Evaluating the National Spectrum Strategy[1]

Randall Berry and Michael L. Honig
Department of Electrical & Computer Engineering
Northwestern University
Evanston, IL

Thomas W. Hazlett
Department of Economics
Clemson University
Clemson, South Carolina

Abstract

The National Telecommunications and Information Administration at the Department of Commerce (NTIA) recently published its National Spectrum Strategy (NSS) along with an implementation plan. The NSS points to particular bands that may be suitable for either repurposing or sharing with other applications, totaling 2790 MHz. These bands include 3.1-3.45 GHz, assigned for use by the Department of Defense; 7.125-8.4 GHz, allocated to a variety of space-based communications systems and other applications; and 37-37.6 GHz, considered for shared use between Federal and non-Federal users. The NSS raises several questions about possible ways in which those bands might be reconfigured for a broader range of applications. We first summarize the four main pillars in the NSS, and then give a retrospective on past spectrum planning efforts, going back several decades. From that review we outline suggestions for future policy decisions concerning spectrum access rights.

Coexistence, and in particular, primary-secondary sharing, plays a key role in the NSS approach. Determining *a priori* what applications may reasonably coexist with incumbents in particular bands is treated primarily as a technical question, requiring measurements to assess the potential for "harmful" interference. We discuss potential benefits and limitations of measurements and associated measurement testbeds, to be developed as part of the NSS. While field measurements may provide some information about spectrum utilization, welfare maximization requires an assessment of economic value. Stakeholders and incumbents, in particular, may not have an incentive to reveal that information to regulators. Measurement testbeds can help to expand the range of possible conflict-mitigation mechanisms as inputs to policy makers. However, testbed capabilities will be shaped by stakeholder incentives (or lack thereof), leading to experimental limitations in terms of both technologies and propagation scenarios that can be demonstrated. We include some recommendations concerning

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measurements and data collection as inputs to policy-makers that should help to minimize rigidities and associated inefficiencies with spectrum use.

1. Introduction

The dramatic growth in the popularity of wireless broadband services over the past three decades has motivated regulators to seek additional spectrum to support this growth. Virtually all target frequencies are encumbered by existing or planned deployments, making such efforts contentious. The complications inherent in balancing interests among rival stakeholders have pushed policy makers to explore innovative ways to manage radio spectrum.

The National Spectrum Strategy[2] along with the associated Implementation Plan[3], recently published by the NTIA, identifies the bands 3.1-3.45 GHz and 7-8 GHz, among others, as candidates for repurposing over the next several years. Several major challenges arise. Conflicts result from coordinating spectrum use among a diversity of new and existing applications (with incumbent operations by DoD in 3 GHz and NASA in 7-8 GHz) combined with the increasing scale and scope of spectrum-based technologies by all parties. Further, the social welfare produced by such wireless applications depends on particular spectrum attributes, e.g., propagation loss, proximity to molecular resonances for passive sensing, the cost of associated hardware and software, while investments in research and development depend critically on the expectation that spectrum access rights will enable product implementation on a compatible schedule with the innovation cycle.

We first summarize the four pillars in the NSS. We then contrast the NSS with prior efforts intended to lay out a roadmap for management of spectrum resources. There have been many such efforts going back several decades. Those include the National Broadband Plan published in 2010, which identified challenges and solutions to spectrum management, followed by the 2012 PCAST report. Those particular documents have influenced subsequent policy decisions to repurpose particular bands, although the total amount repurposed has been significantly less than expectations, and has been accompanied by long delays. During the past several decades regulators have made many changes in access rights, serving as valuable experiments that can

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[2] NTIA, *National Spectrum Strategy* [NSS] (Nov. 13 2023).
[3] Alan Davidson, Assistant Secretary for Communications and Information, *National Spectrum Strategy Implementation Plan*, National Telecommunications and Information Administration {NSSIP] (March 12, 2024).

inform and help guide regulators to achieve more effective spectrum use. Those experiments demonstrate empirically the limitations of top-down planning that impose rigidities in access rules versus the introduction of more flexible access rights that enable the operation of market forces.

The NSS and implementation plan emphasize the importance of spectrum measurements as inputs to the regulator. Measurements can help characterize occupancy and utilization and provide regulators with an improved assessment of how spectrum is currently being used. How should such measurements inform policy decisions? Neither the NSS nor the implementation plan provide much insight into the answer, although the implication is that spectrum that is lightly utilized across particular regions of time-locations is a likely candidate for repurposing. The NSS recognizes that utilization data cannot directly and fully inform the reallocations that may result. Missing from usage data are the economic indicators that instruct stakeholders about the value derived from the spectrum itself as an input to the end application, the associated marginal value of additional spectrum for the applications considered, and opportunity costs associated with alternative uses.

The challenge, then, is to ensure sufficient flexibility in access rights to provide stakeholders with the incentives needed to facilitate negotiations and implementations of mutually beneficial spectrum sharing schemes. Although data concerning utilization can be a useful input to policy decisions, what is needed ultimately are better mechanisms for enabling coordination and competition for marketplace innovation over sharing mechanisms, associated services, and policies. This will inherently produce better valuation data and create new opportunities for experimentation and adaptation, for Federal as well as non-Federal use.

The NSS plans a substantial investment for measurement testbeds over the next several years. Testbeds can be a valuable, even necessary tool for demonstrating the feasibility of proposed innovations for wireless access, and can generate useful measurements for evaluating pros and cons of existing access methods. However, cost constraints limit testbed capabilities in terms of the scope of experiments that can be performed and data that can be collected. Testbed development by a particular stakeholder or third-party regulator runs the risk of focusing on particular access methods that may not facilitate the exploration of tradeoffs in welfare associated with varying interference levels across time, space, and frequency. Better outcomes may be expected if the incumbent is incentivized to negotiate directly with stakeholders interested in secondary access, resulting in testbeds that can inform the incumbent about potential interference concerns and indicate to an entrant the value derived under a particular sharing scheme.

We conclude the paper with some recommendations concerning measurements and data collection protocols that are used to inform regulators concerning future policy decisions.

2. Highlights from the National Spectrum Strategy (NSS)

The NSS was published by the National Telecommunications and Information Administration (NTIA) in Nov 2023 in response to the Presidential Memorandum "Modernizing United States Spectrum Policy and Establishing a National Spectrum Strategy." The NTIA prepared the NSS "to promote private sector innovation and further the missions of federal departments and agencies… The [NSS] reflects collaboration with the Federal Communications Commission (FCC), recognizing the FCC's unique responsibilities with respect to non-Federal uses of spectrum, and coordination with other Federal departments and agencies…"[4]

The NTIA solicited feedback from stakeholders via a request for comments, two public listening sessions, a government-only listening session, two Tribal Nation consultations, and one-on-one meetings. "The result," writes the NTIA, "is a comprehensive strategy to modernize spectrum policy and make the most efficient use possible of this vital national resource to enhance the quality of life for all Americans. This Strategy will expand access to advanced wireless broadband networks and technologies, whether terrestrial-, airspace-, satellite- or space-based, for all Americans."[5]

Subsequent to establishing the NSS, the NTIA published the "National Spectrum Strategy Implementation Plan" (March 2024) which "provides a public roadmap… For each strategic objective, the Plan identifies specific outcomes, with responsible Federal agencies, contributing stakeholders, and a timeline…."[6]

In this section we summarize the main objectives and tasks in the NSS, some of which we discuss in the subsequent sections. "The Strategy adopts and describes four *pillars* with several corresponding *strategic objectives* for immediate and sustained attention and effort:

- Pillar One: A Spectrum Pipeline to Ensure U.S. Leadership in Advanced and Emerging Technologies
- Pillar Two: Collaborative Long-Term Planning to Support the Nation's Evolving Spectrum Needs

[4] NTIA, *National Spectrum Strategy* [NSS], (Nov. 13 2023), p. i.
[5] Ibid.
[6] Alan Davidson, Assistant Secretary for Communications and Information, *National Spectrum Strategy Implementation Plan*, National Telecommunications and Information Administration {NSSIP] (March 12, 2024), p. 1.

