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AMERICA OFFLINE? HOW SPECTRUM AUCTION DELAYS GIVE CHINA THE EDGE AND COST US JOBS

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED NINETEENTH CONGRESS

FIRST SESSION

FEBRUARY 19, 2025

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED NINETEENTH CONGRESS

FIRST SESSION

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JONATHAN HALE, *General Counsel*

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WEDNESDAY, FEBRUARY 19, 2025

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:11 a.m., in room SR–253, Russell Senate Office Building, Hon. Ted Cruz, Chairman of the Committee, presiding.

Present: Senators Cruz [presiding], Wicker, Fischer, Blackburn, Young, Budd, Schmitt, Curtis, Moreno, Sheehy, Cantwell, Klobuchar, Peters, Baldwin, Rosen, Luján, Hickenlooper, Kim, and Blunt Rochester.

OPENING STATEMENT OF HON. TED CRUZ, U.S. SENATOR FROM TEXAS

Chairman CRUZ. All right. We will now move onto the hearing. Good morning.

Auctioning spectrum has been one of the most successful drivers of American innovation, economic growth, and global technology leadership. Spectrum auctions have unlocked billions for the Treasury while enabling our Nation's wireless networks to deliver faster, better connectivity, fueling the rise of breakthroughs from the iPhone to generative AI. This has created millions of jobs, spurred new industries, positioned American companies at the forefront of global innovation, and, most importantly, improved the lives of American consumers.

The next wireless leap, whether it is driverless cars, remote surgeries, or air taxis, may be just around the corner. But whether Americans will reap the benefits—and whether it will be made here or overseas—depends on our will to unlock more spectrum.

We stand today at a critical juncture. It has been two years since the FCC lost auction authority and three years since the last meaningful auction of spectrum valuable to American consumers. The dithering and the inaction sadly characteristic of the prior administration yielded nothing. Meanwhile, our spectrum innovation lags the rest of the world as China, an adversarial surveillance state, threatens to control worldwide communication networks.

Thanks to this new Congress and the historic election of President Trump, we have an opportunity to build better and faster networks, to create tens of thousands of high-paying jobs, and to secure America's global technological lead.

The Spectrum Pipeline Act, which Leader Thune, Senator Blackburn, and I introduced last year, would restore FCC auction authority and end our spectrum drought. Through a clear pipeline of mid-band spectrum, American companies will have the certainty they need to invest billions in their networks and lead the world in revolutionary innovation.

Certain special interests, aligned with adversaries like Huawei, have falsely portrayed a spectrum pipeline as a blunt instrument to deprive the Defense Department of the spectrum it needs to engage in 21st century warfare.

To the contrary, our bill ensures both consumer interests and defense capabilities are protected. The bill has a generous time-frame for performing the necessary feasibility studies so Federal missions are not degraded. And it uses the existing deliberative process, which is carried out by technical experts across the Federal Government, including DoD, to begin auctioning a fraction of underutilized Federal spectrum.

But studies are not enough to spur action: we need clear goals. For many years now, U.S. Government incumbents, particularly bureaucrats at the Pentagon under the direction of Mark Milley, have insisted they are using every single megahertz as efficiently as possible and must maintain absolute control of their vast spectrum holdings.

Look, I am more than open to compromise on what the aggregate pipeline target number should be, but zero is objectively unreasonable. And no institution should be afforded blind deference, especially not one that cannot even pass an audit and that claimed that leaving billions in tanks, helicopters, and weapons in Afghanistan was more efficient than bringing them home.

But do not just take it from me. Military analysts with firsthand expertise agree that we are falling behind, both in terms of its effective usage and in the development of intellectual property and wireless capabilities. Further, the Pentagon is not the only user of the airwaves globally. Many of the bands used by DoD currently are used commercially in countries like Taiwan, Japan, and Korea. If DoD is technically unable to operate alongside wireless carriers using these bands domestically, how on Earth can we expect it to prevail in a Pacific conflict? It simply is not credible.

There are also significant opportunity costs for our national defense in delaying spectrum auctions. A pipeline would be lucrative, raising $100 billion or more that could go directly to rebuilding our military, to funding border security, and to financing Coast Guard polar icebreakers. That is an incredibly valuable offset for the reconciliation process we are undergoing right now.

But the risk of doing nothing is broader than lost revenue. We are fighting a global technology race against communist China. If we do not catch up and lead, it will be Huawei that creates the backbone of tomorrow's global communication networks through which much of the world's economic traffic—and indeed, much of our own government's traffic—will flow. Chinese infiltrations, like the recent Salt Typhoon attack and the release of DeepSeek, are but a small preview of a future where Chinese equipment sets the standards and dominates global networks. Negative ripple effects cascade indefinitely from there, handicapping our efforts in other

adjacent technologies like AI, quantum, and semiconductors, and threatening to make America the loser in the 21st century technology race. We cannot allow that to happen. Now is the time.

Let me make a final point. The Commerce Committee, as we take up reconciliation, will move forward on spectrum. It would be an abdication of our responsibility to do anything otherwise. We must move quickly and together to preserve the Promethean flame of American technology and to bolster our national security for years to come. We must prevail in the race against China.

I recognize the Ranking Member.

STATEMENT OF HON. MARIA CANTWELL,
U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. Thank you, Mr. Chairman. Thanks for convening this important hearing. I look forward to hearing all our witnesses and your expert testimony on this subject, and I look forward to working with the Chairman and all my colleagues in any way possible to resolve our previous conflicts on these issues.

Last Congress, the Committee worked to expand commercial spectrum access while protecting critical Department of Defense and Federal system infrastructure, and I think we can all agree on two facts. First, the commercial industry needs access to more spectrum to innovate and bring new technologies to market. But second, the vital national security, aviation security and essential Federal capabilities that rely on Spectrum must be protected.

One of our witnesses, I think, characterized it best. Mr. Clark, in his testimony, said, "The U.S. military will need to operate in additional areas of electronic electromagnetic spectrum to address the increasing challenges of the threat environment to overcome its numerical and geographic disadvantages to China."

I could not agree more. During the last Congress, I worked to try to balance those access issues with national security efforts, and many of my colleagues on this committee have directed the Department of Commerce to have a larger role in trying to define the issues of agency overlap in this area of spectrum.

That led to the Department of Commerce and the Joint Chiefs of Staff agreeing on the legislation that we put forward that would open up more spectrum for commercial uses, and study basically how we could work together on spectrum sharing. So I want to continue to focus on how we get this right. We need to ensure that our global leadership and advanced wireless technology against China is there. However, we need legislation and leadership that does not abandon our national security goals.

I know it is easy to say this is what I want to do, but I am firmly convinced, when looking at the past history here, the only thing that is going to work is the collaborative, hardworking efforts and probably test bedding of technology that will allow us to get this right for the future.

In 2019, the FCC auctioned 24 gigahertz band, endangering our ability to track and predict hurricanes. In 2020, the FCC approved Ligado's petition to use satellite spectrum for 5G and risk severely disrupting essential GPS service. The U.S. Government is now facing a $39 billion lawsuit because of that debacle.

And in 2020, the FCC also rushed to auction the C-band, which was adjacent to spectrum used by airline altimeters. Concerns about interference with those flight safety systems nearly caused the FAA to ground all flights. It also put $81 billion worth of private investment by wireless industry at risk, significantly delaying the deployment of 5G in the United States.

In early 2000, Congress had to spend about a billion dollars replacing the radar system on the B–2 stealth bomber because of uncoordinated changes to spectrum allocations. This is exactly what I am talking about when we say we need to work together. We cannot continue to have this play out in a way where we are not thinking about our military capabilities.

In Ukraine, we are seeing how essential spectrum is every day. The Russians are jamming Ukraine drones, communications, GPS, and satellites. This all shows that our military needs to be nimbler, more flexible, if we are going to succeed in our operations in that kind of contested and congested spectrum environment.

And let's face it. Today our warfare does depend on spectrum-enabled communications. As one brigadier general who is in charge of cyberspace and war fighting said, "Spectrum is no longer just an enabler of the warfare. It is the warfare."

So today's victories and battles really will depend on us getting this right, and if we lose the spectrum war, we lose the war.

Today's hearing is about how we keep the U.S. globally competitive, while China and Russia and other foreign adversaries are making inroads that we need to assert our leadership in the rest of the world. So I would like to work with my colleagues on legislation that would help us get this right and continue to move forward.

I will also note that President Trump, in Mr. Clark's testimony, has a line, quote, "The most challenging driver of U.S. spectrum policy access requirements will be the Trump administration's initiative to establish a comprehensive missile defense architecture for the United States," end quote. Well, I do not know how we can do that if we give the spectrum away.

So I look forward to today's hearing, and I thank my colleagues and the Chairman for this important hearing.

Chairman CRUZ. Thank you. I will now introduce the distinguished panel of experts we have testifying.

Joining us today is Dr. Thomas Hazlett, Professor of Economics at Clemson University. Dr. Hazlett served as the Chief Economist of the FCC, and is a noted expert in telecommunications policy. His book, "The Political Spectrum," chronicles the history of American spectrum regulation and how spectrum policy reforms, such as public auctions, generated explosive technological innovation and economic growth.

Our second witness is Dr. Charles Baylis, a Professor of Electrical and Computer Engineering at Baylor University, the oldest continuing operating university in the great state of Texas. Dr. Baylis currently serves as Director of SMART Hub, a DoD Spectrum Innovation Center that organizes research efforts among 25 researchers across 15 universities, to revolutionize the increasingly crowded spectrum used by both DoD and non-military users.

Our third witness is Matt Pearl, Director of the Strategic Technologies Program at the Center for Strategic and International Studies. Mr. Pearl has more than 15 years of government service, including most recently as advisor to the National Security Council. Prior to that, Mr. Pearl served as Associate Bureau Chief of the Wireless Telecommunications Bureau at the FCC, where he helped transition the use of DoD spectrum to include commercial wireless use in multiple bands.

And our final witness, Bryan Clark, is a Senior Fellow and Director of the Center for Defense Concepts and Technology at the Hudson Institute. From 1982 to 2013, he served in a variety of roles in the United States Navy. While in the Navy, Mr. Clark received the Department of Navy Superior Service Medal and the Legion of Merit.

And we will start, Dr. Hazlett, with you. You are recognized.

STATEMENT OF PROF. THOMAS HAZLETT, HUGH H. MACAULAY ENDOWED PROFESSOR OF ECONOMICS, CLEMSON UNIVERSITY

Dr. HAZLETT. Thanks very much, and I thank everyone for their kind invitation to participate in today's discussion.

Radio spectrum is a vital component of the modern economy, yet artificial scarcity has been imposed by public policies that prevent entrepreneurs from moving underutilized spectrum resources into their highest-valued uses. Such impediments have long been a problem. Dating to the 1927 Radio Act, facets of the law require "Mother May I?" The term of art describes the slow process wherein idle bandwidth is discovered, defined in scope, and then transitioned into productive employments.

Needless permissions and red tape too often limit markets and impede America's economic growth. Bands have been reserved for maritime communications in Utah. The Forestry Service has enjoyed exclusive frequency rights in New York City. And today, some 35 channels from the TV Allocation Table of 1952 are still reserved for terrestrial over-the-air broadcasting. I Love Lucy may have benefited from this arrangement back in the day, but we now have more efficient means to deliver video using cable, satellites, and broadband internet.

These long lags continue to plague entrepreneurial ventures, reduce competition, and frustrate wireless consumers desiring more bandwidth for enhanced communication. Yet the good news is that U.S. policy has not been static. American regulators have taken corrective actions to promote liberalization, in particular, market-oriented policies have relaxed mandates for how spectrum must be utilized. In granting users and licensees wider discretion via flexible use spectrum rights, enormously valuable new competitive forms have been unleashed. Today, over ten times as much bandwidth is available for mobile wireless than in the mid 1990s. Vast mobile ecosystems have, as a result, bloomed. In addition, competitive bidding—auctions—assigns such rights, replacing arbitrary distributions.

Recent decades have brought experiments with new methods, and even the ones hidebound FCC has innovated. In the early 1990s, the introduction of what became known as second-genera-

tion cellar, or 2G wireless, was held up for some years by protests registered by holders of micro-wave allotments. These incumbents claimed catastrophe would result from any change in band access rights.

As is often the case, such claims were overwrought. The situation was put into clearer focus and resolved by a clever FCC policy, an "overlay." This approach granted emerging 2G networks the right to utilize vacant frequencies in the micro-wave band under "flexible use." Further, the overlays granted to the new licensee secondary rights over spectrum occupied by the micro-wave transmissions. This protected incumbents but gave life to entrants by defining the spectrum access rights needed for bargains to be struck. Investors in 2G networks were able to pay incumbents to move aside, using alternative technologies or other frequencies, so as to free up bandwidth for higher-valued services. The holdup ended, airways became available, and the U.S., then lagging EU countries in digital wireless, began to innovate and forge global leadership in emerging networks service.

The overlay policy has since been used in numerous contexts by U.S. regulators.

Overlays were modified in Auction 107 held in 2020–2021. The 500 MHz allocated there had appeared crowded, congested, and unavailable to entrants. In fact, with Incentive payments, the entrants relocated. Winning bidders paid $94 billion for the new licenses. Of that, some $13 billion was passed through to the incumbents.

The reconfiguration of the band took less than 4 years, lightning fast in spectrum regulation time.

Such mechanisms have improved incentives for cooperation in the process of radio spectrum reallocation. Many more targets of opportunity for efficient reforms in radio spectrum await. Thank you very much.

[The prepared statement of Dr. Hazlett follows:]

PREPARED STATEMENT OF PROF. THOMAS HAZLETT, HUGH H. MACAULAY ENDOWED PROFESSOR OF ECONOMICS, CLEMSON UNIVERSITY

Thank you for your invitation to participate in today's discussion of radio spectrum allocation. I am an economist who has studied this and related issues, publishing numerous research articles and books on the topic,[1] formerly serving as Chief Economist of the Federal Communications Commission, and currently serving as a co-principal investigator of SpectrumX, an NSF Spectrum Innovation Center.

Radio spectrum is a vital component of the modern economy. The airwaves through which communications flow—enabling mobile networks, connections to Internet services, satellite links, and a host of other stunningly useful applications—is limited in supply. But regulatory restrictions have made it even more restricted than nature and economic demand alone. Artificial scarcity has been imposed by public policies that prevent entrepreneurs from moving under-utilized spectrum resources into their highest valued uses.

Such impediments have long been a problem of traditional spectrum allocation. Dating to the 1927 Radio Act, a statute still dictating the basic structure of regulation, many facets of law require *Mother May I*? The term of art describes the slow process wherein idle bandwidth is discovered, defined in scope, and then transitioned into productive employments. Needless permissions and red tape too often limit markets and impede America's economic growth. Bands have been re-

[1] See, *e.g.,* Thomas Winslow Hazlett, THE POLITICAL SPECTRUM: THE TUMULTUOUS LIBERATION OF WIRELESS TECHNOLOGIES, FROM HERBERT HOOVER TO THE SMARTPHONE (Yale University Press, 2017).

served for maritime communications in Utah. The Forestry Service has enjoyed exclusive frequency rights in New York City. And today, some 35 channels from the TV Allocation Table of 1952 are still reserved for terrestrial, over-the-air broadcasting. *I Love Lucy* might have benefited from this arrangement back in the day, but we now have more efficient means to deliver video using cables, satellites, and broadband Internet.

But too often such opportunities are greeted with a spectrum strategy of "hurry up and wait." The famous scientist Edwin Howard Armstrong could, in the 1930s, invent FM radio, a hi-fidelity technology superior to the old AM, only for FCC machinations to prevent its eventual blossoming until the 1960s. The World War II invention of cellular radio ran into a licensing roadblock that delayed wireless telephone networks until the 1980s. Spectrum wars in bureaucratic trenches pit industries against each other, with the upshot that vast bands—and better networks—may go idle for a lifetime.

These long lags continue to plague entrepreneurial ventures, reduce competition, and frustrate wireless consumers desiring more bandwidth for enhanced communications. Yet, the good news is that U.S. policy has not been static. American regulators have occasionally taken corrective actions to promote liberalization. In particular, market-oriented policies have relaxed mandates for how spectrum must be utilized. In granting users and licensees wider discretion via "flexible-use spectrum rights," enormously valuable new competitive forms have been unleashed. Today, over ten times as much bandwidth is available for mobile wireless use than in the mid-1990s. In addition, competitive bidding—auctions—assigns such rights, replacing arbitrary distributions prior to 1994. The trick, however, is that in the underlying allocation process itself, administrative designations are still largely used to define the nature, location, and rules governing what technologies, services, and business models are to be made available for deployments.

Recent decades have brought experiments with new methods, and even the once hidebound FCC has innovated.[2] In 1994, the introduction of what became known as second generation cellular, or 2G wireless, was held up for some years by protests registered by holders of micro-wave allotments. The incumbents claimed catastrophe would result from any change is band access rights.

As is (was) often the case, such claims were overwrought. The situation was put into clearer focus, and resolved, by a clever FCC policy, an "overlay." This approach granted emerging 2G networks the rights to utilize vacant frequencies in the microwave band under "flexible use" rules. Further, the overlays granted the new licensee secondary rights over spectrum occupied by the micro-wave transmissions. This protected incumbents but gave life to entrants by defining the spectrum access rights needed for bargains to be struck. Investors in 2G networks were able to pay incumbents to move aside—using alternative technologies or other frequencies—so as to free up bandwidth for higher valued services. The hold-up ended, airwaves became available, and the U.S.—then lagging E.U. countries in digital wireless—began to innovate and forge global leadership in emerging network services.

The overlay policy has since been used in numerous contexts by U.S. regulators.[3] The 2016–2017 "Incentive Auction" moved 70 MHz allotted to TV broadcasts to flexible use spectrum rights won at auction by mobile carriers; broadcasters were paid to economize on airwave usage with funds bid by the new licensees. Incentive payments to incumbents were also paid from auction revenues in Auctions 101 (2019) and 103 (2020). Overlays were then modified in Auction 107 held in 2020–2021, restructuring the Satellite C-Band. The 500 MHz allocated there had appeared crowded, congested, and unavailable to entrants. In fact, with payments to incumbents, some 280 MHz of prime mid-band spectrum became available for reallocation to entrants. Winning bidders paid $94 billion for the licenses. Of that total, some $13 billion was passed through to the incumbent users of the band, satellite operators. The transfer enabled the companies to upgrade their systems while reducing their spectrum footprint—"relocation costs and incentives" in FCC parlance. This capacious tranche of new flexible-use spectrum was the largest ever released by the FCC for auction in one proceeding, and it energized U.S. 5G buildout. The rapid manner in which the policy was crafted and executed was also nota-

[2] Former FCC Member (and Chair) Jessica Rosenworcel summarized the new spirit of change this way: "When it comes to wireless policy, we have a history of embracing the ideas that are cool, kooky, and new before anyone else. After all, it was more than two decades ago that we took the academic ideas of Ronald Coase and ushered in a whole new era of spectrum auctions. We also pioneered the use of unlicensed spectrum—the airwaves we now know and use every day as Wi-Fi. More recently, we blazed a trail for two-sided incentive auctions." Statement of Commissioner Jessica Rosenworcel, FCC 19–96 (Rel. Sept. 27, 2019), p. 34.

[3] Hazlett, THE POLITICAL SPECTRUM, 276–287.

ble. From a Notice of Inquiry in July 2017 to the conclusion of bidding in Feb. 2021, a relatively short timetable departed from the long delays that the FCC has too often witnessed.[4]

Such mechanisms have improved incentives for cooperation in the process of radio spectrum reallocation. They lubricate transitions that enable the adoption of advanced methods of spectrum sharing, a term that is too often narrowly seen as top-down administrative rules. Most significantly, they help identify where consumers most value airwaves, revealing opportunities for new models and increasingly useful technologies. With attention to economic incentives, demonstrated in both encouraging and disappointing results exhibited in spectrum policy experiments, pro-consumer strategies have been discovered. Many more targets of opportunity for efficient reforms in radio spectrum await.

Chairman CRUZ. Thank you. Dr. Baylis.

STATEMENT OF CHARLES P. BAYLIS, PH.D., PROFESSOR OF ELECTRICAL AND COMPUTER ENGINEERING, BAYLOR UNIVERSITY, AND DIRECTOR, SMART HUB

Dr. BAYLIS. Thank you and good morning. My name is Dr. Charlie Baylis, and I serve as Professor of Electrical and Computer Engineering at Baylor University, and Director of SMART Hub, a Department of Defense Spectrum Innovation Center.

SMART stands for Spectrum Management with Adaptive and Reconfigurable Technology, and SMART Hub consists of 25 U.S. citizen researchers across 15 universities in 13 states. Our unified mission is to make spectrum usage adaptive and reconfigurable, from policy all the way through circuits. We have been established through congressional appropriation support and commissioned through the Army Research Laboratory. We are not a typical collection of academicians. We do not desire merely to publish papers on technology that will stagnate in a laboratory, but to quickly put superior technologies into the hands of our warfighters and into the hands of consumers. We want to put America First in spectrum, arguably the most important dimension of battle and a very valuable natural resource.

As a center, we are creating adaptive and reconfigurable technologies that will provide a "win-win" for military dominance and economic growth. By adapting, we aim to provide flexible, opportunistic spectrum capabilities to military systems and 5G and 6G commercial wireless systems, maximizing performance in whatever band they operate. We can also simultaneously enable the construction of the Iron Dome for America.

Two weeks ago, we demonstrated our initial technologies to the Pentagon, Congress, and the defense industry right here in Arlington. As an example of some of our innovations, we have developed sense-react-and-avoid, sense-predict-and-avoid, and metacognitive techniques to choose the best available spectrum for operation in real time, and are looking to AI to speed spectrum selection.

We are building a Dynamic Spectrum Management System, or DSMS, that will include live interference reports to inform the real-time coordination of spectrum. We are working on reconfigurable plasma circuits and antennas, capable of handling high transmission power levels, that allow us to maximize radar range in under a millisecond after changing frequencies to avoid wireless

[4] Even a generous accounting led the FCC to estimate standard delays as 6–11 years. See: FCC, *National Broadband Plan* (March 2010), p. 79.

communications. We are pioneering a novel measurement module that, when placed inside a transmitter chain, will allow us to assess what we are transmitting to avoid interference and improve our system performance "on the fly." These techniques will allow both incumbent Government systems and commercial wireless systems to have the functionality to work around each other.

Technology innovation will convert congestion into opportunity. Many attempts to organize spectrum have been limited to regulation and re-regulation, but adaptive and reconfigurable technology will revolutionize spectrum use. It will allow us to both provide for the common defense and promote the general welfare.

As the developer of adaptive and reconfigurable technology, the United States will gain an enormous international advantage both economically and tactically. U.S. industries will develop these systems and sell their technology worldwide. China will have to buy the technology from us. Commercial wireless systems will realize heretofore uncomprehensible bandwidths. And our military systems will be the strongest, most agile in the world, dominating in the most important dimension of battle, the spectrum.

How do we get to this situation from where we are today? This is a question that I, as the Director of a congressionally funded Spectrum Innovation Center, have spent a lot of time considering and mapping to direct our research, innovation, and workforce development. If spectrum coexistence is like driving a car down a highway with other vehicles, we must develop adaptive and cognitive techniques to maneuver devices through a congested spectrum. In less congested environments, device-to-device interaction can be used to coexist, just as cars can pass each other autonomously in uncrowded highways. In more congested environments, like a traffic light, a Dynamic Spectrum Management System will be useful for coordinating. So how do we grow into this paradigm from where we are today? You cannot expect a kindergartener to drive a car, and we cannot expect rigid wireless technologies to coexist adaptively. In both cases, maturation and development is needed. We are mapping a technology development trajectory using Bloom's Taxonomy. Widely used by educators in cognitive development, Bloom's Taxonomy shows the progression from knowledge, which is the simple memorization of facts, to evaluation, the mature cognitive and adaptive approach to life.

In elementary, middle, and high school, educators carefully plot the course of these students in subjects such as reading, writing, mathematics, science, and physical education to develop the cognitive and physical skills the children will need to eventually get behind the wheel of a car and drive the car down a road adaptively. In a similar manner, we are moving quickly toward evaluation ?-cognitive and adaptive use of the spectrum.

In conclusion, in the race for spectrum superiority, America needs to win. The opportunity is now, and we must seize it or be left behind. There are 25 patriot scholars in SMART Hub, with their U.S. citizen students, that are determined and working hard to see this happen. With God's enablement and provision, we look forward to continuing to partner with Congress, our President, and our Nation to ensure American superiority.

Thank you for the opportunity to testify, and I look forward to answering questions that you have.

