Comments of Professor Monisha Ghosh, University of Notre Dame

I appreciate the opportunity to submit comments to NTIA's Request for Comments (RFC) on developing a National Spectrum Strategy for the U.S. I am a professor in the EE department at the University of Notre Dame, affiliated with the Wireless Institute in the College of Engineering, the Policy Outreach Director of SpectrumX [1] and an adjunct research professor at the University of Chicago. Please free to contact me at mghosh3@nd.edu if you have any questions regarding this submission.

Disclaimer: I am presenting my personal views which may not necessarily align with the institutes I am affiliated with.

A. Introduction

My comments will address a subset of questions posed under the 3 pillars described in the RFC and will focus primarily on the mid-band spectrum needs of commercial wireless systems of today and the future. The designation of mid-band, for this purpose, will be the one used by the Federal Communications Commission (FCC) [2] and not the one endorsed by the CTIA, which counts 2.5 GHz as low-band [3]. A summary of recommendations for each pillar is below, followed by detailed discussions in Sections B – D.

- **Pillar #1: A Spectrum Pipeline To Ensure U.S. Leadership in Spectrum-Based Technologies**

U.S. leadership will be maintained only if all current and future use cases that commercial wireless networks seek to satisfy have access to the spectrum they need, not just consumer broadband. Given recent allocations and auctions that have substantially increased the amount of spectrum allocated for unlicensed and exclusively licensed high-power terrestrial mobile systems, I recommend that NTIA focus on **increasing the quantity of spectrum that is made available on a locally licensed, perhaps shared, basis.** Increasing such usage serves two purposes: allows new use cases whose needs are not being met by either unlicensed or exclusively licensed spectrum and allows sharing with federal systems that cannot be relocated or decommissioned. CBRS, using shared spectrum, has only 150 MHz of spectrum compared to 1955 MHz in the U-NII-1 to U-NII-8 unlicensed bands and 640 MHz of exclusively licensed spectrum in the mid-bands, including the recent allocations in 2.5 GHz via overlay licenses, using Auction 108 [4]. Please see Section B for details.

- **Pillar #2: Long Term Spectrum Planning**

Long term spectrum planning requires measurements and data on actual spectrum usage beyond mere spectrum allocations. One cannot control or manage what is not measured. Hence, I recommend that NTIA **develop a long-term, sustainable strategy for collecting spectrum measurements**. This effort needs to happen across the country, not just in specific locations and should leverage the many low-cost sensing methodologies that are available today. Please see Section C for details.

- **Pillar #3: Unprecedented Spectrum Access and Management Through Technology Development**

In spite of decades of research and development in cognitive radio and dynamic spectrum access, the sharing mechanisms that have been deployed still rely primarily on database methods: the TV White Spaces database, 6 GHz Automatic Frequency Control (AFC) and the CBRS Spectrum Access System (SAS). The SAS added sensing via the Environmental Sensing Capability (ESC), but most agree that this is cumbersome [5]. I recommend that the NTIA **adopt sharing mechanisms based on distributed sensing that incorporates a probabilistic interference analysis methodology instead of worst-case and fixed interference protection thresholds to manage spectrum more efficiently**. Please see Section D for details.

B. Pillar #1: A Spectrum Pipeline To Ensure U.S. Leadership in Spectrum-Based Technologies

A spectrum pipeline that is future proof needs to evaluate how our commercial wireless connectivity needs are changing and respond appropriately. The cellular concept was introduced in 1947 and has continued, more or less unchanged, as a high-power, nationwide network that relies on exclusively licensed spectrum to deliver ubiquitous connectivity. This has been executed extremely well. However, over time, other modes of connectivity have emerged and spread, like Wi-Fi, and most recently, private networks in CBRS, along with new use cases. What began primarily as a cellular voice network is now a data network: however, today, approximately 70% - 80% of all data is consumed indoors [6] and many of the ultra-high data rate applications that 5G was designed to address are indoors. Continuing to transmit at high power from outdoor base-stations to serve indoor users is not, in my opinion, the best use of spectrum, let alone a green one. Further, NTIA's own BEAD program will result in fiber deployments that will provide wired end-points closer to the consumer and enterprise, thus allowing low-power wireless connectivity, perhaps over shared spectrum, to provide the desired mobility. High-power exclusive use will still be required for ubiquity and providing backhaul connectivity in low-density areas where fiber or even satellite cannot reach. But perhaps the bandwidth requirements can be reduced.

Table 1 show the current primary allocations for unlicensed, licensed and shared bands.