- Pillar Three: Unprecedented Spectrum Innovation, Access, and Management through Technology Development
- Pillar Four: Expanded Spectrum Expertise and Elevated National Awareness."[7]

The stated aim of the strategy is to improve coordination in policymaking, allowing interested parties to more rapidly reach agreements on radio spectrum policies that enhance efficiencies in wireless communications. The NSS notes the "difficult issues surrounding access to spectrum," and specifically cites its interest in enabling "dynamic forms of spectrum sharing."[8] The evident motivation for the effort undertaken stems from the social losses entailed in delaying access to productive airwaves, reducing competition in markets and utilization of publicly-supplied services, and blocking innovation in wireless applications under the gridlock impacting the existing regulatory framework. Ideas are put forward, as summarized in the Four Pillars, to hopefully relieve the roadblocks deterring productive, radio-based activities.

We first discuss these Pillars. We then turn to additional analysis in sections dealing with *Past Spectrum Strategies*; F*uture Spectrum Policies*; and the *Use of Testbeds, Measurements, and Utilization***.**

Pillar One. Strategic objectives are to ensure sufficient spectrum is available to support Federal agency missions and private sector innovation (two objectives) taking into account current and future needs. A third objective is to "maintain the spectrum pipeline by applying guiding principles and leading program management practices to identify additional bands for study." [9] The focus is on bands with Federal allocation that "are being newly considered for more intensive Federal or non-Federal use. It will not examine bands that were previously made available for non-Federal use by the FCC…"[10]

Given these objectives and the NTIA's evaluation of inputs from stakeholders, the NSS identifies the following five spectrum bands, totaling approximately 2,790 MHz, "for in-depth, near-term study to determine suitability for potential repurposing to address the nation's ever-evolving needs. These spectrum bands are a mix of Federal and shared Federal/non-Federal bands—with an emphasis on mid-band frequencies—that will be studied for a variety of uses, including terrestrial wireless broadband, innovative space services, and unmanned aviation and other autonomous vehicle operations."[11]

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[7] NSS, p. 2.
[8] NSS, p. 2.
[9] NSS, p. 7
[10] NSS, p. 3
[11] Ibid

- 3.1-3.45 GHz: This band hosts a variety of radar systems (terrestrial and airborne) operated by the Department of Defense (DoD). The DoD has undertaken its own study of possible ways in which the spectrum might be shared with a commercial entrant with conclusions published in the Emerging Mid-band Radar Spectrum Study (EMBRSS).[12]
- 5030-5091 MHz: "The FCC, in coordination with NTIA and the Federal Aviation Administration, is expected to take near-term action to facilitate limited deployment of UAS [Unmanned Aircraft System] in this band."[13]
- 7125-8400 MHz: This band hosts "a variety of mission-critical Federal operations… (including Fixed Satellite, Mobile Satellite, Space Research, Earth Exploration Satellite, and Meteorological Satellite services) that will make it challenging to repurpose portions of the band while protecting incumbent users from harmful interference."[14]
- 18.1-18.6 GHz: This band hosts fixed downlink satellite services, and will be studied for expanded Federal and non-Federal satellite operations, including space-to-space allocations. This effort must be coordinated via the ITU and WRC conferences.
- 37.0-37.6 GHz: This band "will be further studied to implement a co-equal shared-use framework allowing Federal and non-Federal users to deploy operations in the band."[15]

The NSS states: "Because the spectrum is congested – and as `greenfield' spectrum becomes harder to find – U.S. policy (and stakeholders) must recognize that `studying' a band for potential repurposing to enable more efficient use does not prejudge the outcome of the study (i.e., that all, part, or none of the band ultimately will be repurposed as a result of the study)."[16]

Pillar Two: Strategic objectives are to: "Establish a persistent strategic spectrum planning process guided by the best available science and data"; "Develop and document an evidence-based national spectrum decision-making methodology"; and "Define requirements and implement capabilities to capture essential data and information on spectrum use". The report adds: "This includes implementing an ongoing process for solicitation of new and future spectrum requirements. Users will articulate their future needs through an agreed-to, standardized submission process that includes, at a minimum, a description of requirements, accompanied by supporting data, to ensure they are considered as part of the envisioned long-term planning process…"[17]

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[12] Department of Defense, Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) Feasibility Assessment Report. Sep. 2023.
[13] NSS, p. 6
[14] Ibid
[15] NSS, p. 7
[16] Ibid
[17] NSS, pp. 9-12.

The NSS promises the development of models for valuing spectrum as a guide for reallocations: "Systematic and rigorous analysis of relevant data is required for the timely, evidence-based decision-making needed to best serve the public interest. Leveraging our Nation's intellectual capacity, the U.S. Government will develop models that use a value-based framework to assess the potential impacts of spectrum reallocation options. The societal value of the spectrum will be calculated based on a quantifiable estimation of the direct and indirect benefits of the different uses of the spectrum to the Nation. This approach will enable clearly articulated national priorities to drive policy decisions, based on trustworthy data, in a manner that balances both near-term and long-term costs and benefits, while also recognizing the inherent uncertainty of the future."[18]

A core theme within this pillar is the need for "data about current real-world usage, the purpose and type of use (active or passive), as well as occupancy in the time, frequency, and geography domains." The NSS states that this data "is needed as the basis for assessing the potential for increased capacity. Using the new collaborative framework, stakeholders also will develop a structured schema for documenting and identifying future spectrum access requirements and a recurring process to solicit future requirements, enabling long-term planning. Such a strategic, forward-looking process is important to provide sufficient lead-time for proper planning and implementation of changes to authorized spectrum use."[19]

Pillar Three: Strategic objectives are to: "Improve spectrum efficiency and bolster coexistence by facilitating investments in new and emerging technologies"; "Commit to improving collective understanding of the electromagnetic spectrum through coordinated, focused, and sophisticated research and development (R&D)"; and "Pursue spectrum policies that maximize flexible use of spectrum, accommodate new and innovative technologies, and identify opportunities to expand spectrum access."[20]

The NSS states: "The U.S. spectrum-regulating agencies, benefiting from the improved collaboration framework, will jointly oversee a periodic, targeted assessment of U.S. spectrum policy to determine if it fosters U.S. technology development, incentivizes implementation of new technologies, and maximizes benefits for all Americans, especially to increase spectrum access for rural and underrepresented groups."[21]

Pillar Four: Strategic objectives are to: "Attract, train, and grow the current and next-generation spectrum workforce"; "Improve policymakers' understanding of spectrum

[18] NSS, p. 11
[19] NSS, p. 12
[20] NSS, pp. 13-17
[21] NSS, p. 17

considerations."; and "Improve the public's understanding of radio frequency spectrum and raise awareness of its role in everyday life."[22]

The emphasis of this pillar is on management of government spectrum resources: "Because a whole-of-government approach is necessary, the U.S. Government will develop and periodically update a National Spectrum Workforce Plan to prioritize development of, and enhancements to, the spectrum ecosystem workforce (including the full range of operational, technical, and policy positions involved in spectrum-related activities)."[23]

In what follows, we consider arguments derived from the first three pillars. While acknowledging the importance of offering spectrum-related science and policy material in academic curricula, we view that as a topic for a separate paper.

