COMMERCE SPECTRUM MANAGEMENT ADVISORY COMMITTEE (CSMAC)

Spectrum Efficiency Subcommittee:

Audrey Allison
Michael Calabrese
Mark Crosby
Thomas Dombrowsky
Carolyn Kahn
Paul Kolodzy
Giulia McHenry (NTIA Liaison)
Ed Drocella (NTIA Liaison)
Mark McHenry
Janice Obuchowski
Charla Rath
Richard Reaser
Andrew Roy
Steve Sharkey
Bryan Tramont (co-chair)
Jennifer Warren (co-chair)

REPORT

July 2018

Table of Contents

NTIA Questions

The CSMAC Spectrum Efficiency Subcommittee addressed the following questions from NTIA:

- Question 1: What additional regulatory, procedural, legislative, or policy actions could be implemented to improve spectrum efficiency without harming effectiveness, including enhanced funding options for the federal agencies?

- Question 2: What economic mechanisms could be employed to increase spectrum efficiency via sharing options, such as a federal mechanism to monetize assets on a non-permanent basis (e.g., a secondary markets model)?

Background

NTIA asked CSMAC to explore Question 1 in 2017. To answer the question, CSMAC conducted outreach to multiple departments and agencies, including both agencies that manage/regulate federal spectrum as well as agencies that implement regulatory, procedural, legislative, and policy actions. In its November 2017 Report, CSMAC recommended that the Spectrum Efficiency Subcommittee conduct additional agency interviews and further consider the challenges and opportunities of implementing regulatory, procedural, legislative, and policy actions to create incentives for greater spectrum efficiency.[1] In 2018, CSMAC continued to conduct agency interviews using the questionnaire developed in 2017. Highlights from the agency interviews are included in Appendix C.

The November Report also recommended that NTIA focus a working group on increasing spectrum efficiency via sharing options.[2] NTIA directed CSMAC to consider that question. To address Question 2, CSMAC undertook a broad exploration of mechanisms to increase spectrum efficiency that have been proposed over the last 20 years. CSMAC considered information acquired from the agency interviews in determining which mechanisms promoting spectrum efficiency might be most promising for NTIA and federal departments and agencies ("federal agencies" or "agencies") to pursue, prioritizing models that would permit federal spectrum users to monetize their spectrum assets on either a permanent or a non-permanent basis. Through CSMAC member input and discussions, in conjunction with the interview responses, CSMAC also identified the principal barriers to the development and implementation of mechanisms that would increase spectrum efficiency, while not adversely impacting effectiveness. The approaches are not mutually exclusive, and NTIA should explore whether more than one should be implemented. Many factors may influence whether an approach to spectrum efficiency is "promising" including, the political environment, the administrative burdens, and the legal context, and each approach has its own implementation challenges.

Barriers to Implementing Economic Spectrum Efficiency Mechanisms

Several barriers may impede the development and implementation of economic mechanisms that would increase spectrum efficiency. Federal agencies currently lack the type of "property rights" that would incentivize market behaviors as well as other administrative incentives to conduct secondary spectrum trades. However, the clear priority of all of the interviewed agencies is to ensure mission effectiveness, with spectrum efficiency having varying degrees of focus, whether due to fiscal, resource, risk or other concerns. At the same time, these are not mutually exclusive goals, as spectrum efficiency and effectiveness are intrinsically linked. In addition, federal agencies are subject to budget constraints, and

[1] CSMAC, Spectrum Efficiency Subcommittee Report, at 4-5 (Nov. 2017) ("November Report").

[2] *Id.*

must consider whether more spectrum efficient solutions require new technology development, acquisition of new systems, upgrades, integration, and/or additional operations and maintenance (O&M) costs. Generally, any rules facilitating the monetization of spectrum assets for federal agencies should be clear and predictable, as ambiguous rules could hamper secondary markets. Below CSMAC describes possible legal, structural, informational, and other barriers to the creation of efficient sharing options for federal spectrum.

Legal:

Miscellaneous Receipts Act. The Miscellaneous Receipts Act inhibits relinquishment and sharing of federal spectrum by requiring specific congressional action to authorize non-federal users to reimburse federal agencies through the payment of money or in-kind consideration such as spectrum or equipment.[3] Giving agencies more flexibility to accept private resources subject to anti-corruption safeguards would eliminate this barrier.

Antideficiency Act. The Antideficiency Act prohibits a federal agency from spending money without an appropriation by Congress. This may limit an agency's ability to benefit financially from a spectrum transaction.[4] Additionally, the Antideficiency Act would make it difficult to establish alternative auction arrangements that provide for incremental auction payments and incremental agency draws on the Spectrum Relocation Fund.[5]

Spectrum Relocation Fund (SRF) limitations. While access to the SRF has been expanded in recent years and demonstrated some success, certain barriers remain including limits on how the funds can be used. Federal agencies need additional flexibility in up-front funding to cover planning, research and development (R&D), test and evaluation, equipment upgrades, and employment of commercial services for both realized and potential spectrum enhancements. Solutions that are more efficient sometimes require additional cost. The mechanism for replenishing the SRF may also require further consideration. Expanding the SRF to cover O&M costs for improved, more spectrally efficient solutions may be warranted.[6]

Congressional appropriations process. The Congressional appropriations process may act as a barrier to giving agencies self-funding ability through transferable spectrum rights. It is possible that any gain in revenue from spectrum sales could be treated as a windfall and Congress could offset the gain in

[3] Karen D. Gordon, et al., *A Review of Approaches to Sharing or Relinquishing Agency-Assigned Spectrum*, at 4, IDA Science and Technology Policy Institute (Jan. 2014) ("*A Review of Approaches*").

[4] Dorothy Robyn, *Making Waves: Alternative Paths To Flexible Use Spectrum*, at 15, The Aspen Institute (2015) ("*Making Waves*").

[5] *A Review of Approaches* at 8.

[6] November Report at 4. The RAY BAUM'S Act, adopted as part of the 2018 Consolidated Appropriations Act, requires NTIA, in consultation with OMB, to make recommendations about how to reform the SRF among other things to address costs incurred by federal entities related to sharing radiofrequency bands with radio technologies conducting unlicensed or licensed by rule operations.

subsequent rounds of appropriations undermining the incentives for more efficient use.[7] Agencies such as DoD may also have funds that are set aside subject to sequestration.[8]

Structural:

Lack of NTIA resources and authority. NTIA lacks the authority or resources in many cases to actively support federal agencies in collaborative use of spectrum or to manage federal spectrum through auditing, enforcement actions, or conducting critical examination of spectrum requests.

Resource and staffing shortages. Shortages in funding and staffing for federal agencies may be a barrier. Federal agencies may lack sufficient spectrum management resources to both integrate flexible capabilities into upfront acquisition planning and execution as well as to dedicate for implementation of any spectrum sharing projects that occur over time or affect multiple agencies.[9] Federal agencies must prioritize mission needs first and then lifecycle costs of alternatives to meet those mission needs.

Creation of additional burdens. If adopted, some incentive mechanisms may initially increase administrative burdens (staffing, resources, and funding) by creating additional bureaucratic requirements, such as: managing a synthetic spectrum currency or implementing metrics-based auditing.

Informational:

Lack of updated, comprehensive data regarding federal spectrum use. Federal agencies provide NTIA with their spectrum needs based on the capabilities, systems, equipment and operations that each department or agency is authorized to develop, acquire and deploy to execute their mission and functions. While individual federal agencies are best positioned to determine the capabilities and requirements for their missions and operations, a data solution is needed to track spectrum usage, so that NTIA can actively assess the resource and facilitate more efficient, or intensive, use that still meets mission requirements. An effective data solution would need to accommodate operational challenges, including classified or other national security concerns and/or dynamic spectrum management. Lessons learned from the 3.5 GHz initiative, once operational, may be leveraged in developing various solutions. The current fragmented, decentralized approach to both federal and non-federal spectrum use may not lead to accurate future policy decisions about its most effective and efficient use.[10]

Complexities in quantifying a monetary or economic value for federal spectrum assets. There is little visibility into the budget expense or economic value associated with federal spectrum use. While efforts have been made to encourage agencies to consider the economic value of spectrum in the acquisition of major systems (OMB's Circular A-11), little insight exists into the monetary value that federal agencies

[7] *Making Waves* at 39.

[8] This occurred with respect to SRF disbursements relative to AWS-3. *See* U.S. Department of Commerce, *Commercial Spectrum Enhancement Act (CSEA): Annual Progress Report For 2016*, at II-1 (Apr. 2017) ("*2016 Annual Report*") ("Pursuant to the Balanced Budget and Emergency Deficit Control Act of 1985, as amended, a total of $521,000 of DOD funds was sequestered.").

