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Good morning Chairwoman Rodgers, Chairman Latta, Ranking Member Matsui, Ranking Member Pallone, and members of the Committee and Subcommittee. Thank you for the opportunity to testify today on the extremely timely and important discussions regarding the future of spectrum management and how we can continue to grow America's leadership of the entire wireless ecosystem: current technology, future innovation and workforce development.

Introduction

My name is Monisha Ghosh, and I believe that I can offer a broad and balanced perspective on the matters before this Committee, given my years of experience working in the wireless industry, government research and regulatory organizations, and academia.

To summarize my professional background, I am currently a Professor of Electrical Engineering at the University of Notre Dame. I came to academia in 2015 when I joined the University of Chicago after 24 years working in industry on wireless research and development, starting with designing the first High Definition Television (HDTV) broadcast systems at Philips Research in the early 90's and contributing to various generations of Wi-Fi and cellular systems at Bell Labs and Interdigital. I took two recent leaves of absence from academia to serve in government. From 2017 – 2019, I was a Program Manager in the Computer and Network Systems (CNS) division of the Computer and Information Science and Engineering (CISE) directorate at the National Science Foundation (NSF) where I helped manage NSF's research programs in spectrum and wireless and started the first program to study the applications of artificial intelligence (AI) and machine learning (ML) in wireless networks. From January 2020 to June 2021, I was the Chief Technology Officer (CTO) at the Federal Communications Commission (FCC) where I worked primarily on helping craft the rules for unlicensed access in the 6 GHz band and a pilot project with the US Postal Service (USPS), as directed by Congress, to examine the feasibility of automatically gathering broadband coverage data using apps on smartphones mounted in postal vehicles[1].

[1] REPORT TO THE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION OF THE SENATE AND THE COMMITTEE ON ENERGY AND COMMERCE OF THE HOUSE OF REPRESENTATIVES
https://www.fcc.gov/sites/default/files/report-congress-usps-broadband-data-collection-feasibility-05242021.pdf

I continue to be actively engaged with both industry and government as an academic. I co-chaired the FCC's Technological Advisory Council's (TAC) working group on Advanced Spectrum Sharing in 2022 where we deliberated on how frequency bands between 7 – 24 GHz could potentially be shared with commercial wireless deployment. I am also an active member of industry's NextG Alliance, developing standards for 6G and beyond, and the National Spectrum Consortium's (NSC) Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) Task Group which partners with the Department of Defense (DoD) to explore efficient sharing solutions that will make more mid-band spectrum, specifically in 3.1 – 3.45 GHz, available for commercial wireless applications.

I am also the Policy Outreach Director for SpectrumX[2], NSF's Center for Spectrum Innovation, led by the Wireless Institute[3] in the College of Engineering at the University of Notre Dame. SpectrumX was initiated in September 2021 with a five year $25M NSF grant that brings together 41 researchers and staff from 27 universities and a number of Minority Serving Institutions (MSIs) with broad expertise spanning radio technologies, wireless terrestrial and satellite networks, scientific uses of spectrum and economic considerations related to spectrum allocations. A Memorandum of Agreement (MOA) is in place among the NSF, FCC, and the National Telecommunications and Information Administration (NTIA) to ensure that the research undertaken in SpectrumX can directly impact spectrum issues of importance to the nation. In addition to research, major focus areas of the Center are broadening participation in spectrum research and developing a workforce that can continue to expand America's leadership in spectrum policy and wireless technologies.

Disclaimer: The opinions expressed in this testimony are my own and do not necessarily reflect the positions of the various organizations with which I am affiliated.

Summary of testimony

I will focus my remarks today on the following three areas:

(1) **Developing a Spectrum Strategy** that is sustainable and balances the needs of commercial wireless systems, federal applications and scientific uses while exploring all possible spectrum allocation options, for example, exclusive licensing, shared usage and unlicensed. It is increasingly clear that all these options need to be considered, especially in the next range of coveted mid-bands, 7 – 24 GHz.