[The prepared statement of Dr. Baylis follows:]

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As a center, we are creating adaptive and reconfigurable technologies that will provide a "win-win" for military dominance and economic growth. By adapting, we aim to provide flexible, opportunistic spectrum capabilities to military systems and 5G and 6G commercial wireless systems, maximizing performance in whatever band they operate. Two weeks ago, we demonstrated our initial technologies to the Pentagon, Congress, and the Defense Industry in Arlington, VA. As an example of some of our innovations, we have developed sense-react-and-avoid, sense-predict-and-avoid, and metacognitive techniques to choose the best available spectrum for operation in real time, and are looking to AI to speed spectrum selection. We are building a Dynamic Spectrum Management System (DSMS) that will include live interference reports to inform the real-time coordination of spectrum. We are working on reconfigurable plasma circuits and antennas, capable of handling high transmission power levels, that allow us to maximize radar range in under a millisecond after changing frequencies to avoid wireless communications. We are pioneering a novel measurement module that, when placed inside a transmitter chain, will allow us to assess what we are transmitting to avoid interference and improve our system performance "on the fly." These techniques will allow both incumbent government systems and commercial wireless systems to have the functionality to work around each other.

Technology innovation will convert congestion into opportunity. Many attempts to organize spectrum have been limited to regulation and re-regulation, rather than innovative technology to revolutionize spectrum use. Adaptive and reconfigurable technology provides a better alternative. It will allow us to both "provide for the common defense" and "promote the general welfare."

As the developer of adaptive and reconfigurable technology, the United States will gain an enormous international advantage both economically and tactically. U.S. industries will develop these systems and sell their technology worldwide. Commercial wireless systems will realize heretofore uncomprehensible bandwidths. And our military systems will be the strongest, most agile in the world, dominating in the most important dimension of battle: the spectrum.

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matics, science, and physical education to develop the cognitive and physical skills the children will need to eventually get behind the wheel of a car and adaptively drive down a road. In a similar manner, we are moving quickly toward "evaluation"—cognitive and adaptive use of the spectrum.

In the race for spectrum superiority, America needs to win. The opportunity is now, and we must seize it or be left behind. There are 25 patriot scholars in SMART Hub, with their U.S. citizen students, that are determined and working hard to see this happen. With God's enablement and provision, we look forward to continuing to partner with Congress, our President, and our Nation to ensure American superiority. Thank you for the opportunity to testify, and I look forward to answering questions that you have.

SMART Hub: www.spectrumsmart.org

- Commissioned as a DoD Spectrum Innovation Center headquartered at Baylor University.
- Initial Congressional Appropriation funding through the DEVCOM Army Research Laboratory.
- Leadership:
  - Charles Baylis, Director
  - Tom Brooks, Director of Business Development
  - Austin Egbert, Director of Strategic Initiatives
  - Casey Latham, Industry Liaison
  - Doug Sicker, Associate Director
  - Andy Clegg, Senior Research Scientist
  - Robert Marks, Senior Advisor

SMART Hub Functions:
- Research
- Workforce Development
- Testing and Certification

Focus Area	Researchers	Focus Area	Researchers
Policy	Doug Sicker, Baylor (Lead) Andrew Clegg, Baylor	Radar Systems	Yang Li, Baylor (Lead) Batu Chalise, NYIT
Security & Resiliency	Doug Sicker, Baylor (Lead)	Spectrum Coexistence	Michael Buehrer, Virginia Tech (Lead) Dimitriy Garmatyuk, Miami (Ohio) Yimin Zhang, Temple
Economics	Stuart Benjamin, Duke (Lead) Bill Lehr, Consultant	Reconfigurable Circuits	Abbas Semnani, Toledo (Lead) Nima Ghalichechian, Georgia Tech Hjalti Sigmarsson, Oklahoma Dimitrios Peroulis, Purdue
Passive Systems	Andrew Clegg, Baylor (Lead) Steve Reising, Colorado State	Algorithms	Robert Marks, Baylor (Lead) Charles Baylis, Baylor Liang Dong, Baylor
Workforce Development	Rashaunda Henderson, Texas-Dallas Tim Tuinstra, Consultant		
Communication Systems	Zhu Han, Houston (Lead) Jeff Reed, Virginia Tech Nishith Tripathi, Virginia Tech Alireza Vahid, Rochester Institute of Tech. Erik Perrins, Kansas	Propagation	David Jackson, Houston (Lead) Daniel Onofrei, Houston

SMARTHub

Chairman CRUZ. Thank you. Mr. Pearl.

STATEMENT OF MATTHEW PEARL, DIRECTOR, STRATEGIC TECHNOLOGIES PROGRAM, CENTER FOR STRATEGIC AND INTERNATIONAL STUDIES

Mr. PEARL. Chairman Cruz, Ranking Member Cantwell, distinguished members of the Committee, it is an honor to appear before you to discuss spectrum policy. The Center for Strategic and International Studies does not take policy positions, so the views expressed here are my own.

In my testimony I will explain the importance of establishing U.S. leadership in spectrum policy, draw attention to recent developments that undermine such leadership, and urge Congress and the Administration to act to improve the U.S.'s position.

U.S. leadership in spectrum is critical because the People's Republic of China is spending tens of billions of dollars to subsidize Huawei in an effort to control the future of this strategically vital technology. The U.S. is not, and should not, take the PRC's approach of massively subsidizing a single company. However, the U.S. should make available its other policy levers to counter the PRC, and spectrum is particularly critical.

Until recently, our country was at the forefront of spectrum policy. Since Congress authorized the FCC to conduct auctions in 1993, it held 100 auctions that generated $233 billion for the Treasury. In addition, Congress repeatedly provided clearing targets for making spectrum available for commercial use. These ac-

tions were critical to economic growth, economic security, and national security. During the period of 4G, for instance, U.S. networks supported 20 million jobs and were responsible for 10 percent of GDP growth.

Further, spectrum has played a critical role in fostering a stable, resilient U.S. economy. While we take it for granted that U.S. companies top the App Store on our phones, spectrum played a decisive role in enabling that to happen. In 2008, we were the first country to auction the 700 MHz band, giving us a head start in building high-power 4G networks. As a result, U.S. innovators were able to develop the first mobile apps.

While I have focused on auction spectrum, I must also highlight the importance of unlicensed and satellite use. We were the first country to adopt unlicensed use, leading to the development of ubiquitous, low-power technologies such as Wi-Fi. The U.S. has also been a leader in satellite spectrum, enabling U.S. companies to launch massive, low-earth orbit constellations.

While the U.S. has traditionally played a leadership role in spectrum, we are now at risk of falling behind. In March 2023, the FCC's authority to hold spectrum auctions lapsed. In addition, many countries have launched 5G in prime mid-band spectrum that the U.S. has not made available. It is critical for Congress to restore FCC auction authority and to establish ambitious clearing targets.

Another threat to U.S. leadership involves lengthy delays in acting on a request for satellite licenses, which is another threat to our leadership.

Finally, I will address the relationship between spectrum and national security. I have strong views on this question because during my service at the National Security Council one of the areas that I oversaw was electronic warfare. Some have taken the position that making spectrum available for commercial use is undesirable because DoD uses the remaining bands. I agree that it is critical for DoD to maintain the capabilities it needs to accomplish its mission. However, we have an opportunity to expand those capabilities while creating opportunities for commercial use.

There is also a misunderstanding about whether Congress needs to provide new statutory protections so that spectrum reallocation does not threaten national security. As one example, under an existing statutory provision, DoD cannot surrender spectrum unless the Secretary of Defense and the Chairman of the Joint Chiefs certifies that they will maintain essential military capabilities.

The biggest misconception we confront is that we only need to ensure that DoD has continued access to spectrum to prevail in the electromagnetic domain. The reality is that our military's budget is dwarfed by the commercial sector when it comes to technology, meaning that to prevail over our adversaries, DoD will need to leverage commercial innovation. For instance, wireless networks will be critical to the AI race because developing sophisticated AI services will require more data be sent to and from mobile devices. DoD will need to leverage the most advanced AI technologies, but this will not happen unless we make commercial spectrum available.

I look forward to your questions.

[The prepared statement of Mr. Pearl follows:]

PREPARED STATEMENT OF MATTHEW PEARL, DIRECTOR, STRATEGIC TECHNOLOGIES PROGRAM, CENTER FOR STRATEGIC AND INTERNATIONAL STUDIES

Chairman Cruz, Ranking Member Cantwell, distinguished Members of the Committee, thank you for allowing me to share my views with you on spectrum. I have worked on spectrum issues for nearly 15 years, and so it is a special honor to testify in front of the Senate committee that has repeatedly adopted legislation to ensure that the United States is at the forefront of spectrum policy and wireless technology. The Center for Strategic and International Studies (CSIS) does not take policy positions, so the views represented in this testimony are my own and not those of my employer. In my testimony, I will 1) explain the importance of the United States taking a leadership role on spectrum policy for U.S. economic growth, economic security, and national security; 2) draw attention to recent developments that threaten the ability of the U.S. to out-compete and out-innovate its adversaries in wireless technology; and 3) urge Congress and the Administration to take several key actions so that the United States leads the world in wireless innovation.

Spectrum and U.S. Leadership

It is critical for the United States to play a leadership role in spectrum policy. In recent years, for example, the People's Republic of China (PRC) has spent tens of billions subsidizing Huawei, as part of an effort to destroy the non-PRC wireless industry, dominate the global market for wireless services, and control the future of this strategically vital technology. The U.S. is not—and should not—take the PRC's approach of picking a winner and providing that company with massive subsidies. The threat posed by the PRC, however, makes it absolutely critical for the U.S. to use the other policy levers it has available to advance our position in wireless innovation and technology, and making spectrum available for commercial use is one of the key ways to ensure that we are able to do so.

Over most of the past thirty years, our country has been successful in leading the world in spectrum policy. During that time, our Nation was able to make a massive amount of spectrum available for commercial use, thus providing great benefits to the American people, while at the same time preserving and expanding Federal spectrum-based capabilities,.

In 1993, Congress authorized the Federal Communications Commission (FCC) to allow competitive bidding for spectrum licenses, and we became the first country to hold a major spectrum auction. Since 1994, the FCC has held 100 spectrum auctions that raised over $233 billion for the U.S. Treasury. Moreover, the total cost of the auctions program was less than 1 percent of what the auctions brought in. That represents an incredible return on investment for the American taxpayer.

Auctions have been even more instrumental, however, in promoting technological innovation and economic growth. If we look at the period between 1985 and 2020, when the United States made a tremendous amount of high-power spectrum available, wireless operators invested over $600 billion in their networks.[1] The contribution that the wireless industry made toward the larger U.S. economy was even greater—according to one estimate, U.S. networks supported 20 million jobs, contributed $700 billion to the economy in a single year, and were responsible for almost 10 percent of the GDP increase that the U.S. economy experienced during the period of 4G/LTE deployments.[2] Looking forward, another study estimates that by 2030, 5G will add between $1.4 trillion and 1.7 trillion dollars to U.S. economic growth.[3]

While holding auctions has been critical to economic growth, there were other factors that made the United States a success in wireless policy. In many cases, the United States was successful at achieving international harmonization for the spectrum bands we adopted here, which allowed us to create a global equipment ecosystem and benefit from economies of scale. Moreover, Congress has repeatedly provided guidance to the FCC, the National Telecommunications and Information Administration (NTIA), and the many agencies that use spectrum on making spectrum available, including spectrum that was made available for high-power use, and has given the FCC and NTIA authority and flexibility to orchestrate complex spectrum transitions and determine the rules of the road Each time Congress reauthorized the FCC to hold auctions—in 1997, 2006, and 2012—it provided a statutory target

[1] *https://api.ctia.org/wp-content/uploads/2022/12/Compass-Lexecon-Licensed-Spectrum-Report.pdf*

[2] *https://apnews.com/press-releases/pr-newswire/4g-wireless-transformed-americas-economy-new-study-shows-fbf58a1343f9e7ae38129b48aa1d6b62*

[3] *https://www.bcg.com/publications/2023/accelerating-the-5g-economy-in-the-us#:~:text=The%205G%20economy%20is%20the,trillion%20in%20US%20economic%20growth.*

for making spectrum available for commercial use, enabling the FCC to make high-power spectrum available.

Congress also expanded the ability of NTIA and FCC to manage complex spectrum transitions, such as giving them the ability to reimburse Federal agencies for relocation and sharing expenses in the 2004 Commercial Spectrum Enhancement Act and expanding on the activities that were able to be reimbursed in the Bipartisan Budget Act of 2015. Finally, Congress expanded on the FCC's authority to hold auctions, authorizing it to hold incentive auctions in 2012. Congress has also recognized and preserved the Commission's ability to adopt the rules of the road, so that engineering rather than politics determines the technical details of spectrum management. These actions were all critical to ensuring that the United States adopted a forward-leading, innovative approach to spectrum policy.

I have focused thus far on licensed terrestrial spectrum, but I would also like to recognize the key role of low-power, unlicensed spectrum, as well as spectrum for satellite use. First, the U.S. was the first country to adopt rules for low-power unlicensed spectrum, which has powered innovation and our economy. The FCC first adopted rules for "junk" bands that were undesirable and unused in the 1930s—the concept was that anyone would be allowed to use the spectrum without obtaining permission from the government, provided that the equipment they used could not cause harmful interference to licensed users. During the 1980s, we began to see use of these frequencies for common household applications such as garage door openers and baby monitors. More significantly, beginning in the 1990s, we saw the development of Wi-Fi and Bluetooth. By leveraging the permissionless innovation that the FCC provided in its unlicensed rules, the developers of those technologies have greatly increased our connectivity and contributed nearly $100 billion per year to the U.S. economy.[4]

Second, the U.S. has also been a leader in licensing spectrum for satellite technology. As a result, U.S. companies built and launched many of the pioneering communications satellites in the 1960s. Now, U.S. companies have launched, or are in the process of launching, massive low earth orbit (LEO) constellations that can provide broadband Internet on a global basis. These constellations are particularly useful in rural and remote areas. Thus far, LEO is a critical market in which we have outcompeted the PRC, though I would note that continued leadership in satellite spectrum is critical as the PRC attempts to launch clones of our successful LEO networks.

While the U.S. has traditionally played a leadership role in wireless, I believe that—regretfully—we are falling behind the rest of the world in spectrum policy. As you know, in March 2023, the FCC's authority to hold spectrum auctions lapsed. Many countries have deployed new networks in prime mid-band spectrum such as the lower 3 GHz band that we have not made available for commercial use, threatening to leave the United States behind. There is a lack of logic for failing to make that spectrum available in the U.S., given that key U.S. allies have already deployed in this spectrum using many of the military systems that we use to protect the homeland. It is critical to restore FCC auction authority and to create new opportunities for licensed and unlicensed spectrum use, particularly in mid-band spectrum. We need Congress and the Administration to set ambitious goals for making spectrum available for commercial use, so that we can make spectrum available for high-power and low-power use. At the same time, we must empower the FCC, NTIA, and the agencies to proceed in a systematic way based on sound science and engineering, and preserving key capabilities of the Department of Defense (DOD) and other departments and agencies.

Another area that threatens U.S. leadership involves delays in licensing spectrum for satellite use. As noted, U.S. companies currently have a strong leadership position in providing broadband Internet globally, but they won't be able to maintain that lead if they are unable to obtain timely access to spectrum. In this context, it is important to note that satellite operators have faced significant delays when making requests to modify their licenses—in fact, it has taken an average of three years for the FCC to grant or deny many requests.

Spectrum and Economic Security

As I mentioned, spectrum plays a critical role in ensuring that our economy grows, and that provides a strong rationale to adopt forward-leaning spectrum policies. However, I would also note that spectrum is important to our economic security—that is, our ability to ensure that the United States has a stable and resilient economy. Economic security requires the United States to control key technologies

[4] *https://www.cta.tech/Resources/Newsroom/Media-Releases/2022/January/Unlicensed-Spectrum-Generates-95-Billion-Per-Year*

so that home-grown companies can protect and sustain our economy in the face of potential global risks, shocks, and dislocations.

Spectrum is critical to economic security because it provides a foundation for U.S. companies to innovate. Take, for instance, the app economy. Many Americans take it for granted that U.S. companies such as Uber, Lyft, and Airbnb are at the top of the app store charts. Few understand, however, that it was spectrum policy that played a decisive role in enabling American innovators to make that happen. In 2008, we were the first country to auction the 700 MHz band—and this band was critical to wireless leadership at the time because it enabled mobile providers to broadly deploy new wireless services to the public across wide geographies. After we moved first on this spectrum, the United States quickly built 4G/LTE networks. Once these networks became available, U.S. innovators were the first to experiment and develop mobile apps, enabling U.S. companies to lead the world in the app economy, and unlocking hundreds of billions of dollars in economic benefits.

Looking forward, wireless networks will serve as the proving ground for the next technology that is central to our economic security: artificial intelligence (AI). For AI to be fully integrated in our daily lives, AI-enhanced services and the data traffic they generate will need to be sent to—and from—the mobile devices that we carry around with us. Such devices will be able to rearrange our schedules better than any human assistant, edit our photographs with more skill than any professional photo editor, and get us home faster and more safely than the most experienced professional driver. But U.S. companies won't be able to develop and deploy all those AI applications unless we make additional spectrum available to handle all that increased data traffic, particularly so that there is uplink capacity from devices to mobile networks. Unless the United States is a leader in spectrum, we risk losing the ability to easily develop such applications, and with it control over this strategic technology.

Spectrum and National Security

As discussed, the connections between spectrum, on the one hand, and economic growth and economic security, on the other hand, are underappreciated. When it comes to the role of spectrum policy in protecting our national security, however, we unfortunately face many misunderstandings and misconceptions. I have strong views on this question because I have seen the role that spectrum policy plays from the national security perspective. I spent ten years at the FCC managing spectrum transitions and auctions. I'm incredibly proud of the work we did to advance the U.S. wireless industry there; for instance, in Lower C-band, our efforts resulted in the largest spectrum auction—and likely the largest auction of any type—in world history, with over $81 billion in gross bids. More recently, however, I moved over to the National Security Council, where I oversaw policy related to spectrum and satellite use, including electronic warfare and other national-security related uses of spectrum. I have a deep appreciation for the critical role that spectrum plays in safeguarding the United States and its allies and partners.

Some stakeholders have publicly taken the position that making spectrum available for commercial use is no longer desirable given that most of the commercially-attractive frequencies are used by DOD. I agree with them that DOD uses spectrum to protect our nation, and that it is critical that we ensure that DOD has all the capabilities it needs to do so. Please note, however, that the key term I used is "capabilities"—unfortunately, some stakeholders have confused things by implying that to preserve all of DOD's "capabilities," we need to prevent commercial users from ever gaining new access to the spectrum that DOD uses. To the contrary, it is possible to preserve and even expand DOD's capabilities by modernizing the systems it uses, while creating more opportunities for commercial use.

Take, for instance, the Airborne Warning and Control System (AWACS), which is a key, airborne radar system that operates globally and provides an early warning to the United States, as well as its key allies, regarding potentially hostile ships, aircraft, vehicles, and missiles, in addition to serving a critical command and control function during aerial combat. DOD deployed the first production-model AWACS in 1977, meaning that right now we're still relying on a radar system that was put into service when Happy Days and Three's Company were on television. As DOD plans to upgrade this system, we have a critical opportunity to ensure that we are operating the most advanced radar system in the world, and that such a system is spectrally efficient and future-proof. After all, to address challenges by competitors such as the PRC and adversaries such as Russia, we need to deploy these systems not only in our homeland, but also to key U.S. allies, many of which have already deployed 5G in mid-band frequencies that we have not auctioned.

I would note that AWACS is only one system and that DOD has many other systems in the mid-range spectrum bands that are being targeted for commercial use.

There are numerous issues for the FCC, NTIA, and the agencies to work through, and the spectrum transitions that will result will be complicated. Nonetheless, I've seen technical experts at the FCC, NTIA, and the agencies successfully work through these issues many times in the past, and I am confident that they can do so again now. It is important for Congress to set goals and timelines so that the FCC, NTIA, and the agencies know what to aim for, and so that industry has sufficient certainty regarding the future availability of spectrum. It is equally important for the Administration to make it clear to the agencies that spectrum is a priority and that political actors should not block engineers from working through technical challenges on behalf of the President.

There is also a misunderstanding about whether Congress needs to provide additional statutory protections to prevent the spectrum repurposing process from threatening our national security. Under Section 1062 of the 2000 National Defense Authorization Act, which is a provision that remains in effect, spectrum that DOD uses cannot be surrendered for commercial use unless the Secretary of Defense and the Chairman of the Joint Chiefs jointly certify to key congressional committees that they will have access to other spectrum that maintains essential military capabilities. This is only one example of the numerous statutory protections that Congress has already adopted to ensure that our military can maintain its spectrum-based capabilities.

Another misconception about spectrum and national security is that we only need to ensure that DOD has access to spectrum and can procure equipment, and this will be sufficient to protect our national security needs. This view is extremely short-sighted, as in the future the U.S. military will no longer have the budget to meet all its future needs but rather will need to leverage commercial technology to prevail over our competitors and adversaries. If we look at the example of semiconductors in the 1960s, the U.S. military dominated the market, purchasing all the integrated circuits that were produced. By the 2020s, that number had fallen to 2 percent of the U.S. market. The trend was inevitable across the entire technological sector: as technology has exploded across economic markets, both in the United States and abroad, our military simply no longer has the purchasing power to consistently move markets and ensure innovation. Instead, DOD needs to take advantage of commercial innovation from our companies to ensure that it stays ahead of our competitors and adversaries.

In the domain of wireless technology, we're already seeing this play out in the battlefield in Ukraine, where commercial wireless networks and smartphones have directly transformed command, control, communications, computing, intelligence, surveillance and reconnaissance. For instance, we have seen smartphones used to crowdsource information to predict UAS attacks, serve as nodes in a network that create accurate geospatial maps of developments on the battlefield, and triangulate enemy positions. In the future, as wireless networks carry actionable insights from AI and quantum computing, the side in a conflict that can leverage the most advanced commercial wireless technology will have a significant, and in some cases, decisive advantage. In wireless technology, DOD will not be able to leverage commercial innovation unless the wireless industry has access to spectrum, given that spectrum will serve as a critical determinant of whether the wireless industry is able to develop and deploy innovative technologies. Ensuring that we preserve critical military spectrum-based capabilities while creating opportunities for commercial access to spectrum is therefore essential to our ability to prevail in future conflicts.

RECOMMENDATIONS

I. For Congress

1. Restore the FCC's ability to conduct spectrum auctions.
2. In such legislation, provide targets, goals, and associated timelines for making spectrum available, particularly for mid-band spectrum, including the ability to make spectrum available for high-power and low-power use. This will serve as critical guidance to the FCC, NTIA, and the agencies as they work together on spectrum policy. It is important for these targets to be informed by discussions with the FCC, NTIA, and industry.
3. Adopt requirements that would apply to Federal agencies to cooperate with NTIA and the FCC as they attempt to make spectrum available.
4. Preserve the discretion of NTIA and the FCC to determine the specific bands made available, and the ability of the FCC to determine the technical rules that would apply to spectrum.
5. Update the Commercial Spectrum Enhancement Act by offering agencies the opportunity to receive reimbursement under the Spectrum Relocation Fund

(SRF) for upgrading their systems beyond what they are currently capable of doing, allowing NTIA the ability to receive funds to conduct studies and analyses of spectrum use, and providing the Technical Panel that reviews studies and transition plans further oversight over process after they have approved such studies or plans.

6. Elevate the Administrator of NTIA to an Undersecretary to improve the interagency process on spectrum.
7. Require streamlined procedures for granting satellite applications and shot clocks for granting or denying licenses.
8. To further advance our wireless capabilities, develop a comprehensive "system of systems" for position, location, and timing, which can back up and compliment GPS, and therefore mitigate vulnerabilities and enhance reliability for both Federal and commercial users.

II. For the Administration

1. Adopt ambitious goals and timelines that are informed by discussions with the FCC, NTIA, and industry.
2. Provide guidance and an escalation process to ensure that disagreements or disputes between the FCC, NTIA, and/or the Federal agencies that use spectrum are quickly and properly resolved.
3. Ensure that planned spectrum transitions preserve critical national security, public safety, and other Federal mission capabilities.
4. Develop a process that will enable the United States to arrive at positions on international spectrum allocations well in advance of the 2027 World Radio Conference.

Chairman CRUZ. Thank you. Mr. Clark.

STATEMENT OF BRYAN CLARK, SENIOR FELLOW, HUDSON INSTITUTE

Mr. CLARK. Chairman Cruz, Ranking Member Cantwell, thank you very much for the opportunity to speak today, to you and the rest of the Committee, about spectrum policy.

The national security competition between the U.S. and China in the electromagnetic spectrum is not just a commercial one. It is also a military one, and in a lot of ways it is predominantly a military one, as we look at the future conflicts we might face against China and others.

If you look at the invasion of Ukraine and how the electromagnetic spectrum has played out as the centerpiece, essentially, of that war, early on Russia had a lot of problems in its initial push toward Kyiv. In part, that was because of a lack of spectrum management on its part, the inability to use the spectrum effectively. Later, we see today now that both sides are using sophisticated electromagnetic warfare against each other, but as Ranking Member Cantwell talked about, they are using jamming against GPS, they are using jamming against communications. The recent offensive that Ukrainian forces mounted into Kursk was enabled, in large part, by their ability to gain superiority in the electromagnetic spectrum, so operating in parts of the spectrum where the Russians were trying to operate, and operating outside their coms, putting their own coms in parts of the spectrum where the Russians were unable to jam them. So the spectrum is increasingly where wars are going to be one and lost.

