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Executive Summary

The Presidential Memorandum of June 14, 2013, "Expanding America's Leadership in Wireless Innovation," calls for continued efforts to make more spectrum available for wireless broadband applications. The memorandum encourages sharing of the spectrum that is currently allocated exclusively to Federal agencies while ensuring that the agencies' missions are met. The memorandum builds upon and extends the Presidential Memorandum of June 28, 2010, "Unleashing the Wireless Broadband Revolution," which calls for the government to re-purpose 500 megahertz of spectrum from existing Federal and non-Federal uses to wireless broadband use within 10 years.

One of several steps outlined in the 2013 memorandum was the establishment of a Spectrum Policy Team (SPT), which is co-chaired by the U.S. Chief Technology Officer and the Director of the National Economic Council (or their designees) and includes representatives from the Office of Management and Budget (OMB), the National Security Staff, and the Council of Economic Advisors. The SPT is working with the National Telecommunications and Information Agency to implement the remaining steps.

Purpose

Section 6 of the 2013 Presidential Memorandum directs the SPT to publish a report on "market-based or other approaches that could give agencies greater incentive to share or relinquish spectrum, while protecting the mission capabilities of existing and future systems that rely on spectrum use." The SPT tasked IDA Science and Technology Policy Institute (STPI) researchers to support the SPT in developing the report by identifying and characterizing approaches that have been proposed in the literature for providing incentives for Federal agencies to increase spectrum efficiency through various means. The purpose of this paper is to document the results of the STPI task.

Scope

This paper reviews the regulatory framework that governs allocation of spectrum for use by Federal entities. In particular, it analyzes statutes and administrative regulations relevant to the formulation of approaches for providing incentives to Federal agencies to share or relinquish spectrum. The paper then describes the major approaches that have been identified in the literature. In accordance with direction from the SPT, the paper does not make recommendations on which approaches might be preferred.

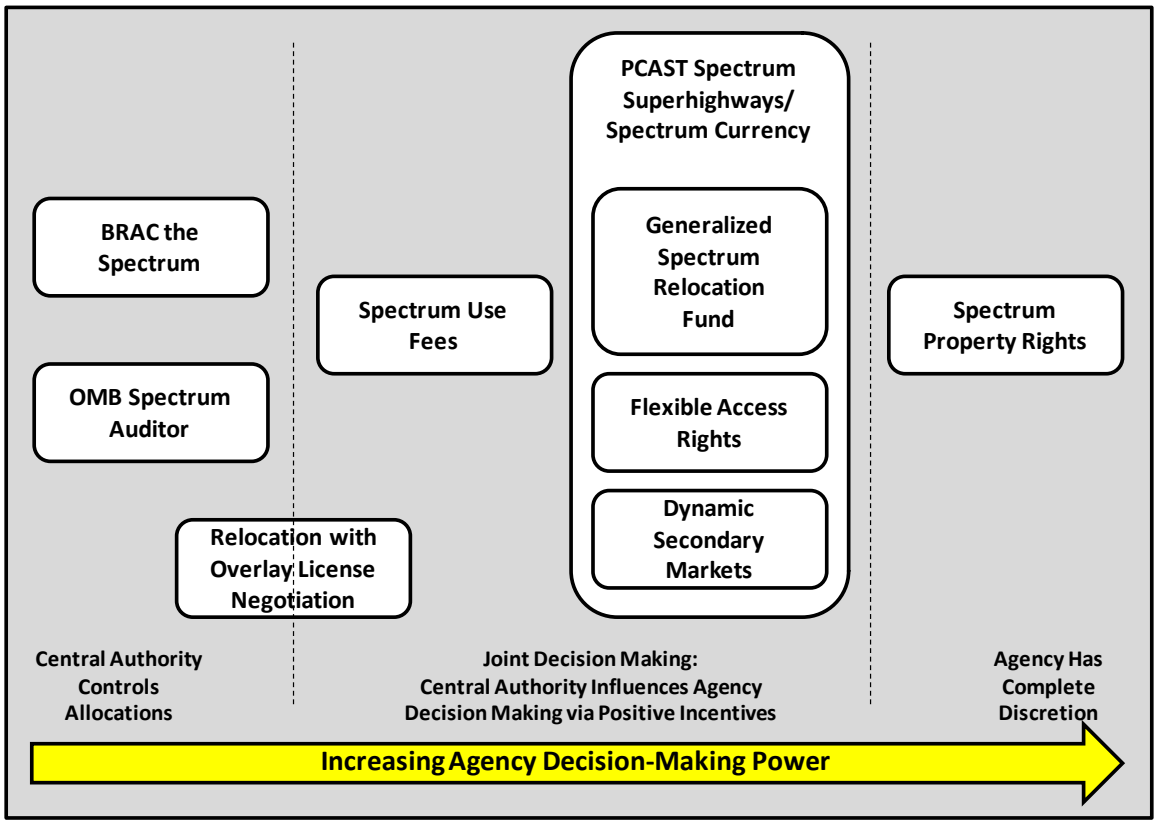
Results

The literature review yielded nine major approaches to providing incentives to Federal agencies to share or relinquish assigned spectrum:

1. *Spectrum Use Fees*. Charge agencies fees related to the market value of their spectrum, thus encouraging efficient use.
2. *Generalized Spectrum Relocation Fund*. Facilitate changes in agency spectrum use by providing agencies with funds for efforts to improve efficiency, increase sharing, and relinquish and relocate.
3. *Spectrum Property Rights*. Grant agencies spectrum ownership rights (including the right to aggregate, subdivide, sell, lease, or share spectrum holdings) and flexible use rights (with respect to technology employed and service provided), thus encouraging efficient use.
4. *Dynamic Federal Spectrum Secondary Markets*. Allow shared access to Federal spectrum through short-term leases, such as via real-time auctions, thus improving efficiency without requiring agencies to vacate spectrum bands.
5. *Flexible Access Rights*. Implement flexible licensing regimes and prioritized access for shared use, enabling Federal incumbents to share spectrum with lower priority commercial users.
6. *President's Council of Advisors on Science and Technology (PCAST) Shared-Use Spectrum Superhighways, Spectrum Currency, and Spectrum Efficiency Fund*. Improve efficiency and increase spectrum capacity for both government and commercial users by establishing 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 synthetic currency) and a related Spectrum Efficiency Fund (a mechanism for trading the synthetic currency for real funding).
7. *BRAC the Spectrum (and Zero Base Spectrum Allocations variant)*. Direct a broad-based reallocation of spectrum leading to relinquishment of Federal bands for commercial purposes, using a process modeled on the Defense Base Closure and Realignment (BRAC) Commission or zero-based budgeting.
8. *OMB Spectrum Auditor*. Use OMB's budget authority (in this case, budgeting spectrum rather than dollars) to achieve broad-based reallocation.
9. *Administrative Relocation with Overlay License Negotiation*. Supplement administrative relocation with a mechanism allowing the overlay license holder to negotiate with the Federal incumbent for better (e.g., quicker) relocation terms.

The first six approaches are *market-based* approaches, while the last three are *directed reallocation and sharing* approaches. All the market-based approaches leave considerable decision-making authority on whether to share or relinquish spectrum to the

agency, but they attempt to influence the decision in a variety of ways, as indicated in the figure below.



Two of the directed reallocation and sharing approaches—BRAC the Spectrum and OMB Spectrum Auditor—rely on a central authority to make the decisions on sharing and relinquishment. The last approach—Administrative Relocation with Overlay License Negotiation—is a hybrid, with a central authority making the relocation decision but the agency negotiating some of the terms. As illustrated in the figure, the PCAST Spectrum Superhighways approach, which employs Spectrum Currency and a Spectrum Efficiency Fund as coupled incentive mechanisms, actually incorporates many of the key features of some of the other approaches.

Some of the approaches, such as Spectrum Use Fees, focus on having agencies relinquish spectrum, while others—most significantly, the PCAST Spectrum Superhighways and the Flexible Access Rights approaches—strongly encourage sharing. Still other approaches, such as the Generalized Spectrum Relocation Fund, can support both sharing and relinquishment.

In all cases, the Federal Government would be striving for increased spectrum efficiency, increased commercial spectrum capacity, and the economic growth associated with these objectives, while ensuring that agency missions are met. Beyond that, the Federal Government accrues some approach-specific benefits. For example, the approaches that result in auctions or leases of Federal spectrum generate revenue for the United States Treasury. The sharing approaches promise to reduce the high costs of relocating government

services to different spectrum bands. Sharing approaches, such as the Flexible Access Rights and PCAST approaches, provide for prioritized spectrum access, which accommodates unlicensed users and stimulates innovation in the wireless industry.

Conclusion

The nine approaches described in this paper represent a variety of paths to satisfying the increasing demands for spectrum capacity from both government and commercial users. No single approach is likely to be the final answer. Many possible combinations, modifications, and offshoots of these approaches could be used to best adapt to the evolving economic, political, and technological environment.

Contents

1. Introduction

A. Background

The Presidential Memorandum of June 14, 2013, "Expanding America's Leadership in Wireless Innovation," calls for continued efforts to make more spectrum available for wireless broadband applications (Presidential Memorandum 2013). The memorandum encourages sharing of the spectrum that is currently allocated exclusively to Federal agencies while ensuring that the agencies' missions are met. Due to growing Federal needs for spectrum, the memorandum calls for easing of restrictions on the ability of commercial carriers to directly negotiate sharing arrangements with Federal agencies. The memorandum builds upon and extends the Presidential Memorandum of June 28, 2010, "Unleashing the Wireless Broadband Revolution," which calls for the government to re-purpose 500 megahertz of spectrum from existing Federal and non-Federal uses to wireless broadband use within 10 years (Presidential Memorandum 2010).

One of several steps outlined in the 2013 memorandum was the establishment of a Spectrum Policy Team (SPT), which is co-chaired by the U.S. Chief Technology Officer and the Director of the National Economic Council (or their designees) and includes representatives from the Office of Management and Budget (OMB), the National Security Staff, and the Council of Economic Advisors. The SPT is working with the National Telecommunications and Information Agency (NTIA) to implement the remaining steps.

B. Purpose

The 2013 Presidential Memorandum directs the SPT to publish a report on "market-based or other approaches that could give agencies greater incentive to share or relinquish spectrum, while protecting the mission capabilities of existing and future systems that rely on spectrum use" (Presidential Memorandum 2013, Section 6). It specifies that the report should address the following (Presidential Memorandum 2013, Section 6):

- Spectrum Currency and Spectrum Efficiency Fund proposals made by the President's Council of Advisors on Science and Technology (PCAST)
- Commercial Spectrum Enhancement Act of 2004 (Title II of Public Law 108-494), as modified by the Middle Class Tax Relief and Job Creation Act of 2012 (Public Law 112-96)

This paper documents the work conducted by a team of IDA Science and Technology Policy Institute (STPI) researchers to support the SPT in developing such a report. The paper identifies and characterizes various approaches to providing incentives to Federal agencies to increase spectrum efficiency through relocation, improved

technologies, and spectrum sharing. The paper also provides other information that could be useful to the SPT in making its recommendations to the President.

C. Scope

This paper covers the major incentive approaches that have been identified in the literature. Both positive and negative incentives are considered. Emphasis is placed on the PCAST report's recommendations, the Commercial Spectrum Enhancement Act of 2004, and the Middle Class Tax Relief and Job Creation Act of 2012, as called out in the 2013 Presidential Memorandum. The salient features of the representative approaches are described in detail and are also summarized in tabular form.

This paper does not include a comparative assessment of the various approaches and does not make recommendations on which approaches might be preferred. Neither does it take into account the schedule, cost, and performance effects of each approach except at a high level. Further, the technologies that are applicable to spectrum efficiency and sharing are not addressed in detail.

D. Approach

For this project, the STPI team conducted a literature review of the publications addressing the various approaches to improving spectrum efficiency[1] that could be applied to Federal spectrum users. Several enablers or inhibitors were identified including key legislative acts and regulations. Spectrum efficiency approaches were characterized as market- or directive-based, and nine representative approaches were selected. These selected approaches are described in terms of their key features, the problems they would address, and potential challenges and issues their use might present. The important characteristics of each approach as well as the incentives employed are summarized in a comparison table to highlight their commonalities and differences.

[1] Throughout this paper, the term spectrum efficiency is used in a general sense to include results of efforts to enhance spectrum use through relinquishment, relocation, sharing, or the use of improved equipment.

2. Regulatory Framework: Enablers and Inhibitors to Agency Spectrum Relinquishment and Sharing

This chapter reviews the regulatory framework that governs the use of spectrum by Federal entities. It includes an analysis of relevant statutes and administrative regulations that form the backdrop for the spectrum efficiency approaches considered in Chapter 3. In the context of this framework, enablers are legislatively or administratively created tools or authorities that serve to promote relinquishment or increased sharing of spectrum used primarily by the Federal government. Conversely, inhibitors are those regulations and practices that thwart efforts to increase agency spectrum relinquishment and sharing.

A. NTIA Federal Spectrum Assignments and Non-Federal Access

The Communications Act of 1934 (Public Law 416-73) created the Federal Communications Commission (FCC) to control spectrum access by non-Federal users and assigned the President the authority to manage Federal spectrum use. Subsequent legislation—the National Telecommunications and Information Agency (NTIA) Organization Act of 1992—confirmed and modified the President's delegation of this authority to NTIA. Accordingly, NTIA assigns "frequencies to radio stations or classes of radio stations belonging to and operated by the United States" and has "authority to amend, modify, or revoke such assignments" (47 U.S.C. § 902(b)(2)(A)).

The NTIA Organization Act also permits the Secretary of Commerce to allow non-Federal users to access Federal bands through an allocation and license issued by FCC. Under 47 U.S.C. 903(e), FCC has the authority to grant licenses permitting non-Federal uses of Federal spectrum, after coordination with NTIA to determine the likely impact on existing and planned Federal spectrum use. Congress has specifically authorized the Secretary of Commerce to allow for sharing ("mixed use") of Federal spectrum with non-Federal licensees for the purposes of "facilitating the prompt implementation of new technologies or services and for other purposes" (47 U.S.C. § 927(b)). Although Federal law specifically requires a license as a precondition for non-Federal use of Federal spectrum, FCC—with NTIA support—has interpreted the term "license" broadly to include unlicensed devices certified under Part 15 of FCC Rules (Feld and Rose 2010a, footnote 11; CSMAC 2010, 1). As a result, unlicensed use of Federal spectrum is permitted in all frequency bands except those specifically listed in Section 205 of Part 15, subject to general use requirements designed to prevent interference (47 CFR §15.209).

B. Miscellaneous Receipts Act and Associated Pre-2004 Spectrum-Related Legislation

1. Miscellaneous Receipts Act

The Miscellaneous Receipts Act mandates that "an official or agent of the Government receiving money for the Government from any source shall deposit the money in the Treasury as soon as practicable without deduction for any charge of claim" (31 U.S.C. §3302(b)). Federal agencies are prohibited from withdrawing such money from the Treasury without a congressional appropriation and cannot supplement their budget with money obtained from other sources unless explicitly authorized by Congress. Thus, the Miscellaneous Receipts Act inhibits relinquishment and sharing of Federal spectrum by requiring specific congressional actions to take place before non-Federal users can reimburse Federal entities for reallocation-related expenses.

During the recent reallocation of Federal 1710−1755 MHz spectrum, which was authorized by the Commercial Spectrum Enhancement Act of 2004, the Miscellaneous Receipts Act prevented negotiation between agencies and purchasers[2] of Federal spectrum that could have accelerated the transition. Because of the Miscellaneous Receipts Act, a purchaser cannot, in general, address specific transition issues with a relocating agency through the payment to the agency of either money or in-kind consideration such as spectrum or equipment.