[2]SpectrumX: https://www.spectrumx.org/

[3] Wireless Institute at Notre Dame: https://wireless.nd.edu/

America needs to continue its wireless leadership in all areas that require access to spectrum: commercial, scientific and national security applications.

(2) **Bridging the digital divide** will require attention to both availability and affordability of broadband to ensure that there is equity of services available between rural, inner-city urban and suburban residents across America. As broadband speeds increase, essential networked applications like remote learning and videoconferencing incorporate features that do not deliver the same experience over lower-quality connections. By not having parity between broadband performance and availability across the nation, we risk disadvantaging large sections of the population, often the most vulnerable. Wireless backhaul, satellite connectivity and private networks should all be considered as potential solutions to this problem.. Each of these options may require additional spectrum to fuel their growth trajectories, and the right mix of allocations and flexibility will be important.

(3) **Creating an entrepreneurial wireless ecosystem** that can leverage America's greatest strength, its start-up culture that unfortunately is not currently as vibrant in the wireless space as it is in, for example, the software and biomedical industries. Here, Congress must ensure that there are synergies that can leverage the CHIPS and Science Act to encourage innovations in wireless chips and semiconductor systems. New application areas for wireless, such as drone control, precision agriculture, connected healthcare and vehicles, and smart manufacturing require new chips that do not necessarily have the volumes required by mobile handsets, but are an important and growing component of the wireless ecosystem.

Detailed testimony

(1) **Spectrum Strategy**

America has long led the world in innovative spectrum policies from allocating spectrum for unlicensed services in the eighties, to developing auction mechanisms and sharing mechanisms in bands like the Citizens Broadband Radio Service (CBRS) in 3.55 - 3.7 GHz. The US was the leader in recognizing that the wide bandwidths available in the millimeter-wave (mmWave) bands (> 24 GHz) could be harnessed for multi-Gbps throughputs. However, it is increasingly clear that in order to continue progressing the wireless ecosystem, new frequency bands need to be made available. As Chairwoman Rosenworcel has often stated, the swath of frequencies between 7 and 24 GHz need to be examined to determine how they can be better utilized for developing the next generation of wireless systems.

While commercial wireless expansion is extremely important, as a nation we also need to ensure that services that are critical to our nation's security continue to have access to the spectrum that is indispensable to their operations and mission. The recent incursions into US air space were detected by Airborne Warning And Control System (AWACS) radars that operate in dedicated spectrum bands. Scientific uses of spectrum are equally important: the awe-inspiring photographs of the black hole at the center of our galaxy were taken by radio telescopes operating at 230 GHz, and these telescopes are becoming even more sensitive. Our weather forecasts have become increasingly accurate due to the number of different frequencies that the sensors use to measure moisture content and other relevant parameters. It will be challenging to balance all of these very vital needs with the growing demands of wireless broadband, not just from consumers but verticals such as manufacturing, healthcare and automotive.

How should we proceed to address these increasingly complex requirements? Exclusive licensed spectrum will continue to be the backbone for delivery of mobile broadband and we must find ways to allocate more of it. If spectrum needs to be exclusively licensed, it needs to be cleared of all incumbents. In some cases, such as C-band, the number of incumbents (satellite) were small enough that the cost to relocate them to other bands was an effective way to make those bands available for 5G. In other cases, like 6 GHz, the sheer number of incumbent licensees (~70,000) would have complicated the process of relocation and hence the approach of creating rules for unlicensed low-power indoor (LPI) usage with no restrictions and standard power unlicensed outdoor usage with Automatic Frequency Control (AFC) was deemed the best way forward. Many countries around the world have since followed the US lead on unlicensed use of 6 GHz. The 3-tiered sharing strategy employed in CBRS is yet another innovative way of sharing spectrum between federal and commercial users that was pioneered in the US. The combination of exclusively licensed, unlicensed and shared spectrum has been used in recent standards developed by the 3rd Generation Partnership Project (3GPP) e.g., License Assisted Access (LAA) and 5G NR-U (5G New Radio Unlicensed) to allow deployments that can intelligently and strategically aggregate any of these bands to provide multiple 100s of Mbps to consumers, without requiring all of the spectrum to be licensed. Our research and measurements in Chicago on deployed cellular networks demonstrate the effectiveness of these approaches[4]. The US leads the world in such deployments due in large part to innovative spectrum policies: this needs to continue.