Against China, the U.S. faces a much more powerful competitor, in general, and also in the spectrum, than Russia poses. To overcome its geographic and numerical disadvantages, when you are fighting as the away team against China, U.S. forces are going to

have to rely on a lot of what we would call counter-ISR, counter-surveillance and reconnaissance, counter-communications capabilities, to degrade the ability of China's reconnaissance intelligence network to be able to target and attack U.S. forces.

If we cannot operate inside frequencies where the Chinese operate, and outside of our normal frequencies so we can deceive them, hide our forces, and degrade their targeting ability, we are not going to be able to amass the number of forces successfully to defeat them in an invasion of Taiwan. So really, fundamentally, winning that invasion of Taiwan comes down to the ability to control the spectrum in that Western Pacific region.

We need to be able to build the capabilities for that and train with them here in the United States before we go overseas, and in a lot of ways that deception campaign has to start here, meaning we are operating in parts of the spectrum that we would not normally operate in, as part of an effort to begin that deception against the Chinese forces.

In addition, as we mentioned earlier, the Iron Dome for America is going to create new demands for electromagnetic spectrum to protect the United States from missile attack. Obviously, there are opportunities to use those technologies to be able to more efficiently use the spectrum, and more effectively manage that surveillance network, we need to protect the United States. But requirements for terminal missile defense and for airborne moving target indication from space are both going to create demands on S-and X-band frequencies that we currently want to make available to commercial users.

So the needs for DoD in the spectrum are becoming larger and more complex. But that does not preclude that we would be able to share that spectrum between military and commercial users. It does mean we need to bring new technologies to bear. We need to bring new policies to bear. And there will be some deliberative process so that we can figure out which parts of the spectrum can be made available and which ones really cannot, because of physics and because of the number of systems we might need to be able to conduct the operation.

Examples like CBRS, the Citizens Band Radio Service, and AMBIT are good examples of where, in the past, we have been able to deconflict users in the spectrum between Federal and commercial users, or share spectrum by taking advantage of new technologies for detection and relocation of spectrum users.

But we need to be able to take the time and the analysis necessary to make those mechanisms feasible in the United States to support both the operations we need to do for things like Iron Dome, as well as the training and preparation necessary to get our forces ready to go overseas and fight in a war where they are going to need the spectrum to make up the difference between their lack of mass as the away team and the large mass that is available to the Chinese, or the home team.

So we should not fall victim to getting into a symmetrical competition with China over who is giving more of a particular part of the spectrum to the commercial users, and we should not unilaterally disarm our military capabilities in the spectrum. We need to work out ways so that both military and commercial uses can be

taking advantage of our spectrum resources, so we can compete on both battlefields.

With that I will be looking forward to your questions. Thank you.

[The prepared statement of Mr. Clark follows:]

PREPARED STATEMENT OF BRYAN CLARK, SENIOR FELLOW, HUDSON INSTITUTE

Chairman Cruz, Ranking Member Cantwell, and distinguished members of the committee, thank you for the opportunity to testify before the committee on the topic: America Offline? How Spectrum Auction Delays Give China the Edge and Cost Us Jobs.

Summary

The U.S. military will require more, not less, access to the electromagnetic spectrum in the coming decade. Facing numerical and geographic disadvantages against an opponent like China, U.S. forces will need electronic warfare systems that can jam, decoy, and deceive enemy sensors by operating outside traditional U.S. frequencies and inside those used by adversaries. At home, the U.S. military will need to continuously operate high-power sensors and defenses from S through K band to defend U.S. territory from air and missile attack as part of the Trump Administration's Iron Dome for America initiative.

China's leaders want the U.S. government to unilaterally disarm by further constraining the Department of Defense's spectrum access. Beijing disingenuously claims that it has given more spectrum to Chinese telecommunication companies when in fact the People's Liberation Army (PLA) retains the authority and mechanisms to routinely displace commercial spectrum users. Instead of engaging in a unproductive spectrum competition against China in S-band, the U.S. government should ensure military and commercial users can co-exist in U.S. spectrum through sustainable and executable sharing schemes. Telecommunication companies should be prepared for the cost and time needed to implement these approaches, especially as military demands for spectrum are likely to grow.

Winning the Fight for Sensing and Sensemaking

Militaries have always depended on the electromagnetic spectrum to communicate and coordinate operations, navigate over vast distances, and attack or avoid enemies. Starting during World War II, electronic warfare made the spectrum itself a battlefield when jammers and decoys emerged as new tools to prevent an opponent from coordinating operations or sensing and understanding its environment.

The war in Ukraine highlights how the electromagnetic spectrum is now the domain in which battles—and wars—are often won or lost. Russian and Ukrainian troops routinely use vehicle-and drone-borne electronic sensors to detect enemy forces by their radio transmissions and enable attacks with artillery or rockets. To protect themselves, troops on both sides have developed work-arounds that enable them to transmit on unexpected frequencies where the enemy is not looking, use directional antennas, or avoid radio communications altogether.[1]

Russian and Ukrainian forces are also extensively jamming each other in the spectrum. Traditional radio communications are often impossible near the front lines.[2] Ukrainian forces stopped using US-provided guided weapons like the Excalibur artillery round and Joint Direct Attack Munition until they are modified to be more jam-resistant or incorporate multiple modes of navigation.[3] Both militaries have turned to using radars or cameras on drones for guidance, sometimes augmented by a human operator connected via a fiber-optic cable to avoid radio jamming.

China is a much more challenging electromagnetic adversary for the United States than Russia. The PLA fields a growing array of electronic warfare aircraft, drones, and satellites that can listen and jam across relevant areas of the spectrum

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[1] Vikram Mittal, "Ukraine Is Now Dominating The Drone And Electronic Warfare Domains," Forbes, August 21, 2024, *https://www.forbes.com/sites/vikrammittal/2024/08/21/ukraine-is-now-dominating-the-drone-and-electronic-warfare-domains/*.

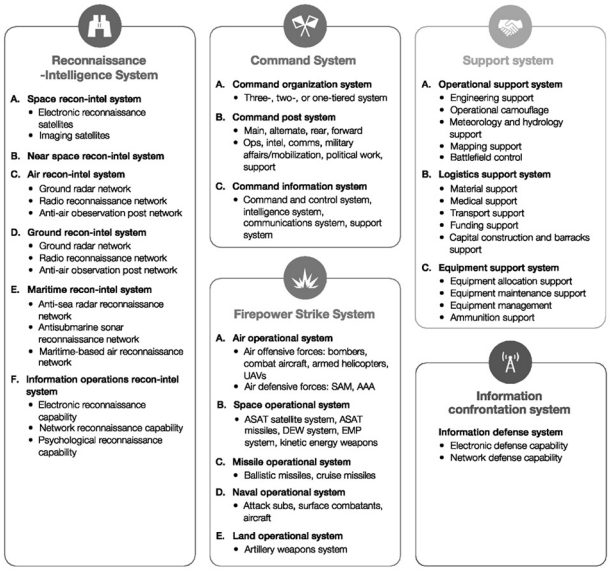
[2] Chris Panella, "A 'hidden electronic warfare battle' is raging in Ukraine and demanding more from the soldiers fighting it, special drone unit says," Business Insider, February 8, 2025, *https://www.businessinsider.com/hidden-electronic-warfare-battle-demanding-more-of-ukrainian-soldiers-2025–2.*

[3] Thomas Withington, "Jamming JDAM: The Threat to U.S. Munitions from Russian Electronic Warfare," RUSI, June 6, 2023, *https://www.rusi.org/explore-our-research/publications/commentary/jamming-jdam-threat-us-munitions-russian-electronic-warfare*

at long range.[4] China's navy, coast guard, and maritime militia ships are equipped with electronic sensors to surveil U.S. and allied communications and radar transmissions.[5] And the Chinese government's space-based electronic surveillance architecture over U.S. territory and the Indo-Pacific region is growing faster than its U.S. counterpart.[6]

China's electronic surveillance network in the air, on the water, and in space is part of an overall Reconnaissance-Intelligence System that leaders in Beijing rely on to assess their opponents' operations in peacetime and target enemy forces in wartime. As shown in Figure 1, this system is one of several systems the PLA plans to use in a potential conflict such as an invasion of Taiwan. China's leaders rely on a systems approach to warfare in part due to their well-publicized lack of confidence in PLA commanders' abilities to engage and defeat enemy forces without suffering unsustainable losses.[7] Chinese leaders would prefer to centrally manage a war, using the Reconnaissance-Intelligence System to find enemy forces, predict their future actions and operations, and target them for long-range precision attacks by the Firepower Strike System.[8]

Figure 1: China's warfare systems[9]



[4] Kristin Burke, "PLA Counterspace Command and Control" (Montgomery, AL: U.S. Air Force China Aerospace Studies Institute, 2023), *https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/PLASSF/2023-12-11%20Counterspace-%20web%20version.pdf.*

[5] John Christianson, "Fighting and Winning in the Electromagnetic Spectrum," War on the Rocks, December 5, 2022, *https://warontherocks.com/2022/12/fighting-and-winning-in-the-electromagnetic-spectrum/#:~:text=The%20Chinese%20concept%20recognizing%20the,the%20Chinese%20coastline%2C%20is%20a.*

[6] J. Michael Dahm, "China C4ISR and Counter-Intervention," Testimony before the U.S.-China Economic and Security Review Commission," March 21, 2024, *https://www.uscc.gov/sites/default/files/2024-03/J.Michael_Dahm_Testimony.pdf.*

[7] Jackson, Kimberly, Andrew Scobell, Stephen Webber, and Logan Ma, Command and Control in U.S. Naval Competition with China. Santa Monica, CA: RAND Corporation, 2020, pp. 23–49. *https://www.rand.org/pubs/research_reports/RRA127-1.html;* Larry Wortzel, "The PLA and Mission Command: Is the Party Control System Too Rigid for Its Adaptation by China?," Association of the U.S. Army, March 2024, *https://www.ausa.org/sites/default/files/publications/LWP-159-The-PLA-and-Mission-Command-Is-the-Party-Conrol-System-Too-Rigid-for-Its-Adaptation-by-China.pdf.*

[8] Joel Wuthnow, "System Destruction Warfare and the PLA," Institute for National Strategic Studies, June 2024, *https://keystone.ndu.edu/Portals/86/PLA%20Systems%20Attack%20-%20JW%20update%20June%2024.pdf*

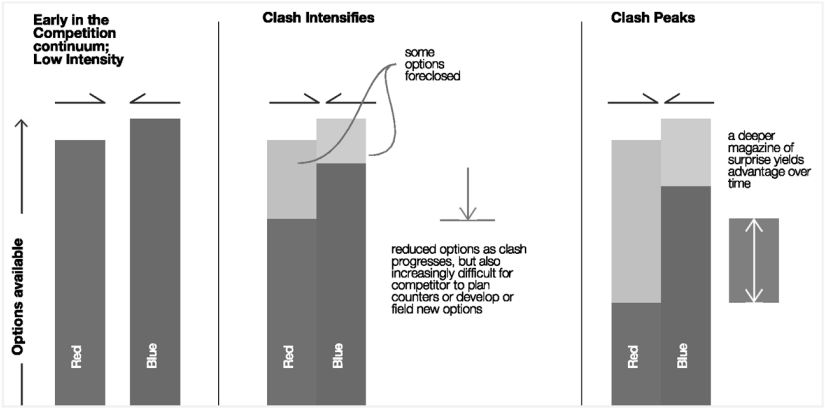
[9] Jeffrey Engstrom, *Systems Confrontation and System Destruction Warfare* (Santa Monica, CA: RAND, 2018), *https://www.rand.org/pubs/research_reports/RR1708.html.*

China's hierarchical approach to command and control creates vulnerabilities that U.S. and allied forces will try to exploit.[10] Chinese leaders depend primarily on their signals intelligence and imaging satellites to build an operational picture because these space-based systems offer continuous coverage of the Indo-Pacific region and do not depend on the competence of ship, aircraft, or ground-based sensor crews. However, U.S. and allied militaries could confuse these sensors by operating their radars and radios in unexpected areas of spectrum; deploying decoys that simulate signals or radar returns from U.S. ships, aircraft, or ground troops; and using jammers against PLA sensors and communication systems to obscure the location of real U.S. or allied forces and prevent Chinese sensor fusion.[11]

Faced with an unreliable operational picture, China's leaders would turn to ground-based sensors and ships and aircraft to verify real vs. false targets. U.S. and allied forces could use the same counter-sensor approaches against these systems, although with less effect. However, the impact will already be felt as China's leaders begin to question their centrally-controlled "fire and forget" military strategy.

U.S. forces will need to sustain counter-sensing and counter-sensemaking operations over months or years to translate Chinese leaders' temporary doubts into an enduring lack of confidence that could deter them from pursuing aggression against U.S. allies. As shown in Figure 2, the U.S. military will need a large number of diverse electronic warfare tools and techniques to support a jamming and deception campaign.

Figure 2: Importance of a deep magazine of electronic warfare effects in a campaign



Electronic warfare techniques are often short-lived in wartime, as demonstrated by the electromagnetic spectrum competition during World War II and more recently in Ukraine.[12] After one side fields a new jammer or decoy, the other side quickly develops a countermeasure or work-around. To sustain the move-countermove competition shown in Figure 2, the DoD will need to develop and test systems, train and certify relevant units, and sometimes conduct operations in the United States to create a deep magazine of diverse electronic warfare effects. These efforts will require access to diverse areas of spectrum not currently or often used by U.S. forces.

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[10] Jon Harper, "Counter-C5ISRT is top priority for nominee to lead Indo-Pacific Command," DefenseScoop, February 1, 2024, *https://defensescoop.com/2024/02/01/counter-c5isrt-samuel-paparo-indo-pacific-command-nomination/*.

[11] This approach is detailed in Bryan Clark, "Winning the Fight for Sensing and Sensemaking," (Washington, DC: Hudson Institute, 2024), *https://www.hudson.org/national-security-defense/winning-fight-sensing-sensemaking-fielding-cyber-electronic-warfare-c5isr-bryan-clark.*

[12] John Stillion and Bryan Clark, "What it Takes to Win: Succeeding in 21st Century Battle Network Competitions," (Washington, DC: Center for Strategic and budgetary Assessments, 2015), *https://csbaonline.org/research/publications/what-it-takes-to-win-succeeding-in-21st-century-battle-network-competitions.*

China's long con for spectrum superiority

U.S. and allied electronic warfare operations threaten the effectiveness of China's war plans. To prevent the U.S. from fielding these critical capabilities, China is attempting to convince the U.S. government to unilaterally disarm in the spectrum.

Numerous studies and industry white papers have asserted during the last decade that the United States is "losing the spectrum competition" with China. These studies argue that the Chinese government has made more spectrum available for commercial telecommunications use compared to the United States—especially in the 3–5 Ghz band.[13]

Mid-band spectrum in the 2–8 Ghz range is coveted by commercial and military system developers because it offers an attractive combination of range, data rate, and resistance to interference. Higher frequency signals can carry more data or achieve higher resolution in radars but suffer higher attenuation due to atmospheric heating and are more susceptible to interference because they tend to bounce off obstacles rather than passing through them. Lower frequency transmissions can travel much farther distances, but carry less data and achieve lower resolution.

By the mid-2030s, China's government reportedly plans to make up to 1,500 Mhz more mid-band spectrum available for commercial telecommunications use compared to the U.S. government.[14] But this potential disparity is an illusion. In China, all frequency allocations—like all commercial endeavors—are contingent. The government retains the authority to force commercial users off the spectrum when needed, and maintains organizations and processes for doing so.[15]

Under the concept of military-civil fusion, China's regional radio management centers are charged with clearing spectrum to enable military and civil defense operations whenever needed for training, exercises, system development, or crisis response. To enable rapidly removing commercial users, each radio management center includes a PLA reserve frequency management unit. These units are led by a core of active-duty PLA officers and mainly comprised of reserve soldiers whose civilian jobs are in the telecommunications industry. Their civilian experience is intended to enable these reserve operators to quickly kick commercial users out of needed spectrum in support of PLA or other government needs.[16]

At the same time its government reserves the right to use any spectrum at will, China's political and industry leaders suggest that China is building a lead in 5G and future communication technologies because the country makes more spectrum available to national champions like Huawei and ZTE. The U.S. government should not unilaterally disarm by taking mid-band spectrum away from U.S. military uses in an effort to win this non-existent spectrum race against China.

Another argument for making more U.S. mid-band spectrum available for commercial use is to align with the frequency allocations of other countries, including numerous U.S. European and Indo-Pacific allies. The World Radio Congress (WRC) has recommended that wide swaths of spectrum in relevant frequency ranges for 5G and potential future 6G communications, which many countries have adopted in their own radio regulations.

However, this argument incorrectly assumes each country has similar needs for spectrum outside of commercial functions. As the world's most sophisticated force and the largest one outside of China, the U.S. military incorporates a more numerous and diverse portfolio of electromagnetic spectrum systems than any of its allies. For example, the U.S. Department of Defense (DoD) maintains more than 100 high-power jamming aircraft, which is more than its European and Indo-Pacific allies combined. The U.S. Navy and Air Force include more than 100 airborne radar surveillance aircraft and nearly 100 air defense destroyers and cruisers carrying high-power radars. To follow through on its alliance commitments, the U.S. military requires access to spectrum across large areas of the country for training, concept development, maintenance, and operations.

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[13] Accenture, "The Case for Global Spectrum Harmonization," CTIA, January 2024, *https://api.ctia.org/wp-content/uploads/2024/01/Advancing-US-Wireless-Excellence-Global-Harmonization.pdf;* James Lewis, "Spectrum Allocation for a Contest with China," (Washington, DC: CSIS, 2023), *https://www.csis.org/analysis/spectrum-allocation-contest-china.*

[14] Clete Johnson, "Next Steps to Close the Gap with China on Licensed Spectrum for Commercial 5G," Center for Strategic and International Studies, February 12, 2024, *https://www.csis.org/blogs/strategic-technologies-blog/next-steps-close-gap-china-licensed-spectrum-commercial-5g.*

[15] Ministry of Industry and Information Technology (MIIT), "Radio Regulation of the People's Republic of China (2016 Revision)," *http://106.15.139.130/Law/LawShowEn?id=222067.*

[16] John Dotson, "Military-Civil Fusion and Electromagnetic Spectrum Management in the PLA," Jamestown Institute, October 8, 2019, *https://jamestown.org/program/military-civil-fusion-and-electromagnetic-spectrum-management-in-the-pla/.*

Enabling the Iron Dome for America

The most challenging driver of U.S. military spectrum access requirements will be the Trump Administration's initiative to establish a comprehensive missile defense architecture for the United States. Announced by executive order last month, the "Iron Dome for America" is intended to field a system of systems that can defeat hypersonic, ballistic, and cruise missiles as well as emerging airborne threats such as drones. The proposed architecture would include weapons to engage enemy missiles soon after launch, in mid-flight, and in the terminal phase when they near a target in the United States.[17]

The U.S. military already maintains a ballistic missile detection and tracking system as part of the national missile defense system, which mainly uses infrared satellites to detect launches overseas and radars in Alaska, Canada, and Greenland to track ballistic missiles coming over the North Pole. The Iron Dome architecture would build on this existing network by adding satellite-borne sensors that the DoD is already developing for tracking ballistic and hypersonic missiles.[18] These space-based and forward-deployed sensors would probably not require new frequency allocations to the DoD.

However, the Iron Dome for America will require a dramatic increase in radar surveillance and tracking in the S and X bands to support terminal defense against ballistic and hypersonic missiles. Terminal defense systems like SM–6 or PAC–3 interceptors engage ballistic and hypersonic missiles in the atmosphere at ranges of only 100 to 200 miles, which requires that they be positioned near the targets they defend. Planned space-based sensors can detect and initially track incoming hypersonic and ballistic missiles, but they cannot provide interceptors the target missile's position and movement precisely or quickly enough for an engagement.[19] Existing surveillance radars used to manage commercial air traffic lack the responsiveness and precision needed to track ballistic and hypersonic missiles. To guide terminal defense interceptors, the DoD will need to operate military radars such as the U.S. Navy's SPY–1, 6, and 7 or carried by airborne warning and control aircraft including the E–2D or E–3 in the interior of the United States.

Greater spectrum access will also be needed to defeat cruise missiles and "other next-generation aerial attacks," which could include advanced drones like those Russia is using against Ukraine. The DoD may need to use airborne or ground-based S and X-band radars to track these threats.[20] But the more significant challenge will be shooting them down. As recent operations in the Middle East, Ukraine, and around the United States suggest, an opponent could attack U.S. bases, government facilities, or public gatherings using hundreds of drones and cruise missiles.[21] To defeat these large salvos the DoD would likely need to turn to high-power microwave (HPM) systems that generally transmit pulses across the X through K (8–27 Ghz) bands also used by some mid-band and millimeter-wave 5G networks.[22]

The commander of U.S. Northern Command testified earlier this month that one of his most significant challenges was air domain awareness.[23] Closing that gap and

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[17] Donald J. Trump, "The Iron Dome For America," January 27, 2025, The White House, *https://www.whitehouse.gov/presidential-actions/2025/01/the-iron-dome-for-america/*.

[18] Center for Arms Control and Non-Proliferation, "Fact sheet: U.S. Ballistic Missile Defense," Center for Arms Control and Non-Proliferation, June 12, 2023, *https://armscontrolcenter.org/fact-sheet-u-s-ballistic-missile-defense/*.

[19] Planned space-based radars or infrared sensors cannot precisely determine the elevation of missiles they are tracking, which is needed to direct an interceptor to the target, and they lack a mechanism for sending target information to the interceptor in flight in real-time.

[20] Cruise missiles and drones are generally too small to be tracked by space-based radars to track and too slow to generate an infrared signature that could be detected by satellite sensors. Space-based electro-optical sensors could track cruise missiles and drones, but would need to be cued to the threat's exact location. Existing civilian air surveillance radars can often track cruise missiles and drones, but are not dedicated to that mission and do not provide data in the form needed for an interceptor to engage the target.

[21] Jim Garamone, "Reports of Drone Incursions Taken Seriously, DOD Spokesman Says," DoD News, December 17, 2024, *https://www.defense.gov/News/News-Stories/Article/Article/4008836/reports-of-drone-incursions-taken-seriously-dod-spokesman-says/*.

[22] Office of Naval Research Code 35, "Directed Energy Weapons: High Power Microwaves," Office of Naval Research, *https://www.onr.navy.mil/organization/departments/code-35/division-353/directed-energy-weapons-high-power-microwaves.*

[23] Gregory M. Guillot, "Testimony on the Posture of United States Northern Command and United States Southern Command in Review of the Defense Authorization Request for Fiscal Year 2026 and the Future Years Defense Program," February 13, 2025, *https://www.armed-services.senate.gov/hearings/to-receive-testimony-on-the-posture-of-united-states-northern-command-and-united-states-southern-command-in-review-of-the-defense-authorization-request-for-fiscal-year-2026-and-the-future-years-defense-program.*

establishing the Iron Dome for America will require operations by military systems in multiple commercially-relevant frequency ranges across large parts of the United States. In contrast to today's needs for episodic military training, testing, and certification, these missions would create a continuous need for spectrum access.

Reconciling spectrum demands

The U.S. military will need to operate in additional areas of the electromagnetic spectrum to address an increasingly challenging threat environment. To overcome its numerical and geographic disadvantages against China, U.S. forces will need to develop, test, and train on systems that emit outside traditional U.S. military frequencies and inside adversary bands as part of its effort to undermine Chinese sensing and sensemaking. The DoD will also need to operate radars and HPM systems in S through K bands across the United States as part of a comprehensive domestic air and missile defense architecture.

However, the DoD's growing need for spectrum does not preclude commercial uses in the same or adjacent frequencies. For example, some regions of spectrum like 6 Ghz could be more efficiently segmented between government, commercial, and unlicensed users. In these frequencies, the government could apply the approach demonstrated by the 2020 White House-DoD America's Mid-Band Initiative Team (AMBIT) initiative.[24] Using the results of AMBIT, the Federal Communications Commission established procedures that allow military and commercial users to both operate in the 3450–3550 Mhz range by separating their emissions in time and geographically.[25] Advances in the spectral efficiency of military and commercial systems could allow static allocation models like AMBIT to be implemented in additional geographies or frequencies.