2. Balanced Budget Act of 1997 and Strom Thurmond National Defense Authorization Act for Fiscal Year 1999

The Balanced Budget Act of 1997 (Public Law 105-33) included an explicit exception to the Miscellaneous Receipts Act authorizing Federal entities to "accept from any person payment of the expenses of relocating the Federal entity's operations from one or more frequencies to another frequency or frequencies" and stipulated that such payments "may be in advance of relocation and may be in cash or in kind" (Public Law 105-33, § 3002).

The Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 (Public Law 105-261) amended the Balanced Budget Act of 1997 by requiring "[a]ny person on whose behalf a Federal entity incurs costs . . . shall compensate the Federal entity in advance for such costs" (Public Law 105-261, § 1064).

The reimbursement provisions of the Balanced Budget Act of 1997 and the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 were superseded by the Commercial Spectrum Enhancement Act of 2004, discussed below, before they could be applied to any particular spectrum band.

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[2] A party that acquires a spectrum license via FCC auction does not, as a legal matter, "purchase" the license or the spectrum. For ease of reference, however, this paper occasionally use terms generally associated with traditional property rights and transactions as a means of explicating a larger point, particularly where, as here, the exact legal nature of the right or transaction is not material to the larger point.

C. Commercial Spectrum Enhancement Act of 2004, as Modified by the Middle Class Tax Relief and Job Creation Act of 2012

1. Commercial Spectrum Enhancement Act of 2004

The Commercial Spectrum Enhancement Act (CSEA) of 2004 (Title II of Public Law 108-494) represents another legislative effort to streamline the process for reimbursing Federal agencies that relocate from NTIA-assigned spectrum, specifically from spectrum that will be reallocated from government to private use.

The CSEA established the Spectrum Relocation Fund (SRF), a fund administered by the Office of Management and Budget (OMB) and financed by auction proceeds of eligible frequencies (47 U.S.C. § 928). Through the SRF, Federal entities can recover costs incurred for relocation from eligible spectrum frequencies without additional congressional appropriations. Eligible frequencies are of two types: (1) frequencies explicitly identified in congressional legislation or (2) "any other band of frequencies reallocated from Federal use to non-Federal use . . . that is assigned by competitive bidding" (Public Law 108-494 § 202). Auctions must recoup at least 110% of the relocation costs projected by the NTIA.

Once a successful auction is completed, the proceeds of the auction are transferred to the SRF.

Federal entities subsequently request reimbursement for costs associated with relocation from OMB. OMB, in consultation with NTIA, determines the appropriateness of such costs subject to certain congressional reporting requirements. Once approved, funds are transferred to the Federal entity to be spent on authorized costs. Unused SRF funds revert to the general fund of the Treasury 8 years after the date of deposit.

2. Middle Class Tax Relief and Job Creation Act of 2012

The Middle Class Tax Relief and Job Creation Act of 2012 (Public Law 112-96) amended the CSEA and made three important changes to the SRF. First, the Act makes SRF funds available to reimburse Federal entities for costs associated with the shared use of spectrum frequencies, stating that eligible frequencies include "any other band of frequencies reallocated from Federal use to non-Federal use *or to shared use* . . . that is assigned by competitive bidding" (47 U.S.C, § 923(g)).[3]

Second, authorization is given for the acquisition of state-of-the-art replacement systems intended to meet comparable operational scope (47 U.S.C. § 923(g)(3)(b)). Prior to this amendment, state-of-the-art replacement systems were not explicitly authorized and Federal entities may not have been able to acquire them even if such systems were intended to meet comparable operational scope. One potential benefit of this amendment is that it could provide an incentive for Federal entities with outdated equipment to relocate or share spectrum in order to upgrade their communications systems technology.

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[3] The phrase "or to shared use" is italicized here for emphasis; it appears as plain text in the source.

Third, Federal entities are authorized to receive reimbursement for costs associated with the planning of spectrum relocations or sharing (47 U.S.C. § 923(g)(3)(A)(iii)). Prior to this amendment, there was uncertainty as to whether certain expenditures (e.g., estimating the costs of relocation or sharing, determining technical or operational feasibility, or planning for a relocation or sharing arrangement) made prior to an auction were reimbursable.

3. Assessing the Effect of the CSEA, as Modified by the Middle Class Tax Relief and Job Creation Act of 2012

The CSEA, as modified by the Middle Class Tax Relief and Job Creation Act of 2012, has influenced Federal efforts to reallocate[4] spectrum to date in the following three ways:

- Facilitation of spectrum reallocation with the SRF
- Congressionally directed reallocation of spectrum bands
- Prioritization of relocation over sharing

a. Facilitation of Spectrum Reallocation with the SRF

To date, only one spectrum band—the 1710–1755 megahertz (MHz) band—has been auctioned and its proceeds transferred as part of the SRF. In 2006, the FCC auctioned the 1710–1755 MHz band, paired with the 2110–2155 MHz band, raising $6.9 billion for the SRF. Since that time, 12 Federal agencies have received ~$1 billion from the SRF to pay relocation costs, and the total cost to complete relocations is expected to reach about $1.5 billion. Four agencies (United States Department of Agriculture, Department of Housing and Urban Development, National Aeronautics and Space Administration, and the Tennessee Valley Authority) have completed the relocation effort and achieved comparable capability of systems either by relocating to new frequency assignments or by utilizing alternative technology. NTIA expects the remaining agencies to complete this relocation effort no later than 2017.

The transition was accompanied by Federal regulations developed by FCC and NTIA to require a form of geographic sharing in the 1710-1755 MHz band (47 CFR § 27.1134). These rules allowed 14 Department of Defense sites to continue to use the band temporarily—until no longer needed or relocation was possible—and two Department of Defense sites, at Cherry Point, North Carolina, and Yuma, Arizona, to continue to use the band indefinitely. Under the sharing requirements, licensees are required to avoid interfering with these facilities, and must accept interference from them.

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[4] A "reallocation" (i.e., a change to the table of frequency allocations) occurs when a frequency band is repurposed from one use to another, for example, from Federal use to non-Federal use. A reallocation of a frequency band can be accomplished through (1) relocation (or clearing) of incumbent users in favor of new users, (2) sharing between incumbent users and new users, or (3) a combination of relocation of some incumbent users and sharing between other incumbent users and new users.

b. Congressionally Directed Reallocation of Spectrum

The Middle Class Tax Relief and Job Creation Act of 2012 directed NTIA to identify 15 megahertz of spectrum between 1675 MHz and 1710 MHz for reallocation from Federal to non-Federal use and for the reallocation to be completed no later than February 2015 (47 U.S.C. § 1451). Pursuant to this directive, in February 2013 NTIA recommended the FCC reallocate the 1695–1710 MHz band for non-Federal commercial use on a shared basis. The FCC adopted NTIA's recommendation and on August 20, 2013, promulgated a notice of proposed rulemaking (78 CFR § 51561) that would make available the 1695–1710 MHz band for commercial advanced wireless services on a shared basis with Federal users within specified "Protection Zones" if clearing of the spectrum is not feasible.

This was not the first time Congress directed NTIA to repurpose Federal spectrum for commercial use. The Omnibus Budget Reconciliation Act of 1993 required the reallocation of 200 megahertz of Federal spectrum to non-Federal users (Public Law 103-66 § 113), and the Balanced Budget Act of 1997 tasked NTIA with the reallocation of another 20 megahertz (Public Law 105-33 § 3002(e)).

c. Prioritization of Relocation over Sharing

In evaluating a band of frequencies for possible reallocation for exclusive non-Federal use or shared use, the Middle Class Tax Relief and Job Creation Act of 2012 requires NTIA to give priority to options involving reallocation of the band for exclusive non-Federal use (47 U.S.C. § 923(j)). NTIA may only choose options involving shared use when it determines, in consultation with the Director of the OMB, that relocation of a Federal entity from the band is not feasible because of technical or cost constraints. This directive has focused Federal efforts on relocation over sharing.

4. Proposed Revisions Not Included in Middle Class Tax Relief and Job Creation Act of 2012

Additional revisions to the CSEA might further facilitate agency relocation and sharing. SRF funds can currently be used only to reimburse expenses related to a spectrum band that is auctioned by the FCC, or is previously identified by statute (47 U.S.C. § 923(g)(2)). Expanding the definition of frequencies eligible for reimbursement would encourage proactive agency efforts to identify sharing opportunities in reallocated bands that are not assigned through the FCC's competitive bidding process, such as the open licensing approach proposed for the 3.5 GHz band or unlicensed bands.

The President's proposed American Jobs Act (AJA) of 2011 would have expanded the "eligible frequencies" definition and made funds available to cover planning for any potential or planned auction or for sharing, including with unlicensed users. It would have also explicitly allowed Federal entities to enter into sharing arrangements with non-Federal users, upon approval of NTIA and OMB, with the stipulation that "[r]emuneration associated with such access shall be deposited into the Spectrum Relocation Fund" (AJA 2011, Section 272 (b) and (d)).

D. Antideficiency Act

The Antideficiency Act, in part, prevents the Federal Government from making or authorizing "an expenditure or obligation exceeding an amount available in an appropriation or fund for the expenditure or obligation" (31 U.S.C. § 1341(a)(1)(A)). In other words, entities of the Federal Government cannot commit to expenditures unless sufficient funds are already appropriated or made available in a fund for that purpose.

Issues. The Antideficiency Act would make it difficult to establish alternative auction arrangements that provide for incremental auction payments and incremental agency draws on the SRF. Though incremental payments would offer the benefit of allowing purchasers of Federal spectrum to make a lower initial payment for spectrum that may not be accessible for multiple years, the Antideficiency Act would prevent incremental agency SRF draws from ever exceeding the incremental purchaser payments. Such an arrangement could be unwieldy, given the unpredictable nature and expense of agency relocation. As a result, the Antideficiency Act would inhibit such potentially more efficient payment arrangements.

E. OMB Circular A−11

Office of Management and Budget (OMB) Circular No. A−11 (OMB 2013) contains two directives (sections 31.12 and 51.18) relevant to Federal spectrum management within the context of receiving approval from OMB for funding system acquisitions. These directives require that spectrum be considered to have value and be included, to the extent practical, in economic analyses of alternative systems/solutions.[5]

Section 31.12(a) requires Federal agencies to consider the economic value of the spectrum being used in the development of their budget justifications for procurement of major telecommunication, broadcast, radar, and similar systems. To demonstrate consideration of the value of the relevant spectrum, agencies should indicate whether the system procured was the most spectrum "efficient" among those that met specified mission/operational requirements.

Section 31.12(b) provides an example methodology for determining the spectrum "efficiency" of a system under procurement. The methodology takes into account the following three factors: (1) a weighting factor based on the frequency used by the system (e.g., 1.0 for 500−999 MHz, 0.5 for 1000−2000 MHz, 0.2 for 3000−4999 MHz, and 0.05 for 0−500 MHz or 5000 MHz and above), (2) the population of the area in which the system will operate and use spectrum, and (3) the amount of bandwidth utilized.

[5] The current version of the directives stems from recommendations made in the Commerce Spectrum Management Advisory Committee (CSMAC) Incentives Subcommittee Report published in 2011. In 2012, the Middle Class Tax Relief and Job Creation Act (Section 6411) directed OMB to update Circular A-11 in accordance with the CSMAC recommendations, and OMB subsequently published a revision of Circular A-11 incorporating the recommended CSMAC changes.

According to the Circular, the product of these factors—a weighted MHz-pops[6] value—yields a baseline that can be used in evaluating spectrum efficiency improvements. The implication is that if an alternative system reduces the product of these factors (by using less valuable spectrum frequencies, affecting less population, or using less bandwidth), then the alternative system is more "efficient."

Section 51.18 requires agencies provide a narrative that: (1) states whether the system will share spectrum with other existing Federal or non-Federal systems or operations and, if so, the nature and extent of the sharing relationship; (2) states whether sharing of an existing Federal system to meet the capability requirement is possible, or whether sharing capabilities of similar Federal users has been considered; (3) describes, compares, and evaluates the spectrum efficiency and effectiveness for various alternatives considered utilizing the methodology described in Section 31.12 or another methodology developed by the agency and approved by OMB; and (4) certifies consideration of non-spectrum dependent or commercial alternatives to meet mission and operational requirements.

Issues. The spectrum directives contained in OMB Circular A−11 are intended to steer agencies to consider spectrum value and spectrum efficiency in system acquisitions. However, at this time, the directives lack solid definitions for some important terms. For example, they offer a simple example methodology for calculating spectrum value (in terms of weighted MHz-pops), which may better capture the value of commercial communications than many government uses. A potential problem with such a simple methodology is that Federal uses requiring broad swaths of spectrum but allowing for significant sharing may not be as inefficient as such calculations would make them appear. In the long run, greater guidance in the form of an overall framework is needed to help agencies weigh spectrum efficiency versus the potential for increased time, agency cost, and risks to agency missions. Some efforts toward such a framework are underway. Specifically, the Presidential Memorandum of June 14, 2013, calls for the Director of OMB, in consultation with NTIA, to develop spectrum efficiency guidelines and incorporate them into budget and procurement processes.

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[6] The term "MHz-pops" is defined as "the product derived from multiplying the number of megahertz associated with a license [or spectrum assignment] by the population of the license's [or assignment's] service area (http://transition.fcc.gov/Bureaus/Wireless/Public_Notices/1994/pnwl4014.txt).

3. Approaches to Sharing or Relinquishing Agency-Assigned Spectrum

This chapter describes nine general approaches to sharing or relinquishing spectrum assigned to Federal agencies. STPI identified these approaches from recent literature on the topic. As Table 1 indicates, the first six approaches are referred to as *market-based* approaches, while the last three are referred to as *directed reallocation and sharing* approaches.

All the market-based approaches leave considerable decision-making authority on whether to share or relinquish spectrum to the agency, but they attempt to influence the decision in a variety of ways, as illustrated in Figure 1. At the right end of the continuum, the Spectrum Property Rights approach turns ownership of spectrum over to agencies, giving them flexible use rights and the ability to aggregate, subdivide, sell, lease, or share their spectrum holdings. Two of the directed reallocation and sharing approaches—BRAC the Spectrum and OMB Spectrum Auditor—rely to a great extent on a central authority to make the decisions on sharing and relinquishment. The last approach—Administrative Relocation with Overlay License Negotiation—is a hybrid, with a central authority making the relocation decision but the agency negotiating some of the terms. As illustrated in the figure, the PCAST Spectrum Superhighways approach is a comprehensive approach that actually incorporates many of the key features of some of the other approaches, namely, the Generalized Spectrum Relocation Fund, the Flexible Access Rights, and the Dynamic Secondary Markets approaches.

As shown in the table, some of the approaches focus on having agencies relinquish spectrum, while others—most significantly, the PCAST Spectrum Superhighways and the Flexible Access Rights approaches—strongly encourage sharing. Still other approaches, such as the Generalized Spectrum Relocation Fund, can support both sharing and relinquishment.

From an agency's viewpoint, there are various possible incentives—both positive and negative—that could motivate the agency to share or relinquish spectrum or to improve the efficiency of the spectrum that they use. These incentives or motivations for Federal agencies to use spectrum more efficiently fall into three general categories: economic, legal or regulatory, and operational. Economic incentives for an agency are of two main types: revenue generation and usage fees. Legal and regulatory incentives can be of various types, such as mandatory requirements, flexible rights, risk reduction, or streamlining of processes. Operational incentives are those that can improve an agency's ability to meet its mission, such as acquiring more spectral capacity.

