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Roundtable Report

Resolving Interference Conflicts Among "Highest and Best" Uses of Radio Spectrum

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In Gratitude

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Table of Contents

Executive Summary

Avoiding and resolving harmful interference has been a core objective of spectrum policy over the last century. Yet, establishing the highest and best uses that should receive priority and policing interference between them has been an unending source of dispute and resists easy resolution. Common definitions, such as what constitutes harmful interference, as well as policy decisions, such as what uses best serve the public interest, remain elusive. On March 21, 2022, the Silicon Flatirons Center for Law, Technology, and Entrepreneurship at the University of Colorado Law School convened an invitation-only roundtable in Washington DC titled, "Resolving Interference Conflicts among 'Highest and Best' Uses of Radio Spectrum." Roundtable participants, comprised of policymakers, academic experts, and stakeholders, gathered to discuss the state of interference resolution policy, identify areas for attention, and suggest possible solutions. Several themes emerged through the day that carried across discussions on the historical, regulatory, and technological approaches to interference resolution.

Common Language and Definitions: Whether in the context of defining the "public interest" standard, identifying highest and best uses, or establishing what constitutes harmful interference, participants highlighted the need for agreement on definitions. Lack of common definitions contributes to uncertainty and conflicts. Similarly, participants agreed that the consequences of an insufficient common language hinders proceedings regardless of the band at issue in a particular dispute. Too often, efforts to engage in joint problem-solving fail to progress because a lack of a common language prevents effective information sharing. As a result, parties become mired in miscommunication, stalling efforts at negotiation until disputes build into catastrophes that often result in outside intervention by the White House or Congress.

Mutual Trust, Respect, and Collaboration: Participants generally agreed upon the need to rebuild good faith and mutual respect, both between various stakeholders across industries, economic sectors, and government agencies. Proceedings, such as the recent C-band proceeding (see Section II), have been marked by mistrust and confrontation as stakeholders in both industry and government are unable to find sufficient common ground for collaboration. Collaboration is also hobbled by the risk that the other party might escalate a negotiation, engaging in collateral attacks and efforts to go-around government authorities. Whether within government agencies, between them, or with and between industry stakeholders, participants called for efforts to rebuild collaboration and common understanding of the issues. Participants also noted that disputes between government regulators, as well as lack of a clear hierarchy, exacerbates conflict in proceedings and breeds uncertainty for participants as to which mission will win out at any given time.

Applying Advanced Technology to Enable a Future of Dynamic Sharing: Through discussion and brainstorming, participants anticipated that changes in policy and regulations will need to be made in support of a future of dynamic spectrum sharing. Increases in both technological capability and demand has strained a regulatory regime originally built on exclusive allocation. Participants emphasized the importance of policy that supports both flexibility and certainty, ranging from deployment of more precise technology, such as receiver standards, to the increasingly important role that mitigation and enforcement would need to play in a dynamic environment.

This roundtable was a starting point. Participants proposed some solutions, but largely focused on the challenges that need to be faced and how they fit into the evolution of spectrum policy. Participants agreed that further work to flesh out these challenges and begin to construct solutions must take place. Silicon Flatirons will host a conference in Fall 2022 to further explore the challenge of interference resolution with the goal of specifying actionable recommendations.

Introduction

On March 21, 2022, Silicon Flatirons convened an invitation-only roundtable in Washington DC titled, "Resolving Interference Conflicts among "Highest and Best" Uses of Radio Spectrum." The half-day event gave a diverse group of interested and informed members of the spectrum community a unique opportunity to engage and develop recommendations that may avoid or quickly remedy future spectrum conflicts. Participants met and conversed under the "Chatham House Rule,"[1] examining topics ranging from specific lessons learned to areas in need of future attention, and the variety of legal, technical, and circumstantial components that undergird spectrum policy as a whole.

The conversation focused particularly on how the spectrum community understands harmful interference and resolves conflicts arising from instances of harmful interference. Radio spectrum allocation and policy battles often result in extended and recurring fights among competing, incompatible uses and users. Recent conflicts include Ligado/LightSquared and the various GPS stakeholders, and 5G and radar altimeters. While stakeholders employ all sorts of tactics to demonstrate to policymakers how their service or technology reflects the "highest and best" use of scarce spectrum resources, a frequent area of dispute often centers around allegations of "harmful interference" between competing uses. Whether in the context of commercial mobile broadband communications, support for national security, safety of life and property, or scientific discovery, a coherent approach to resolving interference conflicts often remains elusive.

The roundtable explored the legal, institutional, technical, economic, and social conflicts that may arise when multiple interests collide over access to spectrum resources, and how these conflicts may be resolved. A series of three moderated discussion sessions considered the history of spectrum policy, spectrum governance, and new developments in spectrum technology. These topic areas served as three lenses through which to explore: the conflicts that exist between spectrum users and how the conflicts came about; why some conflicts were resolved while others were exacerbated; what could have been done to avoid or prevent conflicts; what technologies and policies may help resolve conflicts; and how government agencies, industry actors, and regulators can meaningfully approach conflicts in the future.

This report examines each session in a separate section. Each section begins with a summary of a fifteen-minute keynote that introduced each topic, before reporting the central areas of discussion between participants. Each section concludes with three to five bulleted ideas the session identified for future engagement. These are presented as statements to be evaluated, challenged, and debated to support the development of recommendations during a Fall 2022 conference.

[1] Under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker may be revealed. This rule will be modified to allow participants to be quoted in the report, but only with their permission.

Harmful Interference Session I: Historical Perspective

Keynote Summary

The first session considered interference resolution from a historical perspective, including lessons learned from history that could inform future progress and areas where historical patterns may not effectively meet contemporary challenges. Spectrum policymakers have historically been obligated to "prevent interference" and "generally encourage the larger and more effective use" of spectrum, as purportedly reflected in the public interest standard of the 1927 Radio Act and the 1934 Communications Act,[2] when making spectrum allocations and assignments.

Peter Tenhula gave a brief introduction and history of the past 100-plus years of interference conflicts. Tenhula, a Senior Fellow at Silicon Flatirons, recently retired from federal government service after nearly 25 years (combined) at the National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC), in addition to work at a radio-technology startup, Shared Spectrum Company. He also recently served as the chair of the Interdepartment Radio Advisory Committee (IRAC), which currently advises NTIA and was formally established exactly 100 years ago in March 1922. Tenhula's current research interests focus on the history of spectrum management and policy in the United States and at the International Telecommunication Union (ITU), especially governance frameworks and resolution of interference disputes.

The twin objectives of spectrum policy are to provide radio frequency allocations and assignments for different radio services and users, and to avoid interference between services. This year, 2022, holds special significance as the 100-year anniversary of the establishment of the IRAC. Many spectrum policy proposals teed up in the early 1920s made their way into the 1927 Radio Act and early international agreements, and much of the same regulatory and institutional frameworks and concerns remain central to addressing interference problems today.

Prior to the 1920s, international and domestic policy discussions were approached as an extension of the existing wired telegraph and telephone regulations to new wireless telegraphy technologies, but with the added complexity of ensuring that operations do not cause interference to other countries and users. Early efforts to regulate wireless telegraphy, therefore, were characterized by solving interconnection and compatibility challenges, ensuring high quality maritime communications to respond better to shipping accidents (e.g., the Titanic in 1912), and meeting the needs of the U.S. military in World War I (1917-1919).

After providing an overview of spectrum regulation over the decades from the 1900s to the 1990s, Tenhula focused his presentation on several milestones from the 1920s that, as a result of the radio broadcasting boom, have shaped spectrum policy. National and international conferences held in the 1920s, leading to the 1927 Radio Act as well as a revised International Radiotelegraph Convention (and General Radio Regulations) established the foundation on which the status quo can be traced.

The spectrum policy framework established in the 1920s built upon several key themes. First, of course, was the need to avoid or prevent interference among the various users of the radio frequencies. The chosen approach was the frequency allocation model officially established at the 1927 International Radio Conference held in Washington, DC.[3] Second, the compromise that resulted in the establishment of an "independent" Federal Radio Commission did not resolve the institutional challenges and governance conflicts that have re-arisen through the years. The other recurring themes

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[2] *See, e.g.*, Radio Act of 1927, Pub. L. No 69-632 § 4(f), 44 Stat. 1162, 1163 (Feb. 23, 1927); Communications Act of 1934, Pub. L. No. 73-416 §303(f), (g), 48 Stat. 1064, 1082 (June 19, 1934).

[3] *See* Stewart, Irvin, "The International Radiotelegraph Conference of Washington," 22 Amer. J. of Int'l Law 28, 48 (1928), available at (with subscription) https://heinonline.org/HOL/P?h=hein.journals/ajil22&i=36.

Tenhula identified (but did not discuss) were facilitating interoperability/interconnection; ensuring competition; preserving public safety and the national defense; and maximizing efficiency.

