of various sensing applications – gesture recognition, precision positioning.
4) Emergence of AR/VR/MR applications including for business or mission-critical purposes that require deterministic and low latency operation between devices within a short range or with an edge/cloud service.
5) Real-time network optimizations by way of distributed and integrated compute and intelligence throughout the network (from cloud to devices) that enable many use cases where managing workload, latency, and throughput are key.

Use cases and resulting detailed requirements are being developed in various international collaboration groups and standards development organizations (SDOs) such as ITU-R, Next G Alliance, 3GPP, and IEEE 802.

D) Standard bodies, international agencies, and non-U.S. regulators or policymakers

The U.S. spectrum strategy for 2030 and beyond should be informed by next generation research and work in SDOs to ensure that a) spectrum solutions considered in the U.S. strategy can satisfy the requirements of these technology developments, and b) the evolving U.S. strategy can feed back into and drive the spectrum-related research and SDO work. As international discussions on 6G strategy have started around the world, the U.S. spectrum strategy work could also benefit from early spectrum considerations in other countries and regions with an eye towards global harmonization. For the U.S. to become a leader in 6G, it is imperative to develop and implement a comprehensive strategy expeditiously.

E) Sufficiency of spectrum amount for delivery of current or future services or capabilities

As discussed above, the amount of spectrum needed is driven by the requirements of the envisioned use cases and applications. Generally, spectrum utilization for many established use cases has been increasing over time due to increased users, higher throughput and lower latency needs. In other words, even without growth in nascent use cases, additional spectrum will be needed longer term. However, technological innovations in the use of various techniques to increase spectral efficiency and utilization can also help by slowing the pace of increased spectrum needs. For example, multi-antenna techniques have permitted greater utilization within a given band but are already approaching the theoretical limits of information theory (i.e., spectrum efficiency gain is not expected to continue to increase longer-term). As a result, the combination of increasing numbers of users (including machine endpoints such as arrays of sensors), increasing utilization by established use cases and applications, and future innovative applications are expected to require more spectrum to meet the moving target of expected performance. New spectrum allocations must outpace this growth to prevent widespread service degradation (e.g., due to congestion within existing allocations).

F) Utilization of spectrum and required bandwidths

Historically, advancement in wireless radio design has led to utilization of larger bandwidths to carry more information. Mobile broadband technologies have been at the forefront of such advancements. We have witnessed an increase in utilized channel bandwidths to meet increasing user demands, over generations of both licensed and unlicensed mobile broadband technologies to a point where now use of multiple hundred MHz of bandwidth is becoming the norm for consumer services and applications, depending on spectrum availability and regulations. We expect this trend to continue in the future and the widely used channel bandwidths for consumer applications to double towards the end of the decade.

G) Potential spectrum bands to be studied for repurposing

As discussed earlier, there are a variety of factors affecting suitability of a spectrum band for a given application or service. For wide area networks such as cellular, lower frequencies with propagation characteristics that allow for indoor coverage from outdoor base stations in built-up areas are more suitable. On the other hand, expected next generation services would point to bands where wider bandwidths (e.g., wider than 100 MHz carrier bandwidth currently used in many 5G deployments) could be available for each wide-area network. In addition, spectral proximity or overlap with bands that are already supported by international ecosystem facilitates economies of scale and lower development time.

Local area networks such as Wi-Fi mostly cover indoor or otherwise enclosed environments. Today, these technologies are gravitating toward the use of 5 GHz and 6 GHz bands compared to lower frequencies used by cellular for wide-area coverage.

As a rule of thumb, efficient and economically viable radio design is considered to be bound by channel sizes roughly as wide as 10% of the center frequency. Characteristics of cellular network design, radio wave propagation, the importance of covering indoor users, and the realities of site acquisition processes affecting inter-site distances have historically led network designers towards mid-range frequencies which have the possibility of implementing up to 100 MHz channels for better performance. Even though going higher in frequency leads to smaller antennas and higher gain for the same antenna size (which could compensate for additional path loss), it faces the challenge of indoor penetration and other coverage perils. These propagation effects generally worsen with increasing frequency towards upper mid bands and into mm-wave bands (See figure 1), especially with the global trend towards increasing use of thermally efficient building materials.