Table 1. Overview of Approaches

Approach		Scope of Applicability	Primary Agency Incentives	Federal Incentives (approach-specific only)
Market-Based: Incentivized Sharing and Relinquish-ment	**Spectrum Use Fees**	Relinquishing	*Economic*: Cost to Agency	Revenue from resulting auctions
	Generalized Spectrum Relocation Fund	Relinquishing/ Sharing	*Economic*: Funding for efficiency, relocation, and/or RDT&E	Incentivizes agencies to relinquish and/or share spectrum
	Spectrum Property Rights	Relinquishing/ Sharing	*Operational*: Flexible use *Economic*: Funds from selling, leasing, or sharing spectrum	Upon transfer of spectrum ownership to agencies, spectrum allocation is left to market forces
	Dynamic Secondary Markets	Sharing	*Operational*: Continued access to assigned spectrum, Prioritized sharing	Revenue from leases
	Flexible Access Rights	Sharing	*Operational*: Continued access, Prioritized sharing, Additional spectrum via agency access to other Federal and commercial spectrum	Revenue from secondary users Accommodates unlicensed users
	PCAST Spectrum Superhighways, Spectrum Currency, and Spectrum Efficiency Fund	Sharing	*Operational*: Continued access, Prioritized sharing, Additional Spectrum, Better spectral environment *Economic*: Funding for efficiency, relocation, sharing, RDT&E	Revenue from secondary users Accommodates unlicensed users
Directed Reallocation and Sharing	**BRAC the Spectrum**	Relinquishing	*Legal/regulatory*: Compliance	Revenue from resulting auctions
	OMB Spectrum Auditor	Relinquishing/ Sharing	*Legal/regulatory*: Compliance	Revenue from resulting auctions and/or leasing
	Relocation with Overlay License Negotiation	Relinquishing (with sharing during relocation process)	*Legal/regulatory*: Compliance *Operational*: Some say in relocation process	Revenue from auctions

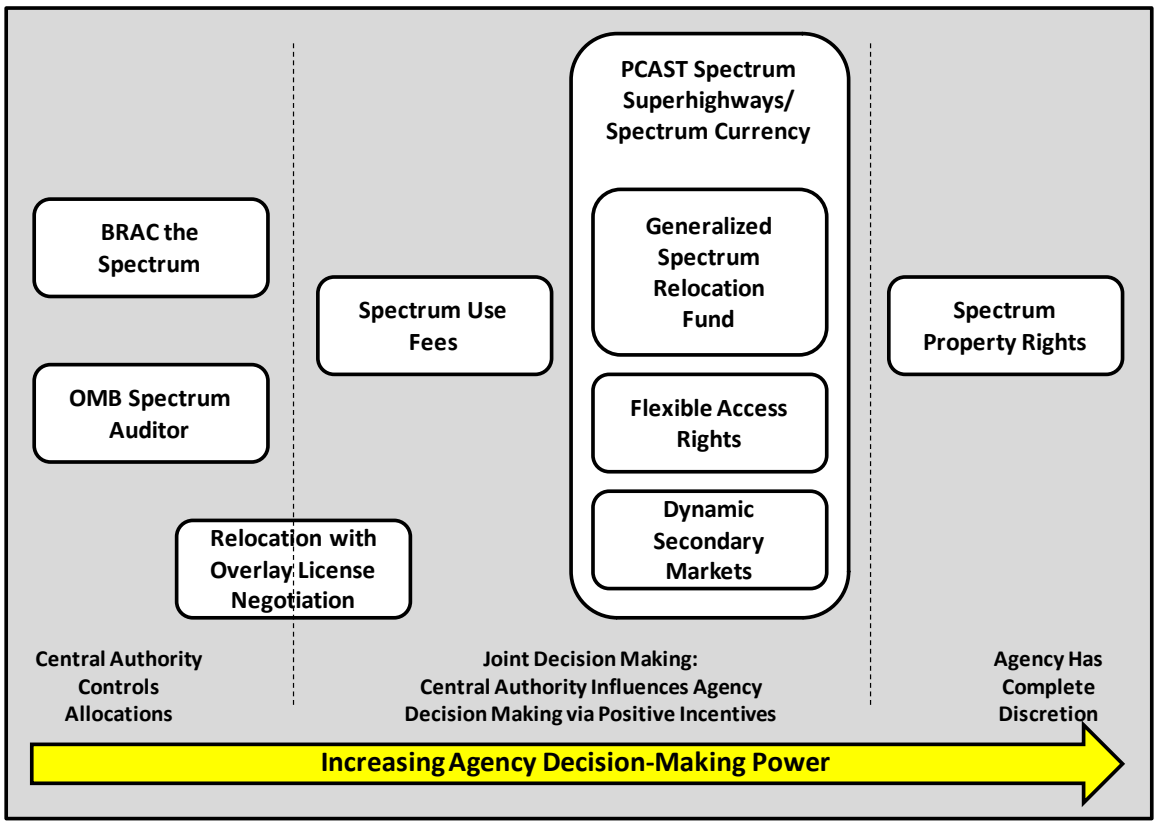

Figure 1. Decision-Making Continuum

In all cases, the Federal Government is striving for increased spectrum efficiency, increased commercial spectrum capacity, and the economic growth associated with these objectives. At the same time, the Federal Government needs to assure that agency missions are not compromised. Beyond that, the Federal Government accrues some approach-specific benefits, as shown in the table. For example, some of the approaches—the ones that result in auctions or leases of Federal spectrum—generate revenue for the U.S. Treasury. Other approaches—such as the Flexible Access Rights and PCAST approaches—provide for prioritized spectrum access, which can accommodate unlicensed users.

The remainder of this chapter describes each approach in terms of the problem addressed by the approach, the key features of the approach, and the major issues and challenges associated with the approach.

A. Market-Based Approaches: Incentivized Sharing and Relinquishment

1. Spectrum Use Fees

Although spectrum use fees are appealingly straightforward in theory, their implementation in an agency setting presents significant challenges. The Government Accountability Office (GAO), PCAST, the Commerce Spectrum Management Advisory Committee (CSMAC), and the FCC's National Broadband Plan have all examined the feasibility of spectrum use fees, which have been implemented with some success in the

United Kingdom (UK). This section examines the spectrum use fees approach in detail and discusses implementation challenges, including lessons from the UK.

Much like agencies currently pay leases to the General Services Administration (GSA) for real property they use, spectrum use fees require Federal spectrum users to pay an annual amount to a central authority for their spectrum use. Because the fee would approximate the opportunity cost of their spectrum holdings, such a system of user fees would, in theory, encourage efficient usage levels. The largest obstacle to successful implementation of spectrum use fees is the difficulty of effectively designing incentives into the agency appropriation process. Although the literature includes little discussion of how to overcome the problem, one promising idea, put forth by Lenard, White, and Riso, involves relying on negotiations with the Office of Management and Budget (OMB) to instill incentives through spectrum fees.

a. Problems Addressed

Spectrum use fees are designed to address the problem of inefficient agency spectrum use. Under current Federal practice, agencies pay only a portion of the administrative cost of their spectrum, which means they do not internalize the full opportunity cost of their use, defined as the value of spectrum when put to its most valuable alternative use. For example, a block of spectrum that might be sold at auction for $1 billion to a commercial user would have an opportunity cost of exactly that amount. If the Federal use is valued below $1 billion, then efficiency demands that the Federal Government sell the spectrum block to the commercial user, raising overall social welfare. Spectrum use fees are designed to approximate this opportunity cost so that Federal agencies fully internalize the costs and benefits of their use, resulting in efficient spectrum allocation and usage.

Divestment is just one of the anticipated outcomes of an implementation of spectrum use fees. Use fees could also give agencies incentive to deploy more efficient technology and engage in spectrum sharing to reduce their fees even when agency uses are more valuable than the highest value alternative use. As technology evolves to allow for more advanced sharing, agencies would be more willing to invest in the latest technology with a positive net present value.

A second problem that spectrum use fees would address is the current lack of an accurate inventory of Federal spectrum holdings. Because agency fees require agencies to be accountable for all of the spectrum they hold, the mechanism would necessarily include a continuously updated inventory of holdings, which would give policy makers far better data than is currently available.[7]

[7] NTIA is in the process of updating its Government Master File of spectrum assignments and, pursuant to the June 2013 Presidential Memorandum, all of the agencies will begin providing more granular depictions of their spectrum assignments and usage.

b. Key Features

The important features of the spectrum use fee approach involve division of ownership and use rights, and a fee implementation mechanism.

Rights. A spectrum use fee approach would lease exclusive or primary use rights to agencies on an annual basis. The literature assumes exclusive agency use rights under a spectrum use fee model, but a more flexible arrangement—primary use rights, for example—that allows for sharing is not inconsistent with spectrum use fees.

The approach involves centralized ownership of Federal spectrum holdings. Under the National Broadband Plan's formulation, NTIA would retain ownership and administer the system of spectrum use fees (FCC 2010). Lenard, White, and Riso propose an alternative ownership body, called the Government Spectrum Ownership Commission (GSOC), which would serve a GSA-like function for spectrum (Lenard, White, and Riso 2010).

Although the literature is quiet on spectrum sharing, it is worth emphasizing that sharing might take place under the proposed arrangements—administered by NTIA or GSOC—or that spectrum fees might alternatively be implemented in conjunction with spectrum property rights, which would give agencies both ownership and use rights.[8]

Implementation. Imposing spectrum use fees would first require calculation of opportunity costs, which the literature suggests may present technical challenges. The National Broadband Plan, for example, points to the difficulty in using prices from the auction of licenses for comparable spectrum as a guide because such comparisons "are imprecise due to differences in technical characteristics, rules, interference environment and temporal variations in the supply and demand of the spectrum being compared" (FCC 2010, 83). But calculation of opportunity costs is a technical problem that the UK has managed to overcome, and several authors have concluded that the Federal Government could likewise calculate opportunity costs with some accuracy.[9]

CSMAC recommends that spectrum fees might be structured as a flat rate per MHz-population (i.e., price per MHz normalized by population = Price / [population × MHz]) (CSMAC 2011). Such a fee would reflect the fact that spectrum in more densely populated areas tends to have greater commercial value. Under the Committee's formulation, the fee would start below market-clearing price—the opportunity cost—but increase over time to reflect fully the opportunity cost to allow agencies time to transition.

CSMAC also suggests that some government uses (satellites, low-frequency transmissions, and maritime and aeronautical applications) could require more traditional management approaches because they are subject to bilateral agreements or are noncommunication uses (CSMAC 2011). Likewise, the National Broadband Plan emphasizes that different approaches to setting fees may be necessary to ensure that essential government services are not disrupted by a fee system (FCC 2010). But

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[8] See Rosston (2013, 8) for a suggestion that sharing could be incorporated.

[9] For information on AIP fee calculation, see Ofcom (2010) and Carter and Marcus (2009, 15).

spectrum fees would nonetheless be useful for encouraging more efficient usage through consolidation and efficient technological upgrades, even for essential uses.

The mechanism for administering fees is a particularly critical feature of implementation. Unfortunately, the literature is largely silent on the specifics of designing a fee system that instills incentives in the context of the budget appropriation process. As Carter and Marcus note (2009, 8), "the UK government has not addressed the central challenge analysts have posed in the U.S.: how to preserve fee-based agency incentives within the context of a budgeting process that is designed to provide adequate funding for agency needs, regardless of efficiency." The challenges presented by these circumstances are discussed in detail in the next section.

A more detailed implementation proposal is Lenard, White, and Riso's GSOC mechanism, which is combined with an OMB fee negotiation process. The authors frame the proposal as a long-run option, which builds off short-run recommendations that are more rapidly implementable. These include commissioning a National Academy of Sciences (NAS) study of government spectrum allocation, opportunity costs, and potential reallocation options, establishing a spectrum reform task force to use the NAS study to recommend spectrum bands to be vacated, directing NTIA to track government spectrum inventory and the associated opportunity costs, and directing OMB to serve as a "skeptical auditor" of government spectrum use, using NAS and NTIA data (Lenard, White, and Riso 2010, 25).

Under the authors' long-run recommendations, GSOC would acquire all spectrum held by governments and grant agencies annual leases for the spectrum they previously held (renewable by the agency in perpetuity) at rates that would approximate opportunity costs, as calculated by GSOC. All proceeds would be forwarded to the Treasury and fees would be phased in gradually. In the first year, OMB would add to each agency's budget the amount required to cover spectrum rental fees. In future years, two factors would ensure efficient use: (1) the spectrum use fees would be adjusted by GSOC on an annual basis to reflect updated information about opportunity costs of particular spectrum holdings; and (2) agencies would negotiate with OMB for spectrum fee budget allocations in the same way they currently do for other resources (real estate, for example). Agencies would be required to justify their use, setting the benefits (importance to agency mission and inability to find alternatives) against the costs (GSOC fees). Because of this negotiation process with OMB, budget appropriations might not necessarily track changes to use fees, and agencies could therefore abandon spectrum not used efficiently or find ways to improve usage efficiency (Lenard, White, and Riso 2010).

c. Challenges and Issues

The literature presents several important challenges inherent in the spectrum use fee approach, two of which have been gleaned from the UK experience with AIP.

Two Lessons from the UK's Administrative Incentive Program. Created in 1998, the AIP phased in spectrum use fees at approximately 50% of spectrum opportunity costs until 2010, when Office of Communications (Ofcom), the UK spectrum regulatory

body (with responsibilities encompassing both FCC and NTIA roles), outlined a plan to bring fees up to the level of opportunity costs (CSMAC 2011). At the 50% level, only extremely inefficient government users would be enticed to vacate spectrum (Rosston 2013). Low fees reflected initial concerns that fees approximating true opportunity costs would be difficult to calculate accurately, and that mistakenly setting fees above opportunity costs would jeopardize important government uses (Ofcom 2009). But the 12-year delay in bringing fees in line with opportunity costs also points to a potential lesson from UK's AIP implementation: fees may be difficult to change once they are set (CSMAC 2011). This conclusion offers a strong note of caution against the National Broadband Plan proposal to follow the UK model in setting low initial fees to be raised gradually, unless that plan also included a commitment to a timeline for raising fees to the level of opportunity costs.[10]

Second, the lesson to be drawn from AIP regarding the effectiveness of spectrum use fees is unclear. Despite the program's long tenure, evidence is inconclusive for two reasons: (1) no rigorous cost-benefit analysis of the program has been performed (Carter and Marcus 2009); and (2) AIP is just one piece of a market-based approach, thus complicating analysis of its impact (Ofcom 2009). Nonetheless, there is agreement that the roster of government spectrum bands vacated since the institution of AIP is short, even if the interpretations of that result differ. While Lenard, White, and Riso's review of the literature finds the results "marginal," Carter and Marcus are optimistic, and Rosston points to several reasons why the program may be more successful than it appears, particularly given that the goal is efficiency, not relinquishment: the initial allocation may have been close to efficient, or effective incentives may nonetheless take time to work owing to the legacy of preexisting investments (Lenard, White, and Riso 2010, 24; Carter and Marcus 2009; Rosston 2013). Without a more rigorous analysis of the program's effectiveness, this remains an open question.

Challenges of the Appropriation Process. Aside from those encountered or addressed by AIP, the primary challenges facing the spectrum use fees approach involve whether and how fees would actually incentivize Federal agencies to use spectrum more efficiently.

The first challenge is that Congress and the agencies are not equipped to pursue efficiency through incentives. Lenard, White, and Riso point out that profit maximization—the necessary prerequisite for incentives to operate efficiently—is not an agency goal (Lenard, White, and Riso 2010). As a result, agencies are unlikely to respond in economically efficient ways. Eisenach frames a corresponding congressional challenge as a concern that the spectrum fee appropriation process would better reflect political costs and benefits than economic ones (Eisenach 2011). In other words, agencies with less congressional support might feel the squeeze of spectrum fees most acutely, regardless of their relative spectrum use efficiency.