Tenhula presented examples of several lessons learned in the 1920s that have helped shaped spectrum policy over the last century. One involved the significant efforts, pushed by then Secretary of Commerce Herbert Hoover, centered around voluntary government and private sector collaboration, the breakdown of which led to "chaos" and enactment of the 1927 Radio Act. The four National Radio Conferences that Hoover convened demonstrated some of the benefits as well as the limits of such multistakeholder, industry-government cooperation.

A series of court cases restricted Hoover's limited authority, and the U.S. Congress enacted a framework that prevented private "ownership" of the airwaves and that required spectrum users to operate in the "public interest, convenience or necessity."[4] As a result, the new statutory and treaty provisions adopted in 1927 to address the current crisis and prevent future conflicts shifted to an *ex ante* approach to spectrum policy that emphasized interference prevention through frequency band allocations. At the same time, policymakers recognized the continued need for *ex post* measures to, for example, address lack of compliance and inevitable surprises.

In the 1930s, the Federal Radio Commission became part of the FCC. President Franklin Roosevelt asked the FCC Chairman, Anning Prall (1935-1937), to oversee the IRAC and advise the President on the allocation and assignment of frequencies under Section 305(a) of the Communications Act of 1934. Nevertheless, the FCC and the IRAC were considered "independent bodies, having equal authority to make frequency assignments in their respective fields, and they coordinate their day-to-day activities through the medium of FCC's membership on the IRAC."[5] This coordination function was embodied in the first memorandum of understanding (MOU) between the IRAC and the FCC in 1940. The IRAC was responsible for managing frequencies for federal agencies, while the FCC was responsible for non-federal agencies, organizations, and interests.

Spectrum activities during the 1940s centered around military needs for World War II with oversight directed by a Board of War Communications established by President Roosevelt. Following the war, the IRAC and the FCC spent several years developing a comprehensive table of frequency allocations that was then was presented to the 1947 Atlantic City International Telecommunication Conference.

In the 1950s, the centralization of telecommunications policy governance was first attempted by the White House with President Truman's appointment of the first Telecommunications Advisor to the President (TAP), Haraden Pratt (1951-1953). This and other recommendations of the President's Communications Policy Board led to the reconstitution of the IRAC under the TAP and the FCC withdrew as a regular "member" of the IRAC, appointing a liaison to the committee instead. These and other changes led to a policy focus reflected by the impact of the Korean War and budding Cold War, that emphasized emergency preparedness and defense mobilization.

More blue-ribbon committees and boards along with comprehensive congressional hearings continued through the late 1950s into the late 1970s, all delving into increasingly complex spectrum management problems. Private sector advisory groups, including the Joint Technical Advisory Committee (JTAC) of the Institute of Electrical and Electronics Engineers (IEEE) and the Electronic Industries Association (EIA) and the Telecommunication Science Panel of the Commerce Technical

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[4] See Bensman, Marvin R., "The Beginning of Broadcast Regulation in the Twentieth Century, Chapter IV, Regulatory Breakdown and the Passage of the Act of 1927" (McFarland & Company, Inc. 2000);

[5] Webster, E.M., "The Interdepartment Radio Advisory Committee, It's History, Motive Operation, and Relationship to Other Agencies," 33 Proc. of the I.R.E. 495, 497 (Aug. 1945), available at https://worldradiohistory.com/Archive-IRE/40s/IRE-1945-08.pdf.

Advisory Board, developed a number of recommendations for the Eisenhower, Kennedy, Johnson, and Nixon administrations for improving how spectrum was allocated and managed by the FCC and the IRAC.

The NTIA was established by President Carter in the late 1970s by Executive Order, moving oversight of most telecommunications policy and spectrum management matters (with the exception of emergency planning/preparedness) out of the White House to the Commerce Department. In the early 1990s, the NTIA Organization Act[6] codified NTIA's telecommunications policy and spectrum management functions.

Since the 1920s, spectrum allocations and licensing had been based on the "public interest" concept being adjudicated among prospective licensees through comparative hearings. This led to elaborate claims as each applicant tried to outdo the others with lengthy justifications and hearings. The 1980s saw a brief experimentation by the FCC with lotteries to assign cellular telephone licenses, which was soon replaced with auctions in 1993 as part of a comprehensive budget bill that also included requirements to reallocate and auction government spectrum to nongovernment uses.

Wrapping the past several decades back to the foundational work of Herbert Hoover in 1920s, Tenhula emphasized the collaborative efforts that took place and the value of multi-stakeholder conferences and communication. The early days of radio regulation also previewed ongoing challenges characteristic of the history of spectrum management: conflicts between users and uses arising from interference; the difficulty of mediating between established users and new entrants; and, development in technology and ever-increasing demand requiring ongoing allocation and reallocation of spectrum. Since the beginning, spectrum policy has been a key component of telecommunications policy with corresponding challenges of maximizing technological capabilities and making difficult policy choices between competing uses.

Throughout the discussion following Tenhula's overview, roundtable participants explored the continued role and importance of the century-old public interest standard, the benefits of planning and reallocation in response to (or anticipation of) technological development, the deep impacts of institutional conflict, and the potential for new or re-imagined policies to meet new challenges.

The Public Interest Standard

One area of discussion considered the application of the public interest standard—the threshold standard for broadcasters to receive and operate a license. The standard currently presents current benefits, but expansion of its scope has caused strain and tension, if not conflict, in its application. Roundtable participants acknowledged the benefits the standard continues to provide. Many agreed that the public interest standard has undergone dramatic changes over time, stretching to encompass various—sometimes competing or conflicting—uses. This led some to question both the standard's coherence and its ongoing utility.

The changes in the use of the public interest standard over time have been vast, shaping both the obligations of broadcasters and the evaluation and application of the standard by government bodies. One participant commented that the standard has never truly been defined, leading to proposed legislative elimination of the standard in 1978-79.[7] And yet, the standard remained, and continues to remain, an important piece of the legal and conceptual framework of spectrum management.

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[6] National Telecommunications and Information Administration Organization Act, Pub. L. No. 102538, 106 Stat. 3533 (codified at 47 U.S.C. § 901904).

[7] ERWIN G. KRASNOW ET AL., THE POLITICS OF BROADCAST REGULATION 253 (3d. ed.,1982).

Participants wondered whether establishing a definition would truly be a useful goal. To start, a precise definition might cause friction given the ongoing evolution of how the public interest has adapted over time as new applications and ways of communicating have developed. Additionally, the use of the public interest as a legislative standard has perversely required all would-be licensees to claim it, leading it to be tacked on to so many opposing uses as to be potentially rendered meaningless. Finally, numerous Congressional declarations in legislation since the 1990s have taken to explicitly stating what the FCC must consider in its public interest analysis, further muddying the waters and complicating the prospect of establishing a single, coherent definition.

Defining the public interest remains one of the persistent challenges of spectrum management. Participants discussed radio astronomy as an important use case exemplifying the difficulty in adopting a consistent/coherent definition of the public interest. At first glance, allocation for radio astronomy poses an apparent paradox since it does not actively use spectrum, but requires access to spectrum not being actively used. Is radio astronomy a "higher and best use" than a consumer application? Allocating spectrum for this beneficial non-use nonetheless requires a policy decision determining not so much what *satisfies* the public interest standard, but what should be *prioritized* under the public interest standard. That is, given the benefits of scientific non-use, how should policymakers weigh public interest against public preference? One participant suggested that public preference would likely come down on the side of ever-increasing consumer demand for increased spectrum access, thereby impacting radio astronomy and other scientific applications.

Taking the use case further, radio astronomy also poses a perfect example of the lack of clarity in defining not only the public interest standard, but even the understanding of "use." There is no requirement that radio astronomy be described as "beneficial non-use." Such a description invokes a narrower understanding of use as exclusively active use; a broader understanding easily encompasses scientific study as "use" without further qualification. Again, the way terminology is understood and employed to establish a "highest and best use" both reflects and perpetuates necessary policy decision-making. While many prioritizations may satisfy the public interest standard, development and justification of the standard to make allocation decisions varies by viewpoint and values.

Participants disagreed about the extent to which importance of the public interest standard may be waning as a practical and political matter. One participant suggested that, of the four government spectrum policymakers—the FCC, Congress, NTIA, and the White House—only the FCC is obligated to consider the public interest standard. Not only do the other three entities have different missions, but, as discussed above, Congress has recently increasingly intervened to instruct the FCC what it must consider under the public interest standard, further attenuating the meaning and relevance of the standard. In that context, the standard may be in the process of being absorbed into Congressional instruction.

Allocation

Another topic of conversation focused on the potential for historical legislation or regulation to aid spectrum planning, provide authority for creative new applications, or inform longstanding areas of uncertainty. Many participants commented on the potential for history to provide rich data points from which to plan or approach new problems. For example, one participant noted that effective usage has grown by an average factor of ten, every twenty years. Given five good data points, this growth trend could allow policymakers to plan in consideration of anticipated growth in usage over the next twenty years. Nonetheless, participants debated the utility of history. Some provided examples where history has provided useful insights and governance models, while others emphasized the importance of looking forward.