[9] T. Randolph Beard, et al., *Market Mechanisms and the Efficient Use and Management of Scarce Spectrum Resources*, 66 Fed. Comm. L.J. 263, at 282-83 (2014) ("*Market Mechanisms*") (citing *GAO Report on Spectrum Management*).

[10] PCAST, *Report To The President: Realizing The Full Potential Of Government-Held Spectrum To Spur Economic Growth* (July 2012) ("*PCAST Report*"); *Market Mechanisms* at 284.

may place on their spectrum.[11] Federal spectrum is a regulated asset, and the economic value of federal spectrum to meet unique federal missions is difficult to quantify or directly compare. There have been significant doubts raised about to what degree OMB Circular A-11 has worked in any meaningful way to introduce more rigor into this process and drive spectrum efficiency into the procurement processes for major systems.

Other:

High transaction costs. Incentives for more efficient and effective federal use generally need to overcome often high transaction costs.[12] Agencies also must incur the cost of conducting upfront strategic assessments to identify potential opportunities for increased spectrum efficiency. Some more efficient solutions might require more expensive equipment due to the requirement for more advanced technologies and/or smaller economies of scale, such as when commercial equipment does not exist for agency operational needs. In addition, agencies must work with an embedded base of legacy systems that continue to work and meet mission requirements as part of a long expected life-cycle (i.e., thus systems will not typically have appropriations for upgrades on the basis of "efficiency" if they are meeting the mission.) Also, any new spectrum-dependent systems also must be designed to be integrated with a baseline of existing systems.

Any incentives would need to overcome those costs, or agencies may not have sufficient incentives to pursue spectrally efficient arrangements among equally effective solutions, which often provide only additional costs and risks to the agencies.

Trust in technology and regulatory interference resolution processes. Many federal missions require elements such as safety, resiliency, redundancy, and flexibility, and such requirements must be preserved. Without reliable and proven interference prevention and prioritization schemes, agencies may be hesitant to pursue mechanisms to improve efficiency without also addressing these other factors, which might also increase interference, especially via sharing arrangements. Ex ante and ex post enforcement mechanisms need to be credible, cost-effective, timely, and compatible with incentives. Similarly, any dynamic spectrum management regimes (such as the Spectrum Access System being developed for the 3.5 GHz Band) must be proven reliable before agencies will be willing to trust these mechanisms with their mission critical operations. A focus on Interference Prediction, Detection, and Resolution (IPDR) is important, particularly as agencies look to move into greater bi-directional sharing. Moreover, the nature of the spectrum domain is multi-dimensional – frequency, time, location, polarization, and direction – and IPDR will have to be able to address all those domains.

Mechanisms to Promote Spectrum Efficiency, Including via Sharing

A number of approaches have been proposed to foster secondary markets for federal spectrum. The more mechanisms available in the federal toolkit, the greater the ability to create opportunities to utilize secondary markets and increase spectrum efficiency. In addition to economic mechanisms, new technologies, standards, metrics, tools/software, etc. will likely facilitate greater spectrum efficiency and effectiveness over time. Solutions for spectral efficiency should consider how new technologies may apply to the systems and services of particular bands and incumbent and adjacent users to meet operating requirements (i.e., mission effectiveness in addition to efficiency). Developing and executing

[11] *Market Mechanisms* at 283.

[12] *Making Waves* at 36.

these mechanisms in a test bed before rolling a mechanism out on a larger scale may be a useful tool to prove the operational and economic viability of a given approach.

Over the past 20 years, nearly a dozen approaches have been proposed to increase federal spectrum efficiency; some proposals that seem politically or practically unobtainable – such as private management of federal spectrum or a wholesale auction of federal spectrum – were considered but not included below. For the purposes of furthering discussion and potential progress, the proposals are divided into three categories: (1) Most Promising, (2) Promising, and (3) Other.

Most Promising:

Funding. Create predictable and flexible funding to support the development and implementation of sharing options to increase spectrum efficiency and effectiveness. CSMAC is exploring whether further expansion of the SRF is warranted. The funding process for agencies is generally annual while the development and implementation of sharing schemes is typically a multi-year process. There are needs for upfront funding, multi-agency coordination, more expensive technology that is more spectrally-efficient, O&M costs, and an expanded definition of "infrastructure" to include all system requirements (i.e., equipage). Selecting certain projects to fund or distributing funds through a centrally managed and coordinated effort, should be refined to maximize the public interest benefit of government investments in efficiency. The best mechanism for replenishing the SRF also requires further consideration to ensure its continuing viability and sustained ability to contribute to more federal efficiency as well as assuring that agencies have adequate spectrum access to meet their missions.[13]

Spectrum Property Rights. Grant agencies flexible use rights (with respect to technology employed and service provided) with property-like rights within their spectrum assignments (such as permitting agencies to aggregate, subdivide, sell, lease, or share spectrum holdings), supervised by NTIA.[14] As federal spectrum bands are shared by multiple agencies, to the extent agencies were granted additional flexibility to manage spectrum usage, NTIA would serve as a manager (much as the FCC serves as a coordinator for commercial spectrum).[15] Some posit that a rights database would be an essential component of a spectrum property rights regime in order to (1) clearly define the rights, (2) make spectrum rights transparent, (3) allow licensees to identify neighbors who may be encroaching, (4) identify potential targets of negotiation with respect to spectrum use, (5) facilitate market transactions, and (6) promote sounder management by NTIA.[16] Squatter rights must also be addressed. Regardless of whether a rights database is created, a flexible use rights approach appears to be dependent on (1) an

[13] *A Review of Approaches* at 45. The Supplementing the Pipeline for Efficient Control of The Resources for Users Making New Opportunities for Wireless ("SPECTRUM NOW") Act introduced in the House and Senate on June 6 proposes would allow OMB) in consultation with the NTIA, to "use existing SRF funding (approximately $8 billion) to support research-related activities that examine the feasibility of federal spectrum users relocating or sharing spectrum with non-federal users as long as those monies are not already obligated to support federal agencies." *See* Press Release, Sen. Roger Wicker (Miss.), *Wicker, Schatz Introduce SPECTRUM NOW Act* (June 6, 2018) ("*Wicker Press Release*").

[14] *Making Waves* at 34; Harold Feld & Dr. Gregory Rose, *Breaking the Logjam: Creating Sustainable Spectrum Access through Federal Secondary Markets*, Public Knowledge ("*Breaking the Logjam*").

[15] Reaching an agreement with one agency to lease, acquire, or share spectrum does not necessarily mean that a federal band is available for non-federal use since, as discussed above, federal bands are frequently shared by multiple agencies.

[16] *A Review of Approaches* at 29.

agency's authority to transfer spectrum to another agency, a non-federal government, or private entity, and (2) its ability to retain the proceeds or other benefits resulting from spectrum trades; therefore, revising the Miscellaneous Receipts Act and Antideficiency Act would be an important step in implementing this mechanism.[17] Additionally, interference protections and enforcement mechanisms would need to be developed. CSMAC acknowledges the complexities in this approach, but further exploration may be warranted as allowing agencies to obtain money or other resources from the sale, lease, or sharing of spectrum could create a positive incentive that would increase spectrum efficiency. This proposal particularly lends itself to experiment through test beds to assess efficacy.

Bi-Directional Spectrum Exchanges or Barter/Swaps. With coordination and approval from NTIA, federal and commercial users negotiate directly and trade licenses; or permit federal agencies to exchange spectrum use rights for equipment upgrades in cases where mission requirements permit such arrangements.[18] Among other advantages, a property exchange allows an agency to avoid risks associated with the budget or property disposal process. Agencies could receive upgrades to outdated radio systems in exchange for some level of access to some of the spectrum that the upgrade would free up.[19] New technologies could promote shared use of the spectrum, clear a portion of the bartered spectrum for commercial use, or facilitate a swap of frequencies. This approach while promising is legally complex. The parameters of such a program will be highly fact dependent and it is difficult to predict how quickly it could be implemented on a widespread basis.

Expanding NTIA Authority and Resources. NTIA's authority and resources should be expanded to allow it to more actively support federal agencies in collaborative use of spectrum or to manage federal spectrum through auditing and enforcement actions, which would allow it to conduct an even more critical examination of spectrum requests. Spectrum efficiency metrics could be used to compare similar systems or systems that provide a similar service to users, and ensure that agencies are familiar with other agencies' systems developments. Congress may wish to consider allowing NTIA to use auction resources generated through reallocation or sharing of federal spectrum bands to further NTIA's advancement of its spectrum management mission.