Challenges to spectrum sharing: When spectrum sharing is being considered, there will be co- and adjacent channel interference concerns that need to be addressed. Even when spectrum is exclusively licensed, adjacent channel concerns such as in C-band and 24 GHz need to be recognized and addressed in a timely fashion. There is no one-size-fits all solution to these potential interference scenarios and sound spectrum policy should be based on fundamental technical analyses, measurements and testing which includes all stakeholders, such as the federal agencies (e.g., FCC and NTIA) and spectrum stakeholders (commercial wireless, DoD, scientists). National centers and institutes such as SpectrumX, the National Institute on Standards and Technology (NIST) and NTIA's Institute for Telecommunication Sciences (ITS) have an important role to play in performing the **unbiased technical analyses** that are required to determine the appropriate power levels, filter roll-offs and other parameters both at transmitters and receivers that are crucial to ensuring that the probability of potential interference is minimized, and spectrum utilization is maximized. The advanced spectrum sharing group in the FCC's TAC began the work of examining the 7 – 24 GHz band to determine suitability for sharing. However, since there are mainly federal incumbents in this range of frequencies, close coordination and cooperation with NTIA is required before meaningful progress can be made on how these bands can shared or reallocated.

Potential solutions to spectrum sharing: Most of the current spectrum allocations that share between incumbent services and new entrants (e.g., Television White Spaces (TVWS), 6 GHz and CBRS) employ some variants of a spectrum-use database to assign channels so that the incumbent is protected. These methods rely on predicted propagation and interference based on models, and often do not take into account many of the details of the systems. Interference protection contours are thus often set to satisfy worst-case interference scenarios which may have a low probability of occurrence resulting in overprotection and spectrum-underutilization. Database-mediated sharing is a proven technique for a number of frequency bands, but may not be suitable for all situations since this method is inherently less dynamic and does not react in a timely fashion to actual propagation

[4] M. I. Rochman, V. Sathya, N. Nunez, D. Fernandez, M. Ghosh, A. S. Ibrahim and W. Payne, "A Comparison Study of Cellular Deployments in Chicago and Miami Using Apps on Smartphones," ACM WiNTECH 2021.

and interference conditions. The FCC TAC in 2022 published a whitepaper on lessons learnt from CBRS[5] that summarizes how future centralized spectrum management systems based on databases could be improved.

More advanced technical approaches for spectrum sharing can be developed that leverage specific characteristics. For example, modern wireless systems, both cellular and Wi-Fi, use smart antenna array systems that tailor the transmitted energy optimally in 3-dimensional space towards intended users. The same systems could also be adapted to steer energy away from incumbent systems. Such approaches require changes in 6G and beyond standards to be **"sharing native"**, i.e., designed from the very beginning to operate in shared frequency bands with incumbents instead of solely in licensed or unlicensed bands. The US, with its rich history of spectrum sharing innovations in TVWS, 6 GHz and CBRS is well positioned to be the worldwide leader in standards development in this space.

(2) **Bridging the digital divide** will require harnessing all the policy and technology tools at our disposal to address the twin issues of availability and affordability. In most rural areas the problem is one of availability of broadband, both fixed and mobile. NTIA's Broadband, Equity, Access and Deployment (BEAD) program will oversee fiber deployments that will bring true broadband (defined as a minimum of 100 Mbps downlink and 20 Mbps uplink, or 100/20) to all "serviceable" locations as identified in FCC's National Broadband Map. However, this will not solve the problem of broadband availability to serve, for example, the needs of precision agriculture in farmland: a tractor or a field of corn is not a "serviceable" structure. While satellite services can address some of these needs, terrestrial services will still be required for many such rural applications: our research and measurements have shown that sensors in a field of full-grown corn are very difficult to reach even with cellular IoT due to the signal attenuation from the corn biomass[6]. So, alternate architectures need to be explored, for example using satellite backhaul with local distribution over shared spectrum using a private network.