On one hand, even if competing demands seem more intense today, allocation and reallocation are not new processes. Consideration of historical proceedings, particularly which use arguments were granted or denied allocation, could inform modern proceedings and policy choices. These considerations could also be expanded, beyond policy and regulatory history, to include the social and technological developments that historically shaped policy. For example, a number of historical changes were the product of changes in boundaries. In the1920s international travel and communication were just beginning, no one was working in outer space, and urban and rural life looked very different. As loss of previously clear boundaries gave rise to issues by, for example, introducing interference in some commercial uses where there was none before, spectrum policy was forced to adapt.

Thus, historical transitions in allocation and reallocation could provide useful insight today. Given the benefit of hindsight, knowing what uses won out previously, the arguments made that led to allocation—and exclusive licenses—for certain uses to be granted, expanded, or denied, could provide insight. For example, how did debate in the era of attaining high band allocations differ from struggles that, for example, led the FCC to carve out TV channels retroactively? It is also possible that creative approaches to using historical legislation might be available and some have already been applied. For example, in 2002 the All-Channel Receiver Act of 1962 was used as a basis to guarantee the transition from analog to digital broadcasting, an unimagined (and certainly unintended) use of the act when it was passed.

On the other hand, there remains a decided "newness" to some challenges today. Unlike previous regulators, policymakers today cannot rely as much on the ability to allocate new, previously unused bands to solve spectrum crowding. Similarly, some interference problems today are novel by definition, characterized by loss of boundaries that, historically, clearly delineated between uses or users.

Specifically, one participant put forth an idea in academia that has specifically challenged the allocation model over the last decade: "spectrum is an infinitely renewable natural resource that has been artificially regulated into scarcity by our policies." Meaning, the approach of making specific allocations that guarantee absolute interference protection on those allocations, is a mindset going back to the beginning of spectrum policy that may no longer be beneficial.

The struggle at each stage of evolution to bridge the gaps between allocation, use, and use for an intended purpose only exacerbates this artificial scarcity. This struggle is made all the harder by an attitude of intense, absolute ownership of spectrum by some licensees. Lack of definitions or common agreement, as well as lack of data regarding how much allocated spectrum is actually used (and how it is used) feed into uncompromising stances and frustrate collaboration and flexibility. In addition to the discussion, below, considering increased data usage, some proposed that these conflicts might give reason to reconsider the current allocation model as a whole—or at least consider "smarter" allocation that might ease tensions arising from absolutist claims to spectrum.

Allocation also continues to be plagued by challenges relating to use, definitions, and enforcement. Allocation does not guarantee use, nor use for the intended purpose. This challenge is aggravated by the lack of common understanding of what constitutes "use" and lack of data on actual use. These, in turn, hamper the ability to evaluate the success of interference management via allocation.

Underlying all of these issues remains the unanswered cornerstone to managing interference: what constitutes harmful interference? While many participants agreed that harmful interference is more than a single dB or loss of a couple nanoseconds of signal that does not damage the coherence of the overall signal—and is less than total debilitation—no clear, quantitative definition currently exists.

These discussions highlight areas where history can only offer limited insights at best, because history has offered no solutions. Historical commitment to a very conservative allocation approach left a void in problem-solving: there are few, if any, cases of actual, systemic interference that resulted in new policy, to draw on. Lack of a clear definition of interference opens the door to heated arguments. Even if most agree that a single dB of interference, for a single microsecond, does not constitute harmful interference, arguments are still made to that effect when conflicts escalate due to the high-stakes nature of these decisions. As increased demands drive smaller and smaller margins between allocations, the next era of policymaking might require not only continued best efforts to avoid interference, but also increased investment in developing policies that accommodate some kinds or levels of interference—i.e., policies that provide for both avoidance and mitigation of interference.

Institutional Conflict

In what became a theme that resurfaced frequently through the day, participants discussed a concept noted on Tenhula's slides: institutional conflict breeds spectrum conflict. The reverse also surfaced: that spectrum conflict can breed institutional conflict. Participants offered a number of differing views on institutional conflict. Some felt that there is a decided newness to institutional conflict today, while others pointed to historical examples of conflict with some resonance to the challenges of today. Participants also discussed several aspects of the importance of "institutional missions" across government agencies in creating and exacerbating institutional conflict.

The loss of "clean" missions of agencies has caused significant conflict. One participant commented that, historically, Congress developed spectrum policy out of committees with the primary interest of building revenue for the treasury, while the FCC only had to focus on public interest, chiefly in the form of convenience and necessity. However, a consistent and intensifying problem has been growing discontent regarding representation of government agency interests. The FCC, NTIA, Congress, and the White House largely pursue different, even conflicting or internally conflicted, missions with no easy reconciliation between them.

In particular, the recent obligation upon NTIA to make the most possible revenue in repurposing certain bands from federal to commercial use[8] *and still* look after the interest of government agencies introduced a fundamental conflict. Some felt that this has contributed to the breakdown of comity between government agencies and has caused agencies to lose trust in the NTIA. Other participants agreed, echoing the sentiment that NTIA's added obligation created a sense within agencies that they no longer have a voice or advocate, and that loss of trust in NTIA to resolve problems has caused more and more agencies to go around the process

The impacts of these mission-driven conflicts are of no small importance; differing institutional missions have real and lasting consequences. In addition to examples given throughout the day from C-band to Ultra-Wide Band (UWB) to Advanced Wireless Services (AWS), participants looked as far back as the 1940s and1950s, where the institutional interests of government agencies significantly shaped the evolution of spectrum,[9] and the impacts of which continue to echo today.

Participants also grappled with the challenges in communication and collaboration arising out of not only opposed missions, but escalation of conflicts when differing missions are layered with an intense sense of ownership. Returning to the definitional theme, participants noted that lack of shared

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[8] This obligation was added by a Presidential Memorandum. Presidential Memorandum: Unleashing the Wireless Broadband Revolution Sec. 1 (June 28, 2010), https://obamawhitehouse.archives.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution.

[9] Winkler, Jonathan R., Blurred Lines: National Security and the Civil-Military Struggle for Control of Telecommunications Policy during World War II, 51 Info. & Culture 500 (2016), https://www.jstor.org/stable/44667587 (available with subscription).

definitions compounds lack of communication in attempts to collaborate or problem-solve. Taking the recent C-band crisis as an example, one participant noted that various government and industry actors lack a common understanding of what it means to be protected from interference. This lack of common understanding can lead to institutional standoffs because no one wants to let go of a belief or tone down an assertion.

Even if there were a common understanding of what it means to be protected, there is no widespread agreement on how to test whether interference thresholds are met. Thus, the gaps left by sorely needed definitions compound conflict and too often leave parties with no common ground to build on, ultimately devolving into unsatisfying battles involving dueling test scenarios. Further, lack of definitions may not only cause conflict, but differing missions of institutions may contribute to conflict regarding definitions.

Disagreement regarding definitions feeds reluctance to accept and adopt the FCC's conclusions in any particular proceeding despite its authority to act as a decisionmaker. Decline in respect for the authority of the FCC over the decade, according to some, has warped the regulatory process considerably in the last ten years and caused increased politicization of licensing processes. While not all agreed with this sentiment, many participants commented on the increased frequency and intensity of conflicts in recent years, which have seen industry and agencies leverage each other to wage collateral attacks, pulling in the White House to mediate and leaving the NTIA as a belated afterthought.

Just as "institutional conflict breeds spectrum policy conflict," the inverse is true as well: "spectrum policy conflict generates institutional conflict." In particular, this arises when a regulated entity "loses" at the FCC and seeks to challenge the outcome by leveraging a collateral agency. Conflicts arising from a multitude of regulators with incongruent missions might, then, suggest a need to establish (or reestablish) a centralized or more authoritative agency, as well as clarify the hierarchy of authority among governmental bodies.

Despite the new application and political intensity of recent conflicts, however, some degree of politicized institutional conflict has consistently appeared throughout the history of spectrum policy. For example, the Department of Defense (DoD) attempted to pull in the FDR White House to give it more authority in the face of concentrated power in the FCC. Similarly, historical documents that suggest that the IRAC mediated significantly in the early days of NASA as it pushed for a greater allocation.

According to some, if political and institutional contests were viewed more as predictable challenges than novel crises, then maybe something like the President's Council of Advisors on Science and Technology (PCAST), or a mediating body that can function similarly to the IRAC, could offer a more productive resource. Such a model would designate a reliable space for parties to go for negotiation and resolution ("to hash things out") at a more appropriate level of policy participation, and leaves open the traditional path to appeal FCC decisions. This model would still face the challenge of finding the "right" level of authority and an acceptable housing institution. The model could be ripe for adoption: Congress's recent recognition of NTIA's Policy and Plans Steering Group (PPSG) for the first time makes it a candidate to serve as a central place of recourse.[10]

Finally, one participant suggested an option to ameliorate bifurcation between institutional missions and authorities through overarching reconciliation on the policy level. The participant suggested that a solution might require broadening policy objectives into a holistic collection: instead of holding on to

[10] National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116-283 § 9203, 134 Stat. 3388(2021).

a single public interest standard that must span all statutory responsibilities and some entity obligations, a suite of articulated national priorities might reduce contention between entities vying to establish their own single mission as the single priority of any given moment or proceeding.