Promising:

Overlay Rights. Overlay rights can be used in two contexts: (1) with a specific relocation date as a path to expedite relocation, or (2) without any mandatory relocation date, thereby allowing the market to determine the pace. In the first case, overlay rights could be accompanied by a deadline for incumbent users to vacate, which would provide certainty about the long-term status of the rights being made available.[20] The latter case could be accomplished by, for example, granting overlay licensees (1) primary rights to any unused spectrum, (2) secondary rights to spectrum in the band that is being used by an incumbent, and (3) exclusive rights to bargain directly with existing users (and directly compensate them for vacating or reducing use in the band).[21] Then a commercial overlay license holder could

[17] *Id.*

[18] *Making Waves* at 41.

[19] *Id.*

[20] The FCC has auctioned overlay rights to spectrum subject to incumbent relocation with some success (PCS spectrum, AWS-1) where rights were clearly defined.

[21] Brent Skorup, *Sweeten the Deal: Transfer of Federal Spectrum through Overlay Licenses*, at 14 (Aug. 2015) ("*Sweeten the Deal*").

negotiate with the federal incumbent for better (or quicker) relocation terms, consistent with the federal user's assessment of mission needs.[22] Allowing agencies and commercial users to privately determine relocation timelines and receive direct compensation may require changes to the current process contemplated under the Commercial Spectrum Enhancement Act as well as modifications to the Miscellaneous Receipts Act. High transaction costs, piecemeal negotiations, or other bargaining problems may create barriers to commercial use where no relocation date is specified. Due to these costs, this approach may have success on a relatively smaller scale than other approaches – but it could result in spectrally efficient solutions where federal and commercial interests are compatible. Regardless of the parties' initial goals for the overlay rights (relocation or some type of sharing scheme), this approach could result in long-term issues if the sharing or relocation is later proved to be economically inefficient, does not meet mission needs, or does not create an economically viable business. A lack of a relocation date or clearly defined rights could also significantly limit the ability to use the spectrum for commercial services, depending on the details of incumbent operations. The Spectrum Property Rights model discussed above may better promote secondary market sharing more broadly.

Spectrum Scoring Reform. The Congressional Budget Office (CBO) could score spectrum efficiency improvements in a way that promotes sharing or reallocation.[23] For example, CBO could score legislation positively if it believes that it "is likely to change the behavior of federal agencies and induce more spectrum to be sold [or shared] than would otherwise be the case."[24] Scoring would allow additional resources to federal users to execute these efficiency improvements.[25]

Dynamic Federal Spectrum Secondary Markets. Allow shared access to federal spectrum through short-term leases, such as via real-time auctions.[26] FCC actions that may inform this model include its public safety/private partnership initiative (700 MHz), White Spaces, and Citizens Broadband Radio Service (CBRS). To have dynamic secondary markets, a database of federal spectrum bands by use and by geographic location would likely need to be created. As competition for non-federal access to federal spectrum develops, there could be real-time auctions among the competing users to determine who gains access through compensation or spectrum swaps. This approach would require revisions to the Miscellaneous Receipts Act and Antideficieny Act. This mechanism may be promising, but untested. Once the CBRS band is tested and proved, it may be worth revisiting. It is unclear whether real-time auctions for short-term leases would be commercially viable, as this model has never been successfully utilized on any widespread basis in commercial bands.

Auction Revenue. Allow government spectrum users the option to receive a portion of net auction revenues for spectrum that is made available for sharing or reallocation as a result of efficiency improvements.[27] Generally, one would expect the higher the amount of auction revenue directed

[22] *Id.*; *A Review of Approaches* at 52.

[23] William Lehr, et al., *Federal-Commercial Spectrum Sharing Workshop: Models, Applications, and Impacts of Incentives for Sharing*, at 12, NITRD Wireless Spectrum R&D Senior Steering Group Workshop VII Report (Mar. 19, 2015) ("Workshop").

[24] *Making Waves* at 40.

[25] *Id.*

[26] *A Review of Approaches* at 40; *Making Waves* at 7-10.

[27] Federal Communications Commission, *Connecting America: National Broadband Plan*, at XII (Mar. 17, 2010) ("National Broadband Plan").

toward the agency, the greater the incentive to enhance efficiency while protecting their mission. This approach would require reform to the Miscellaneous Receipts Act and Antideficieny Act and other appropriate budget reforms to allow the agencies to retain the "benefits of the bargain." This mechanism may also be particularly difficult to implement if Congress continues to view auctions revenue as a "pay for" solution, rather than using proceeds to advance specific spectrum objectives, such as funding agencies' R&D on spectrum sharing technologies.

Other:

Spectrum Auditor. The spectrum auditor approach builds on CSMAC recommendations regarding Circular A-11, which now requires agencies to consider the spectrum efficient solution when choosing between procurement options that both meet operational requirements.[28] Spectrum efficiency metrics could be used in the auditing process to compare similar systems or systems that provide a similar service to users (the metrics would need to account for any potential differences in commercial and federal uses). Alternatively, the budget authority process could be utilized to achieve broad-based reassessment of spectrum use, and where it makes economic and policy sense, it could encourage reallocation, swaps, leasing, or sharing.[29] For example, OMB could assign a value to spectrum usage and then conduct a periodic review of agency spectrum holdings requiring agencies to justify their spectrum needs and pinpoint spectrum to be made available for sharing, swap, lease, or auction. In this way, OMB would assess spectrum use in the same way it examines federal agencies uses of other resources. A spectrum auditor approach would create administrative challenges for the agency tasked with acting as auditor, including a need for additional resources and possibly education in spectrum management. Software could be used to help implement a metrics-based approach. An auditing approach would need to address data requirements and challenges of data availability and transparency. The audit approach has the advantage of relying primarily on existing institutional relationships to boost the efficiency of federal spectrum use.

Spectrum Use/Rental Fees. Charge agencies fees related to the market value of their spectrum, thus encouraging efficient use by having users internalize the costs of the resources they are utilizing.[30] This approach was used in UK's Administrative Incentive Program and has since been determined by many in the UK to not have been successful; it may provide lessons learned.[31] Some note challenges facing the spectrum use fees, including that the prices would not be established in a real market setting, that the value that private sector players who can recoup the cost of spectrum through end-user charges is not replicated among government users who perform spectrum-based missions for free, and that the budget appropriation process could net out any increase or decrease in spectrum use fees.[32] There is real concern about finding a fair and balanced way to "weight" the value of the spectrum against agency missions and priorities.

"Shared-Use Spectrum Superhighways," Spectrum Currency, and Spectrum Efficiency Fund. Establish spectrum superhighways, "with Federal incumbents having highest priority access and protection from harmful interference. Encourage agency participation through Spectrum Currency (a 'fee' based on a

[28] *A Review of Approaches* at 50.

[29] *Id.* at 49.

[30] *Id.* at 15 (noting that while there are no robust proposals, spectrum use fees/rental fees could be used to promote sharing, or could be used in conjunction with property rights to promote sharing).

[31] *Id.* at 16.

[32] *Market Mechanisms* at 277 et seq.

synthetic currency) and a related Spectrum Efficiency Fund (a mechanism for trading the synthetic currency for real funding)."[33] The artificial currency would only allow federal agencies to participate, creating similar concerns as with the rental fee mechanism discussed above.[34] Here too the experience at 3.5 GHz will ultimately prove informative as to how viable this approach is.

BRAC. Direct a broad-based reallocation of spectrum leading to relinquishment or sharing of federal bands for commercial purposes using a process modeled on the Defense Base Closure and Realignment (BRAC) Commission.[35] The BRAC approach would achieve a one-time reallocation of spectrum assigned to federal agencies. This approach is likely to have significant pushback from many federal agencies. Imposing reallocation and determining the true operational and mission critical needs to security agencies may be difficult and politically unpopular.[36]

Recommendations to NTIA

1) NTIA should focus on exploring the promising mechanisms above. NTIA should specifically consider whether some of the mechanisms could be explored on a limited basis through regulatory or operational test beds, etc. to develop a proof of concept. CSMAC believes the proposals under the "other" category may not be worth pursuing, due in part to logistical, legal and/or political challenges that could drain government resources without offsetting public interest benefits.

2) NTIA should work with Congress and the Administration to explore ways to reduce the barriers to more efficient federal spectrum use, in a way that does not impact mission effectiveness.