New technologies can also allow for dynamic spectrum sharing between commercial and military users. For example, the Citizen's Broadband Radio Service (CBRS) allows military, civilian, and commercial users to share spectrum from 3550–3700 Mhz in some regions using a combination of procedures and automated controls that move priority and general access commercial or private users to other frequencies when incumbent government users are detected in the band. This process allows periodic military operations in the spectrum while minimizing the impact on commercial applications.[26]

Models like CBRS could be employed in other tranches of spectrum, such as 6Ghz, or other geographic regions where military and commercial users could share spectrum. However, as identified by the 2023 DoD Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) study, the government will need to evolve the CBRS model to enable the industrial base to experiment with and test new electromagnetic systems, accommodate fast-moving airborne radars, and ensure coordination in more complex electromagnetic environments compared to the current applications of CBRS.[27]

The challenge for regulators and Congress will be creating spectrum sharing schemes that protect necessary DoD access while remaining financially attractive for the telecommunications industry. Time and geographic constraints such as under AMBIT or the need to periodically relocate to other frequencies under CBRS will require companies to maintain access to additional frequency bands, establish automated sensing and control systems, and manage a patchwork of different frequency coverage and control mechanisms across the Nation. The time and investment needed to implement these approaches will reduce the value of spectrum at auction. This cost and complexity will only grow as the DoD's need for spectrum increases as a result of new operational concepts and missions.

Conclusion

The Congress should not fall victim to China's disinformation. China's telecom companies suggest they are winning the 5G race because they can use more frequencies than their competitors in the United States and Europe. However, the PLA

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[24] C. Todd Lopez, "AMBIT Gambit Pays Off, Advances U.S. 5G Efforts," DoD News, August 10, 2020, *https://www.defense.gov/News/News-Stories/Article/Article/2306902/ambit-gambit-pays-off-advances-us-5g-efforts/*.

[25] Federal Communications Commission, "Second Report And Order, Order On Reconsideration, And Order Of Proposed Modification," Federal Register, March 21, 2021, *https://docs.fcc.gov/public/attachments/FCC-21-32A1.pdf*.

[26] National Telecommunications and Information Administration, "An Analysis of Aggregate CBRS SAS Data from April 2021 to July 2024," NTIA, November 18, 2024, *https://www.ntia.gov/report/2024/analysis-aggregate-cbrs-sas-data-april-2021-july-2024*.

[27] DoD Chief Information Officer, "Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) Feasibility Assessment Report," (Washington, DC: U.S. DoD, 2023), *https://dodcio.defense.gov/Portals/0/Documents/Library/DoD-EMBRSS-FeasabilityAssessmentRedacted.pdf*.

retains access to the electromagnetic spectrum whenever and wherever needed, enforced by military personnel at China's radio management centers and in its telecommunications industry.

The U.S. government should not unilaterally disarm in militarily important segments of the spectrum. Chinese leaders want to degrade the DoD's ability to conduct electronic warfare and radar operations that could undermine China's Reconnaissance-Intelligence System and protect the U.S. homeland from air and missile attack. Spectrum sharing schemes could allow the U.S. government to protect its military operations and support commercial uses, but companies and U.S. policymakers should ensure they account for the associated costs and complexity.

Chairman CRUZ. Thank you to all the witnesses for your helpful testimony. We will now move to questions.

Dr. Hazlett, I want to start with you. What are the specific economic benefits that putting more spectrum into the commercial marketplace would produce, and how would my spectrum pipeline legislation, which requires some full-power spectrum to be made available to the commercial sector, benefit everyday Americans and American businesses?

Dr. HAZLETT. Additional spectrum, particularly of the flexible use variety, has been found extremely important to increasing American productivity. It allows more things to be done with wireless, wireless applications, and wireless networks. And, in fact, the reverse I also true. When we have had these delays that have come into the system, we have actually taken the vital inputs out of the sector, and the progress has been stymied.

So, in fact, getting more spectrum into the marketplace, allowing entrepreneurs and competitors to get access to expand, that explains not only the wireless revolution that we have seen, with so much changing in terms of new innovations, but it explains why, going forward, we have to keep our eye on the ball and make sure that there is a pipeline, there is spectrum pouring into the market, to be used in efficient ways, not in the old locked-in, rigid definitions of old.

Chairman CRUZ. Thank you. Mr. Pearl, would you agree that making more spectrum available to the private sector would result in billions in new investments and thousands of new jobs?

Mr. PEARL. Yes, absolutely.

Chairman CRUZ. And history demonstrates that.

Mr. PEARL. Yes, no, consistently. You make the spectrum available, and particularly as I mentioned with the example of the app economy, being first really matters in that because then you have innovators that take advantage of the capabilities that they can use in that spectrum.

Chairman CRUZ. And does my pipeline bill preclude the Department of Defense from accessing the spectrum it needs to accomplish critical missions, or are there ways full-power commercial license use can accommodate the needs of DoD?

Mr. PEARL. So your bill allows for both the possibility of exclusive use as well as shared use. And so in terms of DoD being able to continue to use some or most of the bands in order to maintain their capabilities, it absolutely creates that opening.

Chairman CRUZ. Now, Mr. Pearl, we have also heard concerns that reinstating auction authority could hinder President Trump's initiative to create an American Iron Dome. I am a strong and pas-

sionate supporter of missile defense, and have been advocating for an American Iron Dome for some time.

Based on your experience at both the National Security Council and in the FCC auction room, do you believe those concerns are well founded that having an auction would prevent missile defense here at home?

Mr. PEARL. No, absolutely not. As long as we have the proper interagency process and we make sure that the engineers work together, we can absolutely ensure we have Iron Dome as well as increased commercial use.

Chairman CRUZ. And could an Iron Dome system coexist with commercial 5G use, subject to geographical or location carveouts, like in the AMBIT process?

Mr. PEARL. Potentially it could. We do have some cases of countries that are using Iron Dome, like the Czech Republic, that are using 5G quite close to those systems of Iron Dome, and so that is one possibility. And there are some other ways that you can design Iron Dome so that you could have potential coexistence.

Chairman CRUZ. So we are told by some in the Defense Department that if any of the vast spectrum that they currently have use of goes to the private sector that it will cripple the military's ability to defend our Nation. The facts make that claim highly dubious. Right now, today, about 50 nations across the globe operate commercial licensed 5G networks in the 3.3 to 3.45 GHz bands.

Take an example close to home. Mexico's 5G networks operate on frequencies between 3.35 and 3.45 GHz, at full power, less than 30 miles away from Fort Bliss in Texas, where the U.S. operates ground-based radar systems in the lower third band. Likewise, Japan, South Korea, Taiwan, and the Philippines also have 5G networks that operate between the 3.3 and the 3.45 GHz band.

Now, given the fact that in much of the rest of the world there are commercial players operating in those bands, is it credible that our military cannot operate in the Pacific, and we cannot operate if the commercial sector is operating in those bands?

Mr. PEARL. As long as the process is done responsibly, absolutely not, it will not cripple the military.

Chairman CRUZ. Let me ask you, finally, what would the consequences to national security be if China wins the race for 5G and 6G, and if the global telecommunication network is Huawei and Chinese-based, is that good or bad for national security, and if bad, how bad?

Mr. PEARL. It is catastrophic for national security as well as both DoD and the intelligence community, because we will not have access to advanced, trusted, secure technology. It is true that the U.S. will still ban Huawei, but the rest of the world will use Huawei. It will become more advanced. And it is not only telecommunications networks, which are obviously very important. But the plan the PRC has with Huawei is to leverage its control over telecom up the technology sack, so to be able to control other technologies.

So I would say it is an absolutely catastrophic risk.

Chairman CRUZ. And soldiers use cellphones.

Mr. PEARL. Yes, absolutely, and that is something that we have discovered in Ukraine is that a lot of these mobile technologies can

be incredibly valuable. They have been used to triangulate drone attacks. They have been used to create accurate geographic maps of the combat zones. So we are already seeing how these cellphones and mobile technology is critical.

Chairman CRUZ. Ranking Member Cantwell.

Senator CANTWELL. Thank you, Mr. Chairman., and again, thanks for this hearing. I actually so appreciate the panel of witnesses. Dr. Hazlett, I think lots of members of this committee could give a critique of the FCC and it would probably mirror yours, in the issues of challenges of that agency in addressing our most urgent needs, and probably the fact of good broadband mapping lacking. And even when Microsoft produced one by ZIP code they still did not use it. So there is a long line of concern here about the current FCC structure.

Dr. Baylis, I love that you are training the next generation of young people to understand this dynamic, because we will need it. And there is a reason that the Information Age is just sucking up everybody out of college, now that you can produce, so keep producing them.

Mr. Pearl, thank you for this crystallization of, I think, your exact words are, quote, "ensuring that we preserve critical military spectrum base capabilities while creating opportunities for commercial access to spectrum."

So that is it. That is what we are trying to do. That is what we tried to do in the bill that DoD and NTIA and the Department of Commerce agreed to.

So the challenge becomes—and thank you, Mr. Clark, for your football analogy, of the away game, because I do think that really does give you a picture of what warfighters face.

But the one thing I struggle with is that, if you could, I feel like people misunderstand where we are. I am not saying we are playing a Peewee League, but let's say we are playing at the K–12 league right now. But the shift in the dynamics and capabilities of the warfare that is going to take place, based on spectrum, you are not going to be in K–12 football. You are going to be in a Super Bowl. And how do we get people here to understand, as you said, you cannot unilaterally disarm if the ascending technical capabilities and challenges.

And I wonder if you could address white space. A lot of people talk about, oh, well, we could just have dynamic spectrum sharing, and you could easily. But there are lots of ways that right now that is really detrimental to our effort.

Mr. CLARK. Right, yes, Senator Cantwell. So a couple of things on that. One is that the military is going to have to be much more dynamic in its use of the spectrum. So we are going to have to maneuver a lot more in the spectrum to avoid where our adversaries are looking for us, or to get to where our adversaries are so we can jam them. Using some of the technologies that Dr. Baylis is developing, we will eventually be able to both do those operations as well as maintain some ability to have commercial users operate on that same spectrum. But we are not there yet. Those technologies are not fielded yet.

The reason being that our opponents, like we see in Ukraine, it is a constant cat-and-mouse game in the electromagnetic spectrum.

So you operate in one part of the spectrum, you quickly get detected and jammed, and you have to maneuver to another part in order to be able to continue to communicate with your allies, be able to continue sending targets, and attacking your enemy.

So this cat-and-mouse game in the spectrum requires you to be maneuvering back and forth, and you cannot be isolated to a very narrow band of spectrum during operations, and we have to train to be able to conduct those same types of operations.

Senator CANTWELL. But we are going to grow in complexity here, right?

Mr. CLARK. Right.

Senator CANTWELL. We are just at a very elementary level——

Mr. CLARK. Right.

Senator CANTWELL.—and now it is going to grow in complexity. So I do not think, Mr. Pearl, you are not suggesting that we mandate auctions before we do all those technical feasibility studies, are you?

Mr. PEARL. No. I mean, I think we need to mandate clearing targets and then do the analysis. But certainly before you hold the auction you need to do the work of making sure that we are not going to interfere with essential military capabilities.

Senator CANTWELL. Which is what I think DoD was requesting of us and why they supported the legislation.

But Mr. Clark, back to this work, hard work, like AMBIT and CBRS, how do we go forward here with those ideas? Because in the one case it is Navy spectrum, right, and we hear a lot of great things about this. But there are paths forward, but do we have to test bed? What is it that we have to do to get this right, and how do we do, as Mr. Pearl is suggesting, this more collaborative effort on the innovation that the private sector can drive?

Mr. CLARK. Well, there is a lot of new modeling simulation tools, and obviously test bedding these capabilities is going to be really important. So there is a path forward to be able to identify the opportunities for spectrum sharing. But physics comes into it also, because certain parts of the spectrum just are not going to lend themselves to things like missile defense or to electronic warfare—I have to jam an opponent where his system operates. So we will be limited by physics and being able to just maneuver anywhere in the spectrum to avoid the commercial users.

But within those spaces where we can use the spectrum effectively in the military, we need to figure out if there is a way we can coexist or share.

Senator CANTWELL. Yes, and the Chinese just falsely kick them out, right. They just control everything. I mean, I guess you could have that hierarchy. We do not want that hierarchy.

Mr. CLARK. China's approach to spectrum management is they have PLA personnel embedded inside the radio management centers, and in industry who then maneuver the commercial users out of the spectrum whenever the military wants to conduct routine training operations, development, testing, et cetera.

Senator CANTWELL. Yes. Well, that is our competitor, and that is why we have to beat them. So we have to figure out how to take care of this defense issue.

Thank you, Mr. Chairman.

Chairman CRUZ. Thank you. Senator Wicker.

STATEMENT OF HON. ROGER WICKER,
U.S. SENATOR FROM MISSISSIPPI

Senator WICKER. Thank you. Mr. Pearl, before we auction we have still got to do the work. Could you briefly explain what that means, and how long will that take?

Mr. PEARL. Yes. I think it is important to have clearing targets in the legislation of how much we are intending to make available. I think that really focuses the process. But doing the work occurs at several different levels. The most important level is the engineers from the different agencies. The laws of physics are not political or partisan. The laws of physics are what they are, and you need engineers who are going to share information and work together. And I have seen just the most brilliant solutions come out of that, in some of these bands that we have talked about.

Senator WICKER. Including engineers from DoD?

Mr. PEARL. Yes, absolutely, including engineers from DoD. But you need the White House leadership to work with the heads of the departments and agencies so that the engineers know to share information, to be cooperative, to work together. Because what you do not want is a situation where—and there have been examples—where there is not that collaboration, and as a result oftentimes decisions get made by the FCC or others that are less than optimal.

Senator WICKER. OK. You do not speak for CSIS. You are giving us your own views. Are there persons, learned persons, within CSIS who take the same position as the admirals and generals from the Defense Department, that just absolutely no way this can be shared? Do you have colleagues that believe that?

Mr. PEARL. So I think Clayton Swope, who does a lot of our work on the defense side would certainly advocate for some of the defense equities, although I would not necessarily say that he takes their side on everything.

Senator WICKER. So you are saying—and we could perhaps get him here, or I could call him—but perhaps he would even say there is some scenario in which some of the spectrum could be shared and not

Mr. PEARL. Yes. I think that there is a willingness on the part, through CSIS, to find those practical solutions so that we can accomplish that.

Senator WICKER. Mr. Baylis, do you speak for SMART Hub or for yourself today?

Dr. BAYLIS. That is a good question. I believe I have really tried to consult my team.

Senator WICKER. Is there a minority view there that does not agree with you?

Dr. BAYLIS. I do not believe so. I believe we are unified in the sense that we are trying to develop adaptive and reconfigurable technology to solve the very spectrum crisis we are convening.

Senator WICKER. Would it be helpful if you had somebody inside the team who was the devil's advocate and could bounce these absolute objections against your people?

Dr. BAYLIS. Devil's advocate as to what?

Senator WICKER. I will tell you. When we get the military in the SCIF, I am not giving away any secrets, they say it is just absolutely impossible, we cannot give an inch, and anything that the Chairman might advocate would be detrimental to national security. Am I pretty much correct that that is their testimony?

Dr. BAYLIS. I believe we have objective people on our team that would give me, and do give me, you know, contrasting views when they need to be given. I think we have got a team that is working to try to get the best technological solution to the problem, and I think that is our sole goal.

Senator WICKER. Mr. Clark, tell us about the idea of finding a solution by compression, and compare and contrast that to relocating.

Mr. CLARK. Yes. Great point, Senator. Compression of spectral efficiency is looking at ways to use digital technology to narrow the beam width or bandwidth that a sensor needs for, for example, a radar, to be able to put enough energy downrange to be able to detect a target and track it. So using new digital technologies we are able to reduce the amount of spectrum that a sensor might need to be effective.

Senator WICKER. And there is a history to this.

Mr. CLARK. Yes. Over time the DoD has done this with different sensor technologies. As we replace and recapitalize the new generation of radars that is coming into DoD right now, they are more spectrally efficient.

Senator WICKER. Supplement your answer on that. Can you briefly talk about Mr. Baylis' reference to live interference notices?

Mr. CLARK. Yes. So the idea would be can you, in real time, be able to get a notification. Normally what happens when you try to deconflict spectrum is you just detect the other user out there, and then you have to respond to that. You would want to augment that with a notification that comes from that other user to automatically tell you, I am going to use the spectrum now, and here is the level and power and the frequency I am going to be at. And then the systems can coordinate between themselves. So instead of simply responding to what they see in the environment, they are communicating with each other to coordinate their use of the spectrum in real time.

Senator WICKER. Do you subscribe to his point of view in that regard?

Mr. CLARK. I think, definitely, that technology is certainly viable. The challenge will be getting to implement it into the defense systems that are multiple generations, and in some cases, old.

Senator WICKER. Just quickly, if Dr. Hazlett and Mr. Pearl could respond and perhaps supplement on the record as to that question.

Dr. HAZLETT. Sure. This is an ongoing problem of a general order, and it is having an unpriced asset, and at a zero price, if opportunity costs are not considered, of course there is going to be over-consumption and no give. But the fact is there are social costs. There are economic costs. There are also technology costs in terms of taking the tradeoffs for compression, better radios, better training, better software.

There are other alternatives here that everybody in the room should have the incentives to pursue, and that is where there has

been some progress and there have been real good allocations made that really do bring efficiency. But to say that we are not going to look at efficiency, yet we need more and more and more, you are undermining the quest for efficiency. That is undermining both civilian and military applications.

Senator WICKER. Mr. Chairman, I realize I am way over time.

Chairman CRUZ. Thank you. Senator Fischer.

STATEMENT OF HON. DEB FISCHER,
U.S. SENATOR FROM NEBRASKA

Senator FISCHER. Thank you, Mr. Chairman, and thank the panel for being here today.

We know the context of this hearing about whether and how to use spectrum in a reconciliation bill. One key focus I am hearing is on revenues from the new spectrum pipeline that is only for exclusive commercial use. I want to stress for my colleagues that we must also weigh the cost and the timelines to relocate existing users for this type of pipeline.

The Department of Defense is one of the users, with missile defense radars and satellite constellations providing critical capabilities. DoD losing access to its spectrum bands entirely, which is what vacating or clearing spectrum means, comes with huge risks and will end up costing us more. Replacing national security systems, if that is even possible, would cost hundreds of billions of dollars, and we all know it would take decades to be able to finish.

So a pipeline estimated to raise, by CBO, based on current proposals, between $10 and $15 billion in a 10-year budget window may actually take 20 years to transition. I agree there are technologies that could make sharing spectrum possible. But DoD must have a seat at the table when its spectrum bands are studied and tested. Otherwise, we lose them, we risk losing access to this finite resource forever.

Mr. Clark, what specific military capabilities could we use if lawmakers on this committee do not fully consider these realities before pressing ahead?

Mr. CLARK. Well, Senator, I think the key capability would be sensing technologies needing for air and missile defense. So in the lower S-band, lower X-band——

Senator FISCHER. Could you explain what S and X-band are?

Mr. CLARK. Right. So the lower part of the 3 GHz range in the S-band is really important for air and missile defense, because it gives you that combination of resolution and range that allows a radar to be pretty effective at tracking incoming targets. And then we need radars that operate up in the X-band, which is the 8 to 12 GHz range, but the lower part of that generally, to be able to differentiate small targets and be able to target them and be able to direct an interceptor like a Patriot missile to go hit them and shoot them down.

Senator FISCHER. So we have to see them and identify them.

Mr. CLARK. Right. So you need to both see them and then target them and track them, and that requires essentially two different sensor technologies to be either combined in the same radar or be in different radars. That is how the Patriot system works. That is how the AEGIS system works that the Navy has.

So if we were to relocate out of those parts of the spectrum, you lose the physics that allows those sensors to work effectively, and we would have to either have more sensors or come up with a different approach.

Senator FISCHER. Right.

Mr. CLARK. So that is why sharing might be an effective alternative. But relocating them entirely may not be feasible because of the physics.

Senator FISCHER. You know, Mr. Clark, I have concerns about the role that China has played in influencing our spectrum policy in this country. We are being told that we have to keep up with China, that they have far more mid-band spectrum available, that their carriers can use the lower 3 for mobile networks, and that there have been no negative impacts to China's national security.

Well, you know, in reality, China only has 10 more MHz of mid-band spectrum available for mobile networks. China also recently imposed restrictions in its lower 3 band, limiting commercial access to that low power which is indoor use. And yet we still hear that China comparison from carrier and their effort to gain exclusive use of these bands, which are needed for our radar systems.

If the U.S. blinds its radars purely for economic reasons that only helps foreign adversaries like China. Do you share my concerns?

Mr. CLARK. I do. I think China could be playing a very sophisticated game here, where they are looking to get us to vacate parts of the spectrum that we need for our military sensors while they retain that access. So we unilaterally disarm while they are able to retain their capabilities, because as I said before, they have the ability to move commercial users out of the spectrum basically whenever they need to for their routine government purposes.

Senator FISCHER. Thank you. Mr. Chairman, I would like to submit some questions for the record to Mr. Clark about spectrum management and how that also impacts what we are talking about today. Thank you.

Chairman CRUZ. Thank you. Senator Klobuchar.

STATEMENT OF HON. AMY KLOBUCHAR,
U.S. SENATOR FROM MINNESOTA

Senator KLOBUCHAR. Thank you. Thank you, Chairman, thank you to Ranking Member Cantwell, for this important hearing. I know this has been a good discussion about spectrum. I had a Judiciary hearing at the same time. But this is specifically important to our 911 system. I co-chair the Next Gen 911 Caucus with Senator Budd, and we are dedicated to expanding and improving emergency communications infrastructure.

Yet the FTC spectrum authority expired in March 2023, as we all know, for the first time in nearly 30 years, and I am concerned about this lapse in spectrum authority with the increasing needs for emergency authority.

An estimated 240 million calls are made to 911 centers annually. However, this critical public service relies on outdated technologies. I have led legislation with Senator Cortez Masto to modernize America's 911 system, to help enable 911 call centers to better handle text messages, pictures, videos, and modern communications.

Dr. Baylis, can you give an example of an innovation at your lab that could help make our 911 system stronger and more resilient?

Dr. BAYLIS. So I think this depends on what types of interference the 911 systems are receiving. But an innovation that we are finding our lab that could really be helpful—well, there are two of them. One is we have got reconfigurable circuitry that can reconfigure within under a millisecond, and that would allow us to actually frequencies and then optimize our performance at a new frequency.

What happens is your circuit is designed to operate at the old frequency, so if you change frequencies you may drain your batter because you do not have any efficiency, you may not get the transit power you need. So that is an example of one thing we are doing, is reconfigurable circuitry.

And then I think that the Dynamic Spectrum Management System innovations we are working on, as well as our in-situ measurement capability, which would allow us to actually see when we are causing interference and change our transmissions, and be able to plug AI in through that. Those would help 911 systems as well as any system that is trying to reconfigure. Thank you.

Senator KLOBUCHAR. You know, just recently, in the aftermath of Hurricane Helene, many affected areas experienced local communications blackouts because the flooding was severe enough to override the Internet providers' disaster contingency plans. How could we leverage innovation in spectrum management to ensure that our wireless broadband networks are more resilient when things happen like natural disasters?

Dr. BAYLIS. I am not aware of this particular. I did not research this. I would have to go in and see exactly what the problem was in terms of the technical lapse and then try to be able to bring a team to solve it. If it was an interference issue or frequencies not being available, then I think our team has the solutions we could deal with it.

Senator KLOBUCHAR. Mm-hmm, and getting the spectrum thing set would be helpful, if we had more——

Dr. BAYLIS. I think in the sense that technology is behind regulation right now, technology needs to be developed, and I think that is where our lapse is, really. I really believe that investment needs to be made in technology rather than just re-regulating and re-regulating, because we are slicing the bread thinner and thinner and thinner until it crumbles.

Senator KLOBUCHAR. Thank you. Mr. Pearl and Mr. Clark, during President Trump's first administration there were interagency disputes regarding spectrum. We have seen these interagency disputes through Democratic administrations, as well. Recognizing the importance of providing more order, the National Spectrum Strategy was released in November 2023, and its implementation plan in March 2024.

Mr. Pearl, can you discuss why it is important to continue to improve planning and coordination, and then, Mr. Clark, how can this administration cultivate more agency buy-in to avoid the sorts of disputes that have arisen, especially when it comes to the Department of Defense. Mr. Pearl?

Mr. PEARL. You cannot work out these issues on an engineering level unless you have the proper interagency coordination, and that has to come from the White House really demanding that the agencies work together and participate in a robust way, and have the right engineers who are there to work out the problems, and really mandate that they share information. That is something that we have run into in the past, where an agency that wants to continue to use the spectrum is not willing to play ball and share information so they can work together collaboratively.

And then you need a really healthy interagency process where it starts at the lower levels and eventually escalates if you cannot solve problems. That is incredibly helpful because if you just have the White House weigh in without having all the information and having that refined set of issues that comes from the interagency process, then in some cases the right decisions do not get made.

Senator KLOBUCHAR. Mm-hmm. Yes, we are experiencing a little bit of that right now, but I am not going to go there. OK, Mr. Clark.