Enforcement and Mitigation

Allocation alone does not prevent interference. Poor engineering or flagrant disregard of the rules can lead to interference, and enforcement and/or mitigation are necessary to resolve issues. Underdevelopment of monitoring and sensing has contributed to a lack of enforcement—once again rooted in the lack of a common understanding of what constitutes interference. Regarding data, while the allocation approach has provided benefit in managing spectrum for specific services, there remains a significant gap between allocation and use: we may know for what spectrum usage has been allocated, but there remains a dearth in understanding how much of that spectrum is used. Thus, definitions and data pose notable areas in need of attention not only for allocation and use, but for enforcement as well.

Regarding definitions, historical thresholds that set interference based on RF levels cannot account for today's systems, particularly because many systems have an access protocol that gives significant leeway in how parties share spectrum. One participant noted that interference metrics are not uniform. This might suggest that interference should be evaluated more based on end-to-end performance rather than RF levels alone. This lack of data and understanding precludes most meaningful enforcement, further underscoring the need for better ways to track spectrum usage across allocations.

The need for clear and reliable enforcement holds particular importance as actors anticipate the move to increased sharing and dynamic spectrum management. One participant noted that sharing of spectrum has been done extensively in the past, but generally between systems separated by some distance and with static characteristics such as a fixed power level, antenna with a single radiation pattern. Sharing with newer technologies has in some way mad increased sharing possible and in other ways made it more difficult. Another commented that, by focusing on eliminating interference, the current enforcement regime disincentivizes a transition to dynamic sharing rather than supporting it. Dynamic sharing might require investment in mitigation and enforcement, as well as robust monitoring and sensing. If so, dynamic sharing may not be a practical option as long as the U.S. enforcement paradigm remains underdeveloped, particularly to mediate sharing between entities governed by different regulators.

While there was disagreement regarding how enforcement should develop, most participants agreed that enforcement and mitigation responses need development. Although historic enforcement has focused on exclusive use, development of monitoring capabilities, standards, and measurement tools could all benefit a sharing model.

A few enforcement-development propositions with a practical, market-based focus could drive enforcement evolution, at least regarding consumer or commercial uses. First, a paper by Coase, which examined the IRAC's role in dispute resolution, could inform a market-based analysis to identify what public or private entities have the best resources or expertise to resolve complicated disputes. Second, a market-based evaluation may suggest that dynamic spectrum management arrangements between commercial companies will make ongoing reliance on situating enforcement exclusively with the government ill-advised. For example, commercial services that would require enforcement mechanisms, such as software as a service (SaaS) providers should not be put in the position of reporting its own customers to a government bureau.

Finally, development of receiver standards remains a significant topic of consideration to alleviate interference problems.[11] One option would be for receiver standards to play a second, equal, role in solving the problem of interference alongside transmitter standards. This would certainly be feasible from a legal standpoint; the FCC has historically concluded it has authority to regulate receiver performance.[12] Although the FCC has consistently opted instead to work with industry players when necessary and otherwise leave receiver quality to the market—even though market forces incentivize the cheapest-compliant receivers—this remains an area where increased capability already exists even though it isn't generally deployed.

Key Findings

- The value of the public interest standard may be waning because other factors are increasingly called into consideration. Yet, the community needs a coherent set of guiding principles to work with.
- Agreed-upon definitions of harmful interference as appropriate for various uses are imperative to enable more efficient and effective use of spectrum.
- Institutional conflict breeds spectrum policy conflict, and spectrum policy conflict generates institutional conflict. A framework is required to designate a reliable space for parties to go to for negotiation and resolution.
- Spectrum scarcity requires dynamic spectrum sharing in the future, which in turn would require advancements in interference mitigation and enforcement.

[11] After the roundtable, the FCC announced an upcoming proceeding on receiver performance. *FCC Launches Proceeding on Promoting Receiver Performance*, FCC (Apr. 21, 2022), https://www.fcc.gov/document/fcc-launches-proceeding-promoting-receiver-performance-0.

[12] For example, the FCC concluded it had authority to regulate receivers to address interference both regarding maritime receivers and during a period when CB radios using high-power amplifiers were causing interference to TV signals.

Harmful Interference Session II: Governance Perspective

Keynote Summary

The second session considered the governance capabilities and challenges to addressing harmful interference. Discussion continued to unpack challenges identified in the first session regarding the unique role of institutional actors in mitigating or aggravating spectrum conflicts, as well as identifying a number of areas of consensus and commonality where new governance mechanisms could thrive.

Julius Knapp gave the keynote introducing the discussion. Knapp recently retired after forty-five years with the FCC. His most recent position was the Chief of the Office of Engineering and Technology (OET). He laid out four topics for consideration in approaching spectrum governance: (1) government coordination, (2) spectrum strategy and planning, (3) resolution of technical issues, and (4) receivers.

Regarding government coordination, Knapp acknowledged the conflicts recently featured in the news, and noted that the FCC and NTIA share responsibility for spectrum management, but that other players are involved both in the recent events and government coordination generally. He noted the significantly different processes that the FCC and NTIA conduct under their relevant statutory requirements and considered to what degree those differences fuel challenges and conflict. The FCC acts according to the Administrative Procedure Act (APA) which requires notice and comment for rule changes. The FCC also is governed by ex parte rules where all public comments and meetings with staff must be inserted into a public record. A decision document such as a Notice of Proposed Rule Making or Order is drafted by FCC staff and submitted to the FCC chair for consideration.

If the matter involves a potential impact on federal use of the spectrum it is then sent to the NTIA for coordination under the terms of a MOU. The NTIA shares the draft with the federal agencies and receives comments back, seeks to develop a single position, and returns its comments and any proposed edits to the FCC. The NTIA does not share the draft outside the federal government, Notably, the NTIA is not bound by the APA or ex parte rules relative to FCC rulemakings and may meet with or take input from stakeholders outside the government to help inform its analyses of potential interference.

Knapp noted that with the exception of a few recent major issues that arose in recent years, the FCC and NTIA had successfully coordinated and resolved countless issues. He asked whether the planned revision of the MOU will be able to successfully resolve the recent issues going forward. It seems that in the past there was a fairly clear distinction of public and federal interests but those lines in some instances have become blurred. For example, he noted that the Department of Energy’s objectives for the smart grid rely in part on the use of devices that operate on non-federal spectrum. Similarly, the Department of Transportation’s objectives to reduce crashes and congestion rely in part on the use of devices operating on non-federal spectrum. He suggested that problems today may be new enough and different enough to require different ways of resolving such issues going forward.

Regarding spectrum strategy and planning, Knapp began by voicing wholehearted support of planning—“but,” he asked “what exactly is planning?” Again, planning looks different when considered from the view of the NTIA or FCC. On the government side, the NTIA asks agencies what their spectrum requirements are for growth of existing and future planned systems. The NTIA then assesses how to best meet these requirements. The FCC, meanwhile, has a difficult challenge in assessing spectrum requirements in the private sector because new services and technologies that could not be predicted are constantly emerging in a competitive marketplace. While many of these services and technologies are introduced under existing flexible rules, parties requiring access to new spectrum or changes to existing rules typically initiate this process by submitting a petition for rule making. These matters often involve controversial interference issues. When the process is complete some of these services and technologies succeed in the marketplace while others fail, generally for reasons having nothing to do with potential interference.

In light of these differing postures and challenging circumstances, Knapp wondered what it means to plan for future spectrum use — is it to be targeted in scope such as to forecast potential spectrum requirements for specific types of services or applications? Is it to identify the next spectrum bands for commercial wireless services? Or should it attempt to plan for all services throughout the entire spectrum? He noted that the applications requiring accommodation are ever increasing and distinct, ranging from the Internet of Things (IoT) to telehealth, energy, education, and radio astronomy, and he wondered how to go about accommodating all of these applications from a process standpoint. He suggested that defining scope will be important going forward. He suggested that it may not be advisable "try to plot the entire ocean at once." Rather, he suggested that the FCC and NTIA focus on specific topics or areas so that this does not become an overwhelming task that fails to lead to productive results in a timely fashion.

Knapp proposed resolution of technical issues as a third lens through which to consider spectrum governance. He observed that new services often seek to operate in spectrum that was previously "quiet"; but those new services often have entirely different deployment scenarios and technical characteristics. Meanwhile, the concept of adjacent channel interference has seemingly expanded from an historical analysis of potential interference between two allocations with a shared border to any service anywhere nearby, even if three, four, or five frequency bands away.