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[10] See FCC (2010, 83) and Rosston (2013, 7).

Second, CSMAC members raise the concern that unintended budgetary shortfalls may result when agencies are forced to operate indefinitely under a continuing resolution that does not account for increases in spectrum fees. To counter this problem, CSMAC suggests advance publication of spectrum use fees, perhaps as a 5-year rolling window (CSMAC 2011).

Another challenge identified by CSMAC members and others is that a spectrum use fee mechanism would require additional budget appropriations for agencies (CSMAC 2011). But because spectrum fees transfer money from one arm of the government to another, they need not increase overall Federal expenditures. Instead, the challenge would be to find a funding arrangement that allowed for this redistribution, which the literature reviewed for this analysis does not explore.

Finally, the most compelling criticism of spectrum use fees is that the budget appropriation process could net out any increase or decrease in spectrum use fees, leaving agencies indifferent to their spectrum use levels (Lenard, White, and Riso 2010). It is for this reason that PCAST argues spectrum use fees would be ineffective. In support of this argument, PCAST suggests that agencies might not reap the rewards of relinquishing spectrum: any spectrum that an agency gives up would be met by congressional appropriators with a commensurately lower spectrum fee appropriation (PCAST 2012). Nowhere in the literature is this critique squarely addressed.

Nonetheless, Lenard, White, and Riso's GSOC mechanism represents an effort to overcome this particular obstacle. Rather than relying on agencies to respond to price signals directly, the GSOC model puts OMB in the position of negotiating with agencies over their spectrum expenditures, just as it does for other resources agencies use. In other words, OMB would play the role of independent arbiter steering agencies to use spectrum efficiently.

d. Conclusion

Although spectrum use fees could potentially incentivize agencies to use spectrum more efficiently, the issues surrounding implementation within the context of the budget appropriation process remain a significant challenge to the approach's feasibility.

2. Generalized Spectrum Relocation Fund

Congress and regulators have recognized the need for funding of spectrum efficiency, reallocation, or sharing efforts for agencies. Several variations of a Federal fund have been proposed that would reimburse an agency for upfront costs associated with spectrum relocation, sharing, or other methods of improving use of Federal spectrum, as well as allow an agency to continue to reap some benefits from these efficiencies. In particular, spectrum sharing technologies are viewed as unproven, so agencies may require expensive testing and validation before adopting them. The Commerce Spectrum Management Advisory Committee (CSMAC) and the PCAST have examined versions of this approach, and there are lessons learned from previous efforts such as the Spectrum Relocation Fund (SRF). An ambitious proposal, advanced by a bipartisan coalition in the House of Representatives in December 2013, would aim to

incentivize further agency relocation by giving an agency one percent of the revenue generated by the auction of spectrum vacated by that agency, to be used by the agency to offset sequester budget cuts. This section examines several proposals that will generalize the function of the Spectrum Relocation Fund to further incentivize Federal spectrum relocation, sharing, and efficiency.

a. Problems Addressed

The basic premise of a Generalized Spectrum Relocation Fund is to incentivize agencies by providing funds to cover the costs and risks associated with relocating or sharing spectrum that will lead to increased availability of spectrum for both Federal and non-Federal users. Agencies are reluctant to expend effort to make spectrum available, especially if it will impact an agency's mission, as there are significant costs and risks associated with implementing any of these measures. These costs include factors such as planning, research and development, testing, and upgrading equipment. Federal agencies may have no authority to enhance their use of spectrum if the cost decreases the budget available for their core mission. As a result, they may decide not to take on these substantial costs of relocating, implementing shared access, designing or procuring new and upgraded systems, or moving to more spectrum-efficient and/or interference-tolerant technologies.

The few budgetary mechanisms that cover these costs are tied to an annual process. However, instituting changes to spectrum use is typically a multi-year process, potentially involving some trial and error. In addition, once an agency has implemented an efficiency measure, there may only be a one-time, short-term gain from an incentive fund, and it is difficult for an agency to continue to reap the benefits of its efficiency. At the same time, the agency may be experiencing an increased demand of their own for additional spectrum capacity that may require development of new solutions, since the likelihood of obtaining additional spectrum is small. Some of the risks involved with relocating and sharing could be addressed through a fund that would cover the entire range of costs associated with relocation or adopting sharing technologies, from early inception to implementation across multiple years.

For example, a Spectrum Incentive Fund, as proposed by Representatives Brett Guthrie (R-KY) and Doris Matsui (D-CA) represents an attempt to provide a stronger incentive to agencies than reimbursement of relocation expenses, by offering them an opportunity to gain additional revenue to offset sequester budget cuts through spectrum relocation, regardless of their expenses incurred.

b. Key Features

A historical description of the evolution of funding sources for spectrum innovations is given and describes key features that have been tried in the past and that are being suggested in current approaches.

Spectrum Relocation Fund (SRF). An SRF established by the Commercial Spectrum Enhancement Act (CSEA) of 2004 (Public Law 108-494), was used to reimburse agencies for actual costs associated with relocating from spectrum specifically earmarked for auction to commercial entities, based on a transition plan submitted by the

agency.[11] The SRF was funded through a portion of the proceeds of the auction of the 1710-1755 MHz band that was reallocated in 2006. The SRF is administered by OMB in consultation with NTIA and was intended to be a revenue neutral fund. The SRF did not cover other spectrum bands or many other actual costs, such as planning.

National Broadband Plan. The National Broadband Plan recommended that the SRF be enhanced to ensure that a full range of costs are covered to provide Federal agencies up-front planning, technology development, and staffing for relocation efforts (FCC 2010, Recommendation 5.5.). In addition, compensation should be available to agencies that replace dedicated spectrum use with commercial services or other non-spectrum-based alternatives. Specifically, the SRF should cover costs incurred to obtain telecommunication services from another existing commercial network, thereby freeing up spectrum.

S**pectrum Innovation Fund (SIF).** In 2011 the CSMAC Incentive Subcommittee, in order to encourage Federal agencies to invest in increasing their spectrum efficiency, proposed a Federal SIF that would reimburse an agency's expenses for spectrum relocation, sharing, or other methods of improving use of Federal spectrum. The CSMAC observed that there was no government process for government agencies to move towards sharing spectrum with potential users (commercial or Federal) and that there should be a budgetary mechanism to provide dedicated funds to pay for the required feasibility studies, research and development (R&D), planning, and equipment necessary for implementation of sharing. The report recommended that the scope of the existing SRF, which was strictly limited to the actual costs incurred in relocating Federal systems from auctioned spectrum bands, be expanded to be a SIF, where funds could be used for spectrum sharing and other opportunities to enhance spectrum efficiency, interference tolerance, and higher spectrum utilization, and to modernize the Federal systems. This broadening of the SRF recognized that clearing of the bands is becoming increasingly difficult and that there are many opportunities for productive sharing with no harm to the incumbents. New or upgraded systems can be designed with the improved sharing and efficiency capabilities in mind, and supported by the additional funds available in the SIF.

The recommendations intentionally left the specific size and scope of the fund not defined and suggested it could range from covering only R&D to covering the costs of upgraded equipment and the specifics would be determined by Congress. NTIA was proposed to manage the fund as it has the expertise to make decisions on impact and cost effectiveness (with OMB concurrence). NTIA would have authority to distribute funds, monitor progress, and assess results. The SIF would award funds based on a competitive process with project proposals selected on merit, as well as those responding to any mandates. The CSMAC report suggested several possible methods of funding the SIF and suggested it could be revenue neutral like the SRF. Similar to the case where the SRF uses revenue from the auction of 2006, the SIF could receive funds from the next

[11] See section 2.B.1 for further details on the CSEA.

spectrum auction. Sustaining funds could come from a number of sources such as user fees, lease fees, or equipment certification fees.

American Jobs Act. The President's proposed American Jobs Act (AJA) of 2011 expands the role of the SRF by allowing it to cover relocation and sharing costs, including planning costs, stating that the SRF should cover costs for "planning for a potential auction of spectrum frequencies, a planned auction of spectrum frequencies or the reallocation of spectrum frequencies from Federal use to exclusive non-Federal use, or shared Federal and non-Federal use" (AJA 2011, Section 272 (a) (1)). The Act also clarifies the concept of "comparable capability," stating that the SRF should cover (1) the costs of modification or replacement of equipment, engineering and construction, staff, research studies, transition, and accelerated replacement of equipment required to achieve comparable capability of Federal systems affected, as well as (2) "the costs of the use of commercial systems and services (including systems not utilizing spectrum) to replace Federal systems discontinued or relocated pursuant to this Act, including lease, subscription, and equipment costs over an appropriate period, such as the anticipated life of an equivalent Federal system or other period determined by the Director of the Office of Management and Budget" (AJA 2011, Section 272 (c)(3)(F)). The Act specifies that agencies can allow non-Federal shared access to their spectrum with NTIA approval, with remuneration resulting from such access going to the SRF.

Also included in the proposed American Jobs Act and part of the President's Wireless Innovation Initiative is a fund to promote R&D in spectrum use, primarily for public safety, that will initially be a $100 million fund overseen by the National Institute of Standards and Technology. This Wireless Innovation (WIN) Fund will receive an additional $200 million after successful future auctions. It is not clear if this fund could be used to fund agency efforts toward spectrum efficiency.

The American Jobs Act prompted enactment of the Middle Class Tax Relief and Job Creation Act of 2012, which included some, but not all, of the proposals in the American Jobs Act.

Middle Class Tax Relief and Job Creation Act of 2012 (MCTRA). Subsequent to the release of the American Jobs Act bills and the CSMAC report, the SRF was modified by the MCTRA as follows (Public Law No. 112-196, Section 6701, (a) para (1)):

> Any Federal entity . . . that incurs relocation or sharing costs because of planning for an auction of [eligible] spectrum frequencies or the reallocation of [eligible] spectrum frequencies from Federal use to exclusive non-Federal use or to shared use shall receive payment for such relocation or sharing costs from the Spectrum Relocation Fund. . . .

The MCTRA restricts "eligible frequencies" to those frequencies identified by statute or assigned by competitive bidding.

Thus, as noted in Chapter 2, the SRF can now be used to cover sharing costs, as well as relocation costs. It can also be used to reimburse agencies for costs associated with

planning for spectrum relocation or sharing.[12] However, it cannot be used to cover costs of sharing with unlicensed users, as the American Jobs Act would have allowed.

NTIA is directed by the law to give priority to reallocation of spectrum for exclusive use (versus sharing) by commercial users, i.e., "the NTIA . . . shall choose options involving shared use only when it determines, in consultation with the Director of the Office of Management and Budget, that relocation of a Federal entity from the band is not feasible because of technical or cost constraints" (MCTRA 2012, Section 6701, (j) para (1)). In addition, some of the other language in the Act seems to favor spectrum relocation or clearing over sharing. The MCTRA makes provisions to pay for planning and sharing, but did not explicitly include funding to pay for commercial services for the equivalent life of radio equipment and did not include funding for work to support sharing with unlicensed users.

To date, there has been no further action to cover the remaining CSMAC recommendations concerning the SIF. "A SIF was not included in NTIA FY12 funding and was not included in the President's FY13 budget submitted to Congress" (NTIA 2012, 1).

Spectrum Efficiency Fund (SEF). In a similar approach to promote movement toward spectral efficient technologies, the PCAST report recommended that the current SRF (as modified by the MCTRA) be further redefined and broadened as the SEF (PCAST 2012, Recommendation 5.5). As sharing becomes more prevalent in the future, it will become important to improve Federal systems to make their spectrum attractive for sharing. However, the costs of research, planning, and testing for this purpose are not currently reimbursable by the SRF, unless the shared spectrum is assigned by competitive bidding. The proposed adjustment would allow Federal agencies to be reimbursed for general investments in improving conditions for spectrum sharing, including upgrading for state of the art equipment. The SEF would be administered by the OMB and would reimburse qualifying costs for improvements in any Federal agency's use of their allocated spectrum, not just those in revenue-generating spectrum bands. The SEF should act as a strong incentive, since it would provide agencies with budget dollars above and beyond their normal appropriation.

The SEF is closely coupled with the PCAST "Spectrum Currency" concept.[13] In the PCAST proposal (PCAST 2012), agencies that improve their spectrum efficiency and thus reduce their use of Spectrum Currency—a synthetic currency used to pay for spectrum use—would be able to trade unused synthetic funds for actual funds. The SEF would be one of the key sources of real funds. The PCAST report suggests that the OMB could distribute the SEF funds to agencies by competitive auction, with agencies using Spectrum Currency to bid for SEF dollars.

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[12] For further details on the MCTRA, see sections 2.B.2.

[13] For a discussion on Spectrum Currency, see section 3.A.6.

The SEF would be self-financing and budget neutral and would be replenished from a number of sources related to the PCAST three-tiered scheme, such as fees from secondary users and certification fees from General Authorized Access users. Short-term leases are identified as a likely source of sustaining funds as they would provide a continuous stream of revenue. Ideally, the fund would also be able to borrow against future auction revenue to speed implementations. OMB through the SEF would reward agencies that moved quickly to make spectrum available for sharing.

Federal Spectrum Incentive Act. Introduced by Representatives Brett Guthrie (R-KY) and Doris Matsui (D-CA) in December, the Federal Spectrum Incentive Act of 2013 (H.R. 3674) would bring an incentive auction model to the Federal spectrum reallocation process. Designed to incentivize further agency relocation from valuable spectrum bands, the legislation would offer relocating Federal spectrum users one percent of the proceeds from the auction of their vacated spectrum. The transfer would be made through a new Federal Spectrum Incentive Fund, set up to operate in parallel to the SRF. Though the proposed legislation leaves the SRF intact, agencies would be prohibited from receiving duplicative payments from both funds to compensate expenses incurred for the same spectrum relocation. More specifically, if an agency that receives SRF funds pre-auction sought to receive a Spectrum Incentive Fund payment, it would have the amount of SRF funds subtracted from its subsequent Spectrum Incentive Fund payment by the Director of OMB and transferred back to the SRF. The Spectrum Incentive Fund is designed to offer a stronger incentive than currently available for both agency relocation and discontinuation of operations on valuable bands, especially given that current law provides no reimbursement for agency expenses incurred in discontinuation.

Funds transferred to a Federal entity under the Spectrum Incentive Fund could be used by the entity for two purposes. First, an agency could use the money to offset, but not exceed the amount of, sequestration cuts. Second, an agency that vacates spectrum and moves its operations to share frequencies assigned to another Federal entity would be allowed to transfer voluntarily any amount of the proceeds it receives from the Spectrum Incentive Fund to the incumbent agency so that it may offset its own sequestration cuts. By allowing Spectrum Incentive Fund proceeds to benefit both Federal entities, likely through a process of negotiation between them, this arrangement is designed to incentivize agencies to identify sharing opportunities and negotiate a mutually beneficial sharing arrangement.

The proposed legislation would also revise the definition of sharing costs covered by the SRF to include those incurred by an incumbent Federal entity in accommodating sharing its spectrum with a relocating Federal entity.

Other Activities: Other R&D funding being expended in the areas of spectrum efficiency and sharing (such as projects managed by the National Science Foundation and the Defense Advanced Research Projects Agency) are aimed at improving the underlying technologies. However, these are not generally available for agency specific activities.

c. Challenges and Issues

The concept of a Generalized Spectrum Relocation Fund is an important part of any comprehensive plan to assist agencies in relocating or adopting new spectral sharing and efficiency methods. FCC, NTIA, Federal agencies, and industry stakeholders all agree that relocating or sharing spectrum is costly in both time and money (GAO 2012). Major concerns about such funds are how to initially provide an adequate base of funding and then how to sustain the funds. Obtaining base funds from auctions has worked for the original SRF concept, but future revenue from auctions is uncertain. There is also concern over whether funding from auctions will be sufficient. For sustaining funds, either auction proceeds or shorter term leases are considered. The short-term-lease fees as proposed by the PCAST report face additional implementation issues and are as yet an unproven mechanism and the market demand is unknown.