3) In the context of its development of a national spectrum strategy, NTIA should include the development of a set of guiding principles to focus on spectrum efficiency. Guiding principles should include a definition of spectrum efficiency goals, such as optimizing use of spectrum and functions required, as well the multi-dimensional aspects of efficiency. The guiding principles could include a science-based assessment that leverages spectrum according to its physical or unique properties; considerations in spectrum use include both function and the bands allocated for those services. It could provide guidance on sharing, such as recommendations on opportunities for similar systems to share spectrum and when even dissimilar systems should share. It could also include a process for collaborating and partnering with other agencies to address common needs, such as consolidating systems as part of an architectural strategy or partnering with other agencies or organizations. Some systems may be more efficient and other systems may be better at sharing spectrum.

4) Once the spectrum efficiency guidelines and larger strategy are developed, NTIA should consider working with the FAR Council/OMB on requiring spectrum efficiency factors in RFPs, through the Federal Acquisition Regulations (FARs), with the departments then able to implement according

[33] *A Review of Approaches* at iv.

[34] *Market Mechanisms* at 286.

[35] *Making Waves* at 37; *A Review of Approaches* at 46; Dorothy Robyn, *Buildings and Bandwidth: Lessons for Spectrum Policy from Federal Property Management*, at 7-9, Economic Studies and Brookings (Sept. 2014) ("*Buildings and Bandwidth*").

[36] The Brookings Institution, *New Directions for Public Sector Spectrum Policy Washington*, at 28, 30 (Sept. 23, 2014) ("*Brookings*").

to their own particular missions. A cross-cutting policy could include as an incentive for agencies to select equally effective, but higher cost spectrally efficient solutions provision to increase the appropriations for such a solution.

5) NTIA should continue a constructive two-way dialogue with agencies to address, plan, and implement increased spectrum efficiency collaboratively and strategically (including potentially through enhanced data sharing), while meeting mission objectives. It should evolve cross-agency collaboration, such as the Spectrum Efficient National Surveillance Radar (SENSR) program, to explore spectrum uses systematically and strategically, and to identify more spectrum-efficient cross-agency solutions, address cross-agency challenges and risks, and set timelines for activities. NTIA should continue to collaborate with the FCC to evolve the spectrum efficiency policy for both federal agency and commercial uses of spectrum.

6) NTIA should consider the findings in this report as it works with the FCC, OMB, and the affected federal agencies to develop a report to Congress with recommendations that could incentivize federal entities to improve efficiency through future acquisition to increase opportunities for sharing with commercial services, including wireless and satellite broadband services, without adversely affecting mission effectiveness.

Appendix A: Interview Questionnaire

Additional Policies to Improve Spectrum Efficiency Subcommittee

Questions for the OMB and the Federal Agencies

A. Questions for OMB:

1. How successful has OMB been in encouraging the agencies to be spectrum efficient and consider the economic value of spectrum?
    a. What obstacles or complications exist?
    b. How could OMB improve this?
2. How did OMB arrive at the economic value of the spectrum methodology contained OMB Circular A-11 Section 31.12(b)? What underlying principles were considered? What behavior is OMB trying to encourage on the part of the agencies?
3. Have any federal agencies submitted alternative economic value methodologies for OMB review and approval? If so, what alternative methodologies were used?
4. How do the agencies report their compliance with OMB Circular A-11 Section 31.12? How does OMB enforce compliance?
5. What issues has OMB encountered in implementing OMB Circular A-11, Section 31.13, Spectrum Relocation Fund (SRF)?
6. What additional procedures or policies could be implemented to improve OMB's ability to incentivize greater spectrum efficiency?

B. Questions for NASA, DoD, FAA, NOAA, DHS and DoJ:

1. How does your agency define spectrum efficiency?
2. What are the biggest impediments to your agency to improving spectrum efficiency?
3. In Requests for Proposals (RFP) do you routinely identify spectrum efficiency as a relevant factor?
4. Does your agency use the methodology contained in OMB Circular A-11 Section 31.12(b) to determine the economic value of the spectrum being used in your agency's procurements?
    a. If so, how?
    b. If not, why not?
    c. What impediments does your agency encounter with respect to implementing the spectrum efficiency requirements of OMB Circular A-11?
    d. If there is a need for improving the effectiveness of OMB Circular A-11, what recommendations do you have to drive more spectrum efficient decisions?
5. If your agency uses an alternate methodology to the one in OMB Circular A-11, Section 31.12(b) how does it determine whether the system procured was most efficient?
    a. Have you submitted the alternate method to OMB for approval?
    b. How do you track the investment difference between the chosen solution and the more spectrum efficient system?
    c. Where does spectrum efficiency fall in terms of importance when making source selection decisions?
6. How do you address the possibility of using an existing or alternative Federal system and its already assigned spectrum, instead of procuring a new system? What mission or other barriers are there to considering other department's or federal agencies' systems?
7. How do you address consideration of using the capabilities of similar Federal users to avoid the need for new spectrum when procuring a new system?

8. How do you specify improvements in spectrum efficiency and effectiveness when replacing a system?
9. What process do you use, and how do you certify, that your agency considered commercial or non-spectrum dependent alternatives to meet your mission/operational requirements?
10. How does your agency promote the development and implementation of spectrum efficient technologies? What could be done to make R&D and integration of spectrum efficient technologies more pervasive?
11. Has your agency taken advantage of the Spectrum Relocation Fund (SRF) described in OMB Circular A-11, Section 31.13? Has that been successful?
12. What impediments has your agency encountered with the SRF?
13. What changes to OMB Circular A-11, Section 31.13, SRF, would be helpful to your agency's implementation of the SRF's objectives?
14. What solutions, procedures or policies could be implemented to improve spectrum efficiency?

Appendix B: Agency Interviews

This appendix lists the federal agency interviews conducted by CSMAC.

Agency	Date	Name	Organization/Title
OMB	19 July 2017	Ben Page Steve Cahill	Branch Chief at Executive Office of the President/OMB Policy Analyst
NTIA Institute for Telecommunications Sciences (ITS)	15 August 2017 & 1 November 2017	Keith Gremban	Director of NTIA ITS
DHS	31 October 2017	David Campbell Warren Kendrick Kelly Oliver Chris Wurst	Joint Wireless Program Office, Office of the CIO Joint Wireless Program Office Section Chief, Immigration and Customs Enforcement (ICE) Technical Operations ICE
DoD	27 April 2018	Fred Moorefield Mary Greczyn	Director of Spectrum Policy & International Engagements, DoD CIO Vice President, Freedom Technologies
FAA	7 May 2018	Carl Burleson Nan Shellabarger Rebecca Guy Paul Fontaine Ian Atkins Daphne Fuller Matthew Klein David Balloff	Acting Deputy Administrator, FAA Acting Deputy Assistant Administrator for Policy, International Affairs, and Environment, FAA Acting Deputy Director for Air Traffic Systems, Program Management Organization (PMO), FAA Director of Portfolio Management and Technology Development, FAA Director of Spectrum Engineering, FAA Executive Counsel, FAA Manager of Systems and Policy Analysis Division, FAA Counselor to the Acting Administrator and Deputy Administrator, FAA

Agency	Date	Name	Organization/Title
		Finch Fulton	Deputy Assistant Secretary for Transportation Policy, OST
		Audrey Farley	Executive Director, Office of the Assistant Secretary for Research and Technology, OST
		Loren Smith	Senior Advisor, OST
		James Arnold	DOT Spectrum Lead, OST
		Karen Van Dyke	Director, Position, Navigation, and Timing and Spectrum Management, OST
NOAA	31 May 2018	Ivan Navarro	National Weather Service, NOAA
DoJ	5 June 2018	Quan Vu	Office of the Chief Information Officer (OCIO), Law Enforcement Communications, DoJ
		Julio Laguardia	Justice Management Division, OCIO
		Richard von Bostel	Chief Enterprise Architect, DoJ
NASA	21 June 2018	William Horne	Senior Spectrum Technology Advisor and Communication Systems Engineer, NASA Headquarters
		John Zuzek	National Spectrum Program Manager
		Gene Fujikawa	Technology Manager

Appendix C: Highlight of Interview Responses

Office of Management and Budget (OMB)

- OMB has not seen much progress in implementation of spectrum efficiency initiatives beyond auction and transition planning. Federal agencies are focused on the mission.
- Spectrum is a page within OMB A-11, and the acquisition folks are focused on other parts of OMB A-11. Spectrum needs to be elevated to get more focused attention.
- A set of guiding principles could be developed that identifies targeted areas, including systems and technologies, with the most promising gains in spectrum efficiency. FCC and NTIA could address this together and make sure the technologies can co-exist. OMB could then apply this guidance within the budget cycle as it reviews major system acquisition programs. OMB could give direction to agencies on how to apply and identify applicable systems and funding. This is a multi-agency effort.
- The challenge is to drive improvement of the status quo. OMB has funding to incentivize agencies but has not received any requests. Carrots are not working, and sticks are not being enforced. Enforcement requires resources.
- The SRF is limited to auction situations and a lagging mechanism. Can improvements be made to the SRF that include alternative ways to replenish the funds? Can we can devise mechanisms for federal government to share spectrum, without giving up assignments, i.e., bi-directional sharing? FirstNet is a model for limited access sharing. Real-time coordination is needed.
- The equation in OMB A-11 is a simplified methodology that can be applied by a spectrum lay person universally across all agencies. Weighting factors were updated last year from NTIA's model.
- Not aware of any agencies submitting alternative methodologies. Do not know if the agencies even report that they have tried to comply. There is NTIA certification, but no formal way to convey that back to OMB or examiners. If it is important, it should be a factor when comparing alternative systems.
- NTIA could explore their authorities more fully. NTIA is permitted to charge spectrum management fees.
- Spectrum efficiency needs leadership attention. Spectrum efficiency is a secondary priority to mission, deficit reduction, and cost-cutting.