Given the technical issues that arise from repurposing spectrum and a broadening of potential sources of adjacent channel interference, Knapp identified a handful of the most common categories of disagreements that come up, whether on the commercial or government sides. He noted that stakeholders often characterize their positions as based on the "laws of physics" or " sound engineering". While there are certainly elements of technical analyses of potential interference that are based on the laws of physics such as the way radio signals propagate over the airwaves, he pointed to the fact that such analyses are strongly influenced by a variety of assumptions that can, are, and should be debated, including:

What constitutes harmful interference? (Is it an observable impact on disruption or quality of service? Is it a 1 dB rise in the noise encountered by a service? Is it an impact in the digital vs. RF domain that considers the ability of the device to mitigate interference?)

What model best represents the characteristics and deployment of the new service or technology, especially for complex wireless systems? (Would the proposed model make no sense as an actual deployment model?)

What are reasonable assumptions for separation distances, expected numbers of nearby devices and how their signals add at any given point, antenna directional characteristics, adaptive power control, capability of the new service or technology to deploy interference mitigation techniques, etc.

How are these assumptions influenced by the use of existing systems for safety or security, as well as the need to create opportunities for new services and technologies? Where does the balance fall? If the analyses are excessively conservative, are we creating barriers to new services that could have themselves proven to provide vital new services? If lax, does it create a risk of interference to public safety?

As a first principle for approaching technical issues, Knapp encouraged policymakers to consider processes that might better facilitate dialogue among all stakeholders. He suggested that many challenging interference issues in the past have been resolved successfully when the engineers who truly understand the characteristics of the various systems worked together collaboratively to assess and find ways to prevent harmful interference.

Finally, Knapp considered the role of receivers in quality control and the importance of receivers' ability to reject signals well outside their relevant allocation. However, he also offered perspective on two challenges presented by the ongoing introduction of new services and technologies. First, analyses of potential interference were historically based on the anticipated or measured characteristics of receivers' ability to discriminate against signals outside their allocated spectrum, based perhaps on the 90th percent performance of existing receivers. Second, deployed receivers were designed for the environment that existed at the time they were deployed, sometimes extending into nearby frequency bands that were relatively quiet. Together, these two factors have created a tension between protecting those existing deployed receivers based on those with the "worst" performance characteristics and the ability to deploy a new service. Moreover, information can be difficult to obtain on the number of those receivers, who has them, the costs and timing for replacement, etc. This tends to provoke resistance from incumbents who view the source of trouble as the newcomer, not their technology that continues to function exactly as it was designed.

Therefore, Knapp encouraged regulators to get out in front of issues through more thorough technical research and data collection, commitment to focus on mainstream problems rather than edge cases, and renewed consideration of industry standards for receivers. Regarding technical research, Knapp noted ongoing uncertainty of what devices are deployed and what characteristics they portray—an information problem that plagues government, industry, and researchers alike. Hearkening back to his call to scope when planning, Knapp encouraged actors to focus on problems with real consequences when a service is actually impaired, as opposed to technical analyses based on extreme worst case assumptions when in reality there is no actual impact. Finally, he encouraged renewed attention to industry standards for receiver standards, to potentially uncover a problem before it becomes a crisis and allow development of ex ante standards instead of post-catastrophe standards.

In closing, Knapp emphasized the need for strong leadership and collaboration between both the NTIA and FCC. He considered various forms strong leadership could take, including Congressional initiatives to maintain agency accountability such as requiring agency updates, or top-level direction from the executive branch such as a presidential memo. Regardless, he emphasized the need for full empowerment of both agencies from the top to resolve these highly technical issues as they have done in the past, and particularly for full executive backing of the NTIA as the spectrum experts for the federal government. He also noted the importance of collaboration—not only between agencies, but the need to have mutual trust, respect, and willingness to compromise. Interference issues are best resolved when technical experts (or at least sufficiently technical staffers) who understand the systems are charged with finding a way to make things work.

Knapp stressed the ongoing need to maintain an appreciation for shared national goals—for example, to collaborate to ensure both 5G and aircraft safety systems co-exist —and foster collaborative determination to work through challenges and come to a solution in an environment of trust.

Strong Leadership, Teamwork, and Trust

Many participants agreed with Knapp that we are facing a pressing need for the next generation of strong, collaborative leaders to pick up the reins and expressed concern for an erosion both in relationships between entities and collaborative culture within them. Previous strong and empowering leadership led to a thriving work environment, where staff knew they had support to both make spectrum their first priority and pour whatever attention was needed into it, and to reach out and collaborate with other institutions to problem-solve. The environment set a tone of agreement on purpose and a common commitment to solve challenges, even if there was disagreement on particular issues or how to get there.

Across entities, past collaborations on the federal side between the NTIA's Institute for Telecommunication Sciences (ITS), NTIA's Office of Spectrum Management (OSM), and the FCC's OET drove positive progress but are similarly in need of new proponents as regulators and technologists retire. Agencies not only need strong leaders, but strong cultures: collaboration should not only take place at the top, given how much work is done by staffers to develop the reports that eventually make their way to agency heads.

Now, however, procedural obstacles compound already significant challenges to build bridges. For example, the recent C-Band auction saw intense conflict between new 5G operations and the FAA and aviation stakeholders regarding potential for 5G cell signal interference with aircraft radio altimeters. There, some participants asserted that comments went unaddressed. Others pointed to communication breakdowns between agencies, a lack of information sharing, and a lack of problem-solving (particularly for aircraft with non-predictable flying patterns and landing locations). These ultimately led to a decision that was not universally accepted. The result was a public airing of disagreements and threats of lawsuits and congressional actions—*after* the FCC released its decision. Once the FCC makes a decision it can be quite difficult to change, since many stakeholders may have already made substantial investments and/or deployments.

Experts in the Room

In addition to the need for strong leadership and collaboration across entities, participants discussed the importance of bringing technical experts together for joint problem solving. A need for trust and negotiation in good faith, particularly to establish common definitions or understanding, undergirds almost all other conversations tackling collaboration within and between entities. For example, in order to arrive at some common agreement for what constitutes interference, experts in the room would not only need to be able to hash out technical questions (like whether 1 dB constitutes harmful interference, or whether satisfaction of the ninety-fifth percentile of protection means anywhere, all the time, under the most unlikely and trying conditions), but would also need to be able to do so without having to worry whether one party may abruptly end discussions and pull in the press, the White House, or congressional committees.

However, while including experts remains a challenge, this is only the first step. Basic trust and a sufficient sense of a shared purpose to solve problems remain predicates to bringing experts together to problem solve. Taking the case of C-band as an example, participants pointed to fruitless hours spent with experts in a room. A lack of common purpose to find a joint solution left expert input hamstrung by mistrust, lack of understanding of the opposing viewpoint, and insufficient sharing of basic information—all of which are necessary to garner a shared understanding and enable problem-solving.

While pre-crisis information sharing and mutual trust are critical to avoid crises, other factors must be addressed as well. A lack of common technical vocabulary can lead to information sharing disconnects. This, too, contributed to the recent C-band crisis. Actors struggled because they were operating in relative data vacuums about each other's industries, and were unable to establish either the trust or common vocabulary to communicate successfully.

Participants debated how to increase the ability of technical experts and engineers to influence the process. Some wondered whether FCC commissioners would benefit from a new, engineering advisor position, especially if OET might give overly conservative advice. Others were unsure what position engineers should have, but agreed with the overarching need to have more engineers at the FCC to explain complex and technical questions and improve regulation. On the other hand, having an engineering advisor might be counterproductive given commissioners' tendency to push back on official advice in other settings, like from the general counsel's office. Further, most spectrum decisions come down more to policy decisions—winners and losers—than physics, and the partisan nature of work in the FCC makes the idea of a truly neutral advisor unlikely. Finally, a structural approach to improving conversation and input might be moot-- commissioners get the final say on hiring, and often opt to hire lawyers in any case.

Technical data is supposed to reflect objective calculations as well as policy-driven reasoning to set parameters. Experts and academics may have clearer perspectives and can offer neutral, objective, and unbiased input—but only to a point. As one participant put it, experts can at least provide "a full picture of the pieces," even though everyone will have some amount of bias.

Technological Challenges

Mistrust can not only frustrate near-term problem solving but can prevent much-needed progress and creativity to continue to evolve over the long-term. While support for "getting experts in the room" is nearly universal, without the trust, negotiation in good faith, and room for give and take between collaborators, experts will not have room to hash out crucial definitions such as "what constitutes harmful interference," or "under what conditions is performance considered to be at the ninety-fifth percentile of protection." This also implicates the challenge of mutual respect between policymakers and engineers. Firstly, policymakers should be receptive to technical input from engineers. Conversely, engineers can only get so far with "just science" and must incorporate some value-laden parameters and assumptions.

