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Eno Center for Transportation

Filling Gaps in US Spectrum Allocation: Reforms for Collaborative Management

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Interrelated gaps and failures in the process and policies used to efficiently allocate spectrum demand comprehensive reform. To prevent future failures, policymakers must improve device performance, increase data gathering and sharing, and clarify the spectrum allocation process.

KEY TAKEAWAYS

- Spectrum allocation takes place within an established process defined by international standards, legislation, regulations, and norms.
- There are gaps in this process, such as insufficient information gathering and sharing early in the process, lack of rigorous technical standards and analysis, and inadequate adherence to the process.
- To prevent future breakdowns, spectrum users and regulators should improve their understanding of spectrum-using devices' performance and take steps to enhance it with assistance from auction revenues.
- Government personnel should establish strong working relationships between agencies to better understand and resolve potential interference disputes collaboratively and at a technical, rather than political, level.
- Congress should ensure agencies have sufficient resources to conduct necessary technical analysis, and regulators should apply that analysis to impartially balance competing interests.
- All participants in the spectrum allocation process should adhere to the established interagency process, and the White House should vigorously support jurisdictional boundaries.

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EXECUTIVE SUMMARY

Electromagnetic spectrum is the range of radiation energy that carries everything from visible light to X-rays, microwaves, and gamma rays. A portion of that spectrum is used for communication applications, including FM and AM radios, cell phones, and other forms of wireless applications, such as radar. In the United States, it is the federal government's responsibility to regulate the use of certain bands of spectrum, which can involve allocating bands to certain users and determining how bands are shared. With the rapid rise of wireless technology, demand for access to the spectrum has increased in recent years. Since 1994, the Federal Communications Commission (FCC) has auctioned licenses to use spectrum.

In March 2020, pursuant to a 2018 Notice of Proposed Rulemaking, the federal government auctioned off licenses to operate in a portion of spectrum to companies in the wireless communications industry after the FCC determined that the regulations it enacted would be sufficient to protect incumbent services from harmful interference. The aviation industry disagreed with that assessment, and maintained concerns that the accuracy of altimeters, which are safety-critical instruments that determine aircraft elevation, could be compromised. The debate came to a head in January 2022, when the Federal Aviation Administration (FAA) warned that, without changes to the rollout, planes would be grounded around the country due to safety concerns. Considering the widespread impact of this potential action, the wireless technology companies voluntarily agreed to postpone their deployment and worked with the aviation stakeholders on a modified rollout.

While the immediate crisis was averted, it exposed critical and interrelated gaps and failures in the process and policies used for efficiently allocating spectrum.

For example, in this case, the FCC and FAA were not well coordinated on the timing and sufficiency of information regarding the technical specifications of radio altimeter and protection requirements. In addition, despite the complex, fast-moving, and safety-critical nature of wireless technology, government as a whole does not regularly update its standards for spectrum-using devices. The degradation of stable leadership and lack of working interagency relationships at many levels of government during this period served as another obstruction to amicable dispute resolution.

To address these shortcomings, the Eno Center for Transportation (Eno) and the Information Technology and Innovation Foundation (ITIF) collaborated on an initiative to inform future spectrum allocations. These two independent, nonprofit organizations created a joint advisory group consisting of aviation and wireless spectrum experts, as well as those deeply familiar with federal spectrum allocation procedures. This group informed the research, evaluation, and development of specific, actionable recommendations to improve the process and avoid conflicts in the future.

These recommendations fall into four broad categories:

1. **Agencies and standards-setting organizations should look to improve spectrum-using devices' resiliency to interference.** Reforms are needed to improve resiliency, and periodic reviews of technical standards for spectrum-using devices are also necessary In addition, the federal government should develop rules to incentivize the development of more interference-resistant receivers. Congress should reform the Spectrum Relocation Fund to

allow it to be used by spectrum users to develop technology for more efficient spectrum use.

2. **The federal government should invest in personnel that can properly operate and lead complex spectrum allocation processes.** Given the expected demand for spectrum, the federal government should provide more resources to hire qualified engineers to address issues at a technical level rather than a political one. Federal agencies need to build better working relationships among their staff, while government leaders need to prioritize critical interagency connections.
3. **Final decisions on spectrum allocation need to be established based on clear testing, data, and definitions.** The clash of studies from different stakeholders, each purporting to provide the best evidence, is a hallmark of interference disputes. Though no solution is likely to end all disagreements about the technically superior course of action, additional independence and systematization of basic parameters can help all parties be more confident and contest their analyses on a level playing field.
4. **The federal government should clarify and enforce jurisdictions and areas of expertise within the spectrum allocation process.** Clear, up-front awareness of how disparate concerns are considered, and the preemptive sharing of some of those basic interests between the relevant agencies, will smooth the process when future spectrum management decisions are made.

These recommendations relate specifically to a recent spectrum allocation conflict between aviation and telecommunications. Yet it is important to note that this case was not the norm. While spectrum allocations are often contentious, this case was unusually problematic due to many process breakdowns. Nevertheless, that disagreement was not just a significant problem for both industries but for the nation itself—and it could have been prevented. Targeted reforms to improve the quality of personal relationships and expertise of players in the process, and to enhance the technological capabilities of devices, will go a long way toward averting problems in the future. The federal government should not wait until the next conflict to act.

INTRODUCTION AND METHODOLOGY

The careful allocation of radio spectrum is vital to the successful operations of critical communications and operating systems in the United States and abroad. The radio spectrum is used by a wide variety of stakeholders, both private and public, for uses such as transportation, telecommunications, radio communication, broadcasting, navigation, meteorology, and defense. Coordinating these systems, often by placing different uses in different frequency ranges, prevents harmful interference and ensures accurate and uninterrupted transmission, maintaining a high level of public safety, security, and service quality within each sector.

While each new spectrum allocation discussion has unique considerations and nuances, the process typically follows a formal framework set in the United States at the federal level and in cooperation with global partners. Historically, the process has functioned as designed, accounting for the needs of all its stakeholders and preserving the integrity of existing spectrum operations. However, the process does not always go smoothly.

One recent allocation proceeding generated concerns about potential interference between the new allocation of 5G cellular communications in a portion of the C band (3.7–3.98 GHz) and radio altimeters on aircraft in the frequency band 4.2–4.4 GHz.

This research used the C-band allocation as a case study to review the process for safely and responsibly allocating spectrum, identify gaps in the process, and propose policy solutions that would help identify and resolve issues before they become public safety or industry-wide problems in future allocations.

What Is Radio Spectrum?

Electromagnetic spectrum is the range of radiation energy that carries everything from visible light to X-rays, microwaves, and gamma rays. Radio spectrum is the portion of electromagnetic spectrum that has frequencies ranging from 1 Hz to 3,000 GHz. The waves within this band, called radio waves, are used for many different communication applications, including FM and AM radios, cell phones, maritime communications, and many other forms of wireless transmissions for private, public, and amateur use. The government regulates how radio frequency spectrum can be used and by whom, attempting to prevent harmful interference and achieve both clarity of communications and safety. Depending on the needs of particular uses, bands can either be shared or allocated to exclusive use.

Allocation of the C Band

While most spectrum allocation happens unbeknownst to the general public, the allocation of the C band made national news.[1]

The FCC had been considering the allocation of the band for terrestrial mobile services since August 2017 and, in March 2020, proceeded with an order to auction the lower portion of the C-band frequencies. Despite concerns from portions of the aviation industry, the FCC concluded that a 220 MHz guard band would protect altimeters from C-band interference based only on data and recommendations supplied during the public comment process, as required by the Administrative Procedure Act.[2] But the lingering issue of whether the rules would adequately protect radio altimeters came to a head in late 2021 as winning bidders prepared to activate 5G service in the band. Fearing potential interference with safety-critical radio altimeters, and without another option within its power, the FAA in December 2021 levied operational restrictions at airports where mobile carriers were planning to deploy C-band 5G services.[3] While the initial crisis was temporarily averted, the costly, high-stakes showdown could and should have been avoided.