The management of, and method of awarding, funds needs to be further developed. Approaches differ over whether it should be administered by OMB or NTIA. There is concern that if the awards are given on a competitive basis, then the results may not contribute to the optimal transition to relocation or sharing. It may be beneficial to have a more coordinated plan developed by an interagency group and grant awards to agencies that best match the plan. In addition, a process for sizing the awards should be further defined.

Another challenge is how to realize the longer term benefits to agencies for giving up spectrum. This was only addressed by the PCAST report on using spectral currency beyond annual budget cycles and was not extensively covered.

There is general agreement that further research and development is needed for technologies related to sharing. There is a basic problem of trust in the technologies and the regulatory process that requires extensive testing and experimentation. Many of the technologies, if successfully demonstrated could substantially reduce the risk of sharing as well as the need for additional agreements and regulation. However, industry investment in these activities is limited (GAO 2012). As a result, the government has a large role to play in leading the efforts to prove out the technologies. There are ongoing efforts by FCC and NTIA to establish test beds for sharing and to provide experimental licenses. Government spectrum related research activities are coordinated through the Wireless Spectrum R&D SSG;[14] however, it could be beneficial to coordinate these research activities with an SIF to bring the combined resources to bear on this issue in order to persuade agencies that the methods are robust and predictable.

The Federal Spectrum Incentive Act presents additional challenges that are common to attempts to incentivize Federal agencies. Agencies hoping to offset sequester cuts risk seeing their efforts subsequently offset by congressional appropriators. Moreover, relocation and auction of Federal spectrum can take several years, ensuring a significant

[14] Wireless Spectrum Research and Development Senior Steering Group of the Networking and Information Research and Development program for coordination of Federal research, http://www.nitrd.gov/nitrdgroups/index.php?title=Wireless_Spectrum_Research_and_Development_(WSRD)#title.

delay before agencies might see Spectrum Incentive Fund dollars. It is difficult to predict the effect of sequestration on agency budgets several years from now—a fact that could perhaps diminish the power of the incentive proposed. Finally, one percent of auction proceeds is a modest sum in comparison with the costs of relocation, and may not offer agencies sufficient motivation.

d. Conclusion

The use of some form of fund to cover costs and risks of relocation, efficiency, and sharing is needed. Without a process for funding these activities, it is difficult for a Federal agency to undertake such measures. Experience has shown that such a fund needs to be flexible and have the ability to cover all of the related costs—planning, R&D, test and evaluation, equipment upgrades, and employment of commercial services—for both realized and potential spectrum enhancements. The SRF has been modified to cover many of these cases, but still requires modifications to increase its flexibility. It is also necessary to further refine the procedures for awarding funds to agencies, be it through a competitive process or through a centrally managed and coordinated effort. The mechanism for replenishing the SRF or any generalization thereof also requires further consideration to ensure its continuing viability.

3. Spectrum Property Rights

Spectrum property rights—ownership and flexible use—represent a market-based alternative to traditional spectrum management. Through property rights, spectrum "owners" gain the ability to "buy and sell, rent and lease, divide, aggregate, and modify their uses of the spectrum rights that they own, so long as their activities do not significantly impinge physically (i.e., electromagnetically) on others' uses of their spectrum rights (and so long as their activities conform with the general laws of the U.S. that affect all businesses)" (White 2000, 2).

Property rights are generally accepted in the context of commercially held spectrum, but they have not been applied to Federal agencies to the same extent. Although agencies have some discretion in terms of the use of their assigned spectrum, they do not "own" their spectrum and cannot sell or lease it and retain the resulting monies. However, the idea of granting Federal agencies spectrum property rights dates back to Coase's 1962 article, "The Interdepartment Radio Advisory Committee," in which he concludes (Coase, 1962, 47):

> [T]he existing administrative structure for the allocation of radio frequencies to government departments and agencies does not prevent their wasteful use. There can be little doubt that this situation would be improved by the introduction of the pricing system. Of course, the exact form which this system could take admits of a good deal of variety. For example, radio frequencies could be disposed of for long or short leases or by the creation of property rights. And the use of frequencies could be subject to more or less detailed regulation.

More recently, the NTIA has raised the possibility of introducing spectrum ownership rights to Federal agencies, suggesting that "granting agencies tradable rights and allowing agencies to accept payment for, or otherwise benefit from, allowing others to access their spectrum" be examined as an alternative to fee-based incentives (NTIA 2008, 11).

In this section, a conceptual framework for spectrum property rights is described. The framework, developed by Matheson and Morris over the last decade, lays a technical foundation for spectrum property rights that applies equally well to commercial and Federal owners of spectrum. The framework is based on the concept of licensed electrospace regions (Matheson and Morris 2003, 2005, 2011, 2012). An *electrospace region* is a volume in a seven-dimension hyperspace, where the dimensions are space (latitude, longitude, and altitude), time, frequency, and direction of propagation (azimuth and elevation angle).

A *licensed electrospace region (LER)* is the "property" of the license holder, or licensee. LERs define the boundaries within which licensees are allowed to emit radio signals. In terms of LERs, licensees have the following property rights:

- *Ownership (tradability)*. Licensees may aggregate, subdivide, buy, sell, rent, lease, and share LERs at will.
- *Flexible use (technology and service neutrality)*. For purposes of interference management, licensees are obligated to abide by certain signal strength limits—both outside LER boundaries and within LER boundaries. Otherwise, they are free to deploy any technologies and provide any services in their LERs.

a. Problems Addressed

The traditional spectrum management approach—command and control—is believed to block efficient reallocation of spectrum. Spectrum property rights are advocated as a means of unleashing market forces, enabling spectrum to flow to those who value it most, and encouraging innovation and investment in new technologies and services (Lehr and Crowcroft 2005; ComReg 2007).

As pointed out by Eisenach (2011), ownership and flexible use are among the fundamental principles of the modern consensus on spectrum reform. Matheson and Morris, through their development and exploration of LERs, have contributed to the ongoing debate on spectrum management by laying a technical foundation for spectrum property rights.

b. Key Features

Matheson and Morris define an LER—a volume in a seven-dimensional hyperspace—as the unit of spectrum property. Ownership rights and flexible use rights are based on LERs. This subsection describes key features of the LER approach and variations adopted in other spectrum property rights proposals.

Interference Management. In the Matheson and Morris approach, interference—a fundamental problem in the use of the electromagnetic spectrum—is governed through two signal strength rules (Matheson and Morris 2011, 2012):

- Outside their LER, all signals must have a power level of less than a regulated limit, E0. This rule is aimed at having licensees keep signals within the boundaries of their respective LERs, so that they do not "encroach" on neighboring LERs.
- Inside their LER, licensees must keep all signals below a second regulated value, E_{max}, which can vary by band. This rule limits the presence of strong signals that can cause interference to receivers operating at other frequencies.

Notably, this approach places no regulatory constraints on receivers. The onus is on the transmitter to comply with the signal strength rules. Receivers are responsible for dealing with any interference that does not violate the rules (and thus does not constitute encroachment).

Ownership Rights. In the Matheson and Morris approach, licensees "own" LERs and are free to aggregate, subdivide, lease, sell, or share their spectrum use rights at will, without the approval of regulators. LERs can be subdivided along one or more of the seven electrospace dimensions, as long as the resulting LERs are disjoint (Matheson and Morris 2012).

Flexible Use Rights. Flexible use rights embody technology and service neutrality. In the Matheson and Morris approach, regulators place no constraints on the type of technology or the type of service that may be deployed within an LER. As long as licensees adhere to the established signal strength rules, they are free to innovate and deploy the technologies and services of their choosing (Matheson and Morris 2012).

Role of Central Authority. In the Matheson and Morris approach, regulators or other designated central authorities have a limited role, but nevertheless perform several important functions, including the following: (1) constructing an initial partitioning of spectrum across the seven electrospace dimensions, creating a number of LERs; (2) devolving LER rights to licensees; (3) establishing signal strength rules and periodically reviewing them, updating signal strength thresholds as appropriate to reflect technology improvements and increase efficiency; (4) enforcing compliance with signal strength rules; (5) managing a detailed public database of spectrum rights in support of enforcement and market transactions; and (6) mediating disputes (Matheson and Morris 2012).

Variations on the LER Approach. Several variations on the Matheson and Morris LER framework have been suggested:

- *Dimensions of electrospace*. The number of dimensions is a significant factor, influencing spectrum efficiency. Much early research ignored altitude and the two direction-of-propagation dimensions. White, for example, defined spectrum properties in terms of four dimensions—latitude, longitude, frequency, and time—and referred to spectrum properties as "spectrumband/area/beyond-perimeter-signal-strength-limit/time-period parcels" (White 2000, 17). On the other hand, some researchers have suggested additional dimensions, such as polarization and modulation, which Matheson and Morris reject, claiming that today's technology that makes it difficult to establish robust boundaries between LERs incorporating these dimensions (Matheson and Morris 2011).

- *Interference management*. In the *Digital Age Communications Act (DACA) Report from the Working Group on New Spectrum Policy,* spectrum property rights are defined in terms of the right to transmit over a specified spectrum band, geographic area, and time frame, subject to three limits, intended to address out-of-area interference, out-of-band interference, and in-band interference, respectively (Leonard and White 2006). The UK Office of Communications (Ofcom) defines spectrum usage rights (SURs) in terms of these same three types of limits (Ofcom 2008). The Matheson and Morris LER rights, in effect, cover out-of-area and out-of-band emissions through a single out-of-LER signal strength limit rather than through two separate limits.
- *Priority of access*. Cave and Webb (2012), who envision widespread sharing in coming years, add priority of access as a dimension of spectrum property rights.

c. Challenges

Matheson and Morris specifically call out three challenges requiring further research: (1) initial partitioning of spectrum into LERs, (2) establishment and enforcement of interference rules, and (3) design of infrastructure necessary for enforcement and secondary transactions. This section describes these three and a fourth challenge—Federal agency spectrum ownership rights.

Initial Partitioning of Spectrum into LERs and Assignment of LERs to Owners. As noted by Matheson and Morris, regulators could take one of two approaches to the initial partitioning. In the first approach, regulators would be legacy-technology conscious, granting incumbents LERs large enough to protect legacy equipment. The theory is that incumbents—facing the full opportunity cost of inefficient use of spectrum—would be incentivized to modernize their technology and sell excess spectrum rights. In the second approach, regulators would more proactively seek efficiency by imposing limits based on (1) an assessment of agency spectrum needs and (2) the potential for agency deployment of more efficient technologies. As Matheson and Morris point out, with robust spectrum markets, the initial partitioning should not significantly influence the long run economic efficiency of the regime.

The transition from traditional command and control rights to flexible use rights also presents challenges. An important open question is whether traditional and flexible rights can co-exist in a given band for a period of time, or whether a comprehensive band-clearing would be necessary. Matheson and Morris point out that "grafting flexible-use freedoms into established [command and control] bands may run afoul of incumbents' expectations, depending on how regulators design the LERs." Moreover, "anyone who benefits from regulatory ambiguity could be made worse off when that ambiguity is eliminated" (Matheson and Morris 2012, 791).

Establishment and Enforcement of Interference Rules: Setting Values of Signal Strength Limits E_0 and E_{max}. Matheson and Morris list several factors complicating the establishment and enforcement of interference rules: (1) signals can combine in certain ways to produce inadvertently strong signal environments, (2) real-world receivers cannot reject all signals at unwanted frequencies and from unwanted directions, (3) the

number of potentially affected parties may, in some instances, be too large to allow efficient negotiations, and (4) signal propagation is inherently statistical and varies by time, altitude, weather, terrain, and other conditions, making it hard for users to confine their signals to their LERs at all times in all places with total certainty. In developing interference rules, regulators would have to consider all these factors; they would also have to be prepared to update the rules as technology evolves (Matheson and Morris 2012, 787).

Spectrum Rights Database. A rights database is an essential component of a spectrum property rights regime. It supports the following inter-related functions: (1) clearly defining the rights that the central authority is expected to enforce, (2) making ownership transparent, (3) allowing licensees to identify neighbors who may be encroaching on their LERs, (4) identifying potential targets of negotiation with respect to spectrum use, and (4) facilitating market transactions (Matheson and Morris 2012).

Matheson and Morris cite several database-related issues, including: (1) to what extent can the rights database be made public, (2) what is the appropriate minimum range for each of the LER dimensions, (3) how can the complex boundaries of the seven-dimensional LERs be usefully represented, (4) are current propagation models sufficiently powerful to meet the needs of LER-based spectrum management, (5) to what extent should private contracts (e.g., leases, sharing arrangements, negotiated signal strength limits) be captured in the database, and (6) how can the quick-response needs of opportunistic users be met. Matheson and Morris conclude that the rights database is one of the main aspects of the LER approach in need of further research (Matheson and Morris 2012).

Legal Authorities Required for Federal Agency Spectrum Ownership Rights. Issues include: (1) a Federal agency's authority to transfer spectrum to non-Federal Government or private sector entities and (2) a Federal agency's ability to retain the monies resulting from spectrum trades.

d. Issues

This section reports issues that have been raised in the literature on the potential effectiveness and ramifications of the spectrum property rights approach.

Effectiveness of Spectrum Ownership as an Incentive for Federal Agencies. Some experts have questioned how much impact spectrum ownership would have on Federal agencies. The 2006 DACA report expressed doubts about the effectiveness of spectrum ownership as an incentive for Federal agencies to use spectrum more efficiently (Leonard and White 2006, 20):

> Even if a private market in spectrum establishes prices and thus the opportunity costs of holding spectrum, so long as the agency's budget is not directly affected by its use—or non-use—of spectrum, its hoarding proclivities are unlikely to be changed. Similarly, even if spectrum held by government agencies was propertyzed, if the agency leadership believes

> that the proceeds from sales of surplus spectrum will have to be transferred to the central treasury or, even if retained by the agency, will be fully offset by future reductions in budgetary allocations, then the incentive for hoarding will remain intact.

Spectrum Fragmentation. Spectrum property rights, as described by Matheson and Morris, permit licensees of LERs to subdivide and sell or lease their LERs at will. As pointed out by the Commission of Communications Regulation of Ireland in a report on dynamic spectrum access, this can lead to market fragmentation, "where multiple spectrum trades results in small fragmented sections of spectrum, making it difficult for a single operator to compile a contiguous block of frequency to provide more efficient services, ultimately reducing the value of the spectrum" (ComReg 2007, 5).

The PCAST report sees this kind of fragmentation as a problem, stating that "spectrum should be managed not by fragmenting it into ever more finely divided exclusive frequency assignments" (PCAST 2012, vii). In fact, the foremost recommendation of the PCAST report is the establishment of spectrum superhighways─potentially as wide as 1,000 megahertz─based on a three-tier hierarchy of access to Federal spectrum, with incumbent Federal users having highest priority (PCAST 2012).

Accommodation of Sharing. Matheson and Morris have not addressed sharing in technical depth, but do maintain that their LER approach does not preclude sharing. They specifically mention that LER licensees can choose to allow cognitive systems to opportunistically access their spectrum, and that the LER licensees can impose both monetary charges and usage restrictions for the privilege. They also see the utility of developing pragmatic means of accommodating low-power underlays (Matheson and Morris 2012).