These framing and expertise challenges echo through thorny technical questions about spectrum sharing. The current exclusive allocation structure allows deployment of technology under an artificial presumption that it will remain frozen in place and time, and feeds impractical calculations on one side and unfair narratives on the other as a result. For example, the current catch-22 between honoring existing exclusive use while requiring some sharing has culminated in discussions regarding "poor-performing" receivers. While it very well may be that reliance on an exclusive and frozen environment means some deployed receivers are more vulnerable to interference. The regulatory narrative of licensing would suggest they still operate properly for the environment in which they were designed to operate, which typically did not envision co-existence. Technology only becomes "poor-performing" later when the environment around it changes to impose new demands.

The challenges of framing and interpreting engineering analyses highlight the difficulty that a shift away from spacious bands and exclusive use poses. A paradigm shift away from spacious bands and exclusive use imposes a loss of certainty, while a failure to shift paradigms imposes ever-increasing costs upon capacity and innovation.

Ultimately, a successful shift will require an operational structure for sharing, particularly to allow all users of spectrum to be able to evolve so that the United States continues to have global cutting-edge technology. On one hand, the current governance structure, by design, adapts at a relatively slow pace, and is unable to adequately meet current and future demands. On the other hand, spectrum users already lack sufficient time to conduct thorough analyses to meet a given filing deadline. That reality contributes to overly conservative calculations and resulting regulatory battles and testing arguments. One option could be to seek a middle-ground between exclusive licensing and unlicensed spectrum, possibly as already is seen in non-exclusive licensing, allowing for more band flexibility but maintaining reliable rules and enforcement.

The multi-faceted nature of challenges that already characterize spectrum policy will continue to emerge, likely in conflicting ways, in any sharing paradigm. Regulators may need to shift away from a search for a single policy or regulatory solution that can apply across all allocations. For example, each frequency band might have unique circumstances between the incumbent and new entrants that require flexibility in working through the transition and developing an appropriate sharing model. Regulators must weigh not only technical risks, but also more ambiguous, value-laden policy benefits. Further, any sharing approach must also acknowledge that system variety includes built-in tolerance for some number or degrees of failures.

Another facet deserving attention is the economic interplay between technological advances and governance. The fast pace of technological change—in addition to the increasing interconnectedness of computing and storage with spectrum-reliant systems—strains our governance structure which adapts to changes at a slow pace. Some technological advances may fundamentally change the areas of focus for governance entities, perhaps shifting to emphasize commercial development and common infrastructure for economic reasons.

Data Gathering and Information Sharing

Central to spectrum management is the need for data gathering and information sharing, particularly to mitigate interference. However, data gathering remains an ongoing challenge at all stages of spectrum regulation. Prior to allocation, little data may be available to certify one model over another. After a proceeding, sufficient data has typically not been collected to go back and evaluate the calculations. Further, many participants are reluctant to share data, whether due to classification on the government side or competitive concerns in the private sector.

Future work could consider how regulators can facilitate information sharing in various environments. Information sharing needs to take place between federal agencies. For example, the FCC and the NTIA have a MOU to coordinate their activities. However, some participants expressed lack of confidence that the MOU, a triennial agreement still pending renewal after sixteen years, could provide this facilitative framework. Recently, a Commerce Spectrum Management Advisory Committee (CSMAC) report[13] made recommendations to approach government coordination challenges, that could be part of an updated MOU.

Many recent cases, such as the Citizen's Broadband Radio System (CBRS) and the current discussions on the 3100 MHz to 3450 MHz band, also demonstrate the need for information sharing between federal agencies and non-federal entities. This sharing is complicated by the fact that some of the federal government information may be classified. The lack of a systemic policy to facilitate interaction between commercial and federal users imposes financial costs and uncertainty for commercial users engaging in multiple processes. A potential solution to this problem, currently being applied to the 3100-3450 MHz issue, is enabling an organization such as the National Spectrum Consortium to hold clearances for non-federal entities. However, this leaves open the problem of applying a consistent approach across scenarios.

Participants brought up the need for a neutral party to perform experiments and gather/share necessary data. It was offered that the NSF has served this function in the past, bringing together neutral bodies with technical experts who listen to both sides and can offer neutral input.

From start to finish, gathering and sharing data is a challenge. Questions that seem simple, like, *"just how many receivers are out there that would be overcome with interference?"* may remain unanswered because of data gathering challenges. Some issues that complicate data sharing include:

[13] Commerce Spectrum Management Advisory Committee, "Working Group 1: Governance: Final Report" (July 30, 2020), available at https://go.usa.gov/xzaaU.

organizations are hesitant to share competition-sensitive information; or, some data may be classified. As seen in C-band, negotiations suffer when actors are unable to share essential technical data that would provide each a better sense of the others' requirements and concerns.

Data gathering could be facilitated by resources such as improved test beds, joint testing, and digital twins. Effective test beds should be available over a long-term basis, provide for different kinds of testing, and be easier to use. Digital twins could be used to develop high quality, evolving models of what is actually occurring, thereby aiding ongoing monitoring and enforcement as well as prospective calculations.

Industry roadmaps in other sectors have greatly helped to flesh out issues and speed up consensus. This suggests that roadmap creation for spectrum management by agencies, and at a national level, might prove valuable. Further, regulatory agencies and Congress, to the extent it sets priorities via funding, could emphasize making data available as a concrete and impactful way to facilitate informed dialogue and faster resolution. As one participant put it, data is incredibly valuable, and only requires "money, time, and effort" to generate.

Key Findings

- Agencies need strong leaders and strong cultures, and collaboration should not only take place at the top.
- Policymakers should rely on experts more to offer neutral input and objective analysis, while recognizing that everyone will have some amount of bias.
- Both technology and governance structures must be able to adapt with an evolving spectrum landscape. Rules and technology cannot remain frozen in time and place.
- Regulators should emphasize protected information sharing to facilitate informed dialogue and faster resolution.

Harmful Interference Session III: Technological Perspective

Keynote Summary

The third session considered the technological progress that impact spectrum policy and may help manage harmful interference. Discussion considered important technological milestones, ways to integrate new and old technology in common environments, the role of contextual considerations such as economics, and the interplay between technology and policy in addressing harmful interference.

Dr. Paul Kolodzy gave the third keynote, considering the role of technological development in mitigating or avoiding harmful interference. Kolodzy is an independent telecommunications consultant for government and commercial clients. Prior to forming Kolodzy Consulting, he was the Director of the Wireless Network Security Center at Stevens Institute of Technology. Kolodzy was a Program Manager at the Defense Advanced Research Projects Agency (DARPA), and the Senior Spectrum Policy Advisor at the FCC.

Kolodzy first emphasized the importance of noting the differences between open- and closed-loop systems. An open loop system does not gather feedback about what is causing interference. For example, rules are generally developed from an open-loop perspective because there is nothing inside the system yet to detect if interference is occurring. However, the inability to detect interference leads to more conservative rules and over-protection. By contrast, a closed-loop system can get feedback about system performance, allowing users to get closer to the edge and adopt narrower margins. Rules adopted in open- or closed-loop settings can be compared to walking toward a cliff with one's eyes shut or open: if one's eyes are shut (open-loop), he/she will not be willing to walk as far forward due to uncertainty of where, exactly, the edge lies, so a conservative strategy is appropriate; conversely, with one's eyes open (closed-loop), he/she can walk right up to the edge with confidence.

Kolodzy set the stage with an overview of promising technology trends, drawing on recent technology that has been worked on and proven, although not necessarily provided yet by vendors. Trends mentioned included:

Higher Frequencies - Communications systems are using ever higher frequencies. Higher frequencies provide for greater data rates at the expense of propagation range. Significant current developments are in the use of millimeter wave (mmWave) and optical systems. Research in silicon photonics is enabling the development of circuits that consume less power and generate less heat.

Better Radios - New devices are being built that take advantage of more degrees of freedom to improve performance and reduce sensitivity to interference. More degrees of freedom means the introduction of more "knobs" that can be adjusted. For example, recent progress in filters for analog-digital converters, has improved how close bands can get without causing interference. Mixed mode devices enable finer control of radios at the edge.

Antennas - Advanced antenna systems are increasingly important in communications systems. Because transceivers are now essentially costless, the degrees of freedom in multiple input, multiple output (MIMO) antennae have increased dramatically. MIMO increases spatial diversity, providing more signal paths, resulting in reduced errors, and increased capacity. MIMO has also enabled time transfer in picoseconds.

High-level Control - Optimization is now taking place at higher layers of the stack. For example, 5G allows tuning at the application layer. Additionally, autonomy is beginning to play a larger role in communications systems, and will likely increase in importance, given the opportunities that arise when some control systems are relocated to a higher level of control. For example, fighter planes can now engage in dog-fighting autonomously, allowing pilots to focus on other concerns.

Networking - Networking developments include a new focus on the application layer. For example, named data networking (NDN) allows a node to retain and provide information that passes through it. This allows data sharing close to the edge, eliminating the need to obtain information from the network server and expanding the functional capacity of the network, but also requiring greater control at the application layer to manage the amount of RF energy being used.