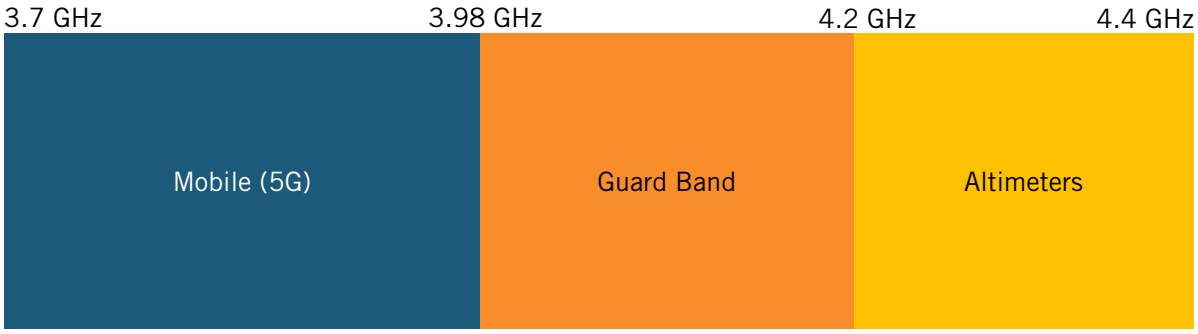
The need for the allocation of the C band to mobile communications follows the compounding growth of wireless data. The amount of data traffic per smartphone has grown substantially since 2015. Traffic in North America increased threefold from about 5 GB per month per smartphone to about 15 gigabytes (GB) per month per smartphone in 2021 and is projected to reach 52 GB by 2027.[4] The number of devices connecting to and accessing data on wireless networks has increased as well with the onset of smart TVs, smart home devices, and wearable technology. A growing portion of the population also relies on mobile devices for life-saving services. For example, 80 percent of 911 calls come from mobile devices.[5] Increased data demand on an increasing number of devices has ultimately led to a need for more bandwidth in order to maintain system speeds and reliability. Insufficient bandwidth has prevented 4G LTE from

attaining its theoretical speed of up to 100 megabits per second, with speeds averaging between 10 and 50 megabits per second.[6] Participants at the World Radiocommunication Conference (WRC), FCC, and leading telecommunications companies identified the 3.7–4.2 GHz portion of the C band, previously used for space-to-Earth signals from satellites, as an ideal band for 5G networks.[7]

Just above the 3.7–4.2 GHz band is a portion of the spectrum used for radio altimeters onboard both military and civil aircraft. Radio altimeters are also used in public safety services, including police and medical helicopters that fly low over urban areas. These safety-critical systems provide information to pilots when they are flying at low altitudes (referred to as "height above ground level"), most prevalently during takeoff and landing. Radio altimeters also provide information to many other safety-critical aircraft systems such as traffic collision avoidance, automated landing systems, and terrain avoidance, among others. A commercial aircraft cannot land in low visibility conditions without the information provided by the radio altimeter. Their performance also must meet the FAA's particularly high safety threshold: By regulation, critical systems such as an altimeter must fail less than one time in one billion, or 10-9. For example, an aircraft landing in dense fog needs assurance that its altimeter will not suffer harmful interference from signals operating in other bands that would cause the device to give an erroneous reading, or no reading at all. To allow flights, the FAA needs to be confident that devices capable of emitting radio waves will not interfere with radio altimeters.

To protect the integrity of these radio altimeters, the FCC has proposed limits on unwanted emissions and a guard band between the bands, as shown in figure 1.[8] Notably, terrestrial 5G antennas operate at significantly higher power than does the satellite downlink that previously occupied that portion of the band. They also have an ability to change their azimuth to concentrate signals to areas of most need.[9] Therefore, despite the limitations imposed by the FCC, portions of the aviation industry raised concerns throughout the allocation process that aircraft could be at risk for interference from new 5G services, even while they complied with existing FAA standards.

Figure 1: C-band allocation proximity to airplane altimeters[10]



After its own analysis that the frequency separation and technical limitations would address concerns over radio altimeter interference, in January 2021 the FCC auctioned licenses to frequencies from 3.7 GHz to 3.9 GHz, which were purchased by mobile companies for a combined $96 billion, including a premium paid to get access to the spectrum on a specific timeline.[11] Because of their ongoing concerns for public and aviation safety—and with few

remaining options in their power—in December 2021, the FAA restricted aircraft operations at airports where 5G C-band transmissions were set to be deployed.[12] The 5G deployments at that time were available only to the "Phase-1" licensees, who were authorized to use only the spectrum between 3.7 and 3.8 GHz, 400 MHz away from the aviation altimeter band. The scheduled deployment near airports was initially delayed for a month, and then, following further delays, the FAA and two major wireless carriers, AT&T and Verizon, agreed to voluntary, temporary mitigations that included buffer zones and power and antenna tilt restrictions around major airports until July 5, 2022.[13] In June 2022, the FAA required aircraft with affected altimeters to be replaced or retrofitted with filters, and it would begin to relax temporary mitigations when it deemed it safe to do so. At the time, the FAA expected the installation of filters and replacement units to be completed by July 2023. However, the aviation industry now seeks a further extension of that deadline in addition to maintaining certain limits on 5G operators' power levels near certain airports.[14]

Throughout 2022, Alternative Means of Compliance (AMOC) approvals by the FAA cleared most commercial aircraft to land in low visibility conditions at airports with 5G mitigations in place, but a handful of aircraft, including most iterations of two popular regional commercial Embraer jets, were still prohibited from doing so at almost all U.S. airports.[15] Currently, the FAA is considering a new Airworthiness Directive that would require altimeters to meet higher standards, though not necessarily standards consistent with the FCC C-band order, by February 1, 2024.[16]

The C-band proceeding exposed vulnerabilities in the spectrum allocation process, potentially placing communications, passenger safety, and cargo operations in jeopardy, along with billions of dollars in multiple segments at risk. Understanding how these vulnerabilities arose and implementing creative, preemptive solutions is essential to enabling future successful spectrum allocations.

Project Goals and Scope

The C-band allocation will not be the last time government agencies work together to reallocate spectrum where there is the potential for interference to systems critical to public safety. Therefore, improving the spectrum allocation process is imperative. This report aims to understand the framework in which spectrum decisions are made, identify where the spectrum allocation process failed in the 5G C-band case, and provide policy recommendations for improvement to the processes and structures that contribute to spectrum allocation.

Importantly, this report does not seek to assign blame for the failures of the C-band allocation. Rather, it uses that example as a case study to identify gaps and potential solutions to ensure that it does not happen again.

Methodology

This report employs an independent look at the issues from Eno and ITIF. The Spectrum Working Group, cochaired by former acting FAA Administrator Dan Elwell and former National Telecommunications and Information Administration (NTIA) Administrator Larry Strickling, includes 20 volunteer members spanning both the aviation and telecommunications industries, with experience in the public and private sectors, manufacturing, operations, broadband access, and spectrum allocation. Below are the group participants at the time of publication:

- Byron Dorgan, ArentFox

- Eugene Freedman, National Air Traffic Controllers Association
- Matt Furlow, U.S. Chamber of Commerce
- Greg Guice, Public Knowledge
- Dale Hatfield, Silicon Flatirons (University of Colorado)
- Bob Ireland, Airlines for America
- Ben Ivers, Boeing
- Christopher Julius, American Airlines
- Julius Knapp
- Grace Koh, Nokia
- Blair Levin, New Street Research
- Karl Nebbia, Huntington Ingalls Industries
- Carl Povelites, AT&T
- Tom Power, CTIA
- Roger Sherman, Quadra Partners
- Bryan Tramont, Wilkinson Barker Knauer
- Patrick Welsh, Verizon
- Jonathan Wood, Intel

Members of this group served as a source of knowledge and expertise, helped identify additional experts for research interviews, and reviewed work products for accuracy. Participation in the group does not mean endorsement of the final products, and not all members agreed with all parts of this document. The authors carefully considered input from all members as well as other individuals who were not part of the advisory group when developing the analysis and recommendations. Any remaining errors are those of the authors.

After initial conversations with stakeholders, the research team reviewed existing data, literature, and other written material covering 5G implementation in the United States and around the world to create an overview of the following elements of the 5G rollout in the C band and the process for allocating spectrum, including:

- Early reports (2015 to 2019) from industry (telecommunications and aviation) and popular news discussing 5G
- Recent reporting from industry and news on the 5G rollout
- Timeline of when FCC, FAA, aviation, and telecommunication stakeholders became aware of the C-band reallocation, and when they started researching its effects on their industry
- History of communications between the FAA and FCC, and the role of NTIA as the voice of the executive branch on spectrum matters
- International best practices on how governments approve allocation of spectrum for 5G

The following sections were informed by continued discussions with working group members and outside experts, with the goal of identifying gaps and developing innovative and pragmatic recommendations to close those gaps.

HOW THE SPECTRUM ALLOCATION PROCESS IS SUPPOSED TO WORK

While the current state of spectrum allocation is far from perfect, understanding the way it has developed and how the overall process is supposed to work is helpful in identifying ways in which deviations from that model cause problems. This section is, therefore, an idealized, high-level description of the organization of spectrum policymaking and the bodies that produce it. The gaps in this process that have caused it to malfunction in practice, and recommendations for how to remedy those gaps, follow in the next section. (Also see "Analyzing Solutions to Process Gaps.")

A Brief History of Radio Spectrum Allocation in the United States

The history of radio spectrum allocation in the United States dates back to the beginning of the 20th century. The process through which it is allocated has evolved since then, incorporating both the executive and legislative branches of the federal government and foreign agencies.