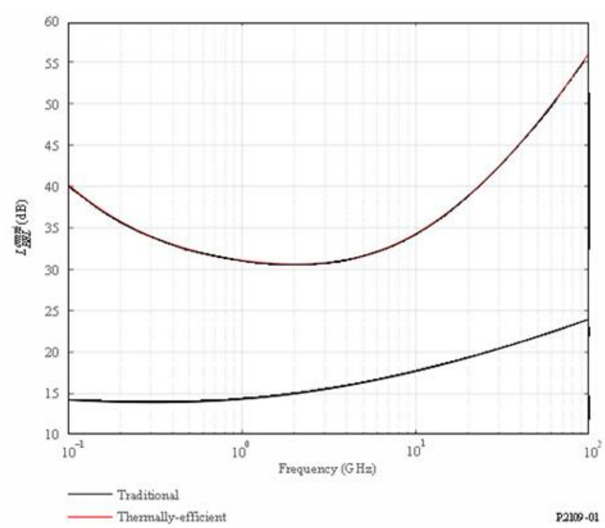

Figure 1 – Building Entry Loss statistics, BEL (dB) vs frequency (GHz) (Source: Recommendation ITU-R P.2109-1)

As a result of these considerations, special attention is needed for frequencies roughly between 3 and 5 GHz. Even though regulations and other uses of spectrum in the said range have not allowed the possibility of implementing networks that can accommodate channels as wide as 10% bandwidth, the opportunity should be pursued. Indeed, a majority of 5G deployments worldwide have occurred in C-band[2].

These factors point us to consideration of the following ranges in the United States:

- Lower 3 GHz (3.1-3.45 GHz) - This band is already under study in the United States for potential repurposing to commercial use. The band, which was included in the Mobile Now Act, is currently being studied under the PATHSS program in NSC focusing on finding ways to share the band between federal and commercial.
- Mid-4 GHz (4.5-4.99 GHz) - Lower and upper part of this range are already in use for 5G in some countries based on 3GPP band n79.

In addition, the following spectrum ranges could be considered for potential repurposing and/or sharing:

- Lower 7 GHz (7.125-7.25 GHz) - For extending unlicensed operation of 6 GHz into adjacent lower 7 GHz to accommodate one additional 320 MHz channel in support of next generations of Wi-Fi and other local area wireless technologies.
- 7/8 GHz (7.3-8.5 GHz) - This range of federal bands, if repurposed and/or shared, could potentially offer 1200 MHz of contiguous spectrum for future generations of licensed mobile networks.

Anticipated concerns for identified bands—particularly in the case of federal incumbents—include a lack of important information regarding incumbent use (frequency/channelization,

[2] "5G Market Snapshots", GSA report, www.gsacom.com

spatial, temporal) and technical operating characteristics, to meaningfully aid coexistence analysis and the determination of new-entrant operating rules. Such information is also valuable in terms of assessing the viability of repacking incumbent services more efficiently. This includes both adjacent and co-channel incumbents. Additionally, in cases where repurposing a band is possible, the identification of suitable spectrum to migrate incumbent services to, and a viable plan (including funding) and timeline for such migration, is a long-standing concern.

H) Significance of international harmonization for repurposing

International deliberations have traditionally focused on the goal of "harmonization" of the use of spectrum bands across different geographies and bands to facilitate global roaming, economies of scale, and reduced device complexity. In the past, different products needed to be developed for even minor differences in spectrum bands. Today, however, consumers and businesses can also benefit from harmonization of "tuning range" solutions covering adjacent or nearly-adjacent bands in which equipment can be reconfigured to operate over multiple bands within the same tuning range. While tuning range harmonization has practical limits due to technology capabilities, it has improved the harmonization prospects in many key bands.

For instance, some of the recent proposals for future 5G/6G spectrum in other regions overlap with bands that are being used by various federal agencies in the United States. In some cases, the concept of tuning ranges can be used to overcome this problem and create de facto global ranges. A tuning range is generally chosen to be wide enough to cover regional differences at least in large markets (e.g., North America and Europe) but small enough to be covered by the same or almost the same equipment features and design. For example, spectrum around 13 GHz and 14 GHz could be accessed by creating such a tuning range, to accommodate differences in use in different regions.