Autonomy – In addition to control, autonomy will play an important role in enforcement. Rather than relying on human operators to detect and respond to interference events, autonomous systems can operate independently, in real time, to identify and adapt to interference.

Technological developments are increasing the degrees of freedom available to address interference. Technologies applicable to mitigating or avoiding interference include: beam-forming; signal spreading via underlays or overlays to broadcast at a lower, non-interfering power level; spatial diversity; and use of polarization. At the device level, improved filters for analog-to-digital (A/D) converters to permit greater dynamic range to capture both powerful and weak signals are on the horizon., offering the potential for digital filters in the future that could completely change our approach to interference resolution.

Several other developments, not directly applicable to managing interference, may also impact the way we use of and manage spectrum. For example, processors, digital filters and RF functions can now be combined at the chip level, thereby allowing multiple radios on a single chip to make many antennae and many spatial degrees of freedom available. Similarly, time transfer information via wide-distributed MIMO is also yielding increased degrees of freedom.

In addition to proven new technologies, three growing areas for exploration deserve to be specifically called out.

Engineers are exploring technology to isolate a desired signal when additional modulated power is present. This technology could be used to automatically reject an interfering signal before it rises to the level of harmful interference. Spatial diversity is aiding this, but more work is needed to separate signals in additional dimensions, including power, frequency, and time. Taken together, these additional degrees of freedom provide a large collection of knobs that systems can dynamically adjust to eliminate or mitigate harmful interference. Once systems can deal autonomously with interference, the implications for policy are dramatic.

Fundamentally, interference only matters if it prevents an application from operating properly. Technology and policy must coordinate to minimize the impact on applications. Regulators must agree that technology has a lifespan. For example, we no longer depend on Morse code for communications, so any policies (if they exist) meant to protect Morse code are unnecessary and potentially obstructionist. Similarly, regulators must acknowledge that environments also have a lifespan. For example, increased use of a technology in an area often requires more infrastructure, which improves tolerance to lower levels of interference. In both scenarios, regulators should consider adopting technical rules that meet or enforce those natural lifespans. One possibility could be to require updates to technical rules halfway through a license, based on ten years of existing data, to guide the remaining ten years of a license leading up to renewal.

Engineers should explore technology to provide active feedback loops across networks and licenses. Moving from open loop networks to closed loop networks is chiefly a problem of commitment. Multiple networks can provide feedback, and computing is already going to the edge, but we are not using the available data to gather feedback and implement controls. Were we to do so, technology such as autonomy could utilize feedback and transform how bands are regulated.

Kolodzy concluded with a few potentially controversial thoughts to begin the discussion. First, he urged a move away from universal rules. Because interference is not universal, universal rules inherently cannot address the various demands that arise from differences in applications, areas of operation and technical specifications. For example, higher density usually permits higher tolerance, meaning that universal tolerance thresholds are likely to lead to thresholds that are too high in some areas and too low in others. Second, he disagreed with a push for receiver standards, opting instead for adopting clear rules and requiring receivers to tolerate those rules.

Technology and Policy

Although most of the discussion remained on the policy level, some technical issues met widespread agreement. First, as emphasized above, harmful interference should not be an absolute concept and may vary depending on the type of use; loss of a few nano-seconds of a signal will not damage its coherence. Loss of a bit or two is unimportant if the application uses error-correcting codes. Second, while pico-second timing is an agreed-upon threshold for precise information sharing, nano-second timing likely affords sufficient accuracy for successful communication. Ongoing, real time information sharing will be crucial to mitigate interference once it occurs. Accurate identification of the source(s) if interference is required.

Two particular developments that would support dynamic sharing include inter-practicing and mitigation solutions. Inter-practicing promotes infrastructure that supports various uses, such that adoption does not only benefit the actor that introduces the technology, but also preserves overall flexibility, efficiency, and spectrum management of the entire ecosystem.

Rapid mitigation is a practical prerequisite for managing harmful interference in a dynamic sharing model. As mitigation and sharing both unfold, technological solutions should also not only address actual risk but, more importantly, address perceived risk regarding introduction of a new technology. The lengthiest delays in regulatory approvals are likely to be staged over perceived risk, before actual risk has a chance to crystallize. Two concrete solutions that address risk include: better test beds that are available on a long-term basis and can be used easily and for aggressive and different kinds of testing; and digital twins to develop high quality, evolving models of what is actually occurring.

The assertion was made that policy solutions should run parallel to technological solutions. One participant proposed that sharing should include a shift away from bands that ossify after initial regulation. Rather, the regulatory framework for licensed bands should foster evolution and adjustment after deployment in a manner more akin to the environment in unlicensed bands. The goal would be to provide certainty that some rule change will occur in the future such that users can plan their design, possibly following Kolodzy's suggestion that rules update halfway through a license period.

Taking unlicensed bands as an example of an approach that can make technology future proof, policy could foster evolution. Meaning, the model would take advantage of the natural lifecycle of devices as systems progress to greater efficiency rather than requiring users to go back and replace technology. That approach, rather than imposing an artificial timeline for rule updates, license revocation, or even the next "G," would work to develop a system that can naturally evolve to be both future proof and backward compatible. Another similar, goal, taking a long view over the next forty to fifty years, could be to shift spectrum access from a capital-expense model to an operational-expense model that takes advantage of the flexibility of technology and reduces constant rebuilding. Instead, it would allow access on an ongoing basis in which users acquire and pay for spectrum that meets their present needs according to both spectrum quantity and characteristics.

Practical Policy Considerations

Traditional economic input could also benefit coordination between technological development and adoption, and policymaking. One participant emphasized the need for attention to economics, asking whether simpler metrics can capture degrees of freedom, and how models can account for other comparisons to the status quo, such as the impact upon how many megahertz are needed *and* the technical abilities thus unleased *and* the potential of those technological capabilities in the market.

Another participant pointed out the constraints of economics: government actors (and their contractors) are always asked to do more or the same with less resources, and the private sector is always able to do more with more resources. That reality has informed investment-backed expectations that licensees are buying perpetual, exclusive licenses. As a result, moving to a more dynamic access system, operating-expense system, or autonomous system is inherently taking away from incumbents, which must be addressed if that transition will be successful. The participant suggested, however, that that constraint has not been resolved, and such economic disincentives represent the primary reason that secondary markets in wireless never took off and that government satellite systems struggle.

Risk-benefit evaluations connect to the challenges discussed in the governance session regarding the need not only for engineers to evaluate technological risks, but for policymakers to identify and prioritize the value-laden benefits of any given approach. Therefore, a consideration of how to determine a benefit for six or seven different application bases, such as economic evaluations, could be a valuable topic for exploration.

Such a consideration should also engage varied goal frameworks. For example, "technology-informed policy" may best shape governance structure, while "policy-informed technology" may produce better technical rules. From a common-sense perspective, these frameworks should remain practical, broadening to encompass multiple systems and environments. Similarly, these frameworks require the expertise offered by engineers and policymakers and the need for collaboration that respects this expertise. For example, engineers are able to identify technical constraints, but policymakers must then develop a real-world response when those constraints are unsatisfying.

Cooperation could be aided by such goal framing. Policy-informed technology could provide a framework for engineers to consider how to make technology to enable a desired policy, as well as provide a tool to think more broadly about systems, environments, and rules for evolution. For example, adaptive systems arguably reflect such a framework, declining extremes that evaluate functionality based on assumptions that interference would always or never occur, but rather accommodate the need to respond to interference when it occurs.

Modeling

Modeling challenges consist of technical uncertainty, policy-dependent assumptions, and applicability. Models are difficult to develop due to lack of consensus on how to model, in addition to lack of actual and repeatable data to be modeled. Similarly, a single model necessarily selects certain parameters; it cannot represent totally diverse cases or circumstances.

Even the appropriate type or category of model is consistently in dispute (i.e., whether to use a deterministic model, stochastic model, deep neural network, etc.). However, models play a crucial role, and a disputed model can taint an entire proceeding. Meanwhile, studies, data collection, and modeling are sorely needed. For example, little study has been conducted of MIMO, distributed MIMO, or multi-antennae systems. Even with the current measurement capabilities we have, though, lack of time, funding, and policy disagreements on appropriate parameters all combine to yield less data and produce less sophisticated models than are otherwise well within reach. Meeting these time, resource and policy hurdles could significantly reduce conflict during proceedings.

Models are too often adopted despite being unproven or unproveable. For example, one participant conducted testing of an interference model; the review suggested significant overestimation of interference. It is worth emphasizing that these failures are more often products of time and resourcing constraints than lack of technological capability or malice. The community has much more ability to take measurements and refine models than is currently employed. Investment and attention to collecting measurements and developing models that stand up to analysis could dramatically reduce regulatory conflicts and unsatisfactory or unrealistic outcomes. While modeling overhaul represents a major undertaking, the starting point could be measured, such as adoption of a principle that guides the degree of sophistication of analysis. Because narrower margins require more sophisticated analysis, the margins needed could guide the necessary level of sophistication in the model.