2. A Retrospective on Past Spectrum Strategies[24]

The NSS notes: "Systematic and rigorous analysis of relevant data is required for the timely, evidence-based decision-making needed to best serve the public interest. Leveraging our Nation's intellectual capacity, the U.S. Government will develop models that use a value-based framework to assess the potential impacts of spectrum reallocation options. The societal value of the spectrum will be calculated based on a quantifiable estimation of the direct and indirect benefits of the different uses of the spectrum to the Nation."[25]

It may seem untoward to disagree with the notion that U.S. spectrum policy should be made with "relevant data" on the basis of "evidence-based decision-making" that serves the "public interest." Yet, it is crucial to observe that policy makers have long experience with just the sort of approach announced in this key passage of the National Spectrum Strategy. Experts, appraising the value of competing uses of bandwidth administratively, have consistently used such approaches and yet consistently failed to achieve their goals in producing social benefits. U.S. consumers and entrepreneurs have been, thus, denied the spectrum necessary to achieve the social gains potentially available. For instance, the use of spectrum by federal agencies often continues according to legacy assignments going back several decades. This rigidity locks in outmoded approaches, ignoring the evolution in technology and service demands. Major economic inefficiencies result. The long delays in new spectrum allocations are a distinct

[22] NSS, pp. 19-21
[23] NSS, p. 19
[24] This section is based on *Comment Submitted to the National Spectrum Strategy* by Randall Berry (Northwestern University), Thomas W. Hazlett (Clemson University), and Michael Honig (Northwestern University), Department of Commerce, National Telecommunications and Information Administration's Implementation of the National Spectrum Strategy: Opportunity for Public Input (Jan. 9, 2024).
[25] NSS, p. 11.

characteristic of this institutional structure, erecting barriers to technological progress and squelching competitive forces. Such outcomes have plagued radio spectrum regulation since, literally, the 1927 Radio Act.[26]

It is important that the NTIA undertakes its current effort, and it is crucial that it be familiar with the fate of previous such projects. These include substantial reform efforts. The impressive string of reports and studies of the matter is beyond our scope, but we choose to emphasize a few telling points.

In the famous Landis Report, written for the incoming Kennedy Administration in Dec. 1960, former Harvard Law School Dean James Landis summarized already long-standing issues in the administration of spectrum allocation by the Federal Communications Commission (FCC).[27] The principal institutional defect, it surmised, was "the inability of the Commission to make up its mind on some of the broad issues that face it." The problem was not one of incompetence or a lack of resources.

> The Federal Communications Commission presents a somewhat extraordinary spectacle. Despite considerable technical excellence on the part of its staff, the Commission has drifted, vacillated and stalled in almost every major area. It seems incapable of policy planning, of disposing within a reasonable period of time the business before it, of fashioning procedures that are effective to deal with its problems.[28]

Such gridlock often still grips spectrum policy, where key allocations can consume more than a decade before resolution. Historic problems in the structure of spectrum governance are seen in several other studies – and in evaluating how the suggestions and recommendations ultimately fared in addressing, or ignoring, the problems cited.

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[26] Thomas Winslow Hazlett, *The Political Spectrum: The Tumultuous Liberation Of Wireless Technologies, From Herbert Hoover to the Smartphone* (Yale University Press, 2017).

[27] Other such reports are notable. "There have been Government reports on telecommunications policy challenges for decades. The Truman Administration in 1951 released a study on how we faced a major spectrum scarcity, for instance. Dean Landis's comments on the FCC were reflected, in part, in the 1968 Rostow Task Force report. Then, there was the 1988 NTIA Telecom 2000 report." Ken Robinson, 26 *Telecommunications Policy Review* (May 23, 2010). Additional such spectrum policy reviews are found in the Spectrum Policy Task Force Report (FCC, 2002); the National Broadband Plan (FCC in 2010); and the Presidential Council of Advisors on Science and Technology (PCAST, Realizing the Full Potential of Government-held Spectrum to Spur Economic Growth, July 2012).

[28] James Landis, *Report on Regulatory Agencies to the President-Elect*, Submitted by the Chairman, Subcommittee on Administrative Practice and Procedure to the Committee on the Judiciary, U.S. Senate (Dec. 1960), p. 53.

This does not deny that progress has been made. Indeed, in some aspects, remarkable gains have obtained with regulators embracing new methods and far more abundant spectrum resources being utilized – unleashing a variety of new, highly valuable wireless technologies. Such gains are notable in the aftermath of the liberalization of non-Federal spectrum use (embracing flexibility, as determined by users), increasing allocations to support additional competition, and a move towards market mechanisms (competitive bidding for license assignments, two-sided auctions to enable "change of use," and overlay rights to facilitate coordination between parties desiring different spectrum use models). Extremely large social gains have been realized.

But prolonged stand-offs stubbornly remain. Each involves a dispute over how to adjudicate access to a resource where one party's gain involves the prospect of another's loss. The goal of policy should not be to extinguish such conflicts – which are themselves the product of progress in seeking a greater array of valuable choices – but to enable outcomes where the most valuable social outputs emerge expeditiously. The administrative methods employed to make key rulings, however, still frequently underperform. They have delayed productive wireless deployments, freezing valuable swaths of frequencies in under-valued uses. Society experiences losses that superior public policy could ameliorate.

3. Implications for Future Spectrum Policy

Three key aspects of the NSS concern future Spectrum Policy.

First, policy makers list five specific bands that form the focus of government efforts to make more spectrum available for new wireless services. These allocations, totaling "approximately 2,790 MHz" of bandwidth between 3 GHz and 38 GHz, are being studied to discern if reallocations are appropriate. The announced aim – "maintaining a spectrum pipeline" – is a worthy goal. Yet, limiting the effort to top-down candidates nominated by regulators will likely prove overly narrow. In the 2010 National Broadband Plan, a list of specific bands were slated for opening to additional mobile market usage, with a 300 MHz overall goal for new authorizations of flexible-use licensed spectrum over 5 years (by 2015).[29] Over that period, the projected FCC allocations – despite being outlined using reasonable assumptions[30] – fell far short.[31] While some of the allocations proceeded, most were completed much beyond the

[29] Federal Communications Commission, National Broadband Plan [NBP] (March 2010), p. 75.

[30] "The forecast of a need to make 300 megahertz available by 2015 reflects a set of reasonable assumptions about the evolution of supply and demand for mobile bandwidth…" FCC NBP, p. 84.