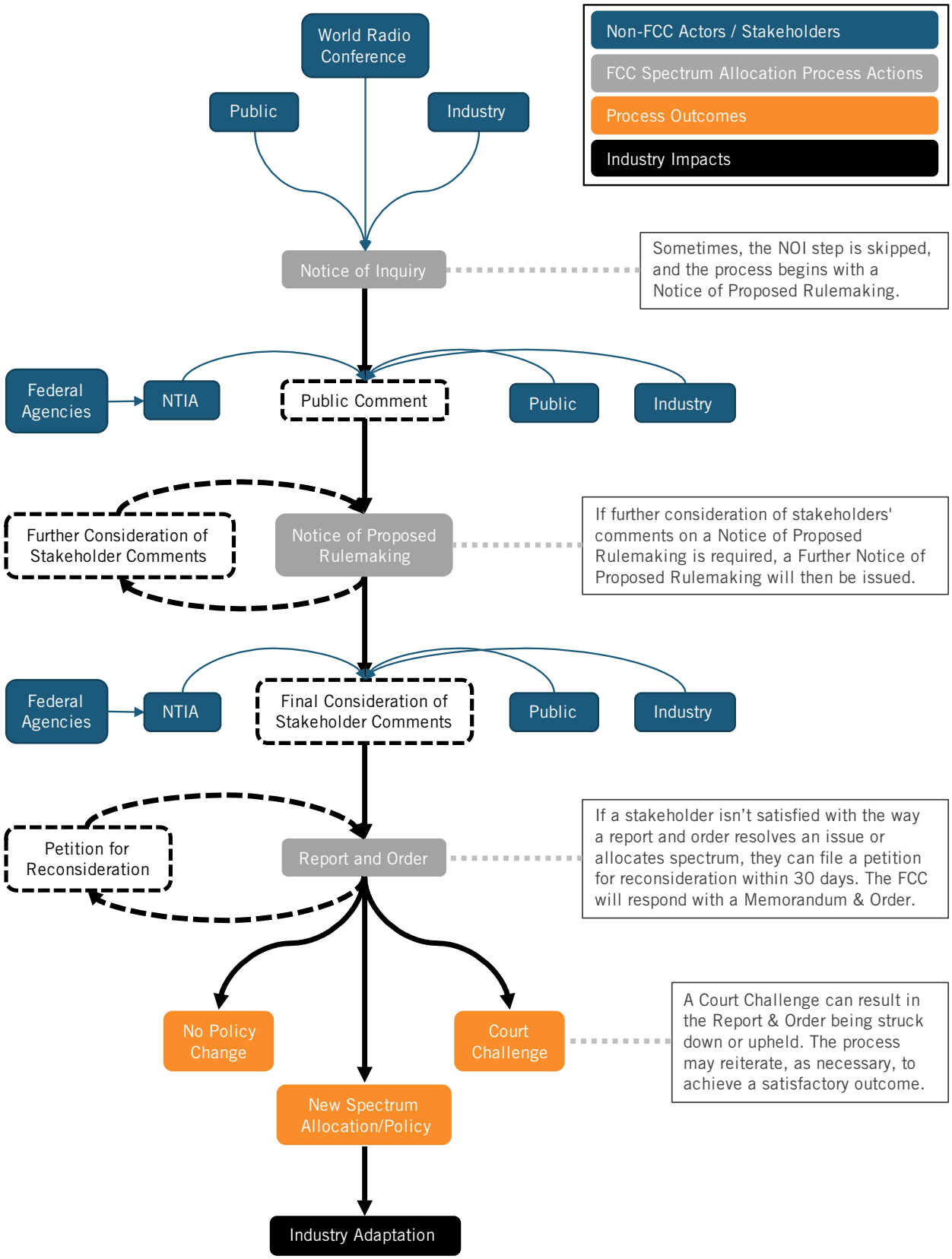
The 1912 Radio Act gave the Department of Commerce the authority to issue licenses to use spectrum, while preserving the Navy's interest in radio communications.[17] Though the history of the period that followed is disputed, the conclusion was the passage of the 1927 Radio Act, which created the Federal Radio Commission (FRC) to replace the Commerce Department's role in allocating commercial spectrum licenses.[18] Then, through the passage of the Communications Act of 1934, Congress replaced the FRC with the FCC.[19] The FCC is an independent agency overseen by Congress, meaning the executive branch does not have direct executive oversight of its actions.

Another significant evolution in the allocation of spectrum came with the Omnibus Reconciliation Act of 1993, which empowered the FCC to allocate spectrum licenses with auctions as opposed to the old system of discretionary, comparative hearings or lotteries.[20]

Today, when the FCC proposes to allocate or reallocate spectrum, it engages with stakeholders, gathers pertinent information, and either proposes or denies new regulations in response to shifts in industry that may require new bands or that have opened existing ones through consolidation or vacancy. The process for this FCC engagement is largely delineated by the Administrative Procedure Act. Stakeholders, including the executive branch and its federal agencies, private industry, and the general public, can comment and raise any relevant concerns in response. The FCC then issues a final rule that officially allocates the spectrum band for a particular purpose.

Auctions are now the primary means by which wireless telecommunications providers access exclusive licenses for spectrum. For newly allocated cellular commercial bands, such as the 3.7–3.98 GHz portion of the C band, the FCC typically auctions licenses to the highest qualified bidder. In recent years, most spectrum licenses have been won by members of the commercial mobile industry. Other spectrum access regimes, such as sharing bands through databases, frequency coordination, environmental sensors, or a combination thereof, have also been identified as ways to increase the productivity of bands with immovable incumbents.[21]

Figure 2: U.S. spectrum allocation process



The FCC regulates state, local, tribal, and commercial uses of spectrum. The services regulated by the FCC include broadcasting (radio and television), mobile cellular, satellite, maritime, aviation, and amateur radio, among others. The FCC does not have jurisdiction over federal government spectrum use; that is instead administered by NTIA, a part of the Department of Commerce.

NTIA was created in 1978 via an executive branch reorganization, later codified by the NTIA Organization Act of 1992, to advise the president on policy issues regarding telecommunications and information.[22] Within NTIA, other participants in the policy process include the Interdepartmental Radio Advisory Committee (IRAC), the Policy and Plans Steering Group (PPSG), and the Commerce Spectrum Management Advisory Committee (CSMAC). The IRAC and PPSG are interagency working groups that provide a venue for federal agencies, under the aegis of NTIA, to understand and coordinate with each other on matters affecting spectrum policy, including consideration of proposals made by the FCC. CSMAC is a federal advisory committee whose industry and academic members are drawn from across the spectrum ecosystem.[23]

The complex nature of the spectrum regulation and allocation processes aims to account for all potential public and private stakeholder concerns and innovations but also creates certain vulnerabilities, which are explored in depth in the section on "Analyzing Solutions to Process Gaps." A visualization of this process is shown in figure 2 and is detailed in the following section.

International Context

Many spectrum allocation (and re-allocation) discussions begin to take shape at the International Telecommunication Union (ITU). ITU is part of the United Nations, where changes to the international radio regulations are decided at the WRC once every three or four years. The WRC makes changes to international radio frequency regulations use in order to promote harmonious use of spectrum throughout the world. For example, a cell phone can work in many different countries, since all those countries designate the same bands for mobile use. Similarly, an aircraft must be able to communicate in every country in which it flies. Therefore, having harmonized spectrum for a particular communications or navigation use is critical. The United States and other countries support these changes through adherence to WRC decisions.

While the unified standards are helpful for international harmonization, national governments are not required to formally adopt these allocations and can move ahead with an allocation other than what ITU decides. In the United States, for example, the 3,550–3,700 MHz band has a three-tier band plan that does not exist in ITU rules or other countries.[24] For the C band, there has been an international allocation of the 3.7–4.2 GHz band for three types of services: fixed, fixed-satellite (space-to-Earth), and mobile.[25] Many countries have permitted terrestrial mobile use under rules similar, though not identical to, those the FCC has adopted for the United States.[26]

The WRC is an important opportunity for all spectrum-using industries and governments to advocate for and raise concerns about proposals to allocate spectrum in particular ways. Various industries, including mobile communications and aviation, can and do participate in the WRC process. For example, in 2015, aviation stakeholders raised concerns about the potential for International Mobile Telecommunications use of the lower C band causing interference with radio altimeters in the 4.2–4.4 GHz portion of the band.[27] The proposal was tabled for a later

conference, though a mobile allocation remains on the band.[28] Another United Nations body, the International Civil Aviation Organization (ICAO), participates to add a further aviation perspective and can assess the impact of WRC outcomes on wireless applications used by the aviation industry.[29]

Statutory Context and the U.S. Interagency Process

In the United States, Congress oversees all FCC and executive branch policymaking, is the source of the statutes that set the boundaries of agency power, and occasionally directs policy through additional legislation. For example, Congress may mandate that the FCC or NTIA identify a certain range of frequencies for reallocation to alternative uses. In 2018, the MOBILE NOW Act did this with the C band, requiring federal agencies to advise NTIA as to the feasibility of allowing commercial wireless services to use or share the 3.7–4.2 GHz band.[30] Congress is often viewed as the only way to break through what would otherwise be a bureaucratic logjam of competing interests across industry and government, whose incentives are not currently aligned to facilitate changes to allocations in the face of entrenched interests.