Table 1: Current Spectrum Allocations

Band	**Unlicensed**	**Licensed**	**Shared but licensed**
2.5 GHz (T-Mobile)		At least 160 MHz [7]	
2.5 GHz (Auction 108)		100 MHz	
3.45 GHz – 3.55 GHz		100 MHz	
3.55 GHz – 3.70 GHz			150 MHz
3.70 GHz – 3.98 GHz		280 MHz	
Unlicensed 5 GHz	755 MHz		
Unlicensed 6 GHz	1200 MHz		
Total	**1955 MHz**	**At least 640 MHz**	**150 MHz**

It is clear that, notwithstanding claims to the contrary such as those in [3], the US has already allocated significant amounts of mid-band spectrum in the 2.5 and 3 GHz for high-power, exclusively licensed use. In absolute numbers, this is less than the unlicensed allocation, but the unlicensed band is shared by many diverse applications and transmission power is limited. It should also be noted that cellular technologies (4G, 5G and future 6G) can be deployed in all kinds of spectrum, and is, e.g. LTE-LAA in unlicensed 5 GHz, 4G/5G in shared CBRS and 5G NR-U in the future in both 5 GHz and 6 GHz unlicensed. Carrier aggregation, where a primary, high-power channel is aggregated with multiple low-power channels in the unlicensed and CBRS bands, is already being used by operators to improve capacity [8-9] and is a proven, efficient method for maximizing spectrum utilization. However, spectrum assigned for exclusive use is usually not shared and available to other users. From Table 1, it is clear that compared to unlicensed and exclusively licensed spectrum, there is a severe shortage of shared spectrum.

Time Division Duplex (TDD) Synchronization impact on spectrum usage: Most new 5G spectrum is being allocated as unpaired TDD spectrum, i.e. downlink and uplink transmissions occur on the same frequency in different time slots. Hence the "TDD Configuration" which determines how many slots are reserved for each type of transmission is an important network design parameter. Most mid-band 5G deployments in the US today employ a 7:2 TDD Config where there are 7 slots reserved for downlink and 2 reserved for uplink transmission: this is clearly geared for consumer broadband use where downlink requirements exceed uplink ones. When TDD 5G is deployed by high-power base-stations, the recommendation from the cellular industry [10] is that all base-stations synchronize, that is, use exactly the same TDD Config in order to avoid adjacent channel interference that may occur if users in one channel are transmitting uplink while a nearby user on an adjacent channel is receiving a downlink transmission. **Hence, a high-power, exclusively licensed, nationwide deployment can only serve one type of application without causing adjacent channel interference.** A deployment such as this cannot serve use cases which require different TDD Configs without causing interference. It is not sound spectrum strategy to create a pipeline of 1500 MHz that is so inflexible.

On the other hand, low-power, locally licensed spectrum can accommodate any TDD Config without causing interference. For example, a factory can deploy a private 5G network over CBRS and customize the TDD Config to meet its needs without interference since the reduced transmission power will ensure that the signal will not propagate very far. The U.K., France and Germany are among the many European countries that have adopted this model in parts of the 3.7 – 4.2 GHz band (see Figure 1.3 in [11]). With the demand for such licenses growing, Germany is considering expanding the 100 MHz it currently uses in the 3.7 – 3.8 GHz band to include the 3.8 – 4.2 GHz band and would like harmonization of this spectrum band for locally licensed use across the EU [12]. Low-power, locally licensed usage also coexists better with federal and other incumbents compared to traditional high-power outdoor cellular systems.

By providing access to spectrum at reasonable costs, use cases being served by CBRS today are ones that are not met well by either Wi-Fi or cellular: factories, warehouses, libraries, schools, precision ag etc. For example, the Wireless Institute at the University of Notre Dame advised the City of South Bend and South Bend School Corporation to deploy a CBRS network that provides another connectivity option to 1000 families who otherwise would not have access to similar levels of connectivity at an affordable rate, even though South Bend is fairly well served by the major providers [13]. However, the small amount of such spectrum, 150 MHz, compared to 400 MHz in the UK, will soon limit the growth of these alternate use cases.

C. Pillar #2: Long Term Spectrum Planning

In addition to developing a National Spectrum Strategy, the NTIA should consider a **National Spectrum Measurement Strategy** that will help in long term spectrum planning. In order to manage and plan spectrum better, especially when it comes to sharing, we need to measure real usage. Our cycle of spectrum management and planning today usually ends with spectrum allocation and deployment. How well is U-NII-2 being used for Wi-Fi? How much cellular spectrum is actually being used in rural areas? Where exactly is 24 GHz mmWave being deployed and will it actually pose an interference hazard to weather satellites? What is the balance of PAL and GAA usage in CBRS? Without answers to questions like these, spectrum management cannot be efficient. Agencies like the FDA and the EPA do not stop with authorizing new drugs or setting emission standards: there is constant monitoring and evaluation so that drugs can be recalled if necessary and emission violators sanctioned. It will never be possible to complete all interference studies prior to a spectrum ruling, hence we need to have a scalable, sustainable way of measuring spectrum usage and interference once new systems are deployed. Past efforts in this direction, funded mostly by NSF, have been one-off projects that are not sustainable. Spectrum usage is distributed, so should spectrum measurements be, and today, we have many more tools at our disposal that allow us to do this. Smartphones have a number of radios spanning all major cellular and Wi-Fi bands, and APIs allow one to extract signal strength and other information from deployed systems, both cellular and Wi-Fi, easily. Purpose built sensors, like the RadioHound being developed at the University of Notre Dame, along with many other commercially available products can be used to perform distributed spectrum measurements: this is not an easy task to accomplish on a nationwide level, but can be done with adequate resources and will go a long way in improving long term spectrum strategy and planning and help in developing new spectrum sharing technologies. Automating spectrum management using AI will require good spectrum measurements to inform the process, and as we look at 7 – 24 GHz, measurements will also be required to build propagation models for both coverage and interference.