[31] "Of the administration's goal of reallocating 300 MHz from specific bands by 2015, we count 135 MHz as having been freed within that time period. As of today, 146.5 MHz of that spectrum has been

window allotted; such policy lags mirrored the estimated historic delays (6-13 years) observed in the FCC's NBP analysis itself. The largest single allocation for new mobile access emerged from reallocation of 600 MHz frequencies previously (in 2010) reserved for over-the-air broadcast television transmissions. But while the "Incentive Auction" procedure employed by the FCC to effect this usage transition occurred, it opened not the projected 120 MHz to new mobile broadband competition, but just 70 MHz. Moreover, while planned to be completed prior to 2015, the FCC's reallocation took over ten years to complete.

The lesson to learn is that spectrum strategy going forward should aim not to plan the market in any precise way, but to encourage and enable innovative ideas to be exercised in the market. Where such innovations require regulatory reforms, petitions to the relevant agency should be processed quickly and favorably so far as they improve coordination between stakeholders. The NSS should include mechanisms for encouraging easier applications and speedier implementation of the latter.

Second, the National Spectrum Strategy appears to insufficiently consider what we might learn from the spectrum reform experiments conducted in recent decades. Much has happened: what do we now know? It is suggested here that empirical studies using standard economic methods evaluate the consumer welfare gains, positive or negative, associated with the:

- introduction of flexible-use radio rights, both in licensed and unlicensed regimes;
- TV White Spaces proceeding, first launched in 2002;
- two-sided auctions conducted for broadcast TV spectrum rights in 2016-17 and mmW spectrum, 2016-2020;
- the format used to incentivize incumbents for relocation in FCC Auction 107;
- overlays defined and then distributed by auction PCS, AWS, and Satellite C-Band spectrum reallocations;
- the use of FirstNet to supply public safety radio on a service model (utilizing procurement bidding) as opposed to (or in tandem with) in-kind subsidies via spectrum grants.

These reallocation mechanisms have been implemented for transitioning both Federal and non-Federal spectrum, and enabling access to a mix of commercial and non-commercial applications.

reallocated." Robert Kaminski, "*Telecom & Media*: Obama Administration Spectrum Report Card," Capital Alpha Partners (Jan. 10, 2017), p. 1.

Third, the call for empirical analysis of trade-offs in spectrum policy appears to miss the point of what currently blocks better decisions. The NSS states:

> Spectrum management relies upon trustworthy data. That means validating current uses and representing future access needs in a comparable manner across stakeholders and uses. Evidence-based decisions require standardized, granular data to ensure that requests for expanded spectrum access are justified by current or likely future needs and to understand the criticality of those operations.[32]

Yes, better data are preferred to inferior data. But the main problem with the data collected for spectrum allocation choices has not generally involved a lack of scientific monitoring, but the use of methods that fail to reveal the economic trade-offs quantifying the choices being made. This stems from rules (regulatory frameworks) that yield poor incentives for spectrum allocation choices, weak and uninformative feedback loops, and a focus on activities that fail to identify social values (including opportunity costs - valuations of sacrificed and unobserved alternatives). As a general rule, rent-seeking engaged in by competing parties becomes visible, while economic trade-offs are hidden. Hence, the stated goal in the NSS appears problematic:

> Leveraging our Nation's intellectual capacity, the U.S. Government will develop models that use a value-based framework to assess the potential impacts of spectrum reallocation options. The societal value of the spectrum will be calculated based on a quantifiable estimation of the direct and indirect benefits of the different uses of the spectrum to the Nation.[33]

But how these data are generated is as important as how they are monitored and recorded. When observations accurately reflect utility-creating choices registered by decision-makers who internalize the relevant costs and benefits of a resource employment, intellectual progress on the matter of spectrum allocation may truly be leveraged. Yet, to capture data revealing trade-offs typically requires exposure to the behaviors of actual buyers and sellers. Fortunately, today's markets often do feature sectors in which spectrum allocation choices are made by myriad consumers, investors, inventors, app developers, radio and network designers and manufacturers, and service providers with respect to prices. But where such data are not readily available they are not well substituted (easily created) in the form of technical usage charting or even market values – say, in revenues expended on various wireless networks or devices – that fail to incorporate costs and benefits resulting from *shifts* in radio spectrum

32 NSS, p. 12.
33 Ibid., p. 11.

allocations.   When approaching cost-benefit analysis in administrative forms that yield no useful information in revealing where marginal spectrum input adjustments yield comparative social gains, we fool ourselves by looking for better data as the solution.

Take the historic example offered in an instructive 1969 article by economist Douglas Webbink (who later long served at the FCC).[34]   Following FCC policy methods, Webbink considered a reallocation that awarded land mobile (a pre-cellular wireless technology) additional frequency space at the expense of television broadcasting. The cost-benefit calculation performed estimated the value of existing TV use against existing land mobile. Revenues for either service were unavailable, so the FCC used associated service costs as proxies (as "costs and revenues are highly correlated"). For the year 1965, the key cost data were:

> * expenditures per MHz assigned for land mobile = $37.3 million;
> * expenditures per MHz assigned for UHF and VHF television = $8.6 million.

The FCC concluded: "land mobile services are contributing to the economy at a rate at least four times that of the TV broadcast industry."   The policy implication was that reallocation of broadcast television bandwidth to land mobile would have thereby been justified. But that was unwarranted based on the evidence.

The data used were the best available. But they did not, in economic terms, inform the necessary trade-off analysis. First, the use of cost data as opposed to valuation (or revenue) data confused the relevant issue. To see this, note that a given technology, under this framework, becomes more desirable to adopt the more it costs to supply it. Under the scale implicitly adopted, efficiency reliably loses in the evaluation of trade-offs.

Second, the data do not identify *marginal* gains or marginal opportunity costs. We should seek to understand how the next frequency allotment (say, a six MHz channel) improves social surplus, not how the first frequencies allocated created benefits. Those costs and benefits fade to irrelevance in efficient reallocations to the competing services.

Third, the comparison between the land mobile option and the TV broadcast option does not exhaust the range of possible uses for radio spectrum. Nor does it allow for mixed solutions (some more broadcasting plus some more mobile radio). As Webbink was careful to explain, even if one accepted the "fallacious" trade-off estimates above, "it by no means establishes

[34] Douglas Webbink, *How Not to Measure the Value of a Scarce Resource: The Land-Mobile Controversy*, 23 Fed. Comm. B.J. 202 (1969).

that the television frequencies necessarily should be given over for land mobile uses; it is equally possible that those frequencies should be made available for communications satellites or scientific research or amateur use, etc."

The chief failing found in such studies is that the cost and benefit data are not derived from revealed preferences. They were actually a snapshot of the economic activities that derived following a grant of radio spectrum; the use rights employed were rigid, and could not be adjusted to supply services not defined in the FCC license. This eliminates opportunity cost from the calculus of the TV broadcaster or the land mobile operator. They therefore do not weigh the benefits that might be realized should a different use of the radio frequencies be organized.