Cave and Webb agree that spectrum property rights can accommodate sharing, and have suggested that licenses "should have an explicit allowance for interference from unlicensed usage allowing subsequent introduction of technologies such as UWB [ultra-wideband], cognitive or some other future technology into the band" (Cave and Webb 2012, 300). This kind of allowance is sometimes referred to as an "easement."

However, some spectrum reform advocates argue that spectrum property rights cannot accommodate what they regard as sharing (Eisenach 2011). Indeed, some researchers see the spectrum property rights and the spectrum commons approaches as lying at opposite ends of the spectrum management continuum, with property rights characterized by licensed users and exclusive use, and spectrum commons characterized by unlicensed users and non-exclusive (i.e., shared) use (Buddhikot 2007; Lehr and Crowcroft 2010; Berg et al. 2013).

As pointed out in a recent article by Berg et al., there is no clear winner. Each end of the spectrum management continuum has its advantages and may best address the needs of particular kinds of services (Berg et al. 2013, 163):

> The long-term licenses serve large and centrally controlled networks that require lots of spectrum, and they allow the licensee to recover the huge investment costs. The unlicensed model, on the other hand, provides low cost spectrum and a testbed for innovation.

Receiver Performance Standards. The NTIA and the FCC have historically addressed harmful interference by focusing on transmitters, for example, by requiring transmitters to limit power and out-of-band emissions. However, even if transmitters follow the rules, receivers can still experience harmful interference if they are unable to filter out signals in adjacent bands (GAO 2013).

As noted in recent congressional testimony by FCC official Ronald Repasi, "Receiver performance is becoming increasingly important as a limiting factor as we move to repurpose spectrum and pack more services closer together on the spectrum chart" (Repasi 2012, 3). Matheson and Morris acknowledge that demands on receivers could become even more intense in a flexible-use regime, because receivers could potentially encounter: (1) a much wider variety of possible interferers, (2) many more types of systems at moderately spaced frequencies, and (3) a more rapidly changing spectrum environment (Matheson and Morris 2012).

There are different ways to address receiver performance. At one extreme are interference limits, such as those in the LER approach; at the other extreme are mandatory receiver standards, which have been employed by the NTIA but not by the FCC. The GAO examined these options in a recent report and listed the advantages and disadvantages of each (GAO 2013):

- *Interference limits*. The advantages are that (1) they provide a clear criterion for claims of harmful interference by receivers and (2) they refrain from mandating specific designs or technologies, thus enabling flexible use and innovation. The disadvantage is that they are complex to establish and enforce, compared to standards.
- *Mandatory receiver standards*. Receiver standards are easier to implement than approaches such as interference limits, since compliance to the standards can be tested. The primary disadvantage of standards is that they can inhibit innovation.

There is no clear consensus on whether mandatory receiver performance standards should be employed as a mechanism to limit harmful interference. Property rights proponents are opposed to receiver performance standards since they constrain flexible use and only indirectly address harmful interference. Sharing proponents tend to favor receiver standards, saying that NTIA and FCC should consider both transmitter and receiver characteristics as they proceed toward spectrum sharing. For example, the PCAST report recommends, "To safeguard primary Federal users, FCC should require that future non-Federal devices will be permitted to share government spectrum as Secondary Access users only if they are certified to operate within the stated interference limits for the band of interest" (PCAST 2012, xii).

e. Conclusion

Spectrum property rights—ownership and flexible use—have been advocated as a superior, market-based alternative to command and control spectrum management regimes. However, spectrum property rights present some complex implementation challenges and pose some potentially serious risks, including spectrum fragmentation. Their ability to accommodate sharing is under debate. Most significantly for the purposes of this report, their potential to incentivize Federal agencies to improve spectrum efficiency and to share or relinquish excess spectrum is unclear.

4. Dynamic Federal Secondary Markets

At a June 2010 Federal spectrum reform conference, Feld and Rose presented a white paper on dynamic secondary markets—based on auctions of Federal spectrum along temporal, geographical, and spectral dimensions—as a means of making more Federal spectrum accessible to commercial users. In the paper, Feld and Rose suggest (2010a, Abstract):[15]

> [R]ather than clear bands for auction, the Federal Government can provide access to Federal spectrum through dynamic "real time" leasing. This would combine the low barriers to entry and flexibility of unlicensed with the higher power and interference protection of licensed.

They also note that dynamic secondary markets would complement, rather than replace, exclusive licensing and unlicensed access.

a. Problems Addressed

The leading methods of providing commercial access to Federal spectrum—FCC auctions of long-term, exclusive licenses to vacated spectrum at one extreme and unlicensed access via FCC's Part 15 rules for low-powered devices at the other extreme—are unable to keep pace with demand, despite the prevalence of unused and underutilized Federal spectrum. Federal users find it difficult, costly, and risky to relocate operations from one spectrum band to another; moreover, their demands for spectrum are growing, just as commercial demands are. At the same time, commercial users are unsatisfied with auctions and unlicensed access. Auctions are accessible only to the largest carriers, due to high bidding costs and long transition times. Unlicensed spectrum is restricted to low power devices and lacks interference protection.

Feld and Rose propose dynamic Federal secondary markets as a new means of allocating spectrum, one capable of addressing unmet needs for spectrum and, furthermore, serving as a source of Federal revenue.

Importantly, dynamic secondary markets allow commercial access to Federal spectrum—within geographical areas and/or timeframes when it is not being used for Federal purposes—without the need for Federal agencies to vacate an assigned spectrum band.

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[15] Abstract appears at Public Knowledge website, "Public Knowledge proposes Spectrum Policy Changes," http://www.publicknowledge.org/node/3130.

b. Key Features

Enabling Developments. Several recent developments, including some significant FCC actions, suggest the viability of dynamic Federal secondary markets:

- *FCC secondary market policies and expanding secondary markets*.[16] In 2000, the FCC issued a policy statement, "Principles for Promoting the Efficient Use of Spectrum by Encouraging the Development of Secondary Markets." This action, along with follow up regulatory actions taken in 2003 and 2004, enabled the development of robust secondary markets in spectrum. As reported in the National Broadband Plan, there have been thousands of secondary-market transactions over the last several years, including license transfers, some incorporating spectrum partitioning (i.e., geographic subdividing) and disaggregation (i.e., frequency band subdividing), and spectrum leases (i.e., time subdividing).
- *FCC's Public Safety/Private Partnership initiative*.[17] In 2007, the FCC put forward the concept of a public-private partnership for the development of a nationwide public safety broadband network in the 700 MHz band. The idea was that a commercial licensee (the winner of the anticipated 10 megahertz D block auction) and a Public Safety Broadband Licensee (allocated another 10 megahertz block) would share a wireless broadband network developed by the commercial licensee on their combined 20 megahertz of spectrum. Under the sharing arrangement, the Public Safety Broadband licensee would have priority access to the commercial spectrum in times of emergency, and the commercial licensee would have preemptible, secondary access to the public safety broadband spectrum. Although the D block auction failed to produce a winning bid, the proposed partnership concept demonstrated a certain level of acceptance of shared, prioritized spectrum access as being reliable enough to meet the needs of mission-critical functions such as public safety.
- *FCC's TV White Spaces initiative*.[18] In 2010, the FCC adopted final rules allowing unlicensed devices to access TV White Spaces—the unused spectrum between TV stations. The unlicensed devices, certified under FCC Part 15 Subpart H (CFR 47 Part 15 Subpart H), include fixed devices (e.g., Wi-Fi hot spots, rural broadband access points) and low-power personal/portable devices (e.g., laptops, tablets, Smartphones). The devices operate in conjunction with TV bands databases, operated by FCC designated administrators (e.g., Spectrum Bridge, Telcordia, and Google). The databases contain information on existing licensed TV and other services, as well as certain unlicensed services, such as wireless microphones. An unlicensed device seeking access to TV White Spaces submits its geolocation to a TV bands database and then receives information from the database on which channels are available for use.

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[16] FCC website, "Secondary Market Initiative," http://wireless.fcc.gov/licensing/index.htm?job=secondary_markets.

[17] FCC website, "Public Safety/Private Partnership," http://www.fcc.gov/encyclopedia/700-mhz-spectrum; http://transition.fcc.gov/pshs/public-safety-spectrum/700-MHz/partnership.html.

[18] FCC website, "White Space," http://www.fcc.gov/topic/white-space.

- *FCC's 3550−3650 MHz Citizens Broadband Service initiative* (FCC 2012). In December 2012, the FCC issued a Notice of Proposed Rulemaking (NRPM) "to create a new Citizens Broadband Service in the 3550-3650 MHz band (3.5 GHz Band) currently utilized for military and satellite operations, which will promote two major advances that enable more efficient use of radio spectrum: small cells and spectrum sharing" (FCC 2012, 2). The NRPM builds on experience gained with the FCC's TV White Spaces initiative and aligns with some of the PCAST recommendations. It proposes a three-tiered access structure for the 3.5 GHz band: Incumbent Access, Priority Access, and General Authorized Access (GAA). Incumbents, including high-powered Department of Defense radars and non-Federal Fixed Satellite Service (FSS) earth stations, would operate in large exclusion zones and be protected from harmful interference; Priority Access Licensees and GAA users would share spectrum outside the exclusion zones. In November 2013, the FCC issued a Public Notice describing a Revised Framework for the 3550-3650 band, based on the following concepts: (1) a Spectrum Access System (i.e., a database similar in concept to TV White Spaces database) to manage shared access, (2) open eligibility (versus eligibility limited to mission-critical applications such as hospitals) for Priority Access, (3) mutually exclusive spectrum rights for Priority Access Licensees, with licenses for specific timeframes, geographic areas, and bandwidth awarded by flexible, dynamic auctions, (4) a defined "floor" of GAA spectrum availability, providing nationwide availability, and (5) additional GAA access to unused Priority Access bandwidth, under management of the Spectrum Access System. The Public Notice seeks comments on several issues, including auction mechanisms, licensing structure, and receiver standards.
- *Routine real-time auctions*, as exemplified by the Google Adwords system.[19] For each Google search, AdWords runs an auction to determine which ads are displayed on the search results page, and where they are displayed. AdWord clients set up an account, specify an average daily budget, and choose how to spend their money (i.e., whether they want to pay on a cost-per-thousand-impressions basis, a cost-per-click basis, or a cost-per-acquisition basis).

Implementation Proposed by Feld and Rose. Feld and Rose suggest that dynamic secondary markets for Federal spectrum be implemented as follows (Feld and Rose 2010a):

- Create a database—modeled on TV White Spaces databases—of Federal spectrum bands by use and by geographic location. Federal users would be allowed to update the database at any time.
- Use the database to manage dynamic access to Federal spectrum as follows. Parties requesting access to Federal spectrum query the database for throughput capacity, specifying mobile, fixed, point-to-point, or mesh. The database determines whether the request can be met. If the request can be accommodated, the database then provides instructions, including power level limits, to the transmitting devices.

[19] Google, "How Costs are Calculated in AdWords," https://support.google.com/adwords/answer/1704424?hl=en&ref_topic=3121763.

- As competition for non-Federal access to Federal spectrum develops, conduct real-time auctions among the competing users to determine who gains access.
- Provide Federal users with immediate access to spectrum as needed, using technology approved in concept by the FCC for the proposed, but never implemented, D block Public Safety/Private Partnership.

Feld and Rose acknowledge that this kind of system would likely satisfy some uses—such as wireless backhaul, machine-to-machine communication, low-bandwidth mobile uses, and other uses not readily accommodated by existing spectrum access schemes—more easily than others. As previously noted, they view dynamic secondary markets as supplementing existing schemes (i.e., auctions of exclusive licenses and unlicensed access) for providing commercial access to Federal spectrum.

Benefits of Auctions. Feld and Rose point out that requiring commercial users to purchase access through real-time auctions has a number of advantages (Feld and Rose 2010a):

- Raises Federal revenue, which could be used, in part, to maintain the infrastructure required to support dynamic secondary markets.
- Creates a market-based mechanism to resolve potential interference issues between users.
- Prevents hoarding and improves competitive access.

The PCAST report points out that compared to long-term exclusive licenses, short-term leases are "turned over more quickly, thus motivating a cycle of faster overall industry competition and resulting innovation" (PCAST 2012, 43).

c. Challenges and Issues

The Feld and Rose proposal for dynamic Federal secondary markets shares many of the same challenges and issues as the PCAST Shared-Use Spectrum Superhighways approach, the Matheson and Morris Spectrum Property Rights approach, and the FCC's proposal for the 3550−3650 MHz Citizens Broadband Service:

- *Defining appropriate units of spectrum for allocation, licensing, or assignment*. What are the dimensions of the units? Frequency, area (including altitude?), time, direction of propagation? How granular are the geographical, temporal, and other divisions?
- *Building and maintaining a database (i.e., Spectrum Access System)*. How are the spectrum units represented? How is classified information on Federal spectrum use handled? How can Federal agencies be compelled to provide accurate information on their spectrum use?
- *Managing interference*. Are propagation models used? Are they accurate enough to avoid overly conservative restrictions on sharing? What role do receiver standards play? What are the enforcement policies, processes, procedures, and mechanisms?
- *Implementing auction mechanisms*. How will real-time auctions of fine-grained units of spectrum be implemented?

- *Facilitating agency readiness for sharing*. If agencies need to upgrade their equipment to be more resilient to interference, how will they pay for the upgrades? Can auction proceeds be used?

The greatest challenge facing the Feld and Rose and related approaches is gaining buy-in from both Federal and commercial users.

d. Conclusion

The Feld and Rose proposal for dynamic Federal secondary markets is similar in concept to the PCAST's proposed Shared-Use Superhighways and the FCC's proposed 3550−3650 Citizens Broadband Service. These approaches all seek to enable commercial access to unused Federal spectrum. They all face resistance from Federal agencies, who lack sufficient confidence in sharing technologies, policies, processes, and procedures to enthusiastically subject their missions to sharing of the scale envisioned by the approaches. The approaches also face resistance from large commercial carriers, who tend to restrict their major investments to spectrum that they exclusively hold.

5. Flexible Access Rights

As demand for spectrum increases and technology for sharing spectrum advances, it becomes increasingly important to modernize the regulatory framework for spectrum access rights. Licensed and unlicensed use must be accommodated. Shared access must be accommodated. This section explores the concept of flexible access rights by reviewing the ideas put forth in four recent papers: (1) "The unfinished history of usage rights for spectrum," a May 2012 article written by Martin Cave and William Webb and published in *Telecommunications Policy* (Cave and Webb 2011), (2) "Increasing Wireless Value: Technology, Spectrum, and Incentives," a February 2013 white paper written by Gregory Rosston of the Stanford Institute for Economic Policy Research (Rosston 2013), (3) "Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," a July 2012 report prepared by the President's Council of Advisors on Science and Technology (PCAST 2012), and (4) "Priority-Based Classification of Spectrum Access Models," an August 2013 article published in I*EEE Communications Magazine* (Berg et al. 2013).

a. Problems Addressed

As stated by Cave and Webb, "The key task in the next stage of spectrum management is to adapt regulation to the prospect of widespread sharing, on a much more sophisticated basis than that phrase is used today" (Cave and Webb 2011, 300). The number of shared bands is expected to grow. These bands can include a number of licensed users and a number of unlicensed users. The regulatory framework for spectrum access rights must evolve beyond exclusive-use licenses and unlicensed access to accommodate increasingly shared and diverse spectrum access models.

b. Key Features

Below, the key features of flexible access are summarized in four parts: (1) the Cave and Webb discussion on sharing among licensed and unlicensed users, (2) the Rosston

proposal for a diversity of licensing regimes, (3) the PCAST proposal for prioritized access to shared-use spectrum superhighways, and (4) the Berg et al. taxonomy of spectrum access models.