Mr. CLARK. It requires leadership, both in the White House but also in the department. My discussion with the leadership of the current team in the Defense Department showed that they are very willing to engage in this interagency deliberation to figure out the best way to use the spectrum. And there are a lot of modeling and simulation tools that Dr. Baylis and others have that could help us to figure out what are the opportunities for sharing, and even coexistence, in adjacent spectra.

Senator KLOBUCHAR. OK. Thank you. Thank you, Chairman.

Chairman CRUZ. Thank you. Senator Blackburn.

STATEMENT OF HON. MARSHA BLACKBURN,
U.S. SENATOR FROM TENNESSEE

Senator BLACKBURN. Thank you, Mr. Chairman, and thank you for this hearing. I think it is one of the things we need to be focused on is what is our leadership going to be as a nation in this area.

So one of my concerns, and I have talked about this with the Chairman, is what I see as spectrum squatting, with our Federal agencies. They control most of the spectrum assets, and they are failing to optimize this. And I have, for years, advocated that we do a good inventory, so we know who is using what spectrum, where, and then be able to recoup it. Because it does not matter what project is being worked on, whether it is wireless, whether it is the MUOS system, whether it is LEO—everybody in the DoD is working with the private sector, because they are leading the innovation. And for Federal agencies, Mr. Chairman, to squat on this spectrum, and to not use it, and to not want to yield it back, and not want anybody to know what they have got, it disadvantages us as a nation.

And we know that recouping it, going through the auction process, would yield billions and billions of dollars, as much as $100 billion, and we need that because we are in a race with China when it comes to leading in this area. And we do not have time to waste, and we do not have time for squatters to bicker with what they are going to do with this spectrum.

Mr. Pearl, let me come to you. This last World Radio Conference was a hot mess for the U.S. We were unprepared. We had not done our homework. And if we are going to continue to be a world leader, we are going to have to be prepared. You mentioned this is in your testimony, and I appreciated that you did, because I think it was embarrassing that we were unprepared for the leadership road.

So I want to hear from you, and if you want to submit this in writing I would appreciate that, but the lessons we should have learned from this last one and the steps that we should be taking to prepare for the 2027 WRC.

Mr. PEARL. Yes. So I think one of the lessons we learned is, so the next WRC is WRC 2027, and that is tomorrow in real terms, which is the preparatory process in incredibly quick in arriving at positions. It is going to give you a huge advantage vis-ă-vis China.

So I think that it is just important to have Congress, when it reauthorizes FCC auction authority, as well as the White House to make sure that these issues are resolved early and that you do not have the U.S. coming in late with positions.

I also think that it is important as we are——

Senator BLACKBURN. And I think that we know what those positions are, rather than squishing through the whole thing. That would be helpful.

Mr. PEARL. Yep.

Senator BLACKBURN. OK. Homework for each of you. You know, there are disputes, center agency disputes, about how to use spectrum. So each of you have touched on this, but in writing I want from you what your recommendation would be to resolve these disputes. We have to recoup the spectrum. We have got to look at how we slice these bands and put more—Mr. Clark, as you were saying—into that bandwidth. So help us with your best thoughts on that.

Mr. Pearl, I want to come back to you on AI, because when we talk about AI and quantum and the utilizations that are there, we know more spectrum is needed. And in Tennessee, we have—I repeatedly hear from innovators, whether they are working logistics, they are working on something for DOE or DoD, or health care, they talk a good bit about this.

But with AI, I think it is important to get on the record how spectrum constraints would actually hamper AI development and deployment.

Mr. PEARL. Yes, I am absolutely happy to submit that on the record. I think one of the important points is it would hamper things not only on the commercial side but also on the DoD side of things, where there are really interesting AI applications for first responders in terrorist attacks and things like that, and leveraging it to make the right decisions. And that is something that is directly applicable to what DoD does in the battlefield.

Another example is, you know, we have talked about spectrum, but to really advance what we need AI to do is to be able to take all the sources of information—spectrum, OPC, cyberspace, thermal imaging—just all of these things and generate real actionable insights. And we cannot do that unless we have those commercial technologies and we are winning the AI race with China.

Senator BLACKBURN. And I will add to that the satellite systems. Thank you, Mr. Chairman. I yield back.

Chairman CRUZ. Thank you. Senator Rosen.

STATEMENT OF HON. JACKY ROSEN,
U.S. SENATOR FROM NEVADA

Senator ROSEN. Thank you, Chair Cruz, Ranking Member Cantwell. Thank you to the witnesses for all of your work, your education, what you bring to the table here because our Nation's spectrum we know is one of our Nation's most important resources. So spectrum policy must be thoughtful, it has to be deliberative, and unlocking innovation while protecting our national security.

I share some of my colleagues' concerns that this Administration and some of the majority want to sidestep having a deliberative, fact-based process, and instead advance spectrum proposals merely to raise as much revenue as possible to fund massive tax breaks for billionaires.

So we must instead take our time to find the right policy that ensures that revenues from spectrum sales actually lower costs for the American people. Last Congress, this committee advanced legislation to use spectrum proceeds to lower my state of Nevada, Nevada's Internet bills, to help our first responders that is so important, and invest in the R&D that we need to share spectrum safely with the Department of Defense. That is a foundation we can and should build upon.

And we know there are key challenges between the DoD, commercial operations. One thing that is particularly concerning, that I have been thinking a lot about, is dynamic spectrum sharing and where we are at with that. Mr. Clark, then Mr. Baylis, where are we really at, in reality, with our capabilities on dynamic spectrum sharing, and how can we deploy, when we get there, dynamic spectrum sharing, to ensure that efforts to expand access do not undermine military access? We still want to unlock possibilities, but is it still a concept? Are we testing it? Where are we at in the dynamic spectrum sharing role, please?

Mr. CLARK. Yes, Senator. Dynamic spectrum sharing is a relatively mature technology at this point. It is being used in applications like the Citizens Band Radio Service, where along the coast we have dynamic spectrum sharing between Navy radars that use the spectrum and then also 5G providers that operate in that same spectrum.

There are obviously new technologies that are being employed, that Dr. Baylis has done a lot of work in, to make it even more sophisticated in terms of how that spectrum sharing happens——

Senator ROSEN. And more nimble.

Mr. CLARK.—and how seamless it can be, right, and how you can start to do that in much narrower parts of spectrum because it gives the ability for both users to jump around into different parts of the spectrum much more agilely than they could today.

The challenge is always the implementation, because now we have got to take those new technologies and got to bake them in, in the case of the military, military systems that span multiple generations of technologies. So we have analog radars still in serv-

ice, and analog communication systems that do not lend themselves. They are on the digital back end.

Senator ROSEN. So we would need a bridge to get there. We would need a bridge to get there.

Mr. CLARK. Right. We are going through this recapitalization of the U.S. military's spectrum-dependent systems that will, over time, make them better able to take advantage of these technologies. And the question is how quickly can we accelerate that in order to make dynamic spectrum sharing more of a reality.

Senator ROSEN. Thank you.

Dr. BAYLIS. So thanks for the question. Incumbent DoD systems need technology development, and I think I want to focus on that for a minute because in the research question a lot of times we are very focused on helping the commercial wireless systems be more adaptive. SMART Hub has really taken what I think is a very unique focus, and looking at the incumbent systems, actually how do we improve the DoD systems? Given where the DoD systems are today, we want to see those move to an adaptive and reconfigurable model. So we are working on flexible circuitry. We are working on flexible communication strategies. We are trying to figure out how can we put AI into actually predicting the spectrum, so these incumbent systems we can hopefully, and with our industry partnerships, we have got a quick pathway to put technology into the hands of the DoD to facilitate the types of economic growth that our Nation needs from the spectral bands.

So hopefully the technology development is a game-charger, where we can have our cake and eat it too.

Senator ROSEN. Well, to your point then, what are the risks associated with mandating the movement of certain bands, or the alterations of certain bands, prior to having first done these studies about what we can and cannot do, and how we need maybe a measured approach to get some of these legacy systems where they can be nimble and more adaptive?

Dr. BAYLIS. Technology development is, I think, the big elephant in the room, and we need to address it, because if we do not we can do a lot of things to posture but we are not going to make improvements because we are just slicing the bread thinner and thinner. By having adaptive and reconfigurable technology, what Congress needs to do is to fund work going forward with entities like SMART Hub, because we are going to bring it to the DoD quickly, and that will be a game-changer. We will not have to have these discussions anymore because the technology will supersede, way supersede what we have today that is available. And it can be done in a reasonably short period of time.

Senator ROSEN. So investing in smart, more things that you are doing in SMART Hub. Thank you very much.

Dr. BAYLIS. Thank you.

Senator ROSEN. I appreciate it.

Chairman CRUZ. Thank you. Senator Budd.

STATEMENT OF HON. TED BUDD,
U.S. SENATOR FROM NORTH CAROLINA

Senator BUDD. Thank you, Chairman, and again I thank the panel for being here. This is a fascinating testimony.

I think we are all trying to find the "both/and" here. I mean, how do we find the revenues from the spectrum auction that is much needed, and how do we secure and protect national defense.

Dr. Baylis, I want to follow up. Thanks for your work at SMART Hub. I did not hear, between Mr. Clark's answer then your answer, what is the timeline for dynamic spectrum sharing? If you saw great promise, how far out before an actual practical implementation of that, in your best estimation?

Dr. BAYLIS. Yes. I would say as fast as possible. We are in a national——

Senator BUDD. Do you have years——

Dr. BAYLIS. We are in a national crisis right now in terms of spectrum. We really are. And so when you have an emergency you try to fix the problem as quickly as possible, and that is what we are doing. We really are trying to work as quickly as possible.

I will say that having a center like this, where we have convened the Nation's top 25 spectrum researchers, in my opinion, to solve a problem, you have got everybody reading off the same sheet of music, working together. You have got policy and economics experts alongside circuit experts. That is really going to speed it up. I say that is going to give you a three-time speed-up rather than a program director funding one-off projects somewhere.

So I will say we can really accelerate it. May be able to put a time scale, I would say as quickly as possible. I really do not want to give you an exact number, just because I do not know exactly what that number is. But I can tell you at our 6-month demo we showed tremendous progress.

Senator BUDD. Mr. Clark, do you have a number?

Mr. CLARK. I can give you a number. To get these technologies incorporated into the military systems that need them it would take 10 to 20 years, because you are going to take these ships offline, these aircraft offline, these radars offline, to go upgrade them. And we cannot have them all do it at once, obviously. So it takes time to run them all through the process of being upgraded.

Senator BUDD. Thank you. Mr. Baylis, you mentioned that Congress needs to fund some more research on this. Do you have a dollar amount on that? Is there something that you are particularly asking for to do more research in dynamic spectrum sharing?

Dr. BAYLIS. Well, thanks for asking. SMART Hub is annually funded by an appropriation right now. We have gotten one so far, and we are in this bill coming from the House side, with Mr. Sessions, and we are asking for $5 million for this year. We have been working off of a $5 million budget.

Senator BUDD. Should industry also bear some of the burden of this?

Dr. BAYLIS. So our technology transfer model actually is going to line up investors very early on in the process. And also industry, we are building industry partnerships quickly, so that essentially investors will start pouring their funds in when they see the technology. And we are already building DoD contractor pipelines that will not only put the technology in the hands of warfighter, but through this pipeline we will fund more research.

So we have got an ecosystem that just needs a runway to get the plane taking off.

Senator BUDD. Thank you.

Dr. BAYLIS. And we are not going to be, hopefully, coming to you infinitely for money. That is not my goal. The reason for me not stating a year is not for me to say, hey, we have got to continue this infinitely, with support. I think I just want to be cautious about promising anything and not delivering on it.

Senator BUDD. You did not give us a year but you did give me a dollar, so thank you very much.

Mr. Pearl, a question for you. I appreciate your statement that spectrum is critical to economic security, and I am quoting you, because it provides a foundation for U.S. companies to innovate. So what is your assessment of when innovation might be stifled, giving the increasing data traffic?

Mr. PEARL. So I think that it has not happened yet because we had some recent auctions in the last administration. But I would say probably in the next 2 years we would see some real impacts. Although I would say Congress has to act much sooner than that, because it takes time, once auction authority is restored, to have the auctions. But in terms of when you will really have an impact on our networks to handle the loads, I think it could be in the next year or two.

Senator BUDD. So would upgrades to existing 5G, would that buy us some time?

Mr. PEARL. It could but, you know, there are some fiscal constraints on that, which is that the companies spent $190 billion so far upgrading their networks for 5G, and that has been great. That got us through COVID. We have all these wonderful, fixed networks. So just their ability to do that might be constrained, and it could be that spectrum is the only solution at this particular time.

Senator BUDD. Thank you. And Mr. Pearl, continuing, in your experience in Federal spectrum management, how important is White House leadership on this, and do we need more and more clear leadership from the White House than we had in the previous administration on this issue?

Dr. BAYLIS. So White House leadership is absolutely critical, although I would say that in my view it does start with Congress in terms of establishing some clearing targets and some guidance. That really strengthens the hand of the White House, and working with the agencies. But yes, without having, from the President on down, and having the willingness from people like the National Security Advisor, Director of National Economic Council to actually spend time on these issues and prioritize them with everything else that is going on. Because that is ultimately how you get things done and ensure that everyone in the interagency has their marching orders of how to make progress.

Senator BUDD. Thank you, Chairman.

Chairman CRUZ. Thank you. Dr. Baylis, you told Senator Budd a second ago, you said that we are facing a national crisis in spectrum. Could you articulate explicitly what you mean by that, what national crisis we are facing?

Dr. BAYLIS. We have applications that need to have spectrum, spectrum real estate, so to speak, and we do not have enough bandwidth for all of them. So the way we are currently doing spectrum, by fixed allocations of spectrum, is just not going to work moving

forward. So we need technology to support the movement of devices in real time between spectral bands, and it is a paradigm shift. We really need a paradigm shift badly, where we have got too much trying to use too little.

Chairman CRUZ. Thank you. Senator Schmitt.

STATEMENT OF HON. ERIC SCHMITT,
U.S. SENATOR FROM MISSOURI

Senator SCHMITT. Thank you, Mr. Chairman. I really do believe that over the last 3 years the U.S. has ceded a lot of leadership in spectrum policy and 5G innovation, both domestically and internationally. That is not good news. Under the first Trump administration, we went from stagnation to global leadership. Congress passed—I was not here but Congress passed the Secure and Trusted Networks Act. But in the time since then, the last 4 years, the Biden administration's failure to act and focus on divisive things like DEI has really set us back.

I am one of the members that serves both on Armed Services, with Senator Budd also, and the Commerce Committee, so there is a bit of a balancing act, I think, that goes with this. And while I think DoD should have a voice in this process, I strongly believe that Congress is has already established the NCIA as the primary authority for spectrum allocation, and it must lead rather than act as a rubber stamp for DoD. I think that is one of the issues. National security has been heard today. It is very multi-faceted, economic security is national security, and China is coming for our lunch, in more than one way.

I wanted to ask just a few questions, and I will try not to ask questions that have already been asked, but it is possible I might. Dr. Baylis, when we talk about spectrum management and enhancing the ability of commercial and defense users to sort of coexist in those shared bands, what role and how far have we come, and how far do we have to go for that to be really effective with AI, as these advancements proceed?

Dr. BAYLIS. So it is interesting. AI can be used in multiple levels in the new spectrum sharing—or I should say the new adaptive and reconfigurable paradigm. One level is to assess, predict the spectrum that is going to be available for our use, and having this technology in the DoD and commercial hands is very useful.

The second is actually inside the devices themselves, to be able to optimize their performance, to make sure a radar transmitter can reconfigure its circuitry after it has to move in frequency to maximize its range so it can detect targets far out.

We can use AI to help us reconfigure the circuits quickly and take measurements on board the device. So a lot of our technology development is actually equipped with this plug-in of AI. In fact, we have one of the world's AI experts, Professor Bob Marks, who has written great books on AI that Congress actually is on the recommended reading list. He is part of SMART Hub and working very actively with us to infuse AI into our decisionmaking for our spectrum adaptive and reconfigurable devices.

Senator SCHMITT. And, of course, that allows you to maximize, right? It allows you to actually maximize the bands of spectrum,

right, as opposed to having maybe overutilization in one place and lack of utilization somewhere else. It is a predictive modeling.

Dr. BAYLIS. It really could. And I think AI has tremendous power, and we need to marshal it for being able to use the spectrum efficiently and to adapt our technologies to where the spectrum is maximally being shared.

Senator SCHMITT. And I will throw this open for any one of the four. One of the things on a topic like this, to try to ask the question. Back home, I actually think this is one of those topics that it just does not come up in a town hall. It does not come up on the stump. But it is of critical importance for our country.

So it is with those kinds of topics then, how do you, if you were in our position, how would you sort of crystallize why this issue is so important for the American people? And I would open it up to any one of you.

Dr. BAYLIS. I will take this quickly. I have to go out and tell people what we are doing, and one of the things that I say is spectrum is the most important dimension of battle. If you can dominate the spectrum, you are going to win the war. So from the DoD side it is unquestionable.

In fact, the Space Force, we are talking with Space Force people now. The Space Force, the only dimension of battle is spectrum. There are no tanks. There are no soldiers on the ground. It is just spectrum, and we are going to have to be dominant in spectrum. So from the DoD side that is really important.

I think from the commercial side, we are more connected than we have ever been through spectrum. We learned that during the pandemic, because we had to use the wireless spectrum to connect with loved ones and other things. So I think our society certainly sees the need for wireless devices.

Senator SCHMITT. Anybody else?

Mr. CLARK. I think the challenge comes into play where we have to afford the military the ability to be agile in the spectrum and be able to maneuver and keep our adversaries off balance, which some of the technology that Dr. Baylis is developing could help us to do. So if we were to field those it would make our military more agile when it comes to sharing spectrum at home and also more agile when it comes to creating problems for our enemies overseas.

So that is really important. It will take time to get to the point where those technologies can be incorporated into our military systems. Until then, we are going to have to have some hybrid approach.

Senator SCHMITT. Thank you, Mr. Chairman.

Chairman CRUZ. Thank you. Senator Hickenlooper.

STATEMENT OF HON. JOHN HICKENLOOPER, U.S. SENATOR FROM COLORADO

Senator HICKENLOOPER. Thank you, Mr. Chair, and thank you all for being here. I appreciate how busy you all are.

I think this is one of the key discussions we are going to have here all year. The Spectrum Relocation Fund, let me start with that, provides funding to Federal agencies to research the feasibility of modifying and, if necessary, upgrading the Federal systems that use spectrum. So SRF, at least as we see it, it seems lim-

ited by only reimbursing a Federal agency for necessary costs to update a system of, quote/unquote, "comparable" capability. So not the next level but comparable capability. Many Federal agencies have stated that the SRF limits their ability to upgrade their systems that use spectrum, just to be able to continue fulfilling their missions.

Mr. Pearl, why don't I start with you. Do you believe SRF could be reformed to better incentivize agencies to share or reallocate spectrum? Why or why not?

Mr. PEARL. Yes, and I would put it stronger and say that SRF must be reformed, I think if we are going to resolve these issues.

Senator HICKENLOOPER. I was trying to say that myself, but I was being generous

Mr. PEARL. But yes, I think you identified one of the key issues, which is that the agencies need to be able to receive upgrades and have more advanced systems. Some of these capabilities we are talking about could be paid for with auction funds.

I think it is also necessary to give NTIA the authority to get funding in order to do studies. Right now, only the agencies can get SRF money to do studies. But as several Senators have said, it is really important, and the NTIA engineers are really looking at this from an honest broker perspective and trying to get to the right answer. So allowing them to do that would be really helpful.

And then I think the last thing is that there is a technical panel under the legislation—NTIA, FCC, OMB—and they have proved what the agency is going to do when they do the study. But they need more oversight of the process after that, because when things to off the rails and the study is not going to be useful, you need that ability for the other agencies and the other engineers to weigh in and get things back on track.

Senator HICKENLOOPER. Absolutely. I could not agree more.

Dr. Baylis, your testimony underscores how collaboration in the academic community and within government and the academic community helps enhance this Spectrum Innovation Center you lead. You see firsthand how our universities educate and create that workforce pipeline that we need to maintain our leadership, in all STEM fields—computer scientists to advanced cybersecurity of the wireless networks, radio frequency engineers—to develop new technologies for sharing spectrum and getting more efficient usage.

As we debate, as Congress debates how to study and share and reallocate spectrum, and try to be as fair and look at the greatest good for the greatest number of people, how do you highlight the importance of ensuring that U.S. grows a trained spectrum and cyber work force?

Dr. BAYLIS. Thank you. I appreciate the question. Workforce development is one of the important things we do, and I think it starts with the fact that our faculty, our staff researchers, our students that are on this project are all U.S. citizens. You will not find that in many academic centers. But we are a bunch of patriots, because we want to see this country succeed, and we want to see this country be the best in wireless technology, so it starts there.

I think we have to develop an American pipeline of students that is going to be able to work on the future spectrum paradigm. We

have been doing a lot of efforts, one of which the National Science Foundation is currently funding, where we actually have undergraduate students from around the country apply to and get the opportunity to come to a 4-day residential workshop on one of our campuses. And we will be holding four of them this summer. Actually one in your state, at Colorado State University, is one of our universities, and we will be holding one there. So you are welcome to come and check it out if you would like.

Senator HICKENLOOPER. I will do that.

Dr. BAYLIS. We are also involved with the Army Research Laboratory, who we are even commissioned through. We have a SMART Hub fellows program, where we actually place students at the lab, working with some of our brightest minds in the laboratory, and working with each other so that they can build cross-disciplinary expertise in spectrum. And we are expanding that to some other agencies now, also.

So definitely that is a big part of bringing in the new adaptive and reconfigurable paradigm. Thank you.

Senator HICKENLOOPER. I appreciate that. I am kind of out of time. Mr. Clark—and I will leave this and you can answer very concisely—this partnership between the Federal Government and the auctions around how spectrum gets divvied up, how do you look when you are evaluating spectrum used for a Federal mission, how important is it for the agencies to have a meaningful and collaborative role in that feasibility study?

Mr. CLARK. It is really important because the physics matter. I think that fundamentally, no matter how much spectrum sharing or division of the spectrum into more efficient bands comes, you still have to deal with the physics of certain bands are going to be useful for certain operations, and you cannot just move to another part of the spectrum. So physics matter, and I think that is fundamentally what it comes down to.

Senator HICKENLOOPER. Thank you so much. I yield back to the chair.

Chairman CRUZ. Thank you. Senator Curtis.

STATEMENT OF HON. JOHN CURTIS,
U.S. SENATOR FROM UTAH

Senator CURTIS. Thank you, Mr. Chairman. Our national security is a top priority. Without it we are a nation at risk of attack from those who would do us harm. I support the Department of Defense. But when it comes to spectrum debate, the DoD and the commercial interests have been at a stalemate for decades. After years of discussion it seems unclear to me why something cannot be worked out. It feels as if there is something I do not know.

I know that DoD is not here today, but I suspect they are listening, and I would challenge them to better articulate just specifically what it is that they are not telling us. Perhaps it needs to be classified, and if so I am game for that briefing. But I think it is fair to say that I do not see it, and I think it is important that as a Member of Congress we better understand just exactly why we cannot come to this consensus.

Mr. Hazlett, the United States won the 4G race, which led to considerable investment and innovation, that resulted the app

economy being developed here in the United States. Looking ahead to the future of 5G and 6G technologies, I share a concern that many have that if the U.S. yields its technology dominance to China, future economies may develop abroad instead of at home.

Can you speak to the importance of the United States being the global leader on 5G and 6G technologies?

Dr. HAZLETT. Well, we simply squander an opportunity to move ahead and to make the economy stronger, have innovation here that, by the way, has benefits way beyond the auction revenues. So in talking about scoring the auction revenues, my economist reaction is you are leaving out the biggest part of this, which is surging the economy, and, in fact, getting tax revenues over time. These are routinely led on the other side.

I would just quickly say one thing. Yes, this debate between civilian and military, it has been going on since——

Senator CURTIS. Let's figure it out.

Dr. HAZLETT.—before 2020.

Senator CURTIS. So I had meant to say this question if I had enough time, but you brought it up so I am just going to hit it right now. The CBO has consistently mis-scored the revenue, and I understand you are talking about additional revenue that comes from that. How is it that we keep getting wrong by such dramatic numbers the value of these?

Dr. HAZLETT. Good question. I do not have an answer to that.

Senator CURTIS. Their score is 51 percent lower than the average sale. All right. We will let you off because I have a whole bunch of other questions.

Mr. Baylis, could you explain the difference between full power, exclusive use spectrum licenses versus potential spectrum sharing models, and how those different policy approaches might impact the rollout of the next generation of wireless technologies?

Dr. BAYLIS. So I think what you mean by exclusive, full power is that is the only device that gets to use the band. I think you mean by dynamic spectrum sharing that there is some level of interplay.

I would say that from my perspective as a director of a center that is developing adaptive and reconfigurable technology, what we need to do, we are here at you service to build the best technology that we can to help our country succeed, and we are happy to inform you where the technologies are. In terms of choosing a side in that game, I prefer not to try to speak out on that, because that is not my lane. I am really trying to develop technologies that will make us the best.