The costs observed to provide the (only) permitted services do imply that the gains supplied are in excess of the costs expended by the service providers, but because these costs do not include market-priced purchases of radio frequency rights, they provide no direct evidence of the surplus value generated by a given spectrum allocation – which is the exercise that is presumably being conducted. In fact, the competing claimants (broadcasters and phone operators) logically seek to fill the void, estimating such marginal spectrum valuations by producing studies that arbitrarily assume values favoring the sponsors' policy objectives. In the extant controversy, broadcaster interests introduced a study that demonstrated annual benefits associated with television to total $101.6 billion – probably a "substantial overestimate," as U.S. GDP that year equaled $865.7 billion.

These analytical failures would be of merely historical interest were they not still rampant in spectrum allocation policy, and were not policy makers and interest groups still making such egregious errors in trying to deduce current trade-offs. These are discussed in some detail elsewhere.[35]

Rather than suggest that better data are needed before policy makers can improve their output, the NSS should focus on the creation of better mechanisms for enabling coordination and competition for marketplace innovation over both products and policies. This will produce better data in the same process that creates superior wireless opportunities. The result will be to infuse markets with greater opportunities for experimentation and adaptation, for Federal as well as non-Federal use.

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[35] *See* T. W. Hazlett & M. Honig, *Valuing Spectrum Allocations*, 23 MICH. TELECOMM. & TECH. L. REV. 45 (2016-2017); T. W. Hazlett, *Rent-Seeking for Spectrum Sharing: The 5.9 GHz Band Allocation*, 19 OHIO ST. TECH. L.J. (2022); T. W. Hazlett, *Cost-Benefit Analysis in the 5.9 GHz Band*, J. BENEFIT-COST ANALYSIS (forthcoming, 2024).

To forge such prospects for progress, regulators should be well versed in the traditional obstacles that have deterred such success. Numerous policy critiques from the FCC, outside agencies, and independent analysts have identified such institutional rigidities. Many assessments also describe how, in recent decades, various regulatory strategies have overcome traditional impediments. These advances include, but are not limited to: competitive bidding to assign FCC licenses; two-sided auctions (as in the 2017 "incentive auction" and the 2021 Satellite C-Band auction) to compensate incumbents for cooperating with a spectrum reallocation; overlays, in which new rights are issued on a secondary basis for a band where incumbents are vested, enabling negotiated deals between the parties to efficiently reconfigure the band (as has repurposed spectrum assigned to both commercial and public use); the use of Third Party Audits wherein independent experts propose transition schemes (and where such auditors may gain access to information by bidding for the right to audit).

In sum, the approach best traveled will embrace proven policy innovations – and search for more. These will necessarily focus not on top-down plans that impose ex ante long-term visions, but which effectively accommodate entrepreneurial activity and spontaneous coordination among spectrum users incentivized to discover emerging efficiencies in wireless.

4. Testbeds, Measurements, and Utilization

In this section we discuss the role of measurement campaigns for informing spectrum management and repurposing, as outlined in the NSS. In particular, as part of the NSS and its associated Implementation Plan the NTIA plans to support the development of measurement testbeds that can inform stakeholders about potential interference in different coexistence scenarios. This initiative is described at the NTIA website "Advanced Dynamic Spectrum Sharing in the National Spectrum Strategy"[36], and further details are provided in the NSS Implementation Plan, including expected milestones and timelines. We discuss the motivation for investing in such testbeds along with expected limitations.

Why Collect Data on Spectrum Usage?

Reiterating a core theme in Pillar 2 is the need to collect "data about current real-world usage, the purpose and type of use (active or passive), as well as occupancy in the time, frequency, and geography domains… [Usage data] is needed as the basis for assessing the potential for increased capacity. Using the new collaborative framework, stakeholders also will develop a

[36] Advanced Dynamic Spectrum Sharing Demonstration in the National Spectrum Strategy | National Telecommunications and Information Administration

structured schema for documenting and identifying future spectrum access requirements and a recurring process to solicit future requirements, enabling long-term planning. Such a strategic, forward-looking process is important to provide sufficient lead-time for proper planning and implementation of changes to authorized spectrum use."[37]

The implication is that the NTIA seeks utilization data to determine what bands are candidates for reassignments and coexistence with other applications. While such reassignments may be warranted, the utilization data cannot directly and fully inform the reallocations that result. As discussed in the preceding sections, utilization can be a useful input to policy decisions; however, valuation must be the guiding metric. Missing from usage data are the economic indicators that instruct stakeholders about the value derived from the spectrum itself as an input to the end application, the associated marginal value of additional spectrum for the applications considered, and opportunity costs associated with alternative uses.

Much of the discussion of measurements in the NSS is motivated by potential opportunities for spectrum "sharing", mainly referring to secondary rights to access spectrum assigned to a primary incumbent. CBRS is a commonly cited example, where the primary incumbent is naval radar, and there are two types of secondary access rights associated with either a Priority Access License (exclusive use when the incumbent permits secondary access) or General Authorized Access (no explicit protection from interference as in unlicensed spectrum). This model is considered a candidate for such sharing in other bands with Federal incumbents.

Can usage measurements further overall social welfare objectives? There are, of course, many possible measurement campaigns that could be implemented. Many of those may not be cost-effective or reasonably scale (to produce social value), or produce no actionable information in improving regulatory decisions that advance the public interest. It is therefore important to consider institutions and trade-offs when making choices. In particular, it would be harmful to pursue data blindly, as irrelevant data generation can waste scarce resources (both in the costs of collection and the ensuing costs of trying to utilize the data) and lead to confusion.

Next we outline the measurement objectives from the NSS and discuss challenges and limitations. We subsequently add our own suggestions for particular data sets that may provide insight into policies that can facilitate efficient spectrum use.

Testbed Objectives

[37] NSS, p. 12

From the NTIA website, “The National Spectrum Strategy calls for the U.S. government (USG) to complete—within 12 to 18 months—a `moonshot’ effort, in collaboration with industry, that will advance research, create investment incentives, and set forth measurable goals for advancing the state of technology for spectrum access, with an emphasis on dynamic forms of spectrum sharing for all users.”[38]

The focus of the initiative is on primary/secondary sharing as previously defined, with DoD as the incumbent: “The Advanced Dynamic Spectrum Sharing (DSS) demonstration, which should be conducted at Lower 3 GHz, specifically from 3.1 to 3.45 GHz, provides an opportunity to demonstrate in the field and go beyond what CBRS enables today while building on the work done in the EMBRSS study. This demonstration should show how to simultaneously create spectrum access for commercial users while enabling DOD to continue to accomplish its mission in a complex spectrum environment. To be successful, DSS must involve a whole-of-government effort, undertaken in partnership with industry and civil society, with a clear commitment to testing and adopting spectrum sharing mechanisms that simultaneously promote economic growth and national security objectives.”[39]

The overall objective of building such a testbed is to demonstrate feasibility for proposed sharing techniques: “The DSS demonstration should be conducted under fully operational conditions, from an industry and government perspective, sufficient to determine the feasibility of the intervention at an adequate scale to properly assess the effects of aggregation, the effectiveness of coexistence solutions at different distances, and interference conditions. This real-world demonstration shall include the detailed involvement of the military services and relevant defense agencies as well as collaboration with industry partners.”

Stated objectives for this effort include improving dynamic spectrum allocation techniques beyond current state of the art (e.g., Automatic Frequency Coordination (AFC) in 6 GHz and CBRS), improving DoD capability to “operate” (e.g., access spectrum) in adversarial environments, and enhance the value of shared spectrum for commercial stakeholders, e.g., by leveraging DoD private networks enhanced with further sensing capability to minimize disruption to the incumbent.