In the United States, spectrum policy is led and managed by two key federal agencies: NTIA and the FCC.

NTIA

NTIA is the president's principal advisory body on telecommunications and information policy issues, including federal spectrum allocation.[31] NTIA exercises its role of managing spectrum used by federal agencies primarily through the Interdepartment Radio Advisory Committee (IRAC), through which the U.S. Department of Transportation (DOT) is represented.[32] NTIA convenes the IRAC and an NTIA employee acts as chair.[33] Members of the IRAC include 20 executive branch agencies and services, including both the FAA and DOT and a liaison from the FCC.[34] The IRAC is a forum for these agencies and the public to raise concerns or provide presentations to NTIA regarding spectrum allocation and use. When a potential FCC action affects IRAC members, the FCC presents the item to IRAC for review, and IRAC members then consider the document and can provide feedback to the FCC. There is room for negotiation and advocacy, but matters are usually resolved in an uncontentious manner.

The outcome of the IRAC process is transmitted to the NTIA Office of Spectrum Management to develop NTIA's own position. Each member of IRAC must be informed about how a potential spectrum reallocation would affect the industries within its jurisdiction. For example, the FAA chairs the Aeronautical Assignment Group of IRAC, which is responsible for the technical specifications of frequency assignments and for determining whether frequency assignments in aviation frequency bands should be approved.[35]

The NTIA administrator makes a policy decision based on the input from IRAC. In making its decision, NTIA's constituency is the president, not the individual executive branch agencies. NTIA is a decision-making body in and of itself, not merely a conduit for others' positions. In making a policy decision, NTIA is obligated to make effective, efficient, and prudent use of the spectrum in the best interest of national policy goals, including deploying commercial spectrum services, maintaining national security, and ensuring public safety alongside the interests of federal agencies. NTIA's position, therefore, results from the consideration of numerous national policy goals.

Once established, the decision of NTIA on an issue of federal spectrum policy becomes the position of the executive branch. Although other agencies may disagree with NTIA's decision, the NTIA process remains the proper avenue to update and advocate for necessary changes to that decision. Agencies also retain the power to take steps to mitigate remaining issues using measures within their own jurisdiction (i.e., non-spectrum measures) The president's support of this process and of NTIA as the preeminent actor on spectrum within the executive branch is critical.[36] On commercial spectrum matters, this means NTIA speaks for the executive branch before the FCC. For FCC proceedings involving nonfederal bands, NTIA's position is intended to be an input to FCC's process, but the FCC remains the final decision-maker.

The FCC

The FCC has authority over nonfederal (state, local, and commercial) spectrum.[37] As it is an independent agency, FCC Commissioners are not subject to direction or termination by the president. The FCC is limited by its statute, but within this framework, it has broad authority to allocate spectrum "as public convenience, interest, or necessity requires."[38]

The FCC also plays a role in approving any devices capable of emitting radio waves, including mobile phones, cell towers, radio altimeters, and even light bulbs.[39] In many cases, this approval is limited to a check to ensure a device's emissions are not such that they will cause harmful interference. The FCC does not, however, play a similar role in regulating devices intended to receive radio signals.

The FCC generally allocates spectrum through rulemaking. This process starts with either a Notice of Inquiry (NOI) or Notice of Proposed Rulemaking. These instruments begin a public proceeding, state the FCC's preliminary view of a proposed reallocation, and pose questions for public input. The FCC accepts comments from any member of the public and must respond to all relevant comments in its record. Ultimately, the FCC must make its decision based on evidence in the record before it, so it is critical that the FCC hold submitted evidence and interference studies to high technical and engineering standards.

The outcome of many spectrum reallocation proceedings involves relocating incumbents or providing interference protection for existing uses. In other cases, the FCC might decide reallocation is not in the public interest or worth the cost and make no changes to regulations. Subject to detailed limits on its statutory authority, the FCC reaches a reallocation decision that can include compensation to incumbents. The details of the mitigation measures, their costs, and their timeline must be part of the record at the time the FCC makes its decision in order to be properly considered.

In evaluating the comments of interested persons and industries, the FCC's role is to be impartial, giving due weight to the reasoned arguments of all parties. At the same time, the FCC must also be a willing and active collaborator, especially in its dealings with NTIA. Open channels of communication and collegiality at the staff level have historically been the keys to finding workable compromises between government bodies and competing interests.

The FCC's decisions are subject to petitions for reconsideration by parties that believe the FCC has made an incorrect decision or based its decision on incomplete information. FCC decisions are also subject to judicial review and can be set aside for a number of reasons, including if they

are not supported by analysis of the information submitted or placed into the record.[40] This record is public except for classified or market-sensitive information.

Other Federal Agencies

Other federal agencies oversee industries that use spectrum, including national defense, transportation, and agriculture. While these agencies do not have the authority to supplant NTIA in making final spectrum allocation decisions, they are an important part of the process and govern how their industries can safely and efficiently operate given the rules for spectrum.

For example, the FAA has authority over the national airspace system, including spectrum-using devices, to maintain a safe and efficient transportation system. The FAA uses industry-generated research and standards to support the adoption of rules detailing the parameters devices must meet in order to be used on aircraft. These regulations bind all users of the national airspace, so, for example, an airline may not use an altimeter that does not meet FAA regulations.

Part of the FAA's critical safety oversight role is to continually monitor developments in spectrum policy to assess how they will relate to aircraft safety given the level of interference immunity required under current standards. This kind of information allows the agency to raise concerns with IRAC and the NTIA. There is an expectation that safety concerns will be accounted for in developing the government's position on a spectrum proceeding.

Industry Participation

Industry groups and companies also play an important role both within and in addition to the interagency process. While their input is necessary for the FCC to make policy decisions, industries generally presume the integrity of the process. Like everyone before the FCC, commercial industries have a responsibility to be both candid and forthcoming with the evidence for their position and in disclosing the parameters of their operations to the extent necessary for the FCC to evaluate the potential for harmful interference with existing services. Once a new regulation is made, affected industries begin the process of adapting to FCC actions, even if the outcome is not one they would have preferred.

The Aviation Industry

The aviation industry, for example, can and does file comments and hold meetings directly with the FCC to advocate for the safety of its operations and promote new ways to advance aerospace communications technology.

RTCA Inc.—formerly Radio Technical Commission for Aeronautics—is an aviation industry standards development organization that works with the public and the FAA, NTIA, and FCC in an advisory capacity.[41] RTCA's deliberations include government and industry stakeholders (airframers, avionics manufacturers, wireless industry, etc.) to develop consensus-based standards. These Minimum Operational Performance Standards (MOPS) detail specific parameters for avionics equipment. RTCA has relied on the Aerospace Vehicle Systems Institute (AVSI), a member of RTCA, to conduct tests and analyses of radio devices for aircraft to understand how resilient they are to interference from other existing or proposed spectrum uses. RTCA incorporates these findings into a report, which recommends standards for avionics and other aircraft devices. These standards are generally adopted by the FAA as primary means of compliance rules for the aviation industry.

The Wireless Industry

The wireless industry also files comments and holds meetings directly with the FCC to advocate for the commercial wireless industry and promote new ways to advance wireless broadband technology.

The 3rd Generation Partnership Project (3GPP) is an international, industry-driven standards body that determines the technological capabilities that characterize each generation (e.g., 3G, 4G, 5G) of mobile communications.[42] Standards released by 3GPP include intended frequency bands for mobile operations, which are then used by device manufacturers and network operators to plan investment and business strategies. When the FCC allocates a band for mobile use, it is generally used by devices that follow 3GPP standards, but the standards themselves are not adopted by the FCC. Rather, FCC regulations set the permissible uses and limits for each band.

Unofficial Cooperation

The process described above is the formal process to incorporate diverse interests into a final decision on spectrum allocation, in practice, the system is most successful when a spirit of cooperation and collegiality accompany adherence to the letter of the law. Behind-the-scenes negotiations as to both the characteristics of wireless systems and the substantive policy have often driven productive solutions more than an adversarial adjudication by industry groups, federal agencies, or courts has.[43] This aspect of the process is heavily dependent on the individuals involved and their willingness to understand competing viewpoints, take the trade-offs seriously, and try to find positive-sum solutions.

ANALYZING SOLUTIONS TO PROCESS GAPS

Comparing the established process laid out previously (see "How the Spectrum Allocation Process Is Supposed to Work") with how it has actually played out in recent years, such as in the C-band reallocation, reveals several gaps that have contributed to its dysfunction in specific cases.