Senator CURTIS. OK. Mr. Pearl, did you want to comment?

Mr. PEARL. Yes. I would just mention that I would separate a bit in terms of full power versus low power, and they both have their benefits and advantages, as we have seen with cellular networks and Wi-Fi, although full power does not necessarily need to be exclusive use. And I am actually not aware of a Federal spectrum transition that is completely exclusive use in the sense that DoD completely cleared out.

So I do think you can look at it both ways, where you are looking at full power but not necessarily exclusive use, and vice versa with low power. So I just would mention that.

Senator CURTIS. OK, good. That is helpful. While we are on you let me ask you a question that was mentioned. DoD is not here, so we will pick on you. The demand, as we all know, for mid-range spectrum is high, and it is not going away. DoD says they cannot afford to give up a single part of their spectrum without negative national security consequences.

Is DoD truly using all of its spectrum with maximizing efficiency, and what other considerations are leading DoD to this conclusion?

Mr. PEARL. No, I do not believe they are, and, you know, if you get into the details with them, in many cases, I think that they would concede that. And I think that it is necessary to work with all the right constituencies in DoD.

One thing I would mention is that you are hearing one thing at the briefings, but there are people in DoD that have a more innovative mindset and see some of the advantages here. And I think figuring out how to empower some of those people and bring them to the table is really helpful, because that is how we can solve some of these problems.

Senator CURTIS. Good. I am out of time. I would like to just close with, I am a DoD supporter, right. I want them to have what they need. But I also think we can work this out.

Thank you all for your time. Thanks, Mr. Chairman. I yield.

Chairman CRUZ. Thank you. Senator Kim.

STATEMENT OF HON. ANDY KIM,
U.S. SENATOR FROM NEW JERSEY

Senator KIM. Yes, thank you, Chairman. Actually, I just want to pick up where we were there. Dr. Pearl, I mean, we are trying to get all this sense of the tradeoffs that are out there and what we are hearing from DoD and elsewhere. And I guess I would just ask you, do you think that this committee would benefit from having a classified briefing conversation with DoD and try to dig into some of those other people that you are talking about that could try to bring to light some of what this is? I am just kind of curious your thoughts on that.

Mr. PEARL. I do, and I think that it would be helpful to work with the right people and bring in some engineers to that process. Because what it really comes down to is not just the high-level briefing. It is getting into here is a critical system, and here is the actual impact it would have on performance if it used less spectrum, and getting very precise about that. And then talking about some of the technologies that might be able to avoid that outcome and preserve the DoD capability. But really focusing on some of those, like, a small number of critical systems and getting into those details.

Because just to be told, "We can't share any. We are using all of it, at all times," I mean, to me, you know, there are important systems in these bands. There are systems that absolutely are essential to our national security. But to say that we cannot share any of it and we are using all of it is just not—that does not pass muster.

Senator KIM. Yes, I think you are right. That precision is incredibly important when it comes to these decisions.

Mr. Clark, I guess I would ask you the same question. What are your thoughts about us, in this committee, diving in deeper in a classified way?

Mr. CLARK. Oh yes, yes, sir. I think that is absolutely what needs to happen, is to get down to that level of precision of what do the systems do, what frequencies do they operate it, what is the purpose of the system and how does it work in the war fight. And then how could it operate differently if we were to try to make it more agile in the spectrum?

So a lot of these systems, they need a band of spectrum that is available so that they can jump around and avoid enemy detection or avoid enemy jamming. So in some cases these systems are not efficient, because they have to have more spectrum made available to them so they can do this kind of anti-jam function. But that means they are not using the frequency continuously. So if you had spectrum sharing schemes and dynamic spectrum sharing you could still do anti-jam operations while being able to free that spectrum up for other users when you are not employing it.

Senator KIM. OK.

Mr. PEARL. If I could just add one point on having—because I think it is a worthwhile conversation. Also looping in what are the possible ways that you could accommodate DoD in other parts of the spectrum. So if we talk about, for instance, lower 3 GHz, which is a really critical area of discussion, there is a Federal band that goes 400 MHz below where is DoD is using it. So also having a conversation about where could DoD potentially move I think could be really helpful.

Senator KIM. Yes. Thank you for that. I agree. I mean, Mr. Chair, I guess I would just, for your consideration, you know, as one of the newer members here on the Committee, you know, I was on Armed Services on the House, but still a lot here to unpack. So if we could consider whether or not that might be doable for us to engage in a classified way, that might be able to make sure that we are all really trying to understand this, especially what Dr. Pearl said about the precision that is necessary here, because so much is at stake.

Just in my final time here, Dr. Pearl, I guess I just wanted to ask you, in your testimony you talked about how critical it is for the U.S. to advance our position in wireless innovation and technology, especially when it comes to the strategic competition that we face with the PRC. I guess I would like you to just expand. Can you explain to us how the spectrum auction authority fits into that goal? How is that embedded within that broader ability for us to advance our position?

Mr. PEARL. So I would characterize spectrum auctions as the first step in a chain reaction that reverberates through the global economy, meaning that the auction is something that, other than us insiders, no one is aware of, raises some money for the Treasury. But that is the opportunity for mobile operators to upgrade their networks. Otherwise, it is too expensive. There is no reason to do it. It is once they have obtained new spectrum that they launch new services, expand their use of it. And then from there it reverberates into the app economy, into tech companies, into like what you can use all that bandwidth for.

And then ultimate that creates an ecosystem, and we want a technology ecosystem outside the PRC that is the most advanced and robust. So it is a key component in terms of building that overall tech ecosystem that is going to be able to outcompete and outinnovate the——

Senator KIM. And that innovation, that is not just good for our own nation but that helps us be able to try to export that and be able to get market share around the world. Is that what you are saying?

Mr. PEARL. Yes, absolutely. So other countries are going to make decisions about what spectrum bands they use, what wireless networks they procure from. So having that ecosystem that is attractive to them means that they will choose the U.S. over the PRC.

Senator KIM. Great. Thank you. I yield back, Chair.

Chairman CRUZ. Thank you. Senator Moreno.

STATEMENT OF HON. BERNIE MORENO,
U.S. SENATOR FROM OHIO

Senator MORENO. First, Mr. Chairman, thank you for holding this hearing. I am glad I sat through the whole thing. It was extremely enlightening. And I know in the Senate you are supposed to abide by the rules that even though a point has been made, it has not been made by everybody. I will break that tradition and thank the four of you for your testimony. I thought the exchange was fantastic. We learned a lot. And with that I yield my time.

Chairman CRUZ. Very good. You may win the prize for brevity. I must say, I am not sure you are going to make it as a Senator.

[Laughter.]

Chairman CRUZ. I am not going to follow that line. There are several things I want to revisit.

There was a claim mentioned earlier that it would take 20 years developed advanced sharing technologies. Mr. Pearl, did it take 20 years to develop the AMBIT process?

Mr. PEARL. No. I think that was a matter of—the study was done in about 6 months, and it was completed within 12 to 18 months, if I am remembering it correctly.

Chairman CRUZ. Mr. Clark, are geographic carveouts another way to share?

Mr. CLARK. Yes, sir, they are, absolutely. And on the point about 20 years, I was just saying it would take 20 years, potentially, to upgrade all the systems with the new technology. The new technology would be available more quickly, obviously.

Chairman CRUZ. And was the AMBIT process successful in enabling DoD and commercial 5G coexistence?

Mr. CLARK. It did. Yes, sir.

Chairman CRUZ. Some of my colleagues have also discussed low-power spectrum sharing or CBRS. Mr. Pearl, do you think CBRS is a panacea, or do we also need full-power spectrum?

Mr. PEARL. We need full-power spectrum, as well. CBRS was the first really serious effort to do dynamic spectrum sharing in a band where it was really difficult. But you need both those high-powered uses to really utilize the ability to penetrate buildings, walls, to really have the capital investment that the carriers need in order to offer a lot of those services. So you need those high-power serv-

ices, you need low-power services, which we have in 6 GHz and elsewhere, and both are important, absolutely.

Chairman CRUZ. Dr. Hazlett, I have heard concerns that CBRS has been underutilized because providers lack the certainty they need to invest in their CBRS spectrum. Do you share these concerns?

Dr. HAZLETT. Well, there are some problems, as the FCC is acknowledging, and it is going back to try to see how it can fix it. You know, the claims were that that was the solution, that that was going to really have what is called sharing. I will just mention the fact that all spectrum is shared, OK. What is called exclusive use is not exclusive at all. You have networks in the United States with 100 million subscribers and they share these aggregations of bandwidth. And, in fact, there are all kinds of models that have developed, between firms, between providers, when you do get the incentives to come together and make deals.

So in terms of, yes, people coming in from the private sector dealing with government assignments, the fact is that paying to share—in other words, paying to separate the allocations between the new users and the existing users—that is a very effective form of sharing.

So it is really not just science. It is incentives to come together. That is why things like overlays are so important. It is why a better system of audits, which has been talked about, this has been suggested 25 years ago to the FCC to, in fact, have, by auction or assignment, have private firms come in and actually audit spectrum that is being used by government agencies to see if there are opportunities there for sharing. But maybe it is money coming to the agency in an improved version of the spectrum relocation process, to get that out there.

Chairman CRUZ. Mr. Clark, we heard from my colleague, Senator Fischer, that a pipeline bill would require exclusive licensed use of, and vacating or clearing DoD out of bands. Now, as you know, the Spectrum Pipeline Act, that I have authored, requires a pipeline of full power, not exclusive use, and does not identify any specific bands.

Mr. Clark, is there anything in that bill that is inconsistent with your testimony or Senator Fischer's concerns?

Mr. CLARK. No. In theory, it is not. And I think the challenge will be implementation, because depending on how much your target is to try to clear, it may prove difficult to be able to work out an arrangement so that the commercial and military users can both employ that spectrum. And the auction may not be attractive from the commercial companies' perspective because the geographic patchwork they may end up with or the spectrum sharing requirements are going to be such that maybe it makes it too expensive for them to pursue.

Chairman CRUZ. So, Mr. Pearl, we had an exchange with Senator Fischer and Mr. Clark where they were discussing the theory that China's public push to lead in wireless technology is just a mind game, that they are somehow baiting the United States with ambitious plans, and they are secretly holding back, trying to trick us into giving up spectrum to the commercial sector.

I find that a particularly odd conspiracy theory, given the actual facts of what we know. First of all, we know that Huawei and other Chinese manufacturers are actively and successfully pushing worldwide adoption of Chinese 6G equipment standards. That would not be possible without China having made its spectrum available for commercial use.

Second, China has aggressively targeted our telecommunication industry, has tapped the phones of top officials, including President Trump and Vice President Vance, and prompted this committee to fully fund a multibillion-dollar rip-and-replace program to remove Chinese equipment from American networks.

Mr. Pearl, would American national and economic security be harmed if Chinese firms, like Huawei and ZTE, set the global standard for 6G network equipment via this first-mover advantage? And how would that affect the global competitiveness of U.S. companies?

Mr. PEARL. So it would have a great deal of harm, and I would echo my agreement that I do not think this is a disinformation campaign. I fought the battle against Huawei and ZTE for almost 2 years. And in order for their businesses to be able to sell equipment outside of China they need to be able to use these bands inside of China and get those economies of scale.

But if they are successful in terms of setting the global standard, that means that the U.S. will have a siloed market with a few of its allies and partners, where it will have much worse technology, much worse networks. We will just have an inferior ecosystem. And ultimately that means that we are going to be put at a military disadvantage, because as others have commented, in a battle the electromagnetic domain can be absolutely decisive, and we just will not have the technology to prevail in that case.

Chairman CRUZ. Well, I want to thank all the witnesses for very helpful testimony. Senators will have until the close of business on Wednesday, February 26, to submit questions for the record, and then the witnesses will have until the close of business on Wednesday, March 12, to respond to those questions.

And with that, that concludes today's hearing. The committee stands adjourned.

[Whereupon, at 12:02 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN THUNE TO DR. THOMAS HAZLETT

Question. I have long been an advocate for increasing access to both licensed and unlicensed spectrum. What are some of the notable innovations in the unlicensed spectrum space, and how have unlicensed technologies, such as Wi-Fi, benefitted our economy?

Answer. The unlicensed bands benefited from two reforms in the 1980s, wherein devices using the ISM (Industrial, Scientific, and Medical) frequencies –which had been regulated so as to exclude advanced technologies—were significantly deregulated in terms of formats adopted. The particular driver was permitting "spread spectrum" technologies. These now enable our local area communications (Wi-Fi) as well as wide area wireless networks (2G, 3G, 4G, 5G). The innovations specifically in the unlicensed bands revolve around wireless local area network (WLAN) applications—signals designed to work within a house or office, a Bluetooth transmissions linking a smart phone to a car speaker, ID tags, off-load for wide area networks (including the Internet, wireless and fixed), security cameras, doorbells, and on and on. These products are purchased by millions and generate significant benefits.

The more difficult part comes in separating the distinct impact ("marginal value") of a specific spectrum allocation. With unlicensed, the allocations are typically imposed by regulators who make an administrative judgement that the spectrum is better under one set of rules than under another. But the popular use of local area networks, and products such as mentioned above, have developed in parallel with other expanding wireless ecosystems. There are multiple ways for an additional dollop of bandwidth to fortify wireless services. Each allocation specifically crafted for unlicensed uses and business models of one sort (including local area networks rather than wide area networks) confronts an opportunity cost. Those costs are generally invisible to regulators and are poorly estimated (in many cases) by the FCC.

For instance, in 2002, the FCC announced it would allocate the large, unoccupied bandwidth set aside for TV broadcasting in the 1952 TV Station Allocation Table for "white space" device use. The regulatory model would by non-exclusive access rights permit unlicensed devices into the set aside spaces, free of charge. Devices would comply with power limits and technology restrictions (checking with a database for instructions as to which channels were available for use, dynamically in time, *e.g.*).

While the approach promised to introduce valuable new services—"Wi-Fi on steroids"—virtually no devices have been made or sold in the nearly quarter-century that the FCC has sponsored the "TV White Spaces" policy. Meanwhile, an adjacent 70 MHz block of former TV spectrum was transitioned to an alternative rights model—with exclusive, flexible-use rights—over 2010–2020. This allocation not only received market feedback in the $20 billion in winning bids generated by their sale, but demonstrably boosted mobile network capacity, intensified wireless broadband competition, and supplied billions of dollars in economic gains. This far outperforms the 210 MHz of over-the-air TV dedicated to the video distribution model of *I Love Lucy,* on the one hand, and TV White Spaces, on the other.

Hence, the choices about how to allocate spectrum must carefully consider appropriate margins, recognize spectrum substitution possibilities, account for opportunity costs, and incorporate the transaction costs consumed in administrative delays.[1]—TWH

[1] Thomas Hazlett & Michael Honig, *Valuing Spectrum Allocations,* 23 MICH. TELECOMM. & TECH. L. REV. 45 (2016–2017); Hazlett, *Benefit-cost analysis in the 5.9 GHz band,* JOURNAL OF BENEFIT-COST ANALYSIS (2025): 1–24.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. TODD YOUNG TO
DR. THOMAS HAZLETT

Question. Dr. Hazlett: In your testimony, you mention success of market-oriented policies like spectrum auctions and overlays. What reforms do you believe are necessary to further accelerate U.S. leadership in wireless innovation?

Answer.

1. *More overlays.* Take the 35 channels still dedicated to over-the-air (OTA) television, as per the TV Station Allocation Table of 1952. It's been a quarter century since OTA was a thing, as cable and satellite TV had nationwide footprints already supplying 90 percent of U.S. households. Today, of course, much video traffic has further migrated—to the Internet. Now the "TV Spectrum Allocation" is positively harming video delivery in the U.S. by constraining networks—both incumbent and new entrants—from delivering more wireless product to U.S. households (in both urban and rural areas). Overlays would allow entrants to get access to a large tranche of effectively unused bandwidth and prove beneficial to consumers, media competition, and U.S. economic growth. And incumbent TV stations would not be harmed. With an overlay, the licensees only make bargains that benefit them.
2. *More FCC deregulation.* Allow the licenses being sold by the Commission to be technology-neutral and business model-neutral. This requires a few changes, like eliminating build-out requirements that block entrepreneurs from bidding on spectrum, winning, and then supplying more "plug and play" services analogized to "unlicensed" use. The build-out requirements have themselves been ineffective and the better way to get networks built is to provide a competitive space—with more access to spectrum—that allows for innovation in business models.
3. *3rd party Audits for Government Spectrum assignments.* Private or public organizations should bid for the rights to audit spectrum holdings of the DOJ, DOD, Forestry Service—all organizations that face zero opportunity cost in holding on to valuable resources. The difficulty in negotiating with such parties is not that the officials in the agencies are wrong or ill-informed, as sometimes charged. It is that they rationally defend "free options" that may perform some valuable function (now or in the future) and cost their agencies nothing. It is predictable that such actors over-protect these assets in pursuing the mission of their agency—they would virtually be violating a public trust not to, given the circumstances in which they operate. (Certainly this is the viewpoint of constituencies within the agency.) The way out is to allow motivated outsiders, perhaps firms with interest and subject matter expertise, to evaluate the costs and benefits facing such firms in making wireless trades. These might include ceding some proportion of bandwidth assignments to other parties in exchange for a new radio system, or a specific funding request, or a change in rules that allows greater efficiency in operations. Companies like, say, Haliburton, might pay to conduct this (presumably CLASSIFIED) audit of the DOD (as it could yield commercially valuable information in forming proposals for transactions post-audit), or the GAO (with expertise in audits) or GSA (expertise in managing government assets) might be selected to evaluate Department of Transportation use of spectrum. These are the sort of ideas that spectrum policy experts do propose.—TWH

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. BRIAN SCHATZ TO
DR. THOMAS HAZLETT

Question. You have contended that commercial providers are often better positioned to deploy spectrum quickly and at scale.

In your opinion, if Congress wants to ensure broadband expansion in Tribal areas, how would policies that encourage partnerships between private industry and Tribal governments–such as infrastructure investment incentives, spectrum-sharing agreements, or Federal funding for public-private partnerships–be more effective than direct Tribal spectrum allocation?

Answer. The best short answer I can give to this provocative and interesting question is: allow Native Corporations in the Tribal areas flexibility in devising contracts for cooperation with wireless service providers.[1] This should, of course, be nested

[1] Failure to do so has led to disappointing results, both for the Tribal population and the investors/owners of the firms. Jonathan Karpoff & Edward Rice, *Structure and Performance of Alaska Native Corporations,* CONTEMPORARY ECONOMIC POLICY (July 1992).

in a productive, pro-consumer business environment in which the Corporations have appropriate incentives to well serve their customer base, develop advanced services, and earn sufficient returns as to make the company effective in delivering services for decades to come. Selection of the Corporations might be by competitive bidding, either in money (a procurement auction) or in franchise bidding.[2]

Using service contracting models to supply public safety radio, an analogy to the idea of extending wireless networks in Tribal areas with contracts or awards of FCC licenses, is an experiment undertaken in the 2017 award of the FirstNet contract to AT&T. The set-up has AT&T, a major commercial wireless network, service its large base of subscribers and then fold-in additional obligations to provide emergency radio service to first responders. The structure aims to achieve economies of scale, and standard efficiencies evolving in the commercial sector, while applying such beneficial developments to supply solutions to fire, policy, emergency medical services and other efforts of keen "public interest" importance. The challenges, successes, and failures of the FirstNet effort offer insights, I believe, for how other such initiatives—tackling important social problems via efficient marketplace platforms—might best proceed.—TWH

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. TAMMY BALDWIN TO DR. THOMAS HAZLETT

Question. As an advocate for bringing Internet access to all Wisconsinites, I am a strong supporter of measures to bridge the digital divide and expand broadband access in rural and underserved communities. In the interest of boosting access and affordability for unconnected Americans, how do you see increases in commercial access to spectrum through the proposed sharing measures impacting ongoing efforts to increase rural network capacities?

Answer. There is no doubt that making more radio spectrum available for productive use is a key in spreading and improving broadband coverage in the U.S. This is true in urban and rural areas, and with respect to both terrestrial and space-based delivery networks.

The problem with resolving to expand spectrum availability through particular sharing mechanisms is that the rules chosen by regulators may not facilitate the task designed or hoped for. First, all spectrum rights models incorporate "spectrum sharing." That is as true for the exclusively assigned, flexible-use rights purchased at FCC auction and intensely utilized by mobile carriers as it is for Wi-Fi, supporting localized networks distributing broadband data through a house or around a campus.

Second, all such systems have strengths and weaknesses, and categorical claims that technology solves all coordination plans—in, *e.g.,* "bandwidth sharing"—has been a costly error. In one important instance, TV band white spaces, channels that have been unoccupied since the 1952 TV Allocation Table, were thought by the FCC to be perfect to host new unlicensed devices yielding valuable new services—"Wi-Fi on steroids." That decision, initially launched in 2002, has proven virtually a complete failure. There is today no substantial "white space device" use, and vast "white spaces" in the over-the-air TV Band lie fallow. Overlay rights transferring these open spaces to exclusively-assigned, flexible-use licenses would have—and still could—generate billions of dollars in annual consumer welfare—by effectively introducing band-sharing mechanisms well developed elsewhere in the wireless marketplace.

Hence, choosing the right set of rights for the task at hand should be informed by economics, history, and the experiences gained in previous endeavors.[3]—TWH

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BEN RAY LUJÁN TO DR. THOMAS HAZLETT

Question 1. Dr. Hazlett, I appreciate your testimony highlighting the need to optimize our processes for freeing up and assigning more spectrum. Spectrum is a limited natural resource, and if we want to fully address our economic needs while safeguarding our national security, we have to invest in innovation. This includes not only exclusive use but also shared and unlicensed spectrum, which are vital to technological development and economic growth.

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[2] Harold Demsetz, *Why Regulate Utilities?* 11 JOURNAL OF LAW & ECONOMICS (1968): 55–65.

[3] My book goes into some detail on the regulatory choice of spectrum rights in supporting wireless services: Thomas Hazlett, THE POLITICAL SPECTRUM: THE TUMULTUOUS LIBERATION OF WIRELESS TECHNOLOGIES, FROM HERBERT HOOVER TO THE SMARTPHONE (Yale, 2017).

Do you think it is possible for the FCC to structure auctions in a way that incentivizes innovation and technological development, and do you believe that can be done in a way that still maximizes economic benefit & auction revenue?

Answer. Thank you for inviting me to testify.

YES—auctions for FCC licenses (adopted in 1993 by congressional legislation) are a positive innovation in public policy, but they can be improved. Specifically, they can reveal—discover—the relative values of what are commonly called "licensed" and "unlicensed" spectrum. Three things need to be reformed.

First, the licenses offered for sale in auctions need to be technology-neutral and regime-neutral, such that they can be used as competitive market conditions suggest. (We are not far from this and the tweak is easily achievable.)

Second, the winner (high bidder) for a particular license cannot be subject to "build-out requirements" of the type imposed today. This regulatory approach assumes that one type of usage will result from the license distribution—a business model wherein the licensee builds and manages a network. In fact, many call this is "licensed use model." But it isn't. There are other ways to use licensed spectrum, and some of them look like the way "unlicensed spectrum" is utilized. In other words, a license winner may sponsor a "spectrum park" (or, as some might say, a "commons") that hosts access for radio users conforming to certain device standards. The build-out requirements make this model essential a violation of FCC regulations. (The regulations, by the way, do very little to encourage actual service build-out.)

Third, the bidders participating in FCC auctions should have authority to create their own business models, not to be constrained to those imposed by the Commission. That is, a licensee who forms a consortium to buy more "unlicensed" bandwidth and pay for it by assessing license fees on the equipment used (perhaps manufactured by companies in the consortium) should not be impeded by FCC rules about what an "unlicensed spectrum band" must be, which would block the business case for the consortium. This more open, competitive way to develop innovative forms of organization was suggested in an important 1992 FCC policy paper.[4] It is time to give it a run.—TWH

Question 2. Do you believe it makes sense for spectrum auction revenues to be reinvested in priorities like innovation?

Answer. In general, I do not favor such dedications. Outlays should be considered on their merits, against all other outlays (by the Federal government). The one exception is where the dedicated expenditures are useful in creating the transactions generating the gains in question. Using auction revenues to compensate firms, as in FCC Auction 107 (2020–2021), where satellite carriers were paid to update their equipment, making more bandwidth available for other parties; and in the 2016–2017 "incentive auction," paying TV station licensees to give up broadcasting rights) or government agencies (as in FCC Auction 66).

Innovation is encouraged in two other ways. By conditions hosting robust entrepreneurial activity, and by support for basic research with organizations like NSF and NIH.—TWH

Response to Written Questions Submitted by Hon. John Thune to Dr. Charles Baylis

Question 1. I have long been an advocate for increasing access to both licensed and unlicensed spectrum. What are some of the notable innovations in the unlicensed spectrum space, and how have unlicensed technologies, such as Wi-Fi, benefitted our economy?