Receiver Standards

Receiver standards were also discussed throughout the day, and particularly in the third session. The capability to produce higher-quality receivers, as well as the generally accepted FCC authority to regulate receiver standards, was rendered somewhat moot by the current policy approach. Market economics incentivize the cheapest receivers that are compliant at the time of deployment; unless receiver standards are regulated, they are unlikely to improve on the basis of industry volition. Ultimately, any additional costs are passed on to the consumer.

Receiver standards are closely related to other uncomfortable demands that would accompany dynamic sharing. Significant hurdles include the cost of upgrading deployed receivers, and the inability of automatic frequency coordinators (AFCs) to manage all interference mitigation and real-time communication necessary for a successful sharing paradigm.

Participants also expressed mixed opinions regarding receivers. Some participants pointed to the high financial cost of upgrading deployed receivers, particularly given the added challenges of moving to dynamic sharing and the unlikely potential of AFCs to manage sharing and avoid interference. Participants echoed Knapp in asserting that receivers are not poor-performing, but are built for the environment at the time they were deployed—often, when the neighboring band was receive-only, making receiver quality less relevant. Others maintained that receivers can and should be built to be much more discerning than they currently are. However, most agreed that the market does not incentivize construction of higher quality receivers and that, even though a previous receiver rulemaking was unable to drive progress, the government must fill the receiver standards gap to ameliorate sharing challenges because industry is not incentivized to produce receivers at any more expense than necessary to meet existing service requirements.

Key Findings

- The regulatory framework should foster evolution and adjustment after deployment.
- Policy-informed technology could provide a framework for engineers to consider how to make technology to enable a desired policy.
- Investment and attention to collecting measurements and developing models that stand up to analysis are required.
- The government must fill the receiver standards gap to ameliorate sharing challenges because industry is not incentivized to produce receivers at any more expense than necessary to meet existing service requirements.
- Technology advancements may lead to a future where strict regulations are not needed to avoid or mitigate interference.

Conclusion

The roundtable participants considered the resolution of harmful interference in spectrum policy through historical, governance, and technological lenses. Through the course of the roundtable they emphasized the importance of better working relationships between regulators and stakeholders as well as three substantive areas in need of attention. First, they emphasized the need for agreed-upon language and definitions. Both stakeholder problem-solving and regulatory decision-making labor under the uncertainty of ambiguous definitions subject to conflicting interpretations. Second, participants emphasized the need to rehabilitate working relationships among and between stakeholders and regulators. Institutional conflict breeds spectrum conflict, as well as the reverse. Third, technology advancements are providing more degrees of freedom that can be utilized to prevent and mitigate interference. Is a future possible where few or no regulations are needed to manage interference?

Participants conversed in light of a future marked by dynamic sharing. Both continued investment in ongoing technological development, as well as application of progress already achieved will play an important role in achieving that future. Data collection and modeling, post-proceeding research and evaluation, and technological rules that facilitate deployment of improved technology are essential features of a dynamic sharing ecosystem. Regulation will need to evolve to encompass effective mitigation and enforcement, and no longer focus upon allocation as the primary strategy to minimize harmful interference.

This roundtable was a starting point. Participants proposed some solutions, but largely focused on the challenges that need to be faced and how they fit into the evolution of spectrum policy. Participants agreed that further work to flesh out these challenges and begin to construct solutions to address them must take place. Much of the discussion took place with the goal of teasing out areas for further attention in an upcoming Silicon Flatirons conference in the Fall of 2022.

Roundtable Participants

Chris Anderson, Director, Wireless Measurements Group, U.S. Naval Academy

Dean Brenner, Chairman, FCC Technical Advisory Counsel

Eric Burger, Research Professor, Georgetown University

John Chapin, Special Advisor for Spectrum, National Science Foundation

Lynn Claudy, Senior Vice President, Technology, National Association of Broadcasters

Charles Cooper, Associate Administrator, Office of Spectrum Management, National Telecommunications and Information Administration

Joseph Cramer, Director, Global Spectrum Management, The Boeing Company

Bill Davenport, Senior Director, Government Affairs, Cisco (former Chief of Staff & Senior Legal Advisor, Office of FCC Commissioner Geoffrey Starks, Federal Communications Commission)

Eric DeSilva, Partner, DLA Piper

Ariel Diamond, Associate, DLA Piper

Tom Dombrowsky, Senior Engineering Advisor, DLA Piper

Adam Drobot, President, Chairman, OpenTechWorks

Al Gasiewski, Director, NOAA-CU Center for Environmental Technology, University of Colorado Boulder

Monisha Ghosh, Director, SpectrumX Policy; Professor, University of Notre Dame

Mark Gibson, Senior Director, Business Development & Spectrum Policy, CommScope

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Kelsey Guyselman, Deputy Director, Policy, Senate Commerce, Science, and Transportation Committee

Dale Hatfield, Co-director, Spectrum Policy Initiative, Silicon Flatirons

Julius Knapp, Federal Communications Commission (retired)

Paul Kolodzy, Owner, Kolodzy Consulting

Bill Lehr, Economist/Research Associate, Massachusetts Institute of Technology

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Joan Marsh, Executive Vice President, Chief Regulatory Officer, AT&T

Eric Nelson, Acting Director, Institute for Telecommunication Services, National Telecommunications and Information Administration

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Steve Sharkey, Vice President, Government Affairs, Engineering, and Technology Policy, T-Mobile

Peter Tenhula, National Telecommunications and Information Administration (retired); Senior Fellow, Silicon Flatirons

Ashley VanderLey, Senior Advisor for Facilities, National Science Foundation

Jennifer Warren, Vice President, Civil and Regulatory Affairs, Lockheed Martin

Acronyms

A/D, Analog-to-digital

AFC, Automatic frequency coordinator

APA, Administrative Procedure Act

AWS, Advanced Wireless Services

CBRS, Citizen's Broadband Radio System

CSMAC, Commerce Spectrum Management Advisory Committee

DARPA, Defense Advanced Research Projects Agency

DoD, Department of Defense

EIA, Electronic Industries Association

FCC, Federal Communications Commission

IEEE, Institute of Electrical and Electronics Engineers

IoT, Internet of Things

IRAC, Interdepartment Radio Advisory Committee

ITS, Institute for Telecommunication Sciences

ITU, International Telecommunication Union

JTAC, Joint Technical Advisory Committee

MIMO, Multiple input, multiple output

mmWave, Millimeter wave

MOU, Memorandum of Understanding

NDN, Named data networking

NTIA, National Telecommunications and Information Administration

OET, Office of Engineering and Technology

OSM, Office of Spectrum Management

PCAST, President's Council of Advisors on Science and Technology

PPSG, Policy and Plans Steering Group

SaaS, Software as a service

TAP, Telecommunications Advisor to the President

UWB, Ultra-Wide Band

About Silicon Flatirons Center

Our Mission

Silicon Flatirons' mission is to elevate the debate surrounding technology policy issues; support and enable entrepreneurship in the technology community; and inspire, prepare, and place students in these important areas.

About the Spectrum Policy Initiative

Spectrum policy dictates how, where, and when wireless services can be delivered to devices—and it has deep ramifications for the economy, scientific development, national security, personal enjoyment, and more. Since 2005, Silicon Flatirons has explored the intersection of policy and engineering in the heavily regulated and rapidly changing wireless services industry.

Silicon Flatirons convenes stakeholders and provides law and engineering students with a foundational understanding of spectrum policy. The Spectrum Policy Initiative engages a wide range of wireless industry professionals, radio engineering professionals, and spectrum policymakers from Colorado, Washington, D.C., and across the country.

Leadership, Faculty, and Staff

- Brad Bernthal – University of Colorado Law School, Associate Professor; Silicon Flatirons, Interim Executive Director and Entrepreneurship Initiative Director
- Kristelia García – University of Colorado Law School, Associate Professor; Silicon Flatirons, Intellectual Property Initiative Director
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- Dale Hatfield – University of Colorado, Adjunct Professor; Silicon Flatirons, Spectrum
- Policy Initiative Co-director and Distinguished Advisor
- Margot Kaminski – University of Colorado Law School, Associate Professor; Silicon Flatirons, Privacy Initiative Director
- Taylor Sanders – Startup Colorado, Managing Director
- Katherine Koebel – Engagement Manager
- Nate Mariotti – Managing Director
- Blake E. Reid – University of Colorado Law School, Clinical Professor; Silicon Flatirons, Telecom & Platforms Initiative Director
- Sara Schnittgrund – Student Programs Director
- Shannon Sturgeon – Events Coordinator
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- Pierre de Vries – Silicon Flatirons, Director Emeritus and Distinguished Advisor

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- David St. John Larkin – Partner, Perkins Coie LLP
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