These gaps are interrelated. Overlapping problems within federal spectrum policy do not allow for easy answers. As such, the following gaps do not assign blame to any agency or individual. Rather, most problems that arose through the process were the culmination of multiple, compounding issues. By the same token, a coordinated effort to address all gaps will become self-reinforcing and revitalize the spectrum allocation process so that it becomes strong precisely where it is broken.

GAP 1: Agencies in charge of standards for spectrum-using devices are not always adequately or consistently knowledgeable about the capabilities of the spectrum-using devices they regulate or how spectrum allocation developments will affect them.

Although the FCC is the agency that has authority over spectrum allocation decisions, many agencies have jurisdiction over devices that use spectrum. These agencies are sometimes insufficiently informed about spectrum policy developments on the horizon and the performance capabilities of the devices they regulate given those developments. As these agencies are the ones with intimate knowledge of the costs and timeframe necessary to accommodate a changed spectrum environment, insufficient awareness on their end early in the process can contribute to delayed testing and research to verify potential interference or other issues.

The FAA was aware of the potential introduction of mobile use in bands frequencies around those used by altimeters when it was addressed at the ITU during the 2012–2015 WRC cycle, and ICAO put out a job card (a document describing the scope of ICAO's work on a given task) to improve standards for altimeters to reject potential interference.[44] Some aviation industry stakeholders believe (whether real or perceived) that the FAA did not substantively engage with the commercial airline industry to describe potential risks and service disruptions until a teleconference roundtable in June 2021.

When the FCC record presents data showing costs to an incumbent user from a new spectrum use, the agency routinely protects the incumbent through regulatory limits or financial compensation taken from auction revenue. This occurred for incumbent services such as fixed-wireless and satellite downlink operating in the 3.7–4.2 GHz band prior to the reallocation.[45] Unlike these applications, the FAA's evaluation of whether their altimeter standards were sufficient to protect aircraft was based on insufficient information—including a lack of public empirical study results—until the October 2020 RTCA study. This study was pursuant to a nearly four-year-old identification of the potential threat of mobile services to altimeters built to existing standards, but it was not filed with the FCC until months after the comment deadline, the adoption of the C-band order, and the deadline for petitions seeking reconsideration of that order.[46]

A comprehensive study of interference would have been difficult, since the specific emissions and deployment characteristics of the new entrant—in this case 5G carriers—were not known until the FCC report and order was released. However, having preliminary data about how incumbent devices work (e.g., the robustness of any extant filter on a receiver) is necessary to create an actionable record at the FCC.

GAP 2: Federal agencies have lacked stable leadership and there has been a degradation of the trust that enables positive-sum negotiations.

The interagency spectrum process works best when the individuals involved in the day-to-day work—not just principal decision-makers—have strong working relationships. A track record of trust and good faith is instrumental in creating a collegial process and convincing all stakeholders that their concerns will get a fair hearing. These relationships take time to form, but they become all the more necessary as the proliferation of wireless applications necessitates cooperation and dispute resolution between more diverse agencies and industries.

Between May 2019 and October 2021, there was no Senate-confirmed NTIA administrator.[47] In the White House, authoritative posts covering spectrum policy at the Office of Science and Technology Policy and the National Economic Council were vacant throughout the C-band proceeding. The FAA administrator also resigned in the midst of 2022 negotiations.[48] While individuals in "acting" roles often serve with distinction, staffing instability weakened NTIA in its ability to serve as the principal advisor to the president on spectrum policy matters and contributed to the ability of other agencies to deviate from the established NTIA process. For example, the lack of a coherent regular order was evident in the C-band proceeding when the FAA asked NTIA to transmit a letter to the FCC that was never delivered.[49] The key role of good-faith relationships starts at the top of agencies, and the lack of stability contributed to the lack of amicable dispute resolution in 2021.

While there is little public record of the behind-the-scenes negotiations during the late-2021 interference dispute, the fact that the process devolved into FAA and DOT officials sending letters to specific telecommunications companies demonstrates a lack of staff-level collegiality in which individuals who could find amicable policy and engineering solutions had not identified each other and developed working relationships.

GAP 3: NTIA's decisions and position are not always vigorously and consistently supported as the position of the executive branch.

Agencies or other stakeholders dissatisfied with established processes and NTIA's decisions have in some instances gone outside those processes, including by applying political pressure and using the press to support a view already rejected by NTIA.[50] The White House, in turn, has not consistently supported the established process by ensuring agencies do not deviate from their role in it. This pattern has undermined the actual and perceived ability of the executive branch to produce unified, evidence-based policy, which, regardless of the legitimacy of stakeholders' concerns, the executive is expected to eventually coalesce around.

Even when the White House made public statements as to federal policy in the dispute, agencies worked at cross-purposes by, for example, continuing calls for delay after the president indicated that 5G deployments should be able to "launch" by a date certain. Agencies that have objections to an FCC proceeding do not always feel that NTIA has given them a fair hearing and transmitted the relevant information to the FCC record. This was seen in the 24 GHz band when internal disagreements pitting NTIA against the National Oceanic and Atmospheric Administration and NASA exploded into public view.[51] In the case of the C band, the FAA and DOT made public statements that they had to respond with aviation restrictions "to protect the safety of the traveling public."[52]

Recall that these gaps are interdependent and process failures in one area are often occasioned by prior failures in other areas. This dynamic is especially present with this gap. The Gap 1 problem of the FAA and aviation community being insufficiently aware of the technical capabilities of the altimeters and, therefore, not raising detailed interference concerns early in the IRAC process resulted in a scramble to include those concerns later on and outside the regular procedures. Given that the FAA had sincere safety concerns, it was compelled to pursue whatever means necessary to avoid grounding aircraft it judged to be at risk from 5G deployments. This reaction, however, was problematic for the reasons listed in Gap 3, which is itself a cause and symptom of Gap 2. This dynamic highlights the need to address the gaps holistically.

GAP 4: Given the historical and technical complexities of wireless deployments, the FCC does not have a broad, forward-looking process to evaluate the performance of receivers beyond the band it seeks to reallocate.

While all services should be operating in compliance with FCC rules, the FCC does not proactively survey the performance of receivers already in the field and evaluate the safety and risk tolerances those receivers need. Nor does the FCC always account for the impact of any necessary reallocation on extant receivers separated from the allocated band by a wide range of frequencies, including assignment of legal responsibility and financial compensation for any necessary upgrades.

Receivers present a challenge unlike the regulation of transmitters because the characteristics of a transmitter can be objectively studied in a lab environment. In contrast, assessing receivers' resistance to interference is highly contextual, and regulating it presents difficulty in that receivers themselves do not directly cause interference. They can, however, foreclose potentially productive uses if receiver operators require protection from emissions in bands separated by a large range of quiet frequencies. In short, in the event of harmful interference, it is easier to tell whether a transmitter is transmitting out of band than it is to tell if a receiver is listening out of band. This asymmetry is reflected in the history of FCC regulations and the scope of its statutory authority, and can result in unforeseen interference problems if a radar device transmits on one range of frequencies but is tuned to receive a much greater range.

Here, the FCC determined technical limits for use of the C band and established a guard band, but it did not know that, due to their inability to filter emissions far outside their assigned band, certain altimeters may have been operating with receivers that could nevertheless experience harmful interference. Even if the FCC had been able to determine that altimeter receivers were open to signals from outside their assigned band, the FCC's authority to take regulatory steps in response is unclear. A better understanding of receiver capabilities would provide the FCC with more tools to accommodate the stringent risk tolerances of the aviation industry.

GAP 5: The FCC, through NTIA, has not been as proactively engaged as it could be when engaging agencies with related jurisdictions and industries that are less-frequent players before the FCC.
Ideally, all agencies would be attentive to potential spectrum policy developments (as highlighted in Gap 1). But more active outreach and involvement with agencies and industries that are not such frequent players in FCC spectrum allocation proceedings would help surface potential conflicts so they could be resolved through regular order.

While the FCC publicly released all documents that explained the proposed usage rules for the C band and invited comments in the relevant dockets leading up to the final reallocation, greater FCC outreach has been suggested, as industries such as aviation are not as accustomed to FCC documents and deadlines. Similarly, the FCC was not accustomed to the aviation industry's careful and measured approach to testing and verifying safety-critical equipment, which often takes longer than a normal FCC procedure. Outreach that is more proactive than the mere publication of official notices in the Federal Register would have opened the door to productive engagement on potential interference concerns and a timeline for addressing them.

GAP 6: The FCC has not been sufficiently clear or stringent with the parameters and assumptions that make up a useful interference study.
Since the FCC can only consider the evidence before it, competing studies with differing assumptions add complexity to its decision-making role. Rigorous and transparent engineering analysis is the lifeblood of successful dispute resolution, but the FCC lacks clear standards for interested parties that produce those analyses.