As an example, Figure 2 presents the concept of a tuning range resulting from the conclusion of agenda item 1.13 of WRC-19. In this case, bands supported by the U.S. and Europe could be considered a tuning range within which standardized common equipment could be deployed in different geographies in accordance with local regulations.

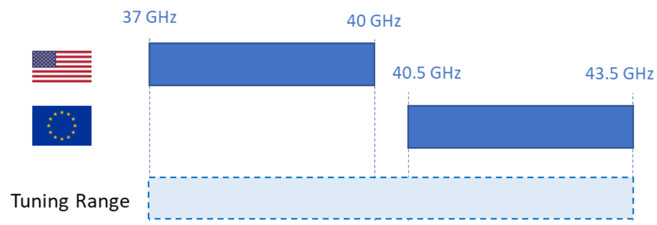

Figure 2 – Concept of tuning range applied to spectrum around 40 GHz

Ideally, a tuning range allows single-radio implementations across the range. However, even in cases where more than a single radio is necessary, there are usually benefits in the tuning range approach due to design similarities leading to cost savings that make tuning ranges an attractive solution to radio designers.

I) Discussion of spectrum sharing techniques

Incumbent services cover a variety of operational and deployment characteristics, leading to different considerations for protection against harmful interference. These conditions play a major role in determination of suitability for sharing.

In general, there are multiple techniques that can be used for sharing, affecting regulatory suitability in various ways.

Time-based Sharing

In some cases, the intermittent nature of some operations could present an opportunity for the spectral resources to be shared by other applications when not actively used in a given geographical area. This kind of sharing requires adequate coordination among the systems involved (e.g., through the Incumbent Informing Capability (IIC) currently under development by NTIA). The complexity of implementation of a secure and effective time-based sharing mechanism increases with the level of dynamism required in this type of sharing. For example, with near-real time or real-time levels of dynamism, this type of sharing could require high speed, low-latency and secure exchange of a large amount of data among the parties involved. One important feature envisaged for 6G, which could help with real-time or near-real-time exchange of information, is ubiquitous computing, i.e., the proliferation of compute resources throughout the network. Ubiquitous computing, also referred to as communication and computing convergence, is the trend by which computing services and data services are expected to become an integral component of future terrestrial mobile broadband systems. Emerging technology trends include the expansion of data processing from the core towards the device, including at the network edge closer to the origination of information. The distribution of compute resources allows for improvements in real-time responses, low data transport costs, energy efficiency and security/privacy protection, as well as scaling device computing capability for advanced application computing workloads such as dynamic sharing.

It should be noted that with regards to sharing with wide-area terrestrial licensed services, the duration and predictability of unavailability periods play a key role in the suitability of this sharing model. Suitability is also related to the availability of other licensed spectral resources by the same network operator in the same area during the unavailability periods.

Location-based Sharing

This type of sharing has been extensively used in the past through creation of exclusion, or coordination, zones around certain locations that need to be protected. The protection could also be time-based, such as in the case of certain radio astronomy sites during observation periods.

Some of the provisions in the 3.45-3.55 GHz spectrum band are examples of this type of sharing mechanism. Coordination contours are usually derived based on predetermined protection levels, (e.g., a maximum I/N level, and expressed in terms of pfd or field strength).

It should be noted that with respect to sharing with wide-area terrestrial licensed operations, the suitability of this sharing model is related to the availability of other licensed spectral resources by the same network operator in the same area at the same time.

Frequency-based Sharing

This is also not a new concept and has been tried in the past, e.g., Dynamic Frequency Sharing, or DFS, in the 5 GHz spectrum band. It is not clear, however, whether this scheme would be suitable for sharing involving licensed operations which require QoS-bounded scheduling of services to users. It should be noted that the suitability of this sharing model is related to the availability of other licensed spectral resources by the same network operator in the same area at the same time.