For example, we conducted a recent measurement campaign that collected measurements using an app, SigCap [14] while driving around the University of Michigan. As shown in Table 2, the number of Wi-Fi APs operating in U-NII-2A and U-NII-2C were much smaller compared to U-NII-1 and U-NII-3 and there was no U-NII-4 usage at all even though U-NII-4 has been allocated to Wi-Fi for more than 2 years. Such usage data is easily gathered and can be used to inform future questions, such as should more spectrum be allocated to cellular and Wi-Fi, given current usage. We have performed similar measurements to understand cellular usage as well [9], [15]. Using smartphones is a scaleable way of collecting data on actual usage of spectrum by commercial wireless systems and should be considered as part of a broader national spectrum measurement strategy. Measurements can also be crowdsourced for wider coverage.

Longitudinal spectrum measurements will also inform discussions on noise-floor increases which are an important factor in interference analyses.

Table 2: Example Wi-Fi channel usage

U-NII Band	U-NII-1	U-NII-2A	U-NII-2C	U-NII-3	U-NII-4	U-NII-5	U-NII-6	U-NII-7	U-NII-8
No. of unique BSSIDs	6624	738	1944	6783	0	72	19	69	21

D. Pillar #3: Unprecedented Spectrum Access and Management through Technology Development

Spectrum access and utilization can be made more efficient by improving interference analyses, which are a necessary first step when considering sharing, both co-channel and adjacent channel. The energy profile for most modern wireless systems is probabilistic: with smart antenna arrays this extends to 3D space. However, most interference analyses consider worst case interference based on simplistic assumptions to determine sharing regimes, leading to underutilization of spectrum. The emphasis on a single RF level as the sole arbiter of interference needs to change: complete information of shared systems have to be considered to determine appropriate sharing schemes. The FCC recently released a policy statement based on the comments received in response to the receiver NOI calling out 3 principles: interference realities (zero probability of interference is unrealistic), shared responsibilities (transmitters and receivers) and data-driven regulatory approaches to promote coexistence: these are excellent guidelines for the future [16]. Probabilistic interference analyses combined with distributed sensing for co- and adjacent channel incumbents can deliver a robust and dynamic sharing ecosystem that is not possible with the mostly static database methods of spectrum sharing used in the TV White Spaces, 6 GHz and CBRS.

In the 6 GHz rules, indoor devices can utilize spectrum at low-power without any other spectrum management method (e.g. authorization by the AFC) by simply relying on attenuation provided by buildings to prevent interference to the outdoor incumbents. However, in the absence of any robust and reliable method to determine whether a device is indoors or outdoors, the FCC had to rely on other mandates, such as APs cannot be battery powered, have detachable antenna or weatherized exteriors and mobile devices have to transmit at 6 dB lower power than the AP. Technologies such as ML based methods described in [17] which can determine whether a device is indoors or outdoors reliably can improve spectrum utilization considerably.

The TDD synchronization problem highlighted in Section B also requires new technology development. The next generation of networks, **6G, should be "sharing native"** so that use cases that require widely varying uplink/downlink throughputs: e.g. security cameras (high uplink throughput) versus video streaming (high downlink throughput) can be deployed on adjacent channels without interference.

Recently, there have been suggestions to revert to Frequency Division Duplex (FDD) for 5G [18]: it should be noted that most spectrally efficient smart antenna configuration such as Massive MIMO benefit from TDD since overheads for channel estimation are reduced. Hence, developing 6G to coexist better in TDD deployments should be a preferred approach. Further, incorporating methodologies for sharing with incumbents should also be explored, for example network-wide "quiet periods" that enable distributed sensing by all devices on the network, as proposed by IEEE 802.22 for the TV White Spaces [19].

E. Conclusions

NTIA's National Spectrum Strategy can truly transform the nation's innovation ecosystem by democratizing access to spectrum and ensuring that the right balance of unlicensed, exclusively licensed and shared spectrum is maintained. NTIA is also managing the Public Wireless Supply Chain Innovation fund, focused on open RAN development, and BEAD, focused on expanding fixed broadband access: the disaggregation of the RAN, combined with accessible spectrum and increasing fiber deployment creates a truly innovative ecosystem that lowers the barrier to entry for new wireless connectivity use cases. NTIA is well positioned to leverage the synergies between all these efforts as well as the CHIPS and Science act to develop spectrum policies that can energize the innovation ecosystem and enable wireless applications beyond just consumer mobile broadband.

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