In the C-band proceeding, multiple parties filed their own technical studies and criticized others' studies without an agreed-upon set of initial assumptions or methodologies. For example, AVSI conducted a study that suggests potential interference with some radio altimeters.[53] Meanwhile, T-Mobile commissioned another study that challenges the initial assumptions of the AVSI study.[54] The FCC's decision, therefore, did not have the benefit of independent or

methodologically comparable studies to determine the potential for interference with existing altimeters and the ways in which it could be mitigated.

The FCC itself does not conduct its own studies, so it had to rely on evidence in the record, which did not include an independent study (e.g., from the Institute for Telecommunication Sciences (ITS) or another body). These facts hampered the ability of the FCC to make objective comparisons between study results and led to unsatisfied parties challenging the FCC's objectivity.

GAP 7: The technical and regulatory standards for spectrum-using devices are not updated by the relevant standards-setting bodies on a regular basis.

Rather than undergoing periodic, official reviews to assess potential changes to the interference environment and how technological developments could improve receiver performance, many standards for devices are updated only as needed. This is especially problematic when there is a discrepancy between the intended lifetime of the devices using the spectrum (e.g., the life of an aircraft) and the timeline of likely changes in the spectrum environment that existed when the standards were first adopted. Even if updates are contingent on an actual change to the interference environment, devices could still be regularly assessed to determine whether technological developments have made improvements possible.

Ultimately, at the time of the C-band proceeding, regulatory and standards bodies did not have the information needed to respond appropriately to changes in the spectrum environment. They were not prepared to update standards to improve the performance of altimeters in the field and ways in which they could be improved to be more resilient. As a result, the aviation industry and FAA needed significant time to ascertain whether their receivers were listening out of their assigned band in a way that would affect aviation safety, and they needed even more time to determine which altimeters would function properly in the new interference environment.

Many altimeters were designed and deployed decades before the reallocation of the C band for 5G under the assumption that high-powered systems would not exist up to 3.98 GHz.[55] However, there were no updates to technical standards (either promulgated by RTCA or adopted by the FAA) in the several years during which the introduction of terrestrial mobile services became likely. As a result, there were no test results that could be relied upon to prove the robustness of radio altimeters in the face of the changes in their environment. Therefore, the aviation industry and the FAA were not knowledgeable about the resiliency of altimeters in the field. For example, testing of higher-performing altimeters, such as the Honeywell ALA-52B, could have been publicly completed and made a part of the FCC record so the FCC could know the extent of its tolerance. Even studies with conservative assumptions about the location of transmitters relative to an altimeter's receiver would have been a helpful benchmark for the FCC during its proceeding and for the FAA as it sought to mitigate potential interference.

Regardless of the feasibility of determining the resiliency of a receiver when the technical characteristics of a new interference source are not known, it is clear that earlier access to better data would have mitigated problems later. The FCC should deliberately solicit experts from affected industries to find agreement on which assumptions should be used for analysis.

Again, these gaps have often been causes and effects of each other. For example, executive-branch agencies' duty to be more informed about spectrum issues and raise issues early before

IRAC (Gap 1) is paralleled by the lack of user-friendly notice from the FCC (Gap 5) and could contribute to the potential for distrust of NTIA decisions (Gap 3), which is itself exacerbated by discontinuity in staffing from the White House and NTIA (Gap 2). The following policy recommendations, therefore, seek to address them comprehensively to break potential cycles of malfunction.

POLICY RECOMMENDATIONS

While these gaps aligned to create a cumulation of challenges with regard to aviation and 5G in the C-band proceeding, it is important to note that such failings are not the norm. Most spectrum proceedings happen within the established process and without significant controversy or conflict. Therefore, the system itself is not fundamentally broken in a way that would necessitate a wholesale overhaul. Rather, targeted reforms are needed to improve the level of personal relationships and expertise of players in the process and enhance the technological capabilities of devices that could lead to conflict. Those recommendations fall into four broad, interrelated categories:

- Device resilience
- Personnel
- Data and testing standards
- Clarification of Agency jurisdictions

Agencies and Standards-Setting Organizations Should Find Ways to Improve the Performance of Spectrum-Using Devices

The basis of the underlying substantive problems in the C-band dispute was the introduction of a new radio frequency application and altimeter performance standards that were not sufficient in the new environment. Reforms that encourage a system's ability to operate within its own frequency band are needed.

Standards-Setting Organizations Should Conduct Periodic Reviews of Technical Standards for Spectrum-Using Devices

As the number of spectrum-using devices proliferates and the frequencies they use grow closer together, it is important for technical standards to stay in sync. Even when devices are designed to last a long time, the standards process should not remain static until a problem arises. There should be periodic review of the capabilities of these devices, the potential for changes in the radio frequency environment, the ability of new technology to improve their performance, and identification of modifications to the standard to which devices operate.

In practice, industry-based standards bodies are best suited to implement this recommendation. 3GPP, for example, has successive releases of new wireless standards that help keep the industry up to date. RTCA is moving toward a more proactive process with Special Committee 242 on Spectrum Compatibility.[56] The federal government, along with communications and aviation industries, should embrace and continue these efforts. Other industries should view them as models and begin to make forward-looking evaluations of devices used by the industries under their jurisdiction.

Essential to these periodic evaluations are:

- reevaluation of current standards and how devices built to that standard would be affected by current or likely future changes in the interference environment;
- a survey of devices currently in the field and their practical capabilities; and
- a survey of technological developments since the adoption of current standards that could improve devices' resilience to interference.

It is important to note that an evaluation of devices, the environment in which they operate, and the standards that govern them does not necessarily entail wholesale remaking of standards. Standards bodies may, for example, conduct research of the performance of an altimeter under various potential interference environments and then report the results. Or they might evaluate ways in which technological or regulatory changes in one industry could affect another. These kinds of efforts fall well below rewriting regulations but would still serve as valuable resources to recognize potential conflicts far in advance and provide more actionable information when regulatory proceedings begin.

In short, the outcome of this process could, but does not need to, be a comprehensive replacement standard or even immediate retrofits of existing devices to state-of-the-art technology. But even simple, up-front awareness of the capabilities of current devices and the options for improving them will realize large gains. When this information is available early in FCC proceedings, it allows the FCC to accurately account for the consequences of its decisions and determine how to mitigate potential harmful interference. Gathering and sharing information about the capabilities of systems and the potential impacts of changes in spectrum allocation can take place even before the FCC specifies the rules for deployments in a particular band. Data about how a device works and performance assessments based on hypothetical predicted changes to the interference environment would be invaluable in setting the stage for FCC proceedings, including identifying relocation or mitigation payments the FCC can set aside from auction proceeds. Such studies would allow the FCC to develop a record that identifies mitigation measures to protect incumbents and perhaps allocate auction revenue to pay for them. Indeed, the FCC did this successfully for fixed-wireless and satellite incumbents within the C band. Auction revenue could also fund or reimburse the costs of conducting the information gathering, though that may require legislative action.

Federal agencies should encourage, incentivize, and perhaps mandate periodic reviews by standards bodies. They should also use the information generated by these reviews to adopt updated standards and rules as appropriate. Here again there are gradations of regulation: An agency need not immediately impose new requirements based on future interference developments, but having a new standard waiting in the wings will keep regulated entities informed about what to expect in the future and significantly ease the transition when heightened restrictions do become necessary.

The FCC, and the Federal Government More Generally, Should Develop a Rule to Incentivize the Development of Interference-Resistant Receivers

Historically, the FCC has not imposed rules or standards for radio receivers. This lacuna may stem the ambiguous grounds for its authority to adopt receiver standards and the fact that receivers themselves are the victims, not the cause, of harmful interference. As the spectrum gets more crowded, however, the resilience of receivers directly impacts the productivity of the

airwaves. Receivers that are not robust in their filtering of unwanted emissions can preclude intensive use of neighboring frequencies, since they will require broad protection.

The details of a final FCC rule that will achieve this goal of more-resilient receivers are beyond the scope of this paper. But it is important to clarify what kind of devices will get interference protection and which will not. It should also include details for how a claim for current or future interference can be shown. Such a rulemaking does not, however, need to result in direct FCC regulation of receivers as devices. The FCC's ongoing proceeding on Receiver Interference Immunity Performance is an opportunity to directly tackle this for commercial and state and local government receivers.[57] The same receiver performance problem also exists for receivers using federal spectrum, not under the jurisdiction of the FCC. An NTIA-led effort parallel to the FCC's rulemaking is necessary to improve receiver performance in all bands.[58]

Congress Should Reform the Spectrum Relocation Fund to Allow It to Be Used for Upgraded Equipment

While not as directly relevant to the C-band proceeding, many potential spectrum clashes could occur with spectrum used by federal agencies themselves. It is notoriously difficult to incentivize federal spectrum users to economize on their spectrum use, but reducing the spectrum footprint of individual uses is often the best way to avoid interference conflicts in the first place.