Answer. Wi-Fi and other unlicensed technologies, such as Bluetooth and Ultra Wideband, have been great innovations. Wi-Fi sharing was developed in part of the 5 GHz band, as well as eventually in the 6 GHz band. In the 6 GHz band, Wi-Fi was shared with incumbent point-to-point microwave links. Sharing was coordinated using an Automated Frequency Coordination (AFC) System.

The AFC used many lessons learned from the Spectrum Access System (SAS) that coordinated spectrum use in the Citizens Broadband Radio Service (CBRS) band.

Unlicensed spectrum usage has been a significant benefit to the economy. Unlicensed bands have allowed devices to use and share a band effectively on an as-needed basis. There are numerous unlicensed users that share small ranges of frequencies, and now are able to share even other frequencies (such as 6 GHz) with incumbent users. This seems to allow for expansion of Wi-Fi unlicensed applications.

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[4] Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum,* OSP Working Paper 38 (Nov 2002).

Question 2. National security and wireless innovation are not mutually exclusive. Please detail how the technology you are advancing at Baylor University's SMART Hub will ensure spectrum policy remains a "win-win" for both the defense industry and the economy at large.

Answer. The adaptive and reconfigurable technology we are developing at SMART Hub is heavily focused toward DoD incumbent systems in the 3 GHz band. As such, this will allow DoD systems to adapt to the surrounding environment given our prescribed approach, examined in part by research preceding SMART Hub, includes the ability to sense and even predict locations and frequencies of other users. If a system can locate bands in which it can operate, it can then reconfigure its circuits and systems to, for example, maximize radar range after changing frequency. This allows the DoD systems to function with maximum performance and be flexible in frequency and spatial operations.

Many of the same concepts we are working on that are applicable to DoD systems are also applicable to commercial wireless systems. As such, when systems can work around one another adaptively, they use the spectrum more efficiently. It is through an adaptive and reconfigurable technology approach that we can do more with less, and accomplish a "win-win" for both defense and commercial wireless users.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. TODD YOUNG TO DR. CHARLES BAYLIS

Question 1. Dr. Baylis: In your testimony, you highlight the potential benefits and exciting new opportunities that technological innovation can unlock in the realm of spectrum management.

From your perspective as a researcher and technical expert, how can AI help transform our management and use of spectrum?

Answer. Artificial intelligence (AI) can be used in several ways within a spectrum-use ecosystem. First, it can predict spectrum and spatial use of a wireless system. The ability to predict how other spectrum users perform, and evaluate different predictive methods to choose the correct one, is an area that SMART Hub members Professor Robert Marks from Baylor University and Professor Mike Buehrer from Virginia Tech have worked on.

Secondly, AI and Machine Learning (ML) can be used to reconfigure systems and circuits. In optimizing an array of reconfigurable circuits, AI may be useful in cutting through the multiple dimensions of optimization to select a "best" setting for range, efficiency, spectral performance, and/or spatial performance, for example. An adaptive and reconfigurable environment must be based on automation, and AI and ML can play a significant role in making these optimizations efficient.

The present thrust toward AI technologies and the need to better optimize spectrum use and spectrum use systems are coming together at a very useful time. As a national center committed to solving the spectrum crisis, we are working to marshal AI in addressing these issues.

Question 1a. What are some of the risks or challenges policymakers should consider?

Answer. Policy should be developed in parallel with and complementary to supporting technology. One danger that should be avoided is where policy outruns technology. Technological limitations, such as propagation challenges and antenna size, must be considered in band allocations; allocations must be reasonable given these limitations. Given this, however, advancements in technology can be enablers for new, advanced policy approaches.

Regulating a small amount of available spectrum will not provide a long-term solution to the problem we are facing currently in the midband spectrum. Innovative adaptive and reconfigurable technology will allow flexibility in wireless communications and radar systems that will support new policy.

Question 2. Dr. Baylis: In your testimony, you also mention the importance of the United States winning the spectrum superiority race. Can you elaborate on this point? What is needed by Congress to ensure continued leadership on spectrum technology?

Answer. Spectrum superiority requires having the best technology: technology that can flexibly use the spectrum. The ability to flexibly use the spectrum allows our radar and communication systems to gain a tactical advantage in wartime: we can avoid the enemy's jamming maneuvers by finding open spectrum and using it. Additionally, in peacetime, being agile allows us to use the spectrum more efficiently. We can reconfigure both radar and communication systems to use available spectrum opportunistically, rather than being confined to a single band.

Adaptive and reconfigurable spectrum use is the new paradigm that is on the way. The nation that builds the technology for this paradigm will be able to sell it to the world. America needs to be the Nation that builds this technology first. If America is the first to build it, we will benefit both economically and (for wartime) tactically. If China wins this race, we will be buying systems from China to build the 6G backbone that may be compromised from a security perspective. We also will no longer have an edge in wartime.

Congress should prioritize funding for research and development in spectrum technologies to ensure America builds the backbone technology for the adaptive and reconfigurable spectrum use of the future. Congress should supervise the results of this funding, ensuring that this funding does not merely create innovations that die in a laboratory, but instead move from academia, through industry, and into the hands of warfighters and consumers. Innovation that has happened at the fundamental level must move to the applied level and then into industry production. The development of this type of pipeline for these technologies must involve universities and industry (both commercial wireless and defense contractors).

An example of this type of model is SMART Hub, which was initially funded by Congress and consists of 15 universities with 25 U.S. citizen, multidisciplinary spectrum researchers across the country, spanning 13 states. SMART Hub is also building industry partnerships that can move technology into the hands of the warfighters and consumers, but it will need additional funds to continue to continue this important work. Congress should appropriate additional funding for these types of activities, as well as consider legislation to authorize additional funding for spectrum technology university-industry partnerships.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. TED BUDD TO DR. CHARLES BAYLIS

Question 1. Can we get to a point where full-power spectrum use can be efficiently shared in a way that allows wireless buildout without excessive negative impacts to national security systems? If so, how far away are we?

Answer. It is possible to get to a point where full-power spectrum use can be efficiently shared without excessive impacts to national security systems. New technology would enable this type of sharing. Adaptive and reconfigurable technology is a "game changer". It would render the current arguments about "auction versus defense" moot. Spectrum surveys show that very little of the spectrum is being simultaneously used in a given geographic region. Yet, problems exist because present incumbent military systems are significantly rigid, and, as such, demand to always have the same part of the spectrum available for their use.

Some of the key developments that will be required to get to this point include: (1) spectrum sensing and/or prediction capabilities to be aware of other users' spectrum usages; (2) spectrum coordination mechanisms for congested bands; (3) reconfigurable circuits, antennas, and arrays (including reconfigurable circuits capable of handling high power levels for radar) that enable increased spectral and spatial flexibility and control of wireless transmissions; and (4) the ability to measure device performance in-situ (on board the device) to assess transmissions to inform reconfiguration algorithms. The good news is that many of these developments are already at the Technology Readiness Levels TRL–2 through TRL–4 and are ready to be carried forward to industry for the buildout of new radar and/or communications systems. Spectrum sensing and prediction has been effectively demonstrated through sense-react-and-avoid and sense-predict-and-avoid methods. We have been able to demonstrate how future Dynamic Spectrum Management Systems (DSMS) can build upon the existing CBRS approach while allowing for incumbents to provide real-time interference reports, enabling a more responsive, closed-loop coordination of the spectrum. In terms of reconfigurable circuits, a high-power reconfigurable circuit, capable of handling 20–68 W that can reconfigure from 2–4 GHz in less than a millisecond provides an entire 2 GHz of reconfiguration capability. This breakthrough means that radars could, using this circuit, optimize their transmission range, within matching limitations of the circuit, anywhere between 2–4 GHz within a millisecond after changing frequencies. If a radar has the ability to move this widely in frequency, then coexisting with communication systems becomes a much less complex problem. Finally, we have demonstrated an in-situ measurement approach to assess signals entering an antenna as part of the reconfigurable circuit chain.

These technologies must now be taken from their current innovation level into actual system implementation. This will not only allow radars to more flexibly use their own bands, but provide them with opportunistic access to bands outside their

current assignments. The range of frequencies that will be able to be flexibly used will increase drastically. If we are successful, China will have to buy this technology from us, and we will have the advantage on the battlefield and in the ability to co-exist in our homeland. Yet, it will take foresight and investment from Congress. Continuing to regulate and re-regulate current frequency usages with present legacy systems without this newly updated technology will only yield temporary gains, and our foreign competitors will build this technology before we do. We need to build it first to give ourselves the best defense systems and to expand commercial access to frequencies. We should strive to win this race, sell this technology worldwide, and build the backbone of 6G and the world's strongest military wireless technology.

Question 2. What lessons can we learn from CBRS in opening up spectrum to commercial use in congested bands?

Answer. The Citizens Broadband Radio Service (CBRS) sharing with Navy radars in the 3.55—3.7 GHz band has provided useful lessons. One significant lesson is that bands whose primary users are in limited geographical regions can often have a second use. Because Navy radars are not usually found inland, it is advantageous to allow communication device access to these frequencies when away from the coastlines. Additionally, the ability to design a third-party system, known as a Spectrum Access System (SAS) in the CBRS case, to coordinate spectrum usage has now been successfully demonstrated.

This lesson should be applied with limitations. First, if geographic limitations of a band-user are known, it makes sense to allow the same band to be used outside of these geographic limitations by another user. Second, third-party coordination can be an effective use to ensure spectrum coexistence, provided its time-frame is fast enough to ensure spectrum to a primary user when needed.

Ideally, the time-scale of spectrum brokering should strive for improvement over CBRS. It would be ideal for such spectrum assignments to approach real-time. However, spectrum assignments should be based on accurate understanding of positions, propagation models, and potential victims of interference.

Caution should be used in applying the CBRS model to other scenarios. The CBRS model, with current wireless systems, works well when geographic separation of systems needing to use the band is present. Additionally, the Dynamic Spectrum Management System (DSMS) needs to be fast enough to parcel spectrum at the needed time-scales (and with appropriate security) for the primary user to gain access when needed.

Another lesson learned from CBRS is that if spectrum sharing is adopted, the technical parameters that govern the sharing, such as the propagation model, should not be based solely on worst-case assumptions. This can result in inefficient spectrum use. In the case of CBRS, after four years of operations, the propagation models were successfully refined, allowing better use of the spectrum while not interfering with critical DoD systems in the band.

Response to Written Question Submitted by Hon. Maria Cantwell to Dr. Charles Baylis

Question. How do we advance commercial spectrum while respecting mission-critical Federal users and national security?

Answer. Spectrum bands are overcrowded, and reallocation of spectrum bands will eventually meet its limit. We need a paradigm shift in how spectrum is used. Currently, spectrum allocations may be drawn with very broad strokes to ensure spectrum is available in certain bands and regions in case it is needed. However, this leads to large portions of the spectrum being reserved but underutilized. The adaptive and reconfigurable use of the spectrum will allow more spectrum to be available to more users when they need it by allowing allocations to be specified more precisely in time, frequency, and location.

The key to unlocking this spectrum availability is the innovation and development of adaptive and reconfigurable technology. For example, researchers now part of SMART Hub have developed reconfigurable circuits that can handle higher power levels (toward the power levels needed for radar operation) to optimize their detection range, within the limitations of the impedance matching coverage, after changing frequencies in a 2–4 GHz octave. If radar systems operating in the 3.1–3.45 GHz band could move to another band and optimize their performance within a millisecond, this would make more and more frequencies available to wireless communication. The inflexibility of current radar system technology limits the growth of wireless communication infrastructure, and it also limits the tactical advantage of our military.

However, with additional investments in innovating, developing, and producing this technology, the financial benefit will dwarf the current argued amounts.

The approach of developing adaptive and reconfigurable technology transcends the present arguments about spectrum allocations. If systems are flexible, they can use whatever band is available, reducing the amount of spectrum that must be held in reserve on a "just-in-case" basis. The capability of both DoD systems and commercial wireless systems to use available bands would give the U.S. a technological advantage in battle, as well as the ability to form a new spectrum-coexistence model that will enormously benefit the American economy. Immediate, sustained focus and investment in innovation and the development of adaptive and reconfigurable technology will reap enormous economic and national security benefits.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BEN RAY LUJÁN TO DR. CHARLES BAYLIS

Question 1. Dr. Baylis, can you elaborate on SMART Hub's current sources of funding?

Answer. SMART Hub was initially funded by a $5 million appropriation in the FY 2023 budget. Our 6-month research demonstration in February 2024 in Arlington, Virginia showed Pentagon, Congressional, and industry spectrum leaders how adaptive and reconfigurable technology is being developed to assist warfighters and to promote the economic benefits of adaptive and reconfigurable technologies for spectrum usage. We are in near-term need of additional funding to allow SMART Hub's innovation to continue.

The SMART Hub leadership team considers Congressional funding as "anchor" funding and has launched an ecosystem by which other funding sources will eventually grow to sustain SMART Hub. For example, the National Science Foundation funded a grant of over $340,000 for spectrum workforce development through an Undergraduate Spectrum Workshop known as the "Spectrum Sizzle". Four SMART Hub universities will host this immersive, residential, four-day, hands-on experience for undergraduates from across the country in Summer 2025, and we expect 160 undergraduate students to be trained in fundamental spectrum technology and policy principles this summer. With our team working together and demonstrating results from our work, we have submitted additional proposals since our first round of anchor funding arrived, and we are in the process of establishing industry partnerships that will further grow the ecosystem through technology transfer and industry sponsored research. We have begun the process of building partnerships with both DoD contractors and wireless network providers, with the goal of continued industry investment in our innovations that will result in technologies placed in the hands of American warfighters and consumers. This ecosystem is designed to thrive on its own after several years of Congressional investment.

Question 2. Is it important to your work that Congress pass a full FY25 funding package?

Answer. We currently have funding pending in the FY 2025 DoD appropriations bill to continue investments in SMART Hub. If Congress does not pass a full FY 2025 funding package that includes this pending funding in it, SMART Hub may have to make difficult decisions about its operations in the future. It is crucial to our development of adaptive and reconfigurable technology that Congress pass a full-year funding package with funding for our work included in it. We encourage Congress to act soon to continue to invest in adaptive and reconfigurable technologies, building American leadership in this area.

Unfortunately, a Continuing Resolution is not helpful to SMART Hub's operations, given we are looking for new funding to carry on SMART Hub innovation. Should Congress decide to move forward with a year-long CR, we encourage appropriators to include an explicit provision for SMART Hub funding.

Question 3. Should the government continue to play a role in developing innovative technologies to solve both commercial and defense spectrum challenges?

Answer. The innovation of adaptive and reconfigurable technology is the key to U.S. global leadership in spectrum. Arguments about allocation and re-allocation do not provide a long-term economic or national security solution. It is imperative that the U.S. solve the spectrum crisis by developing innovative technology that transcends these arguments by using the spectrum differently: adaptively and flexibly. If the U.S. possesses this capability, then more bandwidth will be available to meet the needs of commercial wireless providers as well as national security systems, such as radar. The investment by Congress in American innovation will spur jobs, science, and technology, as well as create national leadership in spectrum. Importantly, U.S. industries will be able to sell this new technology worldwide, which will

build the backbone of 6G, and its commercial wireless industry, defense industry, and technology suppliers will thrive.

If Congress sees this potential and invests in it now, the dividends reaped down the road for American industry will far outweigh the cost of present investment.

Question 4. Do you believe it makes sense for spectrum auction revenues to be reinvested in priorities like innovation?

Answer. Yes. If spectrum is auctioned, revenues should be heavily invested in innovation. Innovation is what will allow America to be the best: in commercial wireless and in national security. The benefits of innovating new systems that can share the spectrum in an adaptive and reconfigurable way will far outweigh the costs of this investment.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN THUNE TO MATTHEW PEARL

Question 1. There have been concerns about expanding commercial access to spectrum and its implications for our national security and defense capabilities.

Can you clarify the National Telecommunications and Information Administration's role in administering spectrum? Specifically, when a conflict arises between wireless and defense use of spectrum, how do agencies coordinate to resolve the issue and ensure that U.S. national security is not compromised?

Answer. NTIA plays an indispensable and underappreciated role in resolving disputes over conflicts regarding interference between commercial and government users, including DOD users. NTIA is responsible for managing the radio spectrum that is used by the Federal government, and it also serves as the President's principal advisor on telecommunications issues. When there are new proposed commercial or Federal uses that could potentially cause interference between the Federal or commercial users (respectively), the FCC and NTIA coordinate before any new access is granted. In the case of an FCC proposed action that is coordinated with NTIA, the draft proposed action is shared by NTIA with the relevant Federal agencies for comment. NTIA then compiles those comments and, assuming any agency concerns have a technical basis, they work with the FCC to resolve the disagreements. As part of the process, NTIA and the FCC convene meetings, including with the agencies who have expressed concerns, to work through any technical issues.

In most cases, NTIA and the FCC resolve such conflicts using the mechanisms described above. In some cases, however, disagreements remain over whether there will be interference to commercial or Federal systems from a proposed action. Historically, in those cases, the White House—led by the National Security Council, with the participation of other components such as the National Economic Council and the Office of Science and Technology—convenes a formal interagency process to resolve those disputes. FCC, NTIA, and agencies who have equities in the relevant spectrum band are all included in this interagency process. At every level (beginning at lower levels), there is an effort by the White House to resolve as many disagreements as possible, and then—if necessary—to escalate any remaining differences to a higher level. This process reduces, clarifies, and refines the issues that must be resolved at the higher political levels, ensuring that principals' (and, in some cases, the President's) efforts are spent on the key issues and that the best information is provided before a decision is made.

Question 2. As the Federal Communications Commission looks to expand access to additional licensed spectrum, would you expect the same coordination to continue across agencies to ensure national security is not compromised in the future?

Answer. Yes. The current MOU between the FCC and NTIA remains in effect, and the White House continues to have the ability to use the interagency process to resolve disagreements and disputes. If these processes are diligently followed by the White House, FCC, NTIA, and the agencies, they provide a highly effective mechanism for ensuring that actions that are taken on spectrum do not compromise national security. Ensuring that the right decisions are made requires high-level White House leadership, so that all the agencies involved understand that they are required to share information, work through technical issues in good faith, and abide by decisions that are made by the White House.

Question 3. I have long been an advocate for increasing access to both licensed and unlicensed spectrum. What are some of the notable innovations in the unlicensed spectrum space, and how have unlicensed technologies, such as Wi-Fi, benefitted our economy?

Answer. The United States was the first country to adopt unlicensed rules, beginning in the 1930s, and these rules have been a tremendous benefit to the American

economy because they allow anyone to experiment and use the spectrum without obtaining permission from the government, provided that the equipment they use cannot cause harmful interference to licensed users.

We first saw the benefits of unlicensed rules to the American economy in the 1970s, when bands in which unlicensed use was authorized began to be used in everyday consumer applications such as baby monitors and garage door openers. While these devices wouldn't normally come to mind as examples of disruption innovation, a significant number of U.S. companies sprung up to produce the equipment used for these purposes, and the devices they old offered practical solutions that benefitted millions of Americans.

Even more importantly, in the 1990s, innovators developed Wi-Fi and Bluetooth. By leveraging the permissionless innovation of unlicensed spectrum, the developers of those technologies have greatly increased our connectivity, and contribute nearly $100 billion per year to the U.S. economy.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. TODD YOUNG TO MATTHEW PEARL

Question 1. Mr. Pearl: During the previous administration, progress on strengthening our spectrum leadership slowed, with few actionable steps taken. While my colleagues have worked tirelessly to advance meaningful spectrum legislation, much remains to be done and we are eager to see it done under the current administration.

If we were to implement an ambitious spectrum policy, how quickly would we see tangible benefits?

Answer. If Congress reauthorizes the FCC to hold auctions and sets ambitious goals and timelines for making spectrum available, we could see auctions within one to two years, thus generating billions of dollars for the American taxpayer, and we could see tangible benefits to the American consumer within months of those auctions, as licensees would begin to deploy spectrum in some areas. There are a variety of bands where some of the spectrum could be made available. While it will take some time for FCC, NTIA, and relevant agencies to do technical analyses regarding which of these bands (and, in some cases, which parts of these bands) to make available, and the conditions under which they do so, it is possible to make progress quickly so that Americans do not need to wait to be able to use these frequencies.

Question 1a. What would those benefits look like for the American people?

Answer. The benefits to the American people would include greater ability to use their mobile devices regardless of the location they are in, and the ability to transmit more data than they can today. By enabling those more data-intensive uses, innovators will be able to develop new applications that benefit consumers in two ways: 1) they will benefit from the capabilities that those apps offer, and 2) they will also benefit from the economic gains that accrue to the American economy, including the jobs created and the increased value of the U.S. stock market, from those new apps. Further, this new spectrum will enable businesses, universities, and other organizations to build better private networks, enabling those businesses to benefit from the capabilities that such networks offer, including increased security and reliability. Additionally, those private networks will enable those organizations to be more efficient, thus increasing their economic efficiency and enabling them to pass on economic gains to their employees and shareholders.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. TED BUDD TO MATTHEW PEARL

Question. Why are power levels important as we consider making new investments of spectrum in mobile wireless connectivity?

Answer. Power levels are a critical aspect of spectrum policy. High power levels are necessary to enable wireless carriers to provide wide-area coverage, and to enable them to penetrate walls, foliage, and other objects. Higher power levels thus enable networks to reach consumers in a variety of places—which is a significant benefit in our highly mobile society. The ability to penetrate walls is particularly critical because we spend roughly 90 percent of our time indoors, and when we are not at home or work (where we often use WiFi), we still need to be able use those devices indoors. Thus, to build networks that satisfy the needs of their customers, carriers need spectrum with high power levels. Unless the spectrum that carriers obtain is useful to their customers in all the places they move during the day, it

does not make sense for carriers to spend billions of dollars investing in their networks.

Providing access to spectrum at lower power levels for unlicensed use is also important, particularly for enabling indoor use of spectrum. When we are at home or in the office, we frequently rely on low-power uses of spectrum, such as WiFi. I should note, however, that low-power use complements high-power use, rather than serving as substitute for it, and vice versa.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO MATTHEW PEARL

Question 1. Relocation Risks are Real. Mr. Pearl, you worked at the National Security Council and with the Department of Defense and other Federal agencies. And from that perch, you've seen firsthand the complexities and interplay between commercial and Federal users of spectrum and know how important it is to get coordination done and done right.

Do you believe that without a smart, evidence-based, well-coordinated spectrum policy we could put critical national security capabilities at risk?

Answer. The United States has essential national security capabilities in some of the bands that we are currently examining for commercial use. For example, DOD uses lower 3 GHz for high-power radars that play an essential role in protecting our homeland. Therefore, I agree it is absolutely critical that the Administration and the FCC have the right process in place, including "smart, evidence-based, well-coordinated" spectrum policy, so that as they make decisions that enable new commercial use, they do not jeopardize national security.

At the same time, to enable the Federal Government to create new opportunities for commercial use (which are urgently needed to compete with the PRC in the economic domain), Congress should set clear, ambitious goals to offer an impetus for the Federal Government to make spectrum available for commercial use, while building in flexibility that enables the United States to fully accommodate national security uses. Providing such an impetus is important to ensuring agencies that use spectrum understand they must cooperate in good faith and find ways to make spectrum available without harming their operations, rather than preserving spectrum in cases where they have no current or anticipated use for it. By providing flexibility, such as allowing the FCC and the Executive Branch to satisfy the requirements of any clearing targets by making the spectrum available for either exclusive use or shared use, Congress can ensure that—before an FCC auction takes place—the Executive Branch has determined how to preserve critical national security uses in bands when relocation proves to be infeasible.

Question 2. Do you think it's wise to auction Federal spectrum, before technical studies are finished, to determine the viability of relocating Federal systems? And have you seen this result in the public being put at risk?

Answer. I do not believe it is prudent to auction spectrum before technical work has been done regarding the conditions under which it will be made available. I should note, however, that all the major bills that are currently under active consideration (of which I am aware) do not propose to hold auctions before the FCC, NTIA, and the agencies do such analyses. For instance, some proposed bills set clearing targets for making spectrum available across a broad range of spectrum—which includes bands that are used for exclusive Federal use, bands that are used for exclusive non-Federal use, and bands that are shared by Federal and non-federal users—and they allow for the possibility that Federal uses will still have access to bands (on a shared basis with new commercial use). Following the passage of a bill, the interagency process and associated technical work would take place to establish the conditions under which spectrum may be made available, including ensuring—before any auction takes place—that commercial use will not jeopardize national security.

Question 3. Spectrum Warfare. We are seeing spectrum's importance on the battlefield, the Russians are jamming Ukrainian drones, communications, and satellite services. We also know that China is a real threat to U.S. innovation and national security.

Could auctioning Federal spectrum put critical DoD capabilities at risk and potentially disadvantage the United States in a conflict with our adversaries?