Cave and Webb: Spectrum sharing among licensed and unlicensed users. Cave and Webb contend that the design of spectrum access rights needs to take into account the potential for a mix of licensed and unlicensed users. They offer a high-level overview of sharing among these classes of users (Cave and Webb 2011):

- *Licensed users*. Licensed users can share a frequency band by exploiting electrospace dimensions such as geography, time, and directionality, as proposed in the previously described Matheson and Morris approach (Matheson and Morris 2011; 2012). In addition, users may have different access priorities (see Rosston's shared access licensing regime and the PCAST tiered access structure below).
- *Unlicensed users*. Unlicensed users will have some restrictions designed to prevent interference with the licensed user(s). Restrictions can be achieved in a number of ways: (1) limiting power levels (e.g., UWB), (2) sharing on a geographical basis (e.g., cognitive access via a database), (3) sensing (e.g., radar avoidance in 5 GHz Wi-Fi band), and (4) politeness protocols.

The introduction of these different users can be managed by the regulator or the primary licensee. Cave and Webb note that there may be some situations in which secondary licensees can also introduce other secondary or unlicensed users.

Rosston: Taxonomy of Licensing Regimes. In a February 2013 paper, Rosston lays out a taxonomy of licensing regimes. The regimes are defined in terms of licensing requirements (licensed or unlicensed) and access (exclusive, prioritized, or open) (Rosston 2013):

- *Exclusive Access, Licensed (i.e., Exclusive Primary Only)*. The licensee has all rights for transmission in a specific band (or partition of a band). Here, the key benefit is that the licensee has an incentive to make significant investments in the band. A potential drawback is that exclusive licenses may incentivize spectrum hoarding to protect market shares.
- *Prioritized Access, Licensed Primary with Licensed or Unlicensed Secondary*. The primary licensee has the right to operate without interference from other users, but secondary users are allowed to operate. The secondary users are restricted from "causing harm" to primary users and have to deal with potential harm from the primary licensees emissions. Here, the key benefit is that the secondary users can make use of unused or underused spectrum. A potential drawback is that it can be hard to evict secondary users. A distinction between licensed and unlicensed secondary users is that it is easier to assess the source of harmful interference in the case of licensed secondary users.
- *Open Entry, Licensed*. Rosston cites private radio bands as an example of this kind of licensing regime. Users are required to have licenses, but anyone meeting certain qualifications can get a license. The private radio coordinators add the new user and there could be some degradation in the quality of service for the pre-existing users. Here, the key benefit is low cost of entry. Potential

drawbacks are (1) contention and (2) difficulty of facilitating efficient spectrum use and migration to new technology.

- *Open Entry, Unlicensed (i.e., unlicensed bands)*. As pointed out by Rosston, unlicensed bands typically have regulation on the operating characteristics of the transmitters to manage the contention for the spectrum. Here, the key benefits are (1) easy entry for users and (2) potential for rapid introduction of new technology. Potential drawback are (1) specified operating characteristics may make transition to more efficient technology lengthy and (2) precluded use by exclusive licensee, and 3) uncontrolled contention.

PCAST: Prioritized Spectrum Access Model. The PCAST report generalizes the concept of prioritized access, adding tertiary access to the model. In particular, as noted in our description of the Shared-Use Spectrum Superhighways approach, the PCAST report recommends that access to the superhighways be governed by a three-tier hierarchy (PCAST 2012):

- *Federal Primary Access*. Federal Primary users are required to register their actual deployments in a database (e.g., the Spectrum Access System, or SAS). For the spectrum specified in these registrations, they receive highest priority access and guaranteed protection from harmful interference. Notably, as described in the PCAST report, these primary users "do not have exclusive use where they have not deployed network assets or in locations where, or times when, underutilized capacity can be put to use without causing harmful interference" (PCAST 2012, 23).
- *Secondary Access*. Secondary Access users must register deployments in a database and may receive some quality of service protections, possibly in exchange for spectrum use fees. Secondary Access is characterized by (1) guaranteed protection of harmful interference from opportunistic use by GAA users, (2) an obligation to vacate spectrum when a conflicting primary deployment is registered in the database, and (3) high power in some cases (i.e., no universal expectation of low power usage for secondary users). As described in the PCAST report, there may be multiple levels of secondary users, with different priorities, because of either fees or a public interest benefit such as public safety.
- *General Authorized Access (GAA) (i.e., tertiary access)*. GAA is characterized by (1) opportunistic access to unoccupied spectrum (as determined by a database or sensing technology), with no guaranteed level of service or protection from harmful interference (and no fees), (2) an obligation to vacate spectrum once a conflicting primary or secondary deployment is registered or sensed, and (3) low power transmissions to avoid interfering with primary and secondary users. In some cases, GAA users are required to register deployments (e.g., when needed by a primary user to facilitate identification of the source of harmful interference). In addition, as noted in the PCAST report, GAA devices should be able to operate on multiple bands, using dynamic frequency selection, to avoid dependency on access to any particular frequency (both real-time, as frequencies become occupied by primary or secondary users, and long-term, as spectrum usage evolves over time).

Berg, et al.: Generalized Priority-Based Spectrum Access Model. The authors contend that the main differences between spectrum access models are the rules between users of different priorities and the rules among equals. Based on this view, they then present a notation for describing the spectrum access model of a frequency band. The notation consists of a string of letter-number pairs—for example, A1B1 (Berg et al. 2013, 164:

- A *letter-number pair* represents a group of zero or more systems operating at the same priority level within the band.
- The *letter* represents the priority of the system(s) in the group, with A representing the highest priority.
- The *number* represents the number of different systems in the priority group, with 0 denoting no use and * denoting unlicensed or free use.
- An optional parenthetical phrase can be used to provide further information, such as the priority-enabling technology (e.g., database, radar detection, and sensing) being employed. (See below for examples.)
- The authors note that "many important regulatory issues are left out of the notation, such as interference issues, resale possibilities, standards, and radio etiquettes, and these issues could be included in the [parentheses]."

To illustrate their notation, they give the notations for a number of familiar access models (Berg et al. 2013, 164):

- A1B0, or, more simply, A1: *Licensed Exclusive use model*. Here, only one system has the right to use the frequency band; all other use is prohibited.
- A*: *Unlicensed use model*. Here, all systems have equal right to use the band under some specified rules.
- A1(database)B*: *Secondary unlicensed use of TV bands*. Here, the TV station's spectrum use and the channel availability are given in a database. If the database shows that the channel is free then any TV band device may transmit on the band.
- A1(radar detection)B*: Secondary unlicensed use of radar bands. Similar to above. Both are overlay sharing models.
- A2: *Underlay sharing model*. Here, the primary user (e.g., radiolocation at 3.1 GHz or radio astronomy at 10.6 GHz) coexists harmoniously with the ultra-wideband (UWB) systems.
- A1Bn: *Authorized shared access (ASA) model*. Here, the license owner shares the spectrum with *n* secondary systems.

Using this scheme, the PCAST model could be represented as A1(database)BnC*, denoting a primary Federal user, one or more secondary users, and any number of General Authorized Access users.

After presenting the notation, which they consider to represent a taxonomy of spectrum access models, the authors describe how the taxonomy can be used to facilitate auctions. The idea is to let the markets decide the winning spectrum access model. The

taxonomy simply provides a formal mechanism for specifying potential spectrum access models.

c. Challenges and Issues

This approach faces several challenges, including extending the licensing framework to accommodate prioritized sharing, tracking spectrum allocations, establishing interference rules, enforcement, and incorporation into auctioning schemes. The PCAST Spectrum Superhighways approach, discussed later in this report, incorporates prioritized spectrum access as one of its central features and so faces many of the same challenges as the Flexible Access Rights approach. Further details are reported in the description of the PCAST approach.

d. Conclusion

As stated by Cave and Webb, spectrum sharing is becoming ever more prevalent, and regulatory frameworks are going to have to evolve to address this. Flexible licensing regimes, such as those proposed by Rosston, and prioritized access, as elaborated in the PCAST report and in the Berg et al. article, are crucial components of a regulatory framework equipped to manage spectrum sharing.

6. Shared-Use Spectrum Superhighways (PCAST Report)

In 2012, the President's Council of Advisors on Science and Technology (PCAST) completed an extensive examination of the issues involved with spectrum efficiency and spectrum sharing. The subsequent report (PCAST 2012) presents a comprehensive set of recommendations for implementing efficiently shared spectrum and incorporates features of several approaches described previously (see Figure 1). The PCAST report proposed managing spectrum by dividing it into large blocks, called Spectrum Superhighways, allowing users with compatible services to dynamically share that spectrum on a priority basis. Users would be divided into three categories: primary, secondary, and tertiary, where primary users (such as current Federal agencies) have priority access, secondary users have some service-level rights, and tertiary users have opportunistic general access. The report addresses incentivizing Federal agencies with a synthetic spectrum currency that is used to "pay" for spectrum and a Federal Spectrum Efficiency Fund to cover costs of research, planning, and implementation. The report identifies a candidate 1000 megahertz of frequency that could be formed into spectrum an initial Spectrum Superhighway.

a. Problems Addressed

The primary motivation for the report was recognition of an exponential increase in demand for spectrum by both Federal agencies and non-government entities that cannot be satisfied by clearing alone, which, at best, yields a linear increase in capacity. According to the report, the current scheme of partitioning spectrum into separate smaller bands for exclusive use is inefficient, causes fragmentation into ever smaller bands, and results in underutilized spectrum and excessive use of guard bands. A key tenet of the PCAST report is that spectrum scarcity can be overcome by efficiently sharing spectrum

that is often idle or lightly utilized. The major incentives for Federal agencies to adopt the Spectrum Superhighways concept are operational in nature; the superhighways would allow agencies to continue to use current spectrum allocations, while providing the possibility of their using additional spectrum (including spectrum currently licensed for commercial use) on a shared basis.

PCAST also recognized that the Federal agencies are not incentivized to invest in any spectral efficiency savings: "Under the current 'command and control' system, Federal users obtain no reward for reducing their own need for spectrum, for sharing spectrum with other agencies, or for sharing spectrum use rights with non-Federal users even when such sharing would be socially optimal" (PCAST 2012, 55). The report recommends an economic incentive to an agency in the form of a synthetic spectrum currency that can provide incentives similar to a market-based approach. The report also addresses several other issues that will further the acceptance of the Spectrum Superhighways approach by Federal agencies including. These issues include:

- Generation of continuous funds for the U.S. Treasury and Spectrum Superhighway investment through short-term leases
- Investing in research and development and large-scale testbeds (with available frequencies) to mature the emerging spectrum sharing technologies (e.g., cognitive, multi-band radios, small cell underlay networks, dynamic spectrum access, spectrum sensing) to develop agency trust in these technologies, encourage commercial product development, and establish a stable market
- Seeking international harmonization of the Spectrum Superhighways approach, to permit overseas and border operations, and to stimulate a global market

b. Key Features:

The key features of the PCAST report are described here with emphasis on the aspects that can be viewed as encouraging an agency to adopt the proposed Spectrum Superhighways approach.[20]

Dynamically Shared Spectrum Superhighways. The main PCAST recommendation describes a general method to increase the use of underutilized spectrum through reorganizing that spectrum into Spectrum Superhighways (e.g., a 1000-megahertz-wide band), which would be dynamically shared between Federal and non-Federal users. Dynamic spectrum sharing methods would replace the current pre-allocations of fixed bands as the normal mode of operation for spectrum users. Underutilized spectrum would be made available for sharing to the greatest degree possible. All Federal agencies would be required to cooperate in the implementation of the spectrum-sharing system, and more importantly, Federal agencies would have the potential to increase their spectrum use through use of other Federal or commercial bands shared within the Spectrum Superhighways.

[20] Unless otherwise noted, information in this section is drawn from the PCAST report (PCAST 2012).

The PCAST approach relies on a flexible-access scheme organized as three tiers:[21]

- Federal Primary Users have the highest priority and protection from harmful interference.
- Secondary Users are able to use the spectrum when not in use by Primary Users and are given some quality-of-service protections.
- General Authorized Access (GAA) Users are given opportunistic access to spectrum that is not in use by either Primary or Secondary Users.

The PCAST report proposes the use of a wider range of licensing options.[22] Secondary Users could be charged a fee for use with long,-, medium,-, or short-term lease arrangements.[23] GAA Users would not be charged a use fee, but could be required to register and pay a device certification fee. They would operate with technology similar to that successfully demonstrated in the unlicensed bands. The rules for GAA devices would also require that they be frequency agile to prevent obsolescence should the bands be reorganized among the primary and secondary users. Medium-term and short-term leases to Secondary Users would provide both a continuous stream of revenue to the U.S. Treasury (with a portion going to sustain the SEF) and some assurance to a Federal agency that it is possible to regain use of the spectrum it has shared once the lease expires.

Spectrum Currency and the Spectrum Efficiency Fund (SEF). The main economic incentive proposed in the PCAST approach is the use of Spectrum Currency combined with a Spectrum Efficiency Fund. Spectrum Currency would act as money to pay for a spectrum use fee whose purpose is "to provide an initial economic score and then incentives to Federal agencies to be efficient in their spectrum allocation use including reducing their own need for spectrum, by sharing spectrum with other agencies and non-government users" (PCAST 2012, xv). The use of synthetic currency is proposed as a method to assign an economic value (the opportunity cost) to the Federal use of spectrum that avoids some of the issues involved with actual spectrum use fees such as being tied to annual budget funds and the annual funding cycle.[24]

A key aspect of Spectrum Currency is that an agency is allowed to realize benefits from sharing or vacating any of its assigned spectrum and thereby reduce its spectrum fee. An agency could thus use any excess Spectrum Currency to buy additional spectrum usage rights or to exchange Spectrum Currency for actual funds to improve its systems through the SEF.

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[21] For a general discussion of flexible access rights, see Section 3.A.5.

[22] For a taxonomy of licensing schemes, see Section 3.A.5.b.

[23] For further discussion of secondary markets, see Section 3.A.4.

[24] For further information on spectrum use fees, see Section 3.A.1.

Spectrum Currency would achieve the following:

- Establish a baseline for the relative amount of spectrum use and the value of that use for all agencies
- Provide a longer horizon than the annual budget cycle to properly plan for the adoption of sharing or other efficiencies with all the stakeholders
- Encourage agencies to upgrade systems to support sharing and to move their systems to the new sharing architecture
- Apply new metrics for spectrum effectiveness to advance efficiency and sharing goals and tie these metrics to spectrum fee adjustments

The Spectrum Currency system would be administered by the Office of Management and Budget (OMB) and can be viewed as an extension of OMB's current spectrum accounting efforts as specified in the MCTRA (2012). Each agency would be given an initial allocation of the synthetic currency to "buy" spectrum usage rights and to pay for costs related to making systems operate in the shared environment. OMB would provide the initial valuations of an agency's spectrum use through comparison with similar commercial market prices. Once established, the Spectrum Currency system could be used by OMB to drive improvements in efficiency and increase sharing through the annual allotments of Spectrum Currency.

Coupled with the Spectrum Currency concept is a proposed Spectrum Efficiency Fund (SEF) that would provide a sustainable funding mechanism to incentivize Federal spectrum sharing.[25] The SEF would be used to convert excess Spectrum Currency into funds outside the normal budget process that could be used in further improving spectrum efficiency. Agencies could trade Spectrum Currency for funds to help them evolve their systems that would, in turn, lower their future Spectrum Currency requirements. Also, Spectrum Currency could be held across budget years to facilitate longer term planning, negotiations, and implementations. The SEF would be administered by OMB, would be self-financing and budget neutral and would be replenished from a number of sources, such as from short-term leases by Secondary Users.