Improvements to Primary/Secondary Sharing

[38] Advanced Dynamic Spectrum Sharing Demonstration in the National Spectrum Strategy | National Telecommunications and Information Administration

[39] ibid

The proposed testbeds could indeed serve to demonstrate methods that facilitate more effective use of spectrum currently assigned to Federal incumbents. State-of-the-art methods deployed for primary-secondary spectrum sharing, in particular, AFC in 6 GHz and CBRS, have been criticized as being overly conservative in protecting incumbents. In particular, incumbent naval radar operators in the CBRS band have not reported any significant interference events[40] suggesting that the Dynamic Protection Areas (DPAs) that restrict secondary access for CBRS could be significantly reduced with low risk of compromising the performance of incumbent systems. This is in part due to the reliance on large-scale propagation models used to predict aggregate interference levels.[41] Those models can exhibit wide variations in estimated interference levels due to the random placement of CBRS transmit devices and incumbent receivers, random environments (including indoor versus outdoor and surrounding "clutter"), and variations in power levels and antenna patterns. One would then expect sharing rules (including specification of DPAs) to be biased towards worst-case interference estimates in order to ensure that the incumbent is willing to participate in negotiations for secondary access.

Additional inefficiencies in spectrum utilization in CBRS arise due to the use of sensors deployed to detect incumbent activity. While those sensors help avoid interfering with the incumbent, they require surrounding quiet zones, i.e., no active secondary transmitters in their vicinity that may disrupt measurements.[42] That further limits the coverage and capacity of a secondary user's network. There are additional issues with coordinating the placement of sensing devices by non-cooperative (competing) SAS (Spectrum Access System) providers. Coordination problems among neighboring SASs deployed by non-cooperative SAS providers also cause significant delays in frequency assignments[43]. The result is that although frequency assignments are intended to be dynamic, adapting to the time-varying demand from CBRS devices deployed by multiple service providers, evidence so far seems to indicate that those frequency assignments are largely static.[44]

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[40] D. Boulware, A. Romaniello, R. L. Dorch, M. G. Cotton. 2023. *An Analysis of Aggregate CBRS SAS Data from April 2021 to January 2023*, NTIA Report 23-567, May 2023.

[41] E. Drocella et al, "3.5 GHz Exclusion Zone Analyses and Methodology", NTIA Report 15-517, March 2016.

[42] Winnforum, "Potential Metrics for Assessing the Impact of ESC Sensors and Networks on CBRS Deployments", Document WINNF-TR-1015, June 2021.

[43] Winnforum, "Spectrum Sharing Committee Policy and Procedure Coordinated Periodic Activities Policy", WINNF-SSC-0008-V1.3.0, 2018.

[44] See A. Chakraborty and R. Rao, "On Temporal and Spatial Behaviors of CBRS SAS", to appear in *IEEE Trans. On Cognitive Communications and Networking*, DOI 10.1109/TCCN.2024.3391331; and A. Chakraborty and R. Rao, "On Reliability of CBRS Communications near U.S. Navy Installations in San Diego", *Proc. IEEE Milcom 2023*.

The Wireless Innovation Forum, which oversees the specifications and evolution of CBRS, has been addressing the preceding issues with design modifications that are being incorporated in "CBRS 2.0"[45]. Rather than rely on static propagation modeling to design DPAs, Incumbent Informant Capability (IIC) provides a mechanism for the incumbent to inform secondary users about planned activities.[46] That, however, can compromise an incumbent's (e.g., DoD's) desire to hide activity. Hence one of the stated objectives for a demonstration is to "Improve Security and Obfuscation", presenting a tradeoff between improving spectrum use by signaling planned activities and obfuscating those activities to maintain covertness.

Testbeds can provide a means for evaluating proposed solutions to the preceding problems. Those solutions can include more sophisticated feedback and signaling methods by the incumbent than simply announcing selected planned activities via a secure database. For example, the incumbent could deploy beacon signals that indicate activity in real time, but with enough ambiguity to maintain covertness objectives. Both incumbent and secondary operations could also employ wideband beamforming that can exploit both spatially selective and frequency-agile transmissions to enable the secondary user to avoid interfering with incumbent receivers.

Testbeds can potentially help to evaluate such advanced methods for sharing by capturing more realistic propagation and interference scenarios than those assumed in simulation models. This may be necessary to convince the incumbent that interference events will be adequately managed and to enable a potential secondary user to improve its estimate of the value it can derive from secondary access. Compelling feasibility demonstrations may also have wider applicability, i.e., to other bands and scenarios with different incumbents (e.g., satellite and scientific users). However, for this approach to lead to a new coexistence scenario that makes more effective use of an incumbent's spectrum, presumably the incumbent and potential secondary users should agree on what types of sharing schemes to evaluate, and to design experiments with outcomes that can address concerns.

Challenges: Incentives and Experimental Limitations

The desire to promote spectrum "sharing" in the primary/secondary sense, reflected in the NSS's plans for testbeds, effectively treats the determination of spectrum access rights as a technical problem. The solution is then to develop, demonstrate, and apply appropriate

[45] OnGo Alliance, "OnGo Alliance Unveils CBRS 2.0, Substantially Bolstering Reliability and Performance of CBRS Networks", June 2024.
[46] IIC is now associated with the "Telecom Advanced Research and Dynamic spectrum sharing system (TARDYs3)". See The impact of TARDYs3 system for P-DPA activation - Ericsson.

technologies that accomplish this type of sharing. This implies a “top-down” approach in which those technical methods for sharing are proposed to regulators who ultimately decide on the access rights, which may or may not include secondary access. An example of this approach is the CBRS band, where the three-tier sharing model, originally suggested in the 2012 PCAST report[47], eventually led to the corresponding set of secondary access rights imposed by the FCC.

This top-down approach to determining spectrum access rights raises several incentive problems. First, the incumbent may not have an incentive to share without either pressure from the government/Congress (the “stick”) or compensation (the “carrot”). In the former case, the incumbent has an incentive to delay any new sharing rules, and can be expected to exaggerate the need for its assigned spectrum. In the case of CBRS, the delay from conception to realization was more than a decade (even though interference to naval incumbents is clearly not a problem in most land-locked states), and the Dynamic Protection Areas along the coast are generally acknowledged to be excessively large, and are being reduced in CBRS 2.0.

The proposed sharing of the 3.1-3.45 GHz band faces similar challenges: The EMBRSS Report from DoD[48] was a self-study on the feasibility of sharing this assigned band and “concluded that ‘[s]haring of the 3100-3450 MHz band between Federal USG and commercial systems is not feasible unless certain regulatory, technological, and resourcing conditions are proven and implemented as part of a coordination framework.’“ These rules, as listed in the EMBRSS report and briefly summarized, are:

- “DoD retains regulatory primacy”:
  The DoD must approve sharing frequencies, ensuring military operations are not impacted, with Federal radiolocation maintaining primary allocation.
- "The Defense Industrial Base retains band access for testing and experimentation.”:
  The report refers explicitly to radar manufacturing and experimentation, ensuring access to this spectrum for DoD and other Federal needs.
- "Maintain national emergency preemption policy”:
  This policy must continue, recognizing that effects of sharing on commercial wireless systems could affect the broader civilian infrastructure, which could in turn affect DoD operations.
- "Expand and improve existing CBRS sharing framework policy and technology (DSS capability):

[47] President’s Council of Advisors on Science and Technology (PCAST), *Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth*, July 2012.
[48] Department of Defense, Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) Feasibility Assessment Report. Sep. 2023. See also M. Dano, 5G takes a big step toward lower 3GHz band, April 2024.