National Telecommunications and Information Administration – Institute for Telecommunication Sciences (NTIA – ITS)

- ITS issued NTIA Technical Report TR-18-530 entitled "*A 53-Year History of Spectrum Efficiency Studies and Recommended Future Directions*." The report summarizes different approaches to spectrum efficiency (SE) that have been proposed and concludes with a consensus metric and recommends future work.
- Neither NTIA nor FCC have implemented actions related to SE improvement for the following reasons: (1) lack of consensus on SE metrics; (2) lack of acceptance by the agencies of the benefits to the agency and nation of using more spectrally efficient systems; (3) reluctance on the part of the agencies to implement or invest in more spectrally efficient systems when current practices adequately achieve missions and are known to work; and (4) inability to find necessary funding when more spectrally efficiency systems require additional investment.

- NTIA has some technical standards in its regulations that are intended to reduce the possibility of interference, enhance frequency reuse, and improve SE, e.g., Radar Spectrum Engineering Criteria (RSEC). Current NTIA technical standards, however, have only limited usefulness in achieving the overall objective of improving SE because the standards (1) only apply to a limited number of systems and bands and (2) have little or no impact on new systems if the agencies do not incorporate them in early requirements-definition stages.
- Motivating or incentivizing spectrum efficiency is different for federal services than it is for commercial services.
- NTIA aims to establish a versatile set of regulator-oriented SE metrics that are implementable, objective, and supported by regulators and the federal spectrum users.
- In addition to the traditional spectrum efficiency metrics offered in units of performance over amount of spectrum resource used, e.g, bits/Hz-sec, NTIA is developing a higher-level, unit-less set of efficiency metrics related to a service/system's (1) detectable energy or occupancy and (2) spectrum assignment or license. The unit-less metrics are based on the mission requirements of the service/system and will allow for cross-service/cross-technology SE comparisons when needed.
- ITS is breaking the SE metric into its component parts - i.e., space, time, frequency – to allow for SE to be analyzed separately in each domain.
- ITS is introducing a compatibility matrix into the SE formulation to reflect efficiencies gained from disparate systems sharing the spectrum resource.
- NTIA is convening a PPSG-SWG tiger team to discuss and flesh-out the fundamental approach for SE metrics and framework.
- NTIA will implement an SE evaluation framework in a collaborative and fact-based approach for priority bands and/or services. The evaluations are to be based on Government Master File (GMF) assignment and license data.
- Foreseeable SE implementation challenges include: (1) poor or lacking information about systems, (2) consensus on mission performance requirements and service/system interference protection criteria, (3) SE formulation in time dimension especially with mobile transmitters and receivers, and (4) formulation of compatibility matrix where coexistence can be achieved via diverse means.

Department of Homeland Security (DHS)

- DHS Law Enforcement video is building a fiber network throughout the U.S. to create an enterprise environment, leverage existing capabilities, and reduce evidence grade video transmissions via radio spectrum. DHS has created a Spectrum Operations Center for intra-operability as well as inter-operability to maximize the dwindling spectrum. DHS continues to work to identify efficiencies, such as video management and operating at the edge to reduce transmissions and archives of collected video.
- DHS is aware of and championing a one-government concept addressing spectrum efficiencies including interoperability and effectiveness across federal law enforcement activities. There currently is no single central agency or driver behind bringing federal LE agencies together collectively in a holistic approach to more efficiently use systems, spectrum, and funding. There is a beneficial need to act as one government in order to continue to operate in the remaining spectrum.

- Impediments to spectrum efficiency include lack of a long term roadmap and expanding border issues. Interference to the remaining spectrum has been increasing, which is a growing concern to LE in general. There are significant benefits for agencies to work together as one government to use the efficient and similar tools.
- Spectrum policy should consider emergent technology that utilize spectrum more efficiently and are adaptable interoperability when needed.
- To be spectrally-efficient, DHS typically uses engineering determinations, such as the user formula in the NTIA manual, during system analysis and development.
- Land mobile radio makes up about 90% of our work across federal LE agencies and an overall gross percentage of GMF assignments. Channelization in these bands are divided up between agencies which has proven to be inefficient in that most spectrum geographically remains fallow while a small amount of channels are overused creating unacceptable congestion.
- Wideband video and radar has been the fastest growing requirement in the department. These services are growing exponentially, but requirements are dictated by commercial services or DoD developments. DHS buys equipment from a small community of vendors or DoD type contractors. They also operate in the same bands being targeted for spectrum auctions or are shared tightly with the FAA and DoD. Spectrum access to these targeted bands are critical to DHS mission.
- DHS has become extremely dependent DoD type radar systems for border security.
- DHS has limited access to radar specific spectrum due to limiting footnotes. However the department is purchasing and fielding direct mission support systems while only secondary or guest users to the necessary spectrum that is needed to support these systems.

Department of Defense (DoD)

- DoD is excited to have this phone call. The issue of spectrum efficiency has been around for a long time. If it were easy to solve, we would have solved it a long time ago. It is hard, but important to DoD, and the first step with CSMAC is to have this phone call for CSMAC to hear the Department's perspective on this.
- There are strategic shots so they hear change we're moving into things. Spectrum sharing is the new normal. It is the prelude into policy change. Policy memos will ultimately be rolled into 4650 or other guidance.
- DoD has a Spectrum Incentives WG. It includes DoD staff from acquisition, R&D, Joint Staff, all of the service labs, DARPA, DISA, the Services, and the Communications office within CIO. It includes a broad breadth of expertise and stakeholders to look at the details of spectrum efficiency, incentives, and effectiveness. Feel free to reach out to us in the future as we continue to evolve on this issue. DoD developed a one-page document on DoD guiding principles of spectrum efficiency principles. It is awaiting CIO's signature. DoD can send to us; it will be public. It will be presented as an Interdepartment Radio Advisory Committee (IRAC) item, as well as provided to the PPSG.
- DoD is balancing many different matters, including spectrum access, programs, and acquisition. Mission and operations are front and center. Everything else stems from that. DoD is doing a good job incorporating spectrum into policy, but can do better. DoD must consider cost, weight, power, and schedule. From a Department perspective, as DoD looks at how to be more efficient, the trade-offs must support operations. Mission/operations front & center, but spectrum efficiency is important.