Answer. If the FCC were to auction spectrum without collaborating with NTIA and following the interagency process, it would potentially put DOD capabilities at risk and potentially disadvantage the United States in a conflict. If the FCC, NTIA, and the agencies conscientiously abide by the FCC–NTIA MOU and the interagency process, and there is White House leadership on spectrum issues, I am confident

that we can make additional spectrum available for commercial use without compromising any DOD capabilities or ceding an EW advantage to our adversaries.

Question 4. How might this affect our deterrence capabilities? And are there any examples you are aware of where this has happened, and if so, can you share them?

Answer. I am unaware of any examples where auctioning spectrum put critical DoD capabilities at risk. It is possible that poor decisions about auctioning spectrum could affect our deterrence capabilities; for instance, if we undermined the effectiveness of EW capabilities by providing insufficient spectrum for testing and training at DOD bases, then we may be unable to deter efforts by our adversaries to jam, spoof, or employ other malicious methods to undermine the United States military's spectrum-based operations outside of the United States.

Question 5. Interagency Cooperation. We can avoid the mismanagement of the past by creating a coordinated approach to domestic spectrum policy, where agencies with critical missions such as the FAA and DoD work together with NTIA and FCC—cooperatively—on spectrum.

Have you witnessed instances where poor government coordination led to decisions that unknowingly compromised our national security?

Answer. In the 15 years I spent working on spectrum policy, I did not witness any instances in which poor coordination of domestic spectrum policy compromised national security missions. In the case of C-band (3.7–3.98 GHz), a lack of coordination involving the FAA led to a public controversy over whether the FCC's actions to authorize commercial use would interfere with radio altimeters, which are used on both civilian and military aircraft. In that case, however, prior to deployment of any 5G operations in the spectrum, there was extensive coordination between FCC, NTIA, DOT/FAA, and the mobile industry, and issues of potential interference were addressed to the satisfaction of the agencies. Thus, while this case involved a *potential* compromise to national security, the interagency process was successful in preventing an *actual* instance of compromising national security.

There were also claims made that the FCC's grant of authority to Ligado near GPS frequencies in 2020 could jeopardize national security, given that both the commercial sector and the military rely on GPS to obtain position, time, and navigation. I was not involved in working on those decisions during my government service. According to reports, however, Ligado never launched in that spectrum, so this decision did not jeopardize national security.

Question 6. Did those decisions put Federal systems and the public at large at risk?

Answer. I have not witnessed instances in which decisions actually compromised national security.

Question 7. What specific interagency coordination mechanisms would you recommend to prevent similar risks in the future?

Answer. First, it would be helpful to have a continuing, robust role for the Interdepartmental Radio Advisory Group (IRAC) and Interagency Spectrum Advisory Council (Council). The IRAC is essential in enabling agencies to advise NTIA as it develops policy, particularly on technical issues. The Council offers an interagency forum for high-level officials from agencies to resolve any spectrum policy issues that cannot be resolved at the working level. Further, for disagreements and disputes that cannot be resolved by the IRAC or the Council, it is essential for the White House—led by the National Security Council—to use the interagency process to ensure the right decisions are made to prevent risks to government missions, including national security missions.

At the same time, I would recommend that we remain open to incorporating new mechanisms, particularly if such mechanisms enhance White House leadership on spectrum, to ensure robust, effective coordination of spectrum policy decisions. While we should not replace any of the mechanisms above without thoughtful deliberation, there is always room for new approaches to ensure that effective spectrum coordination takes place.

Question 8. How do we advance commercial spectrum while respecting mission-critical Federal users and national security?

Answer. Based on most of the instances in which we have successfully made commercial spectrum available without jeopardizing Federal uses of spectrum, we need to take several actions:

- Congress should establish ambitious clearing targets, so that the Executive Branch has guidance on making spectrum available and agencies know that they must cooperate and share information in order for the legislation to be implemented within the timeline set by Congress.

- The heads of the FCC, NTIA, and the agencies should regularly meet and establish good-faith, transparent, and cooperative relationships so that they are able to avoid disagreements and disputes when possible.
- The heads of these agencies should also empower their engineers to work closely with engineers from other agencies so that they can solve technical problems.
- NTIA should play the role of an "honest broker" when agencies and the FCC have differing views, and should use its technical expertise to solve engineering challenges.
- The White House should provide robust leadership, including by instituting an interagency process to resolve disagreements and disputes.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. EDWARD MARKEY TO MATTHEW PEARL

Question. Should the Federal Communications Commission consider the national security implications of our existing GPS system in making spectrum allocation decisions?

Answer. Yes. GPS is used both by our military and the civilian sectors, including for national security operations. In making spectrum allocation decisions, the FCC should consider whether such decisions could interfere with GPS. At the same time, because GPS is extremely susceptible to malicious signals such as jamming and spoofing, it is critical that we develop a comprehensive "system of systems" for information on position, navigation, and time. Such a system could be used to back up and supplement GPS, and therefore reduce risks of interference. It could enhance the accuracy and reliability of position, navigation, and timing for both Federal and commercial users. Finally, I would note that quantum sensing may provide an alternative to GPS that is far more accurate and not susceptible to interference, though unlike other technologies to make GPS more accurate and resilient, it is challenging to predict precisely when quantum sensing will be ready for commercialization.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BEN RAY LUJÁN TO MATTHEW PEARL

Question 1. Is it important that we complete thorough studies on spectrum bands before the FCC moves forward with auctions?

Answer. I do not believe it is prudent to auction spectrum before solid technical work has been done regarding the conditions under which it will be made available. All the major bills that I am aware of under active consideration, however, do not require auctions before the FCC, NTIA, and the agencies to do such analyses. If a bill sets clearing targets for making spectrum available under a reasonable timeframe and allows flexibility for preserving Federal use in auctioned bands when necessary, such as by allowing shared use, then the FCC and the Executive Branch will be able to complete studies and ensure that Federal capabilities are preserved prior to any auction.

Question 2. Is it important that the relevant Federal agencies are coordinating and sharing information with each other regarding spectrum management?

Answer. Yes. It is critical that Federal agencies that use spectrum provide fulsome information regarding their use, plans, and analyses regarding co-existence issues with NTIA and the FCC. Some of our coordination challenges in the past, such as the conflict between the FCC and NOAA over 24 GHz, arose from an unwillingness to share the assumptions that went into agencies studies with the FCC and NTIA. This delays spectrum decisions and makes it difficult to get the Federal Government to adopt a "whole-of-government" view regarding how to proceed on specific spectrum decisions.

Question 3. Should industry and government partners be investing in developing innovative technology to solve spectrum challenges of today and prepare for new challenges down the line?

Answer. Yes. Both industry and the government have a vital role in developing innovative technology. First, government needs to make early-stage investments in R&D that would be too risky for industry, so that the United States is the first to develop new spectrum-based capabilities. Such investments should occur in close cooperation with the private sector. This will enable industry to invest in implementing those innovations in their networks and products when they are ready for commercialization. Further, it is important for the private sector to invest in R&D, given that they are sometimes able to identify opportunities to innovate in spectrum

use, and close coordination with the Federal Government will ensure that there is complimentary rather than duplicative spending on R&D.

Question 4. Should this administration continue the last administration's work in the National Spectrum Strategy to increase transparency around Federal spectrum usage?

Answer. Yes, efforts to increase transparency around Federal spectrum usage will help to ensure the Federal Government adopts the right spectrum policy. It is critical that, for unclassified government uses of spectrum, that those efforts capture not only when the spectrum is used for, but also the precise times, places, and technical details of such use. To capture that information, it is important for NTIA and the agencies to leverage advanced sensing technologies, which can accurately capture all the details of spectrum use.

Question 5. In spectrum reauthorization legislation, should Congress consider setting a dispute resolution process in statute similar to what was included in the National Spectrum Strategy under the prior administration?

Answer. I agree that it would be helpful to the Executive Branch and the FCC to codify long-standing procedures around dispute resolution. I should note that many of those procedures did not begin with the National Spectrum Strategy, but rather were captured and formally adopted in the Strategy. Having Congress codify those procedures will help to ensure that the dispute-resolution process is consistently used when proposed spectrum actions are being considered by the FCC, NTIA, or the agencies that use spectrum. While I agree that codification of procedures is a helpful step for Congress to take, it is also necessary for the White House to have high-level commitment to following those procedures, so that they are effectively implemented.

Question 6. Should this administration continue the last administration's work to bolster the spectrum workforce?

Answer. Yes. For the United States to be competitive in next-generation networks, it is necessary to attract, educate, and grow the spectrum workforce. This will require extensive collaboration between the Executive Branch, the FCC, universities and other research institutions, think tanks, and civil society organizations.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. LISA BLUNT ROCHESTER TO MATTHEW PEARL

Question. Congress typically waits to have technical feasibility studies regarding spectrum allocation in hand prior to authorizing auction authority to avoid problems. A number of studies are under way now. If we were to go ahead now without waiting for the studies, then what are the risks we could expect regarding commercial spectrum use? What are the risks to DoD systems or other Federal spectrum needs?

Answer. I agree that we should not auction spectrum before technical analysis has been done on the specific conditions under which such spectrum will be made available. There are numerous risks that could occur to national security and other Federal uses of spectrum if such an approach were adopted. For instance, we could interfere with the ability of DOD to test next-generation radars on its military bases, thus putting us at a disadvantage with the PRC as it attempts to leapfrog over our radar capabilities. As another example, we could effect the Department of Energy's Power Marketing Administration, which markets and delivers hydropower to dozens of U.S. states.

I would note, however, that all the major bills that are currently under active consideration in Congress (of which I am aware) would enable the FCC, NTIA, and the agencies to conduct such analysis before auctions take place. For instance, bills that set clearing targets for making spectrum available can build in flexibilities, such as allowing the FCC to make the bands available for exclusive non-federal use or shared use. Following the passage of a bill, the interagency process and associated technical work should take place to establish the conditions under which spectrum may be made available, including ensuring—before any auction takes place—that commercial use will not jeopardize national security.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. TODD YOUNG TO BRYAN CLARK

Question. Mr. Clark: My understanding is that China's strategy for wireless technology has been to secure exclusive licensing rights globally while restricting access. What is your perspective on China's approach?

Answer. China's approach to spectrum allocation has made similar portions of mid-band and high-band spectrum available to commercial mobile network operators (MNO) as in western countries.

However, China's government intends to dramatically increase the amount of spectrum available for Chinese MNOs over the next decade, which some fear could create an advantage for Chinese telecomunciations companies by allowing them to mature technologies that exploit wide areas of spectrum for mobile broadband and obtain revenue that allows them to make more inroads into telecommunication networks of U.S. allies.

An element of Chinese spectrum management that is often not discussed is the role of the People's Liberation Army (PLA) in controlling spectrum access. The PLA has reserve personnel embedded in China's radio management centers around the country and in Chinese MNOs.

These personnel are in place to move commercial users out of military frequencies whenever needed. In addition to during emergencies, which is similar to the United States, these reserve PLA personnel also move commercial users out of military spectrum for routine testing, training, and other operations.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. TED BUDD TO BRYAN CLARK

Question. In your written testimony you state "Beijing disingenuously claims that it has given more spectrum to Chinese telecommunication companies when in fact the People's Liberation Army (PLA) retains the authority and mechanisms to routinely displace commercial spectrum users." Can you expand on this and explain the differences between the Chinese and U.S. mechanisms to displace commercial spectrum users for national security purposes?

Answer. An element of Chinese spectrum management that is often not discussed is the role of the People's Liberation Army (PLA) in controlling spectrum access. The PLA has reserve personnel embedded in China's radio management centers around the country and in Chinese MNOs.

These personnel are in place to move commercial users out of military frequencies whenever needed. In addition to during emergencies, which is similar to the United States, these reserve PLA personnel also move commercial users out of military spectrum for routine testing, training, and other operations. See John Dotson, "Military-Civil Fusion and Electromagnetic Spectrum Management in the PLA," Jamestown Institute, October 8, 2019, *https://jamestown.org/program/military-civil-fusion-and-electromagnetic-spectrum-management-in-the-pla/*.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO BRYAN CLARK

Question 1. The Spectrum Pipeline is Flawed. We have seen firsthand how a fractured domestic approach to spectrum management threatens domestic and national security. The former Administration's hands-off policies resulted in interagency disputes.

Mr. Clark, what risks to national security and American defense strategy can arise from decisions to relocate spectrum currently relied upon by military systems?

Answer. Military radars, radios, and electronic warfare systems are essential for military operations at home such as countering missile, drone, and air threats as part of the Trump Administration's Golden Dome initiative. These systems operate predominantly in the S-band (especially the lower 3 GHz band) and X band (8–12 Ghz), which are attractive to commercial telecommunications for the same reasons—effective range, relatively high-bandwidth—that makes them valuable for military operations. Relocating them to new frequencies will take more than a decade and cost more than $100 billion. But forcing military systems to operate in the presence of full-power 5G telecommunications will create interference and prevent effective air defense.

U.S. forces need to train with radars, radios, and electronic warfare systems in and around U.S. territory to enable them to fight effectively overseas. If they are unable to use the spectrum currently allotted for sensors and communications, they will not be able to train in the same way they would fight, reducing their proficiency when troops arrive at the battlefield.

Military operations overseas also increasingly depend on U.S. forces being able to operate in unexpected parts of the spectrum to avoid enemy detection and classification—operations ships and aircraft need to train for in the United States. Moreover, countering adversary sensors will require jammers that operate in adversary fre-

quencies, such as C-band to deceive synthetic aperture radar satellites. U.S. forces will need to begin these electronic warfare operations in U.S. territory to ensure their deception operation is effective. If U.S. forces cannot use these frequencies, they will be easier to track and target.

Question 2. How do shared spectrum approaches help us avoid those risks while still helping us find new spectrum for commercial use?

Answer. Shared spectrum can allow military operations to continue unimpeded while affording access for commercial users. Military systems do not need continuous access to S and X-band frequencies, for example, in all geographic regions. Spectrum can be shared statically, by establishing time and geographic limitations for different users, such as under the America's Mid-Band Initiative Team (AMBIT) effort. Spectrum can also be shared dynamically, as in the Citizen's Band Radio Service (CBRS), by adopting technological and procedural solutions that enable commercial communications to proceed most of the time, but automatically shift them to another band when a military system energizes in the area.

Spectrum sharing approaches like these can enable commercial users to gain at least periodic or geographically limited access to new areas of spectrum. This requires industry to incorporate additional technology or combine multiple regions of spectrum, but is the compromise that allows both military and commercial activities to use the same valuable regions of spectrum.

Question 3. How do we advance commercial spectrum while respecting mission-critical Federal users and national security?

Answer. By adopting geographic and time constraints, as in the AMBIT program, or by using dynamic spectrum sharing, as in CBRS, the government can create commercial opportunities while protecting incumbent Federal users like the military and law enforcement that face an increasingly challenging threat environment at home as well as overseas.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BRIAN SCHATZ TO BRYAN CLARK

Question 1. The Department of Defense (DoD) has significant equities in Hawaii and the Indo-Pacific, including systems that are being actively funded and built with specific spectrum parameters in mind.

How would modifications to DoD spectrum allocations impact existing requirements for ongoing projects related to cruise and ballistic missile radar detection systems that the DoD has established project timelines and appropriations for to develop and procure?

Answer. The DoD operates an Aegis Ashore radar and interceptor launcher at the Pacific Missile Range Facility (PMRF) in Hawaii to test the Aegis Weapons System's ability to defend against cruise and ballistic missile threats. The facility was primarily built to test Aegis Ashore systems that were established in Eastern Europe but is now used to test new capabilities for shipboard Aegis systems as well. The radar for this system operates in the lower part of the 3 Ghz band for search and in the X-band (8–12 Ghz) for targeting. Relocating the system to other frequency bands will increase the system's cost by hundreds of millions of dollars and introduce years of delay in testing.

The DoD is considering using the Aegis Ashore installation at PMRF to also support homeland missile defense, where it could be incorporated into the Trump Administration's Golden Dome initiative. In addition to increasing the system's cost, changing its frequency bands will reduce its performance in defending the United States from ballistic and hypersonic missile threats.

Question 2. The National Oceanic and Atmospheric Association (NOAA) operates earth observation satellites that are crucial to weather forecasting, including tracking extreme weather events.

What technological capabilities currently exist to allow in-band sharing of spectrum?

Answer. Earth observation satellites depend on downlinks in the L (1–2 Ghz) and S (2–4 Ghz) bands to send data to earth. Government and commercial users could employ technologies for dynamic spectrum sharing like that used by the Citizen's Band Radio System (CBRS) to both operate in these bands.

Question 3. What technological capabilities currently exist to block or attenuate out-of-band emissions?

Answer. Radars and radios use a combination of digital beamforming and antenna design to reduce out-of-band emissions from being transmitted or received. For example, by using software and phased array antennas, radars and radios can control

the emissions from each antenna element and use destructive interference to narrow the physical beam of energy being transmitted or received by the system. This can help reduce the likelihood emissions will exceed geographic bounds established under static spectrum sharing schemes like the AMBIT program.

To reduce the likelihood of signals leaving outside their assigned frequency bands, radars and radios can used digital radio frequency systems on a chip (RFSOC) and software-defined radios (SDR) that program their waveforms to include more data in each channel or frequency. These systems can also increase their power level to allow a higher reliability of data transfer and thereby transmit more data on each channel (or frequency) and reduce the need to transmit data over multiple channels simultaneously.

Question 4. In light of potential impacts to adjacent bands, shouldn't emissions that cross into adjacent bands trigger the need for a spectrum sharing agreement similar to in-band sharing? In other words, if one party's use of a band includes both in-band and out-of-band components, shouldn't the Spectrum Relocation Fund be fully compensated for both?

Answer. All radio transmitters experience some level of out-of-band emissions because of imperfections in antenna hardware. Spectrum allocation schemes like those used by the FCC have employed "guard bands" to prevent signals from one assigned set of frequencies from spilling over into adjacent bands. Digital RFSOC and SDR technologies allow the signals generated by radars and radios to be narrowed, which allowed the FCC to shrink or eliminate guard bands in some areas of the spectrum. This creates the potential for out-of-band signals interfering with adjacent frequencies. When this happens, compensation should be triggered if the power level of the out-of-band emission is such that it interferes with the adjacent band's uses.

Question 5. Tribal lands, including reservations, Hawaiian Home Lands, and Alaska Native Corporation lands, account for roughly 11 percent of all land in our country. Private sector investment and thus access to spectrum here is historically low.

What national security and economic risks does the digital divide in rural and Tribal areas present, especially those that are near military installations?

Answer. The governments assignment to the military of frequencies—especially in L, S, C, and X-band—for radars and radios on training ranges and other large facilities can disincentivize telecommunications companies from investing in adjacent territory. To implement dynamic spectrum sharing schemes as in CBRS, mobile network operators (MNO) may need to build more infrastructure to allow transmitters to operate at low power because each tower's coverage will be lower than a high-power installation. If they implement a static sharing scheme like AMBIT, MNOs would need to establish a more complex architecture using different power levels and frequencies around the military installation to avoid conflicts with military systems.

However, MNOs are also disincentivized from investing in these areas due to the low population density, which would offer few users to fund the infrastructure to provide mobile communication services. Bridging this digital divide will likely require government support to build out mobile communications infrastructure and help mitigate the costs of implanting spectrum sharing schemes in rural areas around large military installations.

Question 6. Do you see a role for dynamic spectrum sharing in Tribal areas, especially those that border military spectrum allocations?

Answer. Yes, static spectrum sharing schemes like AMBIT and dynamic spectrum sharing like CBRS could be employed in these regions. However, both will impose costs on network operators.

Government support may be needed to ensure MNOs can recoup their investment in building out these networks.

Question 7. Given the growing competition for mid-band spectrum between military and commercial users, how should policymakers view Tribal governments in this dynamic?

Answer. Tribal governments should be viewed as a partner in allocating spectrum in their regions, although spectrum still needs to be allocated nationally since radio transmissions do not recognize tribal or state boundaries. Tribal governments should be brought into collaboration with regulators, users, and industry to develop approaches for providing telecommunication services on tribal lands, especially mobile communications that are needed for safety and security. Spectrum Relocation Funds may need to be employed to help compensate network operators for the cost of building out infrastructure on tribal land and incorporating spectrum sharing technologies.

Question 8. Do Tribes represent a unique category of spectrum stakeholders, and what role does direct access to spectrum for them play in expanding competition in underserved areas?

Answer. Tribes are a governmental entity and should therefore have a voice in deciding how spectrum is allocated in their region. This is especially true for regions near military installations where a combination of low population density and spectrum sharing requirements disincentive network operators from building infrastructure.

Question 9. As the U.S. seeks to expand broadband to underserved areas—including Tribal lands—while also ensuring sufficient spectrum for national security and commercial purposes, what policies should Congress consider to balance these competing needs?

Answer. Congress should consider ways to incentive industry to invest in a combination of spectrum sharing schemes and network infrastructure that can address these underserved areas while protecting the need of military users to periodically access priority regions of spectrum.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. EDWARD MARKEY TO BRYAN CLARK

Question. Should the Federal Communications Commission consider the national security implications of our existing GPS system in making spectrum allocation decisions?

Answer. Yes. The GPS system operates in the L band (1–2 Ghz), which is also a popular frequency band for satellite communications because it offers a combination of long-range and relatively high data rates. GPS signals are also very low power, which makes them very susceptible to jamming and interference, as seen in Ukraine and Eastern Europe due to Russian electronic warfare operations.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. LISA BLUNT ROCHESTER TO BRYAN CLARK

Question 1. Congress typically waits to have technical feasibility studies regarding spectrum allocation in hand prior to authorizing auction authority to avoid problems. A number of studies are under way now. If we were to go ahead now without waiting for the studies, then what are the risks we could expect regarding commercial spectrum use? What are the risks to DoD systems or other Federal spectrum needs?

Answer. The risks of auctioning spectrum that DoD is currently using are significant to extreme, depending on the mission. U.S. military forces depend on access to commercially-valuable spectrum—such as S-band (2–4 Ghz), C-band (4–8 Ghz), and X-band (8–12 Ghz)—for radars and radios. U.S. forces need to train on these systems in and around the U.S. to prepare for combat overseas. If they cannot train in the United States, they will be less proficient and effective.

More important, the military needs access to these regions of the spectrum in the United States to support homeland defense. Initiatives like the Trump Administration's Golden Dome air and missile defense system will depend on access to S and X-band around priority defended locations around the country and potentially over the whole country if satellite-based radars are used as part of the architecture. If this spectrum is unavailable over the U.S., Golden Dome will only be able to engage threats as they enter the U.S. and would be unable to shoot them down once they are over U.S. territory.

For U.S. military systems to move out of these frequency ranges will take more than a decade and nearly $100 billion, and in the end they will be less capable because they will use less useful part of the spectrum.

Question 2. Maintaining our economic competitiveness globally and creating conditions for innovation are important, and I am open to strategies to put our country in the best possible position. Still, a top priority must be ensuring that we are prepared in the event of aggressive actions by an adversary. Mr. Clark, in your testimony, you noted that ensuring the military has the spectrum they need is important for countering China. Can you expand on how China would benefit if DoD's spectrum access was overly constrained?

Answer. If the U.S. military is limited to narrower ranges of frequency, the Chinese military could more easily detect and classify U.S. forces by their emissions. One of the techniques U.S. forces might use to confuse Chinese sensing and sensemaking is to move to other areas of the spectrum and use different waveforms

than normal. Although U.S. commanders would not want to routinely operate using these "war-reserve modes", their forces would need to periodically train on them in the United States and their capabilities would need to be evaluated on DoD ranges.

Electronic warfare operations require that U.S. forces emit in frequency ranges that U.S. forces do not normally use. Chinese radars and radios use similar frequencies to U.S. systems because their physical properties are beneficial, but Chinese systems do not use the same frequencies. If U.S. forces are constrained to a narrow band of frequencies, then they cannot train or develop electronic warfare systems that are effective against Chinese sensors and radios.

Question 3. Mr. Clark, in your testimony you cited spectrum-sharing as a strategy to move forward. Do you think it is feasible that both DoD needs and commercial needs could be met through carefully planned spectrum-sharing?

Answer. Yes. DoD operations in the United States (except perhaps for Golden Dome) are not continuous and do not happen across the entire country. Static spectrum sharing schemes like AMBIT that use geographic and power constraints to prevent spectrum conflicts could be employed outside the areas around military installations. Dynamic spectrum sharing arrangements like CBRS could be employed in areas in or near military installations, where commercial and civilian users are forced to move to another frequency when a military user begins emitting. However, these schemes create complexity and cost for mobile network operators, and reduce the value of the associated spectrum. The auction approach and timing need to account for the time and investment needed to establish these schemes before commercial operations commence.

Question 3a. Do we have the feasibility studies needed to move forward with spectrum-sharing? If not, what do we need to do?

Answer. These studies are underway now, but these studies may be too open-ended to provide actionable recommendations. The study parameters may need to be adjusted to provide analysts clear goals for the amounts of spectrum they should seek to make available and in which regions, as well as accounting for the costs associated with implementing appropriate spectrum sharing arrangements.