The 2004 Commercial Spectrum Enhancement Act created the Spectrum Relocation Fund (SRF) to incentivize federal agencies to clear spectrum for commercial use.[59] With some targeted reforms, the same mechanism could aid in reducing interference conflicts as well. The fund currently reimburses federal agencies for costs incurred in repurposing spectrum for nonfederal or shared use, but equipment purchased with those funds is limited to that which provides the agency with a "comparable capability." While the Office of Management and Budget should reexamine how the statute actually limits SRF funds, under this requirement, as currently understood, agencies will maintain the same standard of equipment even if more-resilient and efficient devices are achievable. This gets the incentives backward. Congress should remove the comparable capability requirement and increase the flexibility of SRF funds such that federal agencies can better accomplish their missions while also being better neighbors to other spectrum uses. This reform would parallel FCC proceedings in which the costs of relocating or protecting users, including through technological changes, are routinely considered in the reallocation process.

Spectrum Users Should Develop Technology for More-Efficient Spectrum Use

Spectrum is a scarce resource that has gradually become overcrowded with disparate uses as more industries vie for a slice of the pie. As users are pushed ever closer together, disputes between potentially incompatible neighboring users will become more frequent. There are, therefore, gains to be made by making overall spectrum use more efficient in ways that reduce the number of potential collisions and increase the menu of options to resolve disputes when they arise.

For example, advances in technology could make it possible to re-pack incumbent uses into smaller frequency ranges, allowing more space for new services and creating larger guard bands for critical systems.

Technological advancements in spectrum sharing could, in future proceedings, allow for general rules for the majority of uses but give one service priority if worst-case scenarios do occur. This could include new sharing technologies with accurate sensing capabilities that do not overprotect one service at the expense of another. There does not currently exist a market-ready technology that can provide sufficient certainty to incumbent users on both sides of an interference dispute, so this solution was not and is not available to resolve the C-band dispute. But private companies should invest in creating and deploying these technologies in future bands, and Congress should appropriate funding for research and development both inside and outside the government. Wireless operators in exclusively licensed bands also have strong incentives to get the most out of their spectrum, so we should look for ways to leverage those advances to mitigate other interference conflicts.

Improvements in spectral efficiency often take a long time to develop and implement, so many actions taken under this recommendation will require long-term planning. Investments now, however, will result in fewer contentious, zero-sum disputes in the future.

The Federal Government Should Invest in Personnel That Can Properly Oversee and Find Solutions in Complex Spectrum Allocation Processes

The Federal Government Should Provide More Resources to Hire Qualified Engineers

The demand for spectrum engineers grows alongside the demand for spectrum, and government salaries are not competitive with the market price of engineers in the private market. There is broad consensus that almost all spectrum disputes are resolvable on a technical level given sufficient time and personnel with the expertise and interest in optimizing radio systems under constraints.

Congress should appropriate sufficient funding and modify federal pay guidelines as necessary to allow agencies to hire and retain top engineers. While this recommendation would cost money in the short term, the long-run costs of insufficient engineers would be far greater. The best solution to most interference disputes is for engineers to put their heads together and come up with technical solutions. Without sufficient staffing resources, disputes such as the C-band proceeding will only become more common and sap immense resources, not only from the agencies involved in the dispute but also from the industries that are forced to endure costly delays or hasty retrofits to make up for the earlier lack of a technical solution.

This influx of engineering talent must be distributed across the federal government, not concentrated only at agencies with traditional spectrum management roles. Any agency whose jurisdiction includes spectrum-using devices should hire personnel that understand the technical capabilities of the devices in its purview and is skilled in how to optimize them in changing interference environments. Such expertise spread throughout the agencies would greatly assist NTIA in its role as spectrum administrator for the executive branch.

Agencies Involved in Spectrum Allocation Need to Intentionally Build Working Relationships Among Staff

All levels of the spectrum management process require, at their heart, that individuals work together. This includes leadership personnel at the highest levels of the relevant agencies. While regulations encouraging collaboration may ease the process, there is no substitute for personal good faith among leadership.

The updated Memorandum of Understanding between the FCC and NTIA is a good example of this kind of development.[60] This is not to say that past administrations have necessarily failed at this; indeed, informal discussions between the FCC and NTIA, as well as the PPSG and IRAC processes, have long provided venues for robust discussions between agencies, and past successful spectrum allocations are evidence that good faith relationships did exist. Rather, this recommendation emphasizes the need to be intentional in the process of creating good working relationships between agencies, especially at times of transition between administrations.

The fostering of productive working relationships must go deeper than the high command, however. Day-to-day decisions by staff-level employees often play an outsized role in identifying and resolving disputes. These staff, including the aforementioned newly hired engineers, should work to identify their counterparts at other agencies and establish lines of communication and trust that will allow for productive, good-faith interactions when potential conflicts arise. Simply knowing whom to call when something goes wrong can keep options for amicable solutions open where conflicts might otherwise devolve into each side's defense of its own jurisdictional turf.

The existence of these relationships will also fill in information gaps. Rather than having to internalize every potential spectrum move by reading the Federal Register, ongoing communication can help contextualize spectrum policy developments and enable more productive engagement earlier in the process.

The Administration Needs to Prioritize Leadership With Consistent White House Support

The president should promptly nominate and the Senate, where necessary, should confirm individuals to fill vacancies in key spectrum leadership positions within the executive branch. Ensuring these posts have both stable leadership and the clear support of the White House will help them carry out their role in analyzing relevant interests with regard to spectrum and policy decisions.

Just as crucially, the White House needs to provide direct support to NTIA in insisting that other federal agencies follow the existing processes and abide jurisdictional boundaries of agencies involved in spectrum policy. The White House should routinely promulgate a memo that establishes its commitment to the established interagency process and support the aims of that memo when contentious issues arise.

Congress could also consider enhancing the position of the NTIA administrator by elevating the position's designation from assistant secretary to undersecretary in order to counter any possibility that other agencies view the administrator as lacking authority both in dealing with executive branch agencies and with the FCC. Currently, the chair of the FCC is considered a Level III position within the Federal Schedule, while the NTIA administrator is Level IV.[61] Upgrading the position of the NTIA administrator to be on par with the FCC chair signals the primacy of NTIA as both the hub of executive-branch spectrum matters and a more significant voice before the FCC.

Final Decisions on Spectrum Need to Be Established Based on Clear Testing and Data

Another hallmark of interference disputes is the clash of studies, each purporting to provide the best evidence that the party responsible for the study is correct. Though no solution is likely to end all disagreements about the technically superior course of action, additional independence

and systematization of basic parameters, along with complete data and information, could help all parties be more confident and contest their analyses on a level playing field.

The FCC Should Consider Independent Testing and Studies on Controversial Allocation Proposals When It Would Be Helpful to Its Decision-Making

While interference studies prepared by parties to an FCC proceeding can highlight important issues, there is value in including studies by independent third parties as well. ITS could rigorously perform such analyses, but it was not commissioned to produce one for the C-band proceeding until late in the process. When the FCC is unable to reach a firm conclusion about the technical likelihood of harmful interference and the effectiveness of proposed mitigation measures, it should request a study from independent bodies that can then serve as the benchmark for analysis by the FCC. The FCC should be as specific as possible about the characteristics of the deployments it expects to result from a proposed reallocation so that studies are a good approximation of the future interference environment. This recommendation will require substantially more staff for ITS, for which Congress should appropriate the necessary funds.

Importantly, however, studies by ITS and other bodies are not a replacement for the FCC's role in making engineering determinations. The studies envisioned by this recommendation should remain inputs to the FCC's own expert judgment and come during the normal timeline of a proceeding. For its part, the FCC should recognize the unique aviation expertise of the FAA and rely on that agency for perspective.

The FCC Should Have Clear and Transparent Standards for Acceptable Evidence of Harmful Interference

In addition to having its own studies, the FCC should be transparent about what kinds of evidence would be most helpful to inform its determinations about the potential for harmful interference. While the Office of Engineering and Technology is skilled at evaluating interference studies, these studies are most useful when they stem from a common understanding of what constitutes evidence and ideally a shared framework of initial assumptions, including as many technical details of potential deployment as possible. Engineers in different agencies and industries should collaborate to find common ground on which to build experimental tests. While there may still be disagreements over the level of risk different agencies are able to assume, speaking the same language when it comes to types of, and standards for, evidence would remove one area of disagreement and better enable apples-to-apples comparisons.

The Federal Government Should Clarify Jurisdictions and Areas of Expertise Within the Spectrum Allocation Process

Before any other agencies butt heads over spectrum matters, they should understand and embrace the exact roles NTIA and the FCC play in the spectrum allocation process.