- DoD is updating its Spectrum Strategy from 2013 to a 2019 version. Systems have lifecycles that last for years, i.e., 20-30 years and sometimes longer. DoD is becoming more mission effective and efficient, when and where it makes sense; it must be done with a strategically smart perspective, such as via the DoD Roadmap and Action Plan (RM&AP), AWS-3 transition, and testing & training – two of our biggest activities in the U.S.
- DoD is implementing more efficient modulations schemes over time. Pulse Code Modulation/Frequency Modulation (PCM/FM) was used by AMT for 50 years; it was not very efficient, but was the state-of-art at the time. Test ranges are shifting away from this modulation but it is still required for some weapons tests. Shaped Offset Quadrature Phase Shift Keying (SOQPSK) is the current modulation scheme for AMT and has achieved a 50% reduction in required bandwidth compared to PCM/FM. DoD moved from using PCM/FM to Multi-H continuous phase modulation. DoD achieved an 85% improvement in efficiency from an aeronautical mobile telemetry (AMT) perspective over the last 20 years. DoD can send us more information on this. It is an example of the testing community looking at more efficient modulation schemes and working, over time, to get more efficient when DoD has limited spectrum access in a crowded environment.
- DoD often has to schedule testing in addition to other things operating in the band. An example is the Common Data Link (CDL) in the 15 GHz range. A multi-band CDL has been developed, which operates across a variety of pieces of spectrum to be more efficient and effective. The bandwidth-efficient CDL is more efficient and effective in an airborne data link. DoD is trying to be more efficient, flexible and agile.
- For land mobile radios, DoD has channelization plans, which get smaller and smaller channels, e.g., 6.25 kHz channels, and we continue to refine.
- DoD has a lot of projects in R&D to develop more efficient and mission effective spectrum technologies – for AWS-3 but also for other programs.
- Military ranges are overlapping high-density uses. DoD requires a lot of high tech solutions to get slivers of spectrum in high usage areas. DoD might be able to use only one channel. DoD can provide names of those projects.
- Under AWS-3 transition, there are spectrum aggregation technologies, which like white space, and sniff the environment and try to piece together pieces of spectrum. This enables use of whatever spectrum it finds and stitches the pieces together to get the bandwidth needed for the mission. AMT is using this technique on the ranges for their mission. Tactical Targeting Network Technology (TTNT) is looking at this approach for their airborne links. The goal is to free up more spectrum for DoD's own use. DoD is driving to be more efficient and to tack more on to do more.
- Spectrum efficiency metrics is tough for DoD and one of the reasons that the Spectrum Incentives Working Group was stood up (i.e., as a way for DoD to coalesce around such issues). He said it is also hard because it is not clear how to develop a metric that takes into account mission and saving lives, which is critical. DoD's mission is saving lives and bringing folks home safe; this must be part of the equation.
    - DoD wants to use commercial capabilities, not just commercial SATCOM, but also 5G, LTE, and IoT. Capabilities provided by commercial developers can augment and be redundant to DoD capabilities but are not necessarily a substitute.

  - The question is how to weaponize DoD for access to whatever we need to win the war? If SATCOM is denied, we want to use commercial. DoD wants to have both options available to the military so redundancy and resiliency are built into DoD's capability.
  - Trade-offs are not just about spectrum when addressing life cycle procurement issues (i.e., cost, performance, schedule, mission requirements.)

- For augmentation of today's capabilities, whoever controls the spectrum will win the war. Enemies are dynamically evolving their threat capabilities. DoD needs a variety of solutions across a variety of bands and a variety of capabilities. DoD needs dynamic flexibility and resiliency across the network. Do not know how to put these needs against OMB A-11.
- There are opportunities with acquisition, ASD Research & Engineering (R&E), Acquisition & Sustainment (A&S), partnership with the AWS-3 transition work, EW, R&D on spectrum sharing, and building other relationships with the acquisition community. He said DoD has done a good job but needs to do better and to put it into policy. Requests for proposals (RFPs) need to include factors on spectrum efficiency front and center.
- As an example of how DoD is doing better, DoD is in the midst of updating DoD Instruction 4650.01, and there might be an opportunity to incorporate spectrum efficiency more in the update. The point of contact is Col Fred Williams. DoD is planning on an update in the next couple of years, so there is an opportunity now to get some of this language in there. DoD also needs to do a better job following-up so that others across DoD know about the update and what it entails. DoD welcomes feedback, including from CSMAC, to consider what to do better. DoD takes recommendations seriously. It should be a two-way conversation.
- DoD is trying to port spectrum strategy considerations into the acquisition community and program offices. DoD is trying to tell staff across DoD, so they are aware when they develop capabilities (past, current, and future).
  - Legacy systems are old and antiquated. They are stuck where they are at and working fine as-is. They will not change unless the mission requires it and need to wait out the lifecycle.
  - DoD has things in development, which are not caught up to future; they may have newer, but not newest, technology in some cases.
  - DoD also has new stuff coming. It is tough to manage and influence the future.
- Constituents need an indication of the environment they are expected to operate in. More spectrum sharing is the new normal. Systems must be able to share with systems they do not typically share with.
  - The program making the investment depends on what others are doing.
  - Must have systems that can operate multi-band and be flexible and adaptable.
  - DoD has been developing multi-band CDL. DoD needs flexibility to operate across a variety of spectrum. There are some bands DoD cannot get access (i.e., radar bands in which incumbents would have to be accommodated elsewhere). With bandwidth-efficient CDL, more stuff can be fit on the spectrum, including other capabilities to operate in same band. Users need to understand the kind of environments they are expected to operate in, during both friendly as well as wartime scenarios.

- DoD cannot be doing something differently than the federal government and industry. Everyone needs same mindset. We have to understand, from a policy and regulatory perspective, what kind of environment users must share in.
- DoD wants to use 5G, 4G, and IoT, and will use in a military environment. There cannot be standoff differences. We have to develop systems that can share in that environment with commercial capabilities. DoD needs network resiliency, so when you are in a military environment or during times of war, there is a built-in system that enables better co-habitation. It would be helpful for DoD and national/federal policy to clarify the expected environment you have to operate in.
    - There is the 3.5 GHz example, which we still need to determine if it will work or not, for commercial capabilities to share with military radar. The environment stimulates innovation. We have to figure out a way to cohabitate together and make it work, especially as the airwaves get more crowded.
    - DoD was asked if it would be "too big" to have a database that could allow a program of record to assess benefits of sharing. DoD said it should not be too big to do but we need a national and federal policy that should layout how things should be. Need a stimulus. It impacts everyone, and everybody has to embrace it.
- Sharing with commercial and vice versa is important (i.e., Federal-Federal sharing and Federal with commercial). Like 3.5, other cases include the Spectrum Frontiers and higher frequency spectrum. Higher bands have different degrees of freedom, which can be taken advantage of to do more with spectrum sharing, propagation characteristics, directionality, and urban vs rural.
- There is a focus on quantitative calculations for efficiency but sometimes it might be better to start with qualitative parameters that do not have finite numbers, such as capabilities and features, that could be described. It is a delicate balance. Need to give the contractor flexibility for them to tell us what they think they can do without putting too much force on them. Overall, a balanced approach toward many factors is needed.
- DoD is doing a lot to improve spectrum efficiency other than RF, including:
    - Free space optics for tactical radio, laser comms (NASA is front and center on laser comms)
- The National Defense and National Security strategies both address satellite communications with regard to commercial sitcom and both talk about 5G and IoT. Must figure out the encryption and how to make it "hard."
- Using passive and multi-static radar is also part of the mix.
- Partnerships with other agencies have been good, NASA (space mission), DoE (nuclear mission), Service labs, DARPA, etc. have been front and center on sharing and spectrum efficiency. DoD plans to increase its partnerships in the area of the National Spectrum Consortium and NASCTN.
- R&D work is important because it feeds into capabilities, tools and waveform development. This work will start to bear fruit.
- Wish DoD could hire more people, but there are no more resources. We are doing the best possible, with less.
- The biggest obstacle to being more efficient is what could be done to be more efficient, within mission needs?

Federal Aviation Administration (FAA)

- The FAA uses 14% of the civilian-allocated spectrum in its National Airspace System mission. FAA is a robust user, seeking to maximize use of its allocated spectrum for its safety of life mission. DoD missions use 20% of the National Airspace System (NAS).
- FAA interest in assessing the potential for spectrum sharing started with the LightSquared episode. Secondly, Wall Street interests asked FAA for spectrum sharing. This was the impetus for the MITRE study to evaluate our spectrum needs to ensure our safety of life mission and technology options that eventually led to the Spectrum Efficient National Surveillance Radar (SENSR) program. There was a lot of work done before the SENSR plan. Because of the push by the market for spectrum resources coupled with our need to ensure our mission, the FAA took a top-down look to explore systematically and strategically. Spectrum is a strategic resource that the whole government is interested in.
    - Radars have historically used a lot of spectrum, but technology has changed the equation. Newer systems tend to be more spectrum efficient.
    - To create the SENSR program (the first program to leverage the Spectrum Relocation Funds (SRF) the FAA started with the concept validation process underway with ATC radars. The FAA approached other agencies and found that they were interested in exploring the opportunity, but they all stressed that they did not have the necessary funds. Plus, concept validation is only one element, resources for implementation are often more of a challenge.
    - FAA traditionally has worked closely with DoD in radars and ATC. FAA's priority in the SENSR effort has always been to get agencies to work together and assemble necessary funding.
    - SENSR includes 3 other agencies and it has provided insights into how the government is trying to take a national approach. It is a constrained optimization problem. What are we trying to achieve? How do we do that efficiently and effectively within a certain time period?
    - SENSR has a timeline – a constraint. This is helping shape the requirements definitions and choices the agencies must make.
        - Is 2021 either "too soon" or "not soon enough?" Once FAA moves out of the band, it is lost forever. A maturity of the system is needed – it cannot be a research project. We need an alternative technology that will not be at risk of failing at vital safety and security missions of various agencies. Timing is the driver, and there is a risk, but we are feeling confident due to the technology that has already been developed.
        - The timing of the deployment depends on when the monies are available to the agencies. There is a gap in the money –between when we can declare a solution and award a contract to when the money is available by the auction.
        - Multi-agency coordination is not insignificant. FAA is testing for safety, and DoD and DHS is testing for security. Beyond upfront acquisition costs, long term O&M costs that will be shared among the agencies are a significant concern with the SENSR program.
- Safety is paramount to the FAA mission, and sharing will only be undertaken when their safety-of-life mission allows for it. There are issues when sharing spectrum with others that do not

have safety at the heart of what they are doing. Steps can be taken to figure out new technology but, because of safety-of-life needs, will we have to hold onto that spectrum?