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[5] Recommendations to the Federal Communications Commission Based on Lessons Learned from CBRS, FCC TAC, December 2022, https://www.fcc.gov/sites/default/files/recommendations_to_the_federal_communications_commission_based_on_lessons_learned_from_cbrs.pdf

[6] S. Balida, G. Grant, X. Zhang, M. Ghosh, S. Guha and R. Matamala, "A Wireless Underground Sensor Network Field Pilot for Agriculture and Ecology: Soil Moisture Mapping Using Signal Attenuation," Sensors 2022.

In areas where fiber cannot be deployed, we must also consider alternate modes of connectivity, often wireless. mmWave and THz links can provide the fiber-like bandwidth required for backhaul services; however, attention must be paid to appropriate coexistence and sharing mechanisms with scientific missions that operate in those bands. Information sharing between incumbent users and new backhaul services can facilitate sharing in these bands. Even when backhaul is available, it may not be cost effective for a commercial provider to serve small numbers of consumers. Spectrum policy that makes available cost-effective spectrum to small providers and communities to deploy and manage their own wide-area networks can be very effective in bridging the digital divide in both urban and rural communities. 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[7]. There are many such examples of community networks that are leveraging the innovative spectrum access policies enacted by the FCC to connect their citizens to broadband services. Finally, although 5G networks have increased the available throughputs considerably, newer devices required to access these networks are often more expensive. Hence programs such as the Affordable Connectivity Program (ACP) need to continue to ensure that all segments of the population derive equal benefits from the newest technologies.

(3) **Creating an entrepreneurial wireless ecosystem**: America is at its best when innovations are incubated in small companies and start-ups. We see evidence of that in the software industry where a vibrant start-up ecosystem in the US has led the world in delivering innovations in many areas. A similar environment needs to evolve in the wireless industry. Disruptive applications in wireless are often harder to bring to the marketplace due to the limited number of options for wireless chipsets and spectrum availability. As the CHIPS and Science Act begins to be implemented Congress must ensure that innovations encouraged by forward looking spectrum policy are not held back due to limited access to chipsets. The FCC has issued a number of Notices of Inquiry (NOIs), Notices of Proposed Rulemaking (NPRMs) and Report and Orders (R&Os) in diverse frequency bands: spectrum

[7] Bridging the Digital divide in South Bend, https://www.nd.edu/stories/bridging-the-digital-divide/

allocations for drones in 5030 – 5091 GHz[8], sharing of the 4.9 GHz band with public safety[9], and sharing of the 12.7 – 13.25 GHz band for mobile applications[10]. These forward looking actions will result in many applications that will drive innovation, but will require electronic materials and devices, manufacturing and packaging processes, chips, and test and measurement equipment that support these new bands.

Concluding Remarks

America leads the world today in innovations in spectrum policy that have delivered wireless applications that impact all aspects of our life, from broadband connectivity to national security and scientific breakthroughs. Congress, and this subcommittee in particular, must continue its leadership to ensure that we continue to evaluate all options available to create a sustainable spectrum strategy for every system that requires access to spectrum. Exclusive licensing, shared and unlicensed options should all be evaluated in an unbiased manner. This will allow future wireless systems to bridge the digital divide using many complementary options, develop new applications and in the process create a flourishing economy. I thank you for the opportunity to share my thoughts on this very important topic and welcome any questions.

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[8] FCC Starts Rulemaking on Licensed Spectrum for Unmanned Aircraft Use, January 4, 2023 https://www.fcc.gov/document/fcc-starts-rulemaking-licensed-spectrum-unmanned-aircraft-use

[9] FCC Expands 4.9 GHz Band Rules, Seeks Further Comment, January 18, 2023 https://www.fcc.gov/document/fcc-updates-49-ghz-band-rules-seeks-further-comment

[10] FCC To Examine 12.7 GHz Band For Next-Gen Wireless, October 28, 2022 https://www.fcc.gov/document/fcc-examine-127-ghz-band-next-gen-wireless-0