For example, the Government Accountability Office's 2022 report on the spectrum management process includes recommendations for improvement, one of which is that NTIA clarify the methods by which it considers various agencies' spectrum concerns before arriving at a cohesive view for the executive branch.[62] Clear, up-front awareness of how disparate concerns are taken into account, and the preemptive sharing of some of those basic interests between the relevant

agencies, would help smooth the process when future spectrum management decisions are made.

Since spectrum-using devices are embedded in larger systems, different agencies often have roles to play in their regulation. But they should not all compete to play the same role. It is important to differentiate between standards for evaluating radio interference, the application of that data to a given safety margin, who makes the decisions about each, and what steps could mitigate harms. There are three considerations that are relevant to that determination:

1. The probability that harmful interference will occur under given circumstances. This is a technical question the FCC (specifically its Office of Engineering and Technology) and NTIA (with respect to systems used by the federal government) are well positioned to answer with the input of all stakeholders.
2. Whether that probability is sufficiently small to satisfy the safety requirements of another agency. This is a question for that agency.
3. Given the answers to both of the above considerations, whether the FCC should proceed with an allocation decision is a question for the FCC. Other agencies may not like the impact such a decision will have on the industries they regulate, and should argue through interagency channels that those downstream impacts make the FCC's decision unwise. But ultimately, the FCC's spectrum allocation decisions need to take into account a vast number of interests, and will sometimes entail compromise on the part of all users. In those cases, the affected agency should take other measures to mitigate safety concerns.

CONCLUSION

The public clash surrounding the rollout of 5G in the 3.7–3.98 GHz band revealed significant gaps in U.S. spectrum policy. The confrontation between government agencies and aviation and wireless industries was regrettable and unnecessarily pitted public policy priorities for safety and technology against each other. Though the varying interests eventually came together at the last minute to prevent further damage, the disjointed process has been costly to both the aviation and wireless industries and the American people.

While all parties have made progress on the C band, this is not the last time the FCC, NTIA, or FAA will confront conflicts with spectrum allocation—and interference with safety-critical systems can happen on any mode of transportation. The nation needs to develop improved processes to avoid such a conflict in the future.

This paper's collaborative approach was designed to do just that. By engaging in a productive dialogue between industry experts, better understanding the problem, and identifying critical gaps, we were able to develop policy recommendations for device performance, personnel, data and testing standards, and agency jurisdictions. The hearings and negotiations regarding the upcoming reauthorization of the federal aviation law and potential updates to the Communications Act present an opportunity to put these recommendations in place.

APPENDIX: C-BAND ALLOCATION TIMELINE

2003: WRC 03 proposes studies on additional spectrum for mobile services.[63]

2007: WRC 07 discusses potential for C Band to provide mobile service.[64]

2015: WRC 15 discusses spectrum for 5G, including the C band.[65]

2016: ICAO Job Card FSMP.006.01, "Develop radio frequency and interference rejection characteristics for radio altimeters."[66]

August 2017: FCC Mid-band NOI.

- Goal was to find "bands between 3.7 and 24 GHz with the most potential to support increased flexible uses, including wireless broadband services."[67]
- Sought comment on "how existing service rules governing GSO FSS and FS could be modified to further promote flexible use in this band, stimulate investment, and encourage more intensive deployment in the 3.7–4.2 GHz band for wireless broadband."[68]
- At least some members of the aviation industry recognized that C-band reallocations were on the horizon around this time and filed comments raising concerns about potential interference.

March 2018: Mobile Now Act.

- 605(b) of the Consolidated Appropriations Act.
  - "Not later than 18 months after the date of enactment of this Act, after notice and an opportunity for public comment, and in consultation with the Secretary, working through the NTIA, and the head of each affected Federal agency (or a designee thereof), the Commission shall submit to the Secretary and the appropriate committees of Congress a report evaluating the feasibility of allowing commercial wireless services, licensed or unlicensed, to use or share use of the frequencies between 3700 megahertz and 4200 megahertz."[69]

July 2018: Notice of Proposed Rulemaking on 3.7–4.2 GHz for terrestrial mobile.

- "We note that the adjacent 4.2–4.4 GHz band is allocated to the aeronautical radionavigation service on a primary basis and that, at WRC-15, the 4.2–4.4 GHz band was also allocated to the aeronautical mobile (R) service on a primary basis in all ITU Regions with use reserved for WAIC systems.... We solicit comment on the needed out-of-band emission limit required to protect the aeronautical radionavigation service in the 4.2–4.4 GHz band."[70]

October 2018: FCC comment deadline.

November 2018: FCC reply comment deadline.

December 2018: AVSI reply comments suggesting a study of "RF performance of existing avionics" will be available "by the end of 2018."[71]

October 2019: AVSI files "preliminary test results."[72]

January 2020: T-Mobile files rebuttal to AVSI results.[73]

February 2020: FCC 3.7-4.2 GHz Report and Order.

- Discussion of Coexistence with Aeronautical Radionavigation (paras 390-395). Excerpts:
  - "By licensing only up to 3.98 GHz as flexible-use spectrum, we are providing a 220 megahertz guard band between new services in the lower C-band and radio altimeters and Wireless Avionics Intra-Communications services operating in the 4.2–4.4 GHz band. This is double the minimum guard band requirement discussed in initial comments by Boeing and ASRC."[74]
  - "We find the limits we set for the 3.7 GHz Service are sufficient to protect aeronautical services in the 4.2–4.4 GHz band. Specifically, the technical rules on power and emission limits we set for the 3.7 GHz Service and the spectral separation of 220 megahertz should offer all due protection to services in the 4.2–4.4 GHz band. We nonetheless agree with AVSI that further analysis is warranted on why there may even be a potential for some interference given that well-designed equipment should not ordinarily receive any significant interference (let alone harmful interference) given these circumstances. As such, we encourage AVSI and others to participate in the multi-stakeholder group that we expect industry will set up—and as requested by AVSI itself. We expect the aviation industry to take account of the RF environment that is evolving below the 3980 MHz band edge and take appropriate action, if necessary, to ensure protection of such devices."[75]

August 2020: FCC establishes C-band auction procedures.

October 2020: RTCA releases study.

- "The results presented in this report reveal a major risk that 5G telecommunications systems in the 3.7–3.98 GHz band will cause harmful interference to radar altimeters on all types of civil aircraft—including commercial transport airplanes; business, regional, and general aviation airplanes; and both transport and general aviation helicopters."[76]

October 2020: CTIA files competing analysis that disputes the findings of the RTCA report.

December 1, 2020: FAA sends letter to NTIA seeking auction be deferred; asks NTIA to send letter to FCC; it was not.

December 8, 2020: C-band auction begins.

February 2021: C-band auction concludes.

June 2021: FAA holds industry Zoom forum to gather information and viewpoints on impacts of the C-band auction.

November 2, 2021: FAA issues Special Airworthiness Bulletin.

November 4: AT&T and Verizon agree to postpone activation of Phase 1 (up to 3.8 GHz) from December 5 to January 5.

December 30: Airlines for America files emergency petition for stay with FCC.

December 31: DOT and FAA ask AT&T and Verizon to delay an additional two weeks.

January 4, 2022: AT&T and Verizon agree to two-week delay.

- President Biden issues statement: "This agreement ensures that there will be no disruptions to air operations over the next two weeks and puts us on track to substantially reduce disruptions to air operations when AT&T and Verizon launch 5G on January 19th."[77]

January 18: AT&T and Verizon agree to extend buffer zones and lower power limits until July 6.[78]

June 17: AT&T and Verizon agree to extend limitations for an additional year; FAA agrees to require regional aircraft to retrofit altimeters.[79]

September 15: RTCA starts SC-242 on "Spectrum Compatibility."[80]

October 3: Members of the aviation industry meet with FCC to request permanent extension of the previously temporary restrictions on 5G power and antenna uptilt.[81]

October 11: ITS releases a study on "Measurements of 5G New Radio Spectral and Spatial Power Emissions for Radar Altimeter Interference Analysis."

- "5G unwanted-emission power levels in the radalt band are upper-bounded by our results as being between -37.5 dBm/MHz (for the radio on which we achieved the smallest measurement dynamic range) to -48.5 dBm/MHz (for the radio model for which we achieved the largest measurement dynamic range) …This low level of unwanted 5G emissions within the radalt spectrum band reduces the potential for a 5G-to-radalt harmful interference scenario which would be due to 5G unwanted emissions on radalt receiver frequencies."[82]

October 21: FAA sends a letter to NTIA, cc'ing the FCC, requesting that the government "codify certain additional operating limits in the 5G C-Band environment" because "data indicates that even retrofitted aircraft would be susceptible to interference if the report and order is not modified, resulting in renewed concerns about unsafe interference."[83]

January 11, 2023: FAA publishes proposed Airworthiness Directive, which recognizes C-band licensees' voluntary mitigations and would impose obligations on aircraft to operate with resilient radio altimeters.[84]

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