- FAA does not define "spectrum efficiency" and does not find the term currently useful the way it is framed. FAA's best way of framing the issue would be "how to get the optimal use of the bandwidth available", i.e., optimization of bandwidth is the start of effectiveness optimization. OMB Circular A-11 does not address the value of the function; for FAA, it is safety-of-life. If it can operate in the optimal bandwidth, it is less likely to have interference. Spectrum efficiency is achieving optimal bandwidth for the function we need to do. Improvements in spectrum efficiency and effectiveness when replacing a system, for FAA, simply comes down to accomplishing the same mission with less bandwidth—there are no "white spaces" in FAA aviation missions.
    - OMB Circular A-11 does not work for FAA. Any calculation that would penalize a spread-spectrum device is "not a particularly mature calculation."
    - The FAA did not submit an alternative method, but it would be hard to identify an agency at PPSG that did support the OMB methodology.
- OMB A-11 does not weight the criticality of the function. For instance, preserving life vs. speeding up trading markets. Can I trade fast vs can I save someone from crashing? What else can you do in the same bandwidth? Sharing is one way to get more utilization of bandwidth. But for safety-of-life, system sharing with an unlicensed user (with no record of where they are) significantly impacts systems operating in that band. There is no issue with like systems sharing with like. FAA has found effective ways to share spectrum by using one system to do two things. But getting two systems in the same spectrum is harder than getting one system to do two things.
    - Here is an example of spectrum sharing with unlike systems. There was interference from unlicensed Internet devices with Terminal Doppler Weather Radar (TDWR) systems that was greater than with the legacy NEXRAD radars which TDWR was meant to replace. FAA must find where the unlicensed equipment is. This is a cost to an agency, and it impacts safety.
    - Also, manufacturers were allowed to dilute the requirement and build to a lesser standard. The design of the system enabled field technicians to make changes. The issue is whom you are sharing with. Sometimes equipment is certified, but the location is not correct; users can move around considerably, and/or be certified at the head office, but deployed all over.
    - FAA is responsible for conducting an investigation to identify the source of interference, but is then supposed to turn that information over for enforcement to the FCC field offices, which have scarce personnel.
- Technology is not the impediment to greater spectrum efficiency, as FAA would define it. Rather the two key impediments are avionics and cost. The plant of installed avionics takes significant time to change while having to support the oldest operating system. While remarkable success has been achieved in getting commercial carriers to adopt the Next Generation (NextGen) Data Communications system ("DataComm") and the Aeronautical Mobile Airport Communication System ("AeroMACS"), all the older, AM-based avionics in use by the General Aviation ("GA") community must still be supported. That older technology often requires 50-100 kHz channel spacings. 8.3 kHz channels are coming out in Europe where GA activity is relatively low. It comes down to an overall cost, and it is a huge cost to totally change an infrastructure. There is a shared cost, which includes users and government. It is least costly

and most time efficient (fit, form, function) to just replace in-kind, which does not impact users or data systems and is simpler and cheaper.

- We have to tear apart the systems approach. Replacing radar for radar is fairly straight forward. We have to rely on the user community to get comparable avionics to go along with a change. This is a limitation because we can only drive the user space with a mandate. What is the definition of "infrastructure?" An expanded definition could include everything to make the system perform, i.e., buy/maintain infrastructure. If the view of infrastructure is changed to include avionics, there could be a bigger solution set. The impediment is definitional.
    - For example, FAA can't move the ADS-B system because of equipage issues.
    - Aviation is both land-based and what is on the aircraft. One-quarter million General Aviation aircraft are in the U.S. They aren't necessarily new; might be around for 50 years, and equipage might be worth more than the aircraft. Business aircraft can afford, but we have a large segment of recreational fliers. General aviation comprises about one half of the operations at towered airports.
- FAA does not routinely identify spectrum efficiency as a factor in its Requests for Proposals (RFPs). With newer systems, FAA's main consideration is where they will go within the spectrum. Spectrum efficiency is about non-interference with others and FAA. FAA's primary spectrum-related motivation in acquisitions is to buy ground systems with tight filters; some airports service planes which cannot tune in ranges less than 100 kHz. The methodology in OMB Circular A-11 Section 31.12(b) for estimating the economic value of spectrum is not a mature calculation.
- Perhaps there could be consideration of assigning property rights. There are all kinds of joint users. The current system is not designed to make it easy for an agency to free things up. There are squatter rights.
- How the SRF is setup makes a difference. Paying for one-for-one equipage is an issue. Using money elsewhere to improve other technology might incentivize better behavior. Funding for implementation is an issue since this causes a gap in funding between the contract award to when the auction occurs. Being able to release spectrum and get something for it would be an incentive. Maybe there is some way to encourage policy-makers to consider such approaches.

National Oceanic and Atmospheric Administration (NOAA)

- The definition of spectrum efficiency differs depending on a particular manager's perspective. At the program or project level, staff may be supporting spectrum efficiency or not without thinking about it intentionally because spectrum is a resource needed to do the job. The spectrum manager is focused on frequency and bandwidth covering a particular geographic area. Some people characterize spectrum efficiency in terms of spectrum use 24x7, in all places. However, NOAA capabilities are typically static (e.g., satellites, handheld radios, weather balloons) and have existed for decades. They have authorized assignments, and efforts are focused on sustainment and continuation of these capabilities. Spectrum authorization is requested for what is required, but that often covers the US&P to enable cooperative global weather and climate observations.
- Spectrum requirements decisions are usually based on contract factors (e.g., technical performance, price, reliability, low sustainability cost). The acquisition process buckets factors into price factors and non-price factors.
    - Spectrum efficiency is one factor in the non-price factor bucket; all of the non-price factors are compared to price.

  - Spectrum is not seen as a core mission. Spectrum cannot successfully compete against budget initiatives that the agency really cares about (to fulfill its core mission).

- It would be helpful to include spectrum efficiency in the Federal Acquisition Regulation (FAR). [*It is included in the Defense Acquisition Regulations System (DFARS). – CSMAC interviewer*] Economics or regulations are needed to drive efficiency. OMB Circular A-11 is used for budgeting. The budget staffs use OMB Circular A-11 at higher, more aggregate levels, and are not involved with procurement detailed technical factors, as do Contracting Officer's with the FAR.
  - Spectrum efficiency is not always a factor in RFPs. Spectrum managers cannot make it an evaluation factor when they learn of it too far down the line, when an RFP is about to be released.
  - NOAA will choose the solution that does the best job to measure accurately and send data back reliably to the collection station.
  - NOAA often does not apply OMB A-11 calculations because it typically does not have to consider options requiring new spectrum. NOAA generally launches new satellites that follow previous satellites. It is constrained by its spectrum allocations and must squeeze transmission of additional data into its existing allocations or seek other existing federal allocations appropriate for that particular scientific application.
- Lifecycle costs are a first priority; we must be good stewards of taxpayer dollars. Other factors are tradeoffs. Spectrum efficiency does not give an agency anything or help the federal agency user in anyway; it sometimes makes the system less reliable. An agency does not receive payback of benefit of sharing or relocating, just the risks and costs.
  - More spectrally-efficient solutions often require longer schedules and higher costs. Solutions are often driven by lowest cost, and deficiency is a by-product of lifecycle cost. Some more efficient solutions might require finding another government band or more expensive equipment due to smaller economies of scale. The agency strives to get a solution awarded and implemented in the shortest period of time. The spectrum assignment process is often long and results in higher priced equipment.
  - Radios that operate in federal bands sometimes cost five times more than radios in commercial bands. NOAA has sometimes had to alert programs of the risk of buying radios that have a secondary assignment, even though they might be cheaper, due to interference concerns.
- NOAA is a small agency with a relatively small budget. Its budget does not include R&D for spectrum efficiency. NOAA scientists are concerned with their science mission and focused on getting better data for the next pilot program or initiative. For example, NOAA and NASA use passive sensing bands for satellites observing residences of various gases in the atmosphere. Spectrum requirements depend on the physical property of the gas and, in particular, the frequency at which it resonates. Requirements are science-based and extend to design-dependent parameters. Another example is that NOAA needs to use the S-band to see the weather. The right physical properties of the attenuation are required to see features inside the storm, neither reflecting off the closest heavy rains nor completely passing through it. Radar has to be in S-band, so NOAA's spectrum options there depend on the federal allocations. Similarly, L-band signals from geostationary satellites attenuate even less, and can pass through the weather to earth-based receiver stations without rain fade. Spectrum use depends on function and the bands allocated for those services.