Time/Location/Frequency-based Sharing

Intelligent sharing techniques are likely to be incorporated into next generation protocols that can enable spectrum to be shared at a more granular level and in more flexible ways. Such techniques could help select the best approach for particular bands/use cases. It can be argued there is no single universal sharing scheme that can address all sharing concerns. Instead, sharing can be facilitated through a “toolbox approach”. This approach would have various sharing tools available to the parties involved, which can then (through either a distributed or centralized decision-making process) be adapted to optimally solve the problem at hand through KPI-based analytics[3] relying on the envisaged ubiquitous intelligence and computing power present

[3] Optimally, the KPIs guiding the analytics are those of 6G services as well as the incumbent systems.

throughout the networks extending from devices/users to the cloud. An example of the KPI-based analytics would be choosing a mechanism from among various sharing options that maintains a minimum user data rate over a specified time interval at a given location. Another example would be choosing a mechanism from among various sharing options that minimizes latency for a given application at a specified time and location. The suitability of this sharing model depends on the availability of well-defined KPIs and computing resources for performing the analytics needed to find optimum solutions.

Power Restrictions

This method provides for operation of terrestrial services under a capped transmit power, TRP or EIRP(ɵ,ϕ), which curtails interference to incumbents at an acceptable level, but at a level still suitable to provide meaningful connectivity to enable sharing the spectrum band. This sharing solution may be most suitable for sharing between federal incumbents and local-area networks and other short-range communication services.

Indoor Restrictions

In some cases, sharing between incumbents and certain terrestrial services can be facilitated through imposing an indoor restriction on the terrestrial service. While this restriction might not be appropriate for some applications (e.g., wide-area connectivity), it might be a suitable solution for other services, such as private networks that operate inside enterprises, factories, or other enclosed structures. The increasing trend in use of energy-efficient building materials such as metal-coated glass could facilitate use of this type of sharing in some cases. The suitability of this sharing mechanism depends on the deployment model of the new entrant and whether it can operate exclusively indoors and maintain a maximum pfd level just outside of the service area, e.g., a factory boundary that protects the incumbents while still at a level that provide meaningful connectivity for the indoor operation.

Based on the diverse sharing options described above and given the diversity of sharing conditions and characteristics of systems involved, it is reasonable to take the “toolbox” approach on spectrum sharing and avoid a one-size-fits-all approach. Creating pragmatic and specific solutions to specific problems is preferred over devising impractical or theoretically universal and highly dynamic models that enable “ideal” sharing mechanisms without regard for complexity.

J) Incentives to facilitate federal and non-federal spectrum sharing

The role of funding should also be considered within the national spectrum strategy. For example, it appears that the current process for reimbursement of relocation or sharing costs may not adequately incentivize the study or analysis of spectrum frequencies for potential repurposing. Potential ways to improve the process and address long-standing concerns regarding funding of any migration of federal spectrum users could be considered. Similarly, some technology advancements can facilitate more efficient use of spectrum so mechanisms to incentivize timely adoption of these technology could also be beneficial.

K) Experiences in other nations

There have been variations around the world in allocation, implementation, and regulations of various mobile broadband spectrum bands, both for licensed and unlicensed technologies. On the licensed side, the majority of 5G deployments in the mid-ranges have occurred in the mid to upper 3 GHz band as stated earlier.

Some regulators in Europe and Asia have designated some bands as locally licensed to help enable vertical markets for 5G. Many of these vertical industries operations are confined indoors or occur in enclosed areas, which could facilitate sharing with outdoor users of the same or adjacent spectrum. To date, there have been mixed experiences with this approach; it has been successful in some cases but it has not been widely adopted in some other cases.

II) Pillar #2 –Long-Term Spectrum Planning

A) Long-term planning timeline

A wireless communication product life cycle consists of the following major phases: 1) research and development, 2) prototyping and trials, 3) standardization, and 4) productization. Some phases could overlap. Historically, this life cycle has taken about 10 years for each generation of mobile wireless technologies. As a result, long-term planning for regulatory actions that facilitate implementation of the technology need to take into account this timeline. The timing of decisions regarding spectrum availability for deployment should be cognizant of the lengthy product life cycle and intercept key timelines. This is a critical matter for industry due to development times and the cost of investment required for each phase of the development lifecycle. For example, information about forthcoming spectrum availability and proposed technical regulations is important in earlier stages in the lifecycle while spectrum availability is crucial at the very beginning of the final phase of the cycle (when products are ready to be introduced into the market).