The CBRS model should be evolved to meet DoD needs, incorporating flexible interference mitigation techniques.

- "Current and future Federal systems accommodated equally":
  Both current and future Federal systems need to be accommodated without hindering military operations.
- "Government is not liable for damages to commercial systems":
  Explicitly mentioned is potential interference to commercial systems from an incumbent radar system.
- "Establish interference safeguards: Federal users are not required to assume the responsibility of mitigating interference from USG operations to 5G users. Non-Federal users must not cause harmful interference to Federal incumbent users and Non-Federal users must accept interference from Federal incumbent users."
- "Address resource requirements":
  Cost and resource issues related to maintaining the sharing framework must be addressed, including long-term sustainment costs.
- "Address information / operational / cyber security concerns: As a result of the operational analysis conducted by DoD to address the operational security requirements of the Services and minimize the exposure to cyber threats, the [Dynamic Spectrum Management System] must be operated by and within the DoD."

This creates technical challenges for managing interference to an incumbent airborne radar system, which operates in lower 3 GHz. The rapidly time-varying nature of the transmitted and received radar signals over time, frequency, and locations makes it difficult to avoid interference via sensing the radio environment, as in CBRS. (Naval radar signals are easier to detect and predict.) Furthermore, announcing incumbent activities in advance raises security concerns. This is reflected in the report, which adds that even if the preceding conditions are met "spectrum sharing between Federal and non-Federal users in the 3100-3450 MHz band will remain challenging. DoD is concerned about the high possibility that non-Federal users will not adhere to the established coordination conditions at all times; the impacts related to airborne systems, due to their range and speed; and required upgrades to multiple classes of ships. Developing a DSS [dynamic spectrum sharing] capability presents a massive engineering challenge."[49]

The NSS attempts to address this challenge: "The DSS demonstration builds on the EMBRSS effort by developing a mechanism to resolve the technological barriers identified by the

[49] Ibid

EMBRSS Report, specifically in the 3.1 to 3.45 GHz band. At the same time, the development of this mechanism is intended to have potential application to other spectrum bands."[50]

The EMBRSS report and DSS demonstration effectively treat the challenge of making more effective use of the lower 3 GHz spectrum as an engineering problem – the solution is to develop better primary-secondary sharing methods. Yet the EMBRSS report serves to illustrate that the engineering problem is subordinate to the incentive problem. The stipulation of preventing "harmful interference", which is ill-defined, suggests that any proposed sharing with a secondary user cannot affect current incumbent activities and plans for future activities within the band. The conclusion being that any marginal loss in social welfare associated with "harmful interference" to the incumbent cannot be offset by a corresponding gain in social welfare to a secondary user. Hence the report leaves little room to explore potential tradeoffs in social welfare associated with more flexible use of the spectrum.

The main challenge once again is to engage the cooperation of DoD despite the additional effort it must devote to sharing (or relinquishing) its spectrum resources due to regulatory pressures. Lack of adequate compensation for this additional effort is likely to lead to similar delays as for CBRS, and inefficient sharing rules that guard against any significant interference regardless of the actual loss in utility to the incumbent application.

Of course, incentives are also a concern for secondary users – the success of the proposed testbeds in terms of facilitating the adoption of efficient sharing mechanisms depends on engaging all stakeholders. If the testbed design and implementation is led by the NTIA and DoD, then that is likely to bias the experiment design towards identifying and preventing all significant interference scenarios (e.g., via an overly conservative power constraint), reducing the value of the shared spectrum and consequently muting stakeholder interest. As a result, a significant number of stakeholders may choose not to participate, or narrow the range of applications considered, lowering the value of the spectrum. This is reflected in the current controversy surrounding CBRS: advocates point to widespread deployments and diverse applications whereas cellular operators claim that the sharing rules reduce the value derived from the spectrum resource.[51]

Although testbeds can be a valuable demonstration tool, they have limitations in terms of the scope of experiments that can be implemented. For example, there is a wide range of design choices that can be considered involving antenna arrays, hardware (power amplifiers, tuning range, signal processing capabilities, etc), frequency range and agility, and modulation and

[50] NTIA website, "Advanced Dynamic Spectrum Sharing Demonstration in the National Spectrum Strategy".
[51] See R. Berry, T. Hazlett, M. Honig, "Evaluating the CBRS Experiment", TPRC 2023.

coding schemes to name a few. While some aspects of these may be programmable, cost constraints limit the types of transmitters, receivers and resource management schemes that can be demonstrated. For example, the testbed will not capture efficiencies and performance gains that come from dedicated hardware designs. Also, there are likely to be many "real-world" scenarios which the testbed cannot adequately capture, given the complexity of incumbent operations and potential stakeholder applications. Instead, the testbed may be limited to particular scenarios and applications of interest, e.g., the effect of a particular secondary user on an incumbent at a particular location.

Given these limitations, it is crucial to engage stakeholders at the design stage to ensure that the testbed can support experiments that satisfy both incumbents and potential secondary users in terms of demonstrating the feasibility of possible sharing schemes. A testbed developed by the DoD or overseen by a third-party non-market participant, such as the NTIA, runs the risk of excluding participation by some stakeholders who may be critical of imposed limitations. This may be an unavoidable consequence of the process for funding testbed proposals – such a process may have to align with a subset of stakeholders, biasing the testbed design and experiments so as to narrow the range of use cases that can be considered.

Minimizing Rigidities

The testbed objective to demonstrate the feasibility of primary-secondary sharing together with limitations that further constrain use cases impose rigidities that are not necessarily efficient (welfare-maximizing). That is, other sharing schemes may be warranted based on economic considerations. The NSS acknowledges this: "Please note, however, that there will also be an effort to study other opportunities for private-sector access in the band under several different scenarios (relocation, repacking, sharing, and a combination of different approaches)". The NSS also recognizes the incentive problem, and plans to "Assess the Economics, Incentives, and Public Interest Benefits of Spectrum Sharing"[52].

The main challenge with the proposed studies is that incentive issues are endogenous to the centrally managed (top-down) planning process. As previously discussed, informed third-party analysis of "other opportunities for private-sector access" requires reliable inputs from incumbents and all potential stakeholders. However, parties generally have incentives to misreport any measurements (usage or otherwise), either through selectivity bias, distorted calibrations, emphasis on worst- or best-case scenarios, or other means.

[52] NTIA website "Advanced Dynamic Spectrum Sharing Demonstration in the National Spectrum Strategy".

In economic terms, the fundamental problem the regulator faces is an information asymmetry: the measurements may be manipulated to support distorted estimates of actual valuations that are private information, hidden to the regulator. To discourage this rent seeking behavior, the regulator can attempt to verify submitted measurements, but at some cost. Depending on the private values held by stakeholders and the verification cost, this can lead to unreliable measurements and potentially erroneous conclusions.[53] For example, if the value to a stakeholder is relatively low compared with the verification cost (say, known to the stakeholder), then the stakeholder still has an incentive to distort the measurements, and those measurements provide unreliable input to the regulator. Testbed experiments overseen by the regulator can help to ensure transparency of any measurements produced by experiments; however, the incentive problem still manifests itself in limiting the types of experiments that can be implemented.