- Commercial solutions can be leveraged when available. However, commercial products have historically not existed for much of NOAA's operational needs. NOAA must fit all of its radars into its authorizations. Scientists are generally opportunistic and NOAA is routinely looking to leverage existing assets.
- There is a prioritization risk in sharing infrastructure or assets among government users. Technology is needed to solve this challenge. Relying on other agency capabilities is a fallback option, but agencies prefer to keep their own mission under their control, as they are the ones held accountable.
- The Spectrum Relocation Fund (SRF) is a necessary enabler. The SRF should be expanded to address the problem of perpetuity. The current setup includes sharing, transition to sharing, and then agencies are on their own. Post-SRF is the issue, and agencies must continue to share and coordinate on an increasing basis. Additionally, with 5G/IoT and future technologies on the horizon, what an agency builds to share with today will be something else tomorrow. O&M and sustainment is also needed, not just recapitalization for the immediate needs. There needs to be acknowledgement of the costs and new way of doing business. Congress and OMB should acknowledge the full extent of sharing costs to make sure they are covered for as long as the spectrum is to be shared.
- Some antiquated equipment still exists in operations. Some allocated spectrum channel sizes have been decreased from 25 to 12 to 6.25 kHz. However, there is not an inherent driver to replace reliably functioning equipment with new, more expensive spectrum efficient equipment; the existing equipment does its job. When it reaches the end of its lifecycle and needs to be replaced, more spectrally-efficient technology could be inserted, but a forcing mechanism is needed. More efficient technology is used in many cases, when the marketplace offers new equipment that is more efficient and cheaper equipment.
- NTIA could decide not to certify the equipment if it is not state-of-the-art when it is readily available. This would force agencies to choose the more efficient option.

National Aeronautics and Space Administration (NASA)

- NASA uses spectrum for the following purposes:
    - Science: NASA measures the Earth, sun, planet, universe etc. Measurements utilize spectrum, from radio frequency (RF) through infrared and visible light. NASA's missions include observing the world and the universe.
    - Communication with platforms and systems: NASA has a variety of communication with platforms and systems, such as the International Space Station, balloon missions over the Antarctic, etc. This entails moving data from the ground up, from space down, or on the ground.
    - Navigation: NASA uses spectrum for navigation purposes, including GPS for science missions, locating satellites, and locating platforms around the world as well as radiometric measurements to help locate satellites in deep space where GPS does not work.
- There is not one way to define spectrum efficiency. It is difficult to compare efficiencies, and there are physical laws of nature, which are not necessarily definable by efficiency.
- Spectrum is a multi-dimensional domain. Dimensions include: frequency, time, location, polarization, and direction. Direction is particularly important to NASA, which typically uses directional, large dishes.

  - Must look at multiple uses of spectrum.
  - NASA does not have any exclusive use of spectrum. NASA uses spectrum on a shared basis. It shares spectrum with other government and space agencies and commercial industry. Space and terrestrial systems share spectrum. Signals from space are typically low power such that they do not necessarily limit the introduction of new systems.
  - NASA coordinates its sharing to mitigate interference. NASA can accommodate large numbers of commercial systems in some cases.
  - NASA uses spectrum efficiently because it does not limit other uses. For example, there are a lot of smallsats operating in the same band, almost the entire band, but it can be shared.

- NASA uses spectrum for many types of operations, from space to land mobile radio (LMR) to radars (e.g., tracking radars, weather radars) to communications for sensors on balloons and sounding rockets.
  - Terrestrial communication comprises 70% of NASA's Radio Frquency Authorizations (RFAs).
  - NASA uses frequencies from other planets. We communicate with a deep space network, so it is very far away and uses very low-level signals. It is very difficult to communicate over such great distances. The efficiency of these types of communication cannot be simply compared to normal telecommunication applications.
- NASA does not always use the most advanced modulation scheme. For example, the James Webb Space Telescope has been in development for many years and costs multi-billions of dollars, of which very little of that is devoted to the telecom part other than what is needed to make it work.
- On a day-to-day basis, NASA works to narrowband all of its LMR systems and strives to buy the latest equipment from vendors.
- Internationally, NASA works in collaboration with National Oceanic and Atmospheric Administration (NOAA) and international partners, including foreign governments, to take advantage of other capabilities and systems.
- NASA strives to be as efficient as possible, which is specified in NASA's Policy Directive. Trying to fit in as many bits as possible benefits NASA in getting the data.
  - NASA's Policies (NPD 2570) and Procedural Requirements (NPR 7123) provide spectrum-related criteria for development and procurement activities.
  - NASA works to make sure its programs are aware of spectrum efficiency needs, policies are clear, and programs are engaged with their NASA Center Spectrum Office.
  - NASA must stay within the bands that are appropriate for its uses.
- There may be multiple measures of value, not just one.
  - NASA is not sure how to use OMB A-11's valuation methodology. For example, it does not make sense to apply this methodology to a sensor system. Atmospheric temperature can only be sensed around certain frequencies, per the laws of physics; alternative spectrum cannot be used.
  - Spectrum value goes beyond just an auction-based value.

  - Must address sharing, mixed use of spectrum, and whether or not other uses of the spectrum are being limited.

- NASA leverages other systems when reasonable. NASA is a consumer of commercial systems and devices. It shares assets – including deep space assets, ground station support, and data – across agencies and with international partners. NASA also uses technologies that can support commercial standards.
- NASA is conducting R&D to improve effective use of spectrum and get smarter in how NASA uses spectrum in future systems. Higher bands offer new opportunities, such as Ka-band for higher downlink data rates. Other opportunities include software-defined radios, bandwidth efficient waveforms, modulation decoding schemes, and lower swaths of spectrum for technologies onboard spacecraft. NASA is also leveraging optical communication and developing optical terminals for space and on the ground. NASA is developing the Laser Communications Relay Demonstration project (LCRD). There are multiple opportunities to demonstrate and experiment.
- Interference must be mitigated. NASA uses directionality of point-to-point signals with satellites to avoid interference and support terrestrial and space-based sharing. It is difficult to mitigate the effects of radio frequency interference (RFI), particularly on the science sensor side with large amounts of data.
  - NASA promotes out-of-band emission limits when next to passive remote sensing. Even with advanced modulation schemes that use less spectrum, not as much efficiency will be achieved unless out-of-band emissions are managed.
  - Users must be good neighbors. Should ensure that users are only transmitting the signal needed, and nothing in excess of that.
  - NASA recognizes that there are costs to filtering systems and making tighter receivers to prevent interference from things operating within the regulations, but such measures are often necessary to limit RFI to systems in adjacent bands.
- A system can have the best transmitter standards, but it will not matter if receivers are built that are not very attuned to that and have wide front ends. Good spectrum standards are needed on both transmitters and receivers. Greater standards for manufacturers could help.
- NASA has not been able to take advantage of the Spectrum Relocation Fund (SRF). It could be helpful if it were more flexible and usable, such as not tied to auctions. Secondary effects must be appreciated. NASA uses shared bands, which are not likely to be auctioned. For AWS-3, NASA moved one system into a different band. The SRF would be more valuable if agencies could write a proposal for funds to enhance spectrum efficiency.
- Spectrum efficiency does not directly help agency missions. If costly, it would be helpful for other funding to be available to support spectrum efficiency efforts and costs.
  - Spectrum is a means to an end.
  - There is no magic bullet. Updated policies can help increase effective use of spectrum. Technology development, including machine learning and cognitive radios, could help mitigate interference; these are currently in the research phase.
  - As an aside: The value and efficiency of unlicensed services (e.g., Wi-Fi) is not always appreciated when compared to exclusive licensing.

- Availability of R&D funds is one of the biggest impediments. If a technology has not been used before, it is hard to convince a mission to use it. Agencies do not want to risk their missions. Procuring capabilities outside of the mission funds, may assist. Mandates could also diminish the mission.