Regulatory processes also follow their own timeline to fulfil all necessary legal and procedural steps. These include collecting information from a wide cross section of stakeholders in the matter including existing and prospective users of the spectrum as well as any rule changes. A fully vetted and transparent process takes time, and this should be taken into consideration when an eventual target for completion of a process is in mind.

III) Pillar #3 – Unprecedented Spectrum Access and Management through Technology Development

A) Policies to enable new and innovative uses

As mentioned in our response to Pillar #1, sharing can be conducted in time, location and frequency. Utilization of unutilized time-frequency resource units based on a parametrized incumbent protection criterion (by users at known reported locations) is the objective of a number of spectrum sharing systems such as Automated Frequency Coordination (AFC) in 6 GHz, Dynamic Spectrum Access (DSA) in TVWS and Spectrum Access System (SAS) in CBRS band.

Different sharing mechanisms may be more suitable for different terrestrial incumbent services with different characteristics such as mobile/time varying, static or semi-static nature. Sharing assumptions such as incumbent characteristics, protection criteria, geo-location determination mechanism, propagation models and use of databases, need to be parametrized to protect incumbent services. In addition, characterization of users and associated deployment models, such as mobile/portable/fixed and indoor/outdoor, may be parameterized in sharing mechanism for enhanced spectrum utilization. To push the spectrum utilization envelope while improving incumbent protection, it is critical to build on today's spectrum sharing systems for multifaceted advanced and innovative spectrum sharing mechanisms.

B) Incumbent Informing Capability (IIC)

NTIA is pursuing a time-based spectrum sharing solution called the incumbent informing capability (IIC) to support spectrum sharing between federal and non-federal users[4].
The following feedback is provided based upon what is currently known about the proposed solution.

- Some indication of the level of availability in time, frequency, and geography needs to be made available to prospective users before the band is repurposed for sharing, to justify business models, etc.
- Development and implementation of IIC should be done in an expeditious manner – perfection shouldn't be the enemy of the good. For example, more granular phases of implementation of NTIA's vision could be more effective.
- Possibility of partnering with third parties (e.g., government contractors with appropriate security clearance) to accelerate the development of IIC should be considered.
- Availability and procurement of distributed and extensive compute resources is essential to enable IIC and its real-time decision-making processes.

IV) Implementation Plan

As NTIA takes steps towards the development and implementation plan for the National Spectrum Strategy, it is important to recognize the importance of concrete milestones and timely results of studies to meet the spectrum needs of both the public and private sectors. Coordination with the FCC, as appropriate, would also be beneficial. The National Spectrum Strategy should

[4] MICHAEL DIFRANCISCO ET AL., INCUMBENT INFORMING CAPABILITY (IIC) FOR TIME-BASED SPECTRUM SHARING (2021), https://www.ntia.gov/sites/default/files/publications/iic_for_time-based_spectrum_sharing_0.pdf (last visited Mar. 4, 2023).

also consider the timing of key milestones relative to international deliberations; every three to four years, the WRC reviews, and if necessary, revises the Radio Regulations (the international treaty governing the use of radio frequency spectrum), so key international deliberations will occur in November 2023, approximately 2027, etc.

Given the tremendous growth in adoption of wireless technologies fueled by innovation in many existing and emerging applications, it is imperative to replenish the spectrum pipeline for mobile broadband technologies, for both near-term and long-term deployment needs. Replenishing the spectrum pipeline requires not just deciding which bands will be studied, but also ensuring the timely results of studies, and making spectrum available for commercial use. Given the crucial role spectrum plays, the development and implementation of a National Spectrum Strategy should not focus efforts on a theoretical "ideal" state but rather adopt pragmatic, expeditious solutions to this imperative.

Respectfully submitted,

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