Rather than assigning responsibility to the regulator to determine which particular sharing scheme (broadly defined to include partial clearing) to *mandate*, an alternative is to introduce flexible use rules that incentivize stakeholders (including the incumbent) to negotiate amongst themselves for spectrum access. That would incentivize interested parties to develop their own testbeds, and make their own measurements that inform them of potential returns on investment, depending on proposed schemes for interference management. Access schemes, including the development of rules for coexistence, can then arise organically, incentivizing cooperation among interested parties as in the development of cellular and WiFi standards.

A challenge is then to define the access rights in a way that facilitates transfers to the incumbent so that voluntary sharing (or partial clearing) can take place. We have proposed overlay rights as a possible framework for accomplishing this.[54] A simple version of an overlay right might grant the incumbent flexible use of its spectrum, including the possibility of accepting a buy-out of their access rights, ending the incumbent's operation in some or all of the band. At the other extreme, the incumbent could choose to reject any bid to share, and continue the status quo operation of the band. In between are a range of possibilities for dynamic coexistence across subsets of LTF. Alternatively, an overlay right, or license, may be assigned to an entrant that wishes to share the band occupied by the incumbent. The overlay right would enable the new licensee to strike voluntary deals with the incumbent, granting constrained spectrum access to the entrant. In this way the choice among possible "sharing

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[53] See, for example, E. Ben-Porath, E. Dekel, and B. L. Lipman, "Optimal allocation with costly verification", *American Economic Review*, 104(12):3779–3813, December 2014. The paper presents an analytical model for the inefficiencies that can arise when strategic agents are asked to report measurements to a third party social planner that incurs a verification cost.

[54] See, e.g., R. Berry et al, Overlay Rights for Transitioning Spectrum Use1

schemes" (broadly defined) is left to market participants, including public agencies and non-profit organizations.

5. What Measurement Data Might be Helpful?

Here we suggest examples of measurement data sets that could be particularly useful in informing policy decisions concerning access rights.

CBRS utilization: There are currently plans by the National Institute of Standards and Technology (NIST) to conduct extensive measurement campaigns on CBRS utilization via their National Advanced Spectrum and Communications Test Network (NASCTN).[55] Those should help to assess the relative success and value generated by CBRS versus other access methods, and help determine whether or not such coexistence schemes are appropriate for other bands. While data from the PAL auctions and deployment of Citizen Band Services Devices from the NTIA can help to infer certain aspects of the value created by CBRS in particular locations, it provides very limited (or no) insight into several important questions: To what extent is CBRS spectrum being used (e.g., urban versus rural, inland versus coastal) and at what power levels? Where and when are PALs used versus GAA channels? Are channel assignments relatively static, modestly dynamic, or highly dynamic? In addition to SAS data (which may or may not be available), utilization data for CBRS over a wide geographic area would help to answer those and similar questions. Data sets that provide insight into answers might advance analysis of the value supplied by CBRS in the context of alternative access schemes.

Satellite bands: There is current interest in sharing spectrum allocated to satellite services with terrestrial-based systems. Utilization data for the satellite systems can help determine where interference may pose coordination problems for coexistence. However, the purpose of collecting such data should not be assumed to imply that rigid "one-size-fits-all" rules should be specified, as perhaps regions in Time-Location-Frequency (TLF) where the rival systems can operate. Rather, rules should be designed to incentivize the interested parties to cooperate in collecting useful data and designing interference mitigation methods that balance costs and benefits. Those methods have the end goal of optimizing system performance, and allow usage patterns that may vary both within and across TLF regions.

Other legacy bands: Spectrum occupancy statistics do not map value generation. Moreover, low or under-utilization, if that can be defined, does not generally justify the replacement of one set of narrowly defined access rules by another such set. Rather, alternatives should be considered

[55] See CBRS Sharing Ecosystem Assessment | NIST.

that reduce rigidities by introducing flexible use rules, allowing market forces to shape the evolution of wireless applications, services, and access technologies.

We add that utilization data in cellular and unlicensed bands can help to provide answers to questions pertaining to rural versus urban use and coverage, indoor or low-power versus outdoor or high-power usage, coverage in low- versus high-income areas, and adoption of new bands, such as millimeter wave. That can provide insight into how new technologies are affecting markets and business models and, importantly, impacting disputes over access conflicts that regulators are called on to resolve. However, low utilization in a particular TLF region does not in itself imply a market failure. Where utilization appears to be low, but operators or users have the freedom to expand wireless use, the observed market may reflect optimizations by market participants that include the relevant cost-benefit tradeoffs, as well as competitive pressures across bands.

Recommendations

Given the emphasis in the NSS on data collection and analysis, we conclude by adding some recommendations regarding the collection and use of data as inputs to policy decision-making. Data sets should be submitted with the following expectations:

- They are transparent, meaning the community involved in spectrum-related research has access to the data. That includes not only technical measurement data, but also data sets useful for economic analysis. The data should be posted in forms that can be easily deciphered by analysts.

- They are subject to discussion at regulatory public hearings.

- Cost-benefit studies by regulators that rely on the data sets are transparent and, perhaps, refereed by experts in various fields.

- There is a shot clock (time limits for regulators) to decide on petitions filed by parties requesting rules/allocations that rely on submitted data sets.[56]

Finally, we see the formulation of access rights by the regulator as an opportunity to afford providers of all stripes, for-profit and nonprofit, full opportunity to reveal their demands for

[56] See, for example, FCC, *In the Matter of Expediting Initial Processing of Satellite and Earth Station Applications, Report and Order and Further Notice of Proposed Rulemaking*, IB Docket No. 22-411 (Rel. Sept. 22, 2023). See also: FCC Modernizes Satellite and Earth Station Licensing Process.

valuable opportunities. This can and has been achieved in many contexts in spectrum allocation. The FCC has instituted multiple reforms designed to support such policy innovations, including license auctions for flexible use spectrum, overlays, PCS, AWS-1, incentive auctions, C-Band satellite relocation payments, relaxation of ISM band restrictions against spread spectrum, and shot-clocks for license applications.

Ideally, there should be common standards for creating spectrum access rights[57]. This has the desirable feature that standard legal forms, as with property rights in general, tend to be well-understood and more easily developed. Customization occurs, but benefits by starting from default rules that are widely utilized. With spectrum this means that the regulator should be cognizant of transaction costs related to the productive uses, and strive to enable a coherent system that allows incumbents, entrants, innovators and consumers clarity in understanding access rights boundaries. Service deployments can then reflect improvements from freedom of contract, without imposed rigidities, based on limited foresight by either regulators or entrepreneurs as to how technologies and business models may evolve. That will help to achieve greater coordination and efficiency, on the one side, but supports diversity, competition and innovation on the other.

[57] This is reflected in the FCC Notice of Inquiry, *In the Matter of Advancing Understanding of Non-Federal Spectrum Usage*, WT Docket No. 23-232, August 2023.