Other Key Features. In addition to the above, there are several other key features of the PCAST Spectrum Superhighways approach:

- *Spectrum Access System (SAS) Database*. The Shared Superhighway architecture relies on the creation of a Federal SAS that contains the registration information and conditions of use that will apply to all users. The SAS would be used to control access to the shared spectrum superhighways.[26]
- *Transmitter and Receiver Regulation*. For each shareable spectrum band, the PCAST report recommends that strict controls on both receiver performance and

[25] For more details on the Spectrum Efficiency Fund, see Section 3.A.2.

[26] We note that similar database systems are required for the Spectrum Property Rights (3.A.3), Dynamic Federal Secondary Markets (3.A.4), and Flexible Access Rights (3.A.5) approaches.

transmitter emissions be established to make it easier to both certify compliance of new devices and deal with interference issues.[27]

- *Test City and Mobile Test Service*. The PCAST report calls for support for the development and testing of the technologies and policies needed to realize dynamic spectrum sharing. Federal users will not be comfortable with dynamic sharing until there is convincing data and field trial results that demonstrate that their systems can still operate safely in this environment without experiencing harmful interference. A Test City is proposed that can test the technologies in a large-scale setting.
- *Policy and Governance*. The PCAST report proposes that a new, high-level Federal Spectrum Management Team be established to guide the implementation of the Spectrum Superhighways.28 Further, it recommends that a Public-Private Partnership composed of government, industry, and academia be established that can ensure that the shared spectrum approach will meet industry needs.

Ongoing Efforts. The PCAST report suggests that there be an immediate extension of the TV White Space concept to include general authorized access to the 3550−3650 MHz (radar) band. This band is of less interest to the cellular providers and could be a good testing band for sharing technologies. A recent FCC Notice of Proposed Rulemaking proposed implementing the PCAST approach through the creation of a Citizens Broadband Service that includes use of small cells and spectrum sharing with three tiers of users (FCC 2012).

Summary. The risks of potential interference with Federal agency missions are clear, but the benefits may not be as obvious. The benefits, which can serve as operational incentives for agencies to participate in the PCAST approach, are (1) increased access to shared spectrum for additional capacity; (2) ability to remain in their current allocation; (3) acquiring new, robust, efficient systems and technologies; and (4) funding to cover long-term commitments to adopting sharing. There are also potentially large national economic benefits from stimulating the development of spectrum-sharing technologies to address the capacity demands of the commercial market and generating revenue through spectrum leasing.

c. Challenges and Issues

PCAST-Identified Issues. The PCAST report identifies several areas that present challenges to adoption of the Spectrum Superhighways concept. The dynamic sharing of spectrum superhighways will require extensive efforts to establish trust in the technology, demonstrate that Federal operations will not be compromised, and ensure that agencies will not be coerced before they are ready. The development of interference limits, receiver regulations, overhauling the Federal frequency assignment process, and

[27] See Section 3.A.3 for a discussion of receiver performance standards.

[28] Note that a Spectrum Policy Team (SPT), similar to the management team proposed by PCAST, was established in 2013 in accordance with a recommendation in the Presidential Memorandum of 2013.

developing enforcement mechanisms are all difficult and must be phased in slowly over time to not cause disruptions to agencies' missions. The process could take many years.

A critical unknown is what will be the market demand for short- and medium-term leases for shared spectrum. Although some evidence points to the probability of commercial interest in short-term leases of shared spectrum (e.g., expected demand for machine-to-machine communications), there is no reliable data as yet. Also, the transaction times must be reasonable and the costs of administering the system must be economically viable to support such a market. These methods will need to be well tested before any large-scale rollout by commercial interests is initiated.

Issues with Spectrum Currency and the Spectrum Efficiency Fund. Several concerns are associated with the PCAST-proposed Spectrum Currency and SEF approach. A major concern is whether the OMB will be able to enlist the necessary expertise to properly value the Federal spectrum and assess the costs and benefits of sharing efforts. Rosston (2012) observes that market pricing is the best way to determine the proper amount of sharing that should be targeted, an aspect not directly covered by Spectrum Currency. There are also concerns with the establishment and operation of the SEF, including developing criteria for use of funds and the method of allocation of funds.[29]

A recent position paper by Beard and others of the Phoenix Center for Advanced Legal and Economic Policy Studies expressed concerns on the long-term effectiveness of the Spectrum Currency approach, which is characterized as a "ghost market" approach involving artificial currency and off-budget funding (Beard et al. 2013). They question whether Congress would allow an agency to have uncontrolled use of any real funds that are obtained through cashing in Spectrum Currency. They also interpret the Spectrum Currency as being used for intra-government exchange of spectrum, rather than for exchange with the commercial industry and that this would not allow market pricing to have the intended effect. Beard et al. (2013) claim that the real problem is that the government is not an efficient manager of spectrum and that scarcity problems are due to government control of the spectrum allocation process. In their view, the government should control only the minimum amount of spectrum required to accomplish its missions (the public good), and that all other spectrum should be auctioned to the private sector. The government would then purchase spectrum use in the same way it purchases other resources. The authors also claim that leasing of spectrum is not as economically beneficial as auctioning of permanent exclusive rights.

Issues with Spectrum Superhighways. Although there is general agreement that spectrum sharing will become increasingly important over time (GAO 2012; Goldfarb 2013), there is concern over the feasibility of the Spectrum Superhighways approach (Rysavy 2012). A recent GAO report states: "Moreover, some experts and industry stakeholders suggest that sharing 1,000 megahertz of Federal spectrum may be no easier

[29] For more information on issues related to the SEF and other generalizations of the SRF, see 3.A.2.

or less costly than previous efforts to vacate half that amount, given the barriers to sharing that exist" (GAO 2012, 26).

The large cellular providers also recognize that spectrum sharing is becoming more popular but have concerns with the PCAST approach in three broad areas: investment, technology, and spectrum efficiency (Parker 2012). The providers feel that priority should be placed on clearing spectrum, as is being done in other countries (e.g., Germany, UK, France, and Spain), where "hundreds of megahertz of spectrum that is clear" have been found (Goldstein 2012). In addition, the providers claim that "a shared access system with limited licensing rights, no renewal expectancies and the prospect of service pre-emption by the primary government user creates a challenging environment for the commitment of investment dollars" (Parker 2012).

d. Conclusion

The PCAST report lays out a comprehensive approach to sharing Federal spectrum with commercial and non-government users that could potentially reduce the spectrum scarcity problem. Federal agencies would be incentivized to participate in this approach through several means: (1) Spectrum Currency and a Spectrum Efficiency Fund to cover both long- and short-term investments; (2) potential for increased spectrum capacity within current allocations and with little threat to ongoing mission operations; (3) heavy Federal investment in research, development, test, and evaluation through a Test City to validate the sharing technologies; and (4) continuous revenue-generation streams for the U.S. Treasury through medium- and short-term spectrum leases.

B. Directed Reallocation and Sharing

1. "BRAC the Spectrum"

The "BRAC" approach to Federal spectrum management—named for the Defense Base Closure and Realignment (referred to as "BRAC") Commission's process for consolidation of military bases—was first proposed in 1996 by Senator Larry Pressler (R-SD) (Pressler 1996). It has recently resurfaced in the form of a 2011 "BRAC the Spectrum" proposal put forth by Senator Mark Kirk (R-IL) and Representative Adam Kinzinger (R-IL) (House 2011). Their proposal would create an independent nine-member Federal Spectrum Reallocation Commission (FSRC) to identify Federal spectrum to be vacated and auctioned, much like the BRAC process has been used to make politically difficult decisions about military base closings.

a. Problems Addressed

A BRAC approach would aim to overcome agency intransigence and the opposition of congressional allies through an independent process that sidesteps political obstacles in order to determine appropriate opportunities for spectrum reallocation (Eisenach 2011, 133). Key to its appeal is the approach's ability to arrive at efficient reallocation decisions through the independent analysis of the nine-member FSRC. The FSRC, with input from the Secretary of the Department of Commerce and the approval of the President, would be charged with making determinations about agency spectrum use that

agencies are either unwilling or incapable of making on their own. The process would insulate tough spectrum decisions from political pressure, which, as Skorup (2013, 25) notes, is a particular challenge in regard to the Department of Defense (DOD), and the political liability associated with constraining resources for national defense.

A second problem addressed by the "BRAC the Spectrum" approach is the lack of information about agencies' utilization and holding of spectrum. The proposal would require agencies to submit an annual Spectrum Utilization Plan as part of their budget requests, which could facilitate future spectrum allocation decisions even after the FSRC process concludes (Maximizing Spectrum Efficiency and Value Act 2012, Section 119(c)).

b. Key Features

The FSRC approach would be designed to mirror the BRAC process used to close military bases. Under that system, which was invoked on five separate occasions between 1989 and 2005, the Secretary of Defense made recommendations for base closures, which the BRAC Commission—composed of independent military experts—evaluated and revised before making its own recommendations to the President. The President then had the opportunity to review and approve or disapprove the list of closures in their entirety. If approved by the President, Congress could block the base closures only by passing a resolution disapproving the entire list (Brito 2011).

Under the proposal that Representative Kinzinger introduced to a House committee in 2012, the nine-member FSRC would be appointed by the President in consultation with the House and Senate for a one-time review and reallocation of Federal spectrum. The President would be required to ensure "robust" private sector representation membership on the FSRC, including at least one representative of the mobile telecommunications industry, and not more than one current DOD employee or contractor (Maximizing Spectrum Efficiency and Value Act 2012, Section 119(b)(3)). To make more information available about agency spectrum usage, each agency would be required to submit a Spectrum Utilization Plan to Congress each fiscal year, outlining total spectrum used, radio equipment used, the extent of the agency's use of its spectrum (including geographic information), and other pertinent information (Section 119(c)).

Kinzinger's proposal would require the Commerce Secretary to recommend Federal spectrum for reallocation. The FSRC would then evaluate these recommendations according to specific criteria. In particular, the commission would be required to seek to promote (1) use of commercial substitutes for Federal communications services, (2) efficient Federal spectrum use, (3) Federal utilization of non-spectrum options, and (4) Federal development and use of new and efficient communications technologies, while avoiding degradation of Federal services and operations or excessive Federal costs or service disruptions (Maximizing Spectrum Efficiency and Value Act 2012, Section 119(d)(2)). Like the BRAC process, the FSRC's recommendations, provided to the President along with justifications for any departures from the Secretary's recommendations, would be subject to Presidential review for approval of the changes in their entirety, with Congress able to block the implementation of the changes through a

joint resolution within 45 days (Section 119(e)(2)). Federal relocation would take place within a 5-year window and would be facilitated by the Spectrum Relocation Fund and agency-specific implementation plans, and FCC auctions of vacated spectrum would be required within 2 years of Presidential approval (Section 119(f) and (g)). If a Federal agency does not comply with its spectrum relocation plan, Congress may decrease its appropriations in the following fiscal year by up to one half of one percent (Section 119(f)(4)).

Implementation Variation—Zero Base Spectrum Allocations. An alternative proposal that would entail a one-time review of Federal spectrum allocations is that advanced by Feld and Rose to "zero base" spectrum allocations. Like zero-based budgeting, this approach would require agencies to justify their existing allocations as if they are new expenditures. Feld and Rose propose canceling existing spectrum allocations and requiring every agency to reapply, subject to approval by the Secretary of Commerce, the Assistant Secretary of NTIA, and the Federal CTO (as designee of the OMB Director). Not only would this process generate a comprehensive database of all Federal users and allocations, but it would weed out inefficient spectrum uses and set up a system for central spectrum planning through an annual agency spectrum budget process, overseen by NTIA and the CTO. Feld and Rose contend that the proposal could be carried out without legislative changes under existing administrative authority (Feld and Rose 2010b).

c. Challenges and Issues

BRAC the Spectrum. The challenges facing the BRAC approach could jeopardize its ability to arrive at efficient Federal spectrum allocations.

First, the problem of spectrum reallocation differs from military base closure in at least one significant respect. Spectrum relocation is difficult not only because of agency intransigence and political challenges, but also because making efficient decisions about which spectrum to reallocate requires sophisticated analysis and a difficult evaluation of tradeoffs. Efficient reallocation of agency spectrum would require the FSRC to calculate and compare the opportunity costs and benefits of agency spectrum use, while taking into account the costs of agency spectrum relocation. While putting these decisions in the hands of an independent commission has its advantages, doing so also raises questions about the Commission's composition and evaluation criteria. Not only does the Kinzinger proposal fail to require that the Commission include economists and spectrum experts, but its stated evaluation criteria place greater emphasis on privatizing Federal communications functions where possible than it does on defining efficient Federal use. Moreover, the proposal neglects spectrum sharing altogether, even though Federal-private spectrum sharing represents a significant opportunity for efficiency gains.

Second, as with any administrative relocation plan, information asymmetries may present a significant challenge because agencies may not fully reveal to the FSRC information about their valuation or costs of moving. The FSRC will be less adept at

finding unexploited agency spectrum consolidation opportunities, for example, than the agency might be if it were incentivized to use spectrum efficiently.

A challenge facing the FSRC approach is the potential for inflexibility in spectrum reallocation decisions. Not only would the FSRC make only one round of recommendations, but the proposal includes no provision for agencies to appeal FSRC decisions and present additional information about their valuation or costs.

Finally, the inclusion of a congressional mechanism to overturn the President's decision may be unnecessary, or even unwise. Agency, not congressional, opposition is the chief problem the FSRC approach aims to overcome, and inviting congressional involvement into an area of administrative oversight where it may otherwise be unnecessary could have unintended consequences.

Zero Base Spectrum Allocations. This approach, like the BRAC approach, involves a complex review of current spectrum allocations and requires significant input from Federal agencies. It differs from the BRAC approach in that it places review responsibility with the CTO and the NTIA, rather than with the FSRC. Feld and Rose do not discuss the process through which reallocation would occur, beyond suggesting that the CTO and the NTIA should lead the reviews, so defining the process stands as a challenge at this time.

d. Conclusion

The BRAC the Spectrum and Zero Base Spectrum Allocations approaches would each achieve a one-time reallocation of spectrum assigned to Federal agencies. However, both approaches entail potentially lengthy and arduous implementation processes, and thus may incur substantial transaction costs. Moreover, both face uncertain gains in spectrum efficiency, since there is a chance that agencies' allocations may change little. Therefore, the big question with respect to these approaches is whether the costs of the one-time reallocations can be justified. This question is especially important in light of alternative market-based approaches that can drive reallocation toward efficiency regardless of what the initial spectrum allocation may be.

2. OMB Spectrum Auditor

The OMB Spectrum Auditor approach relies on an administrative mechanism to identify opportunities for efficiency improvements in agency spectrum allocation and encourage agencies to implement them. Under the three distinct proposals considered here, OMB would use its influence in agency appropriations to steer agencies toward more efficient spectrum management. These proposals have the virtue of feasible implementation, though they may not work as effectively as an approach that incentivizes agencies.

a. Problems Addressed

The OMB Spectrum Auditor approach is designed to address the problem of inefficient agency spectrum use by requiring agencies to work with OMB to identify spectrum to be shared or vacated. As formulated by Lenard, White, and Riso, the

proposal would also tackle the problems of inadequate accountability and transparency in agency spectrum use by relying on outside analysis and reports, including an annual NTIA reporting process that tracks government spectrum inventory and associated opportunity costs (Lenard, White, and Riso 2010).

b. Key Features

Rights. The OMB Spectrum Auditor approach would not affect use or ownership rights of agency spectrum for Federal spectrum holdings not identified for clearing or sharing. The various proposals are less clear about the process by which OMB would bring about agency spectrum relinquishment, whether through removal of their use rights directly or by wielding pressure through the appropriation process to make agencies relinquish their rights.

Implementation. Far from mutually exclusive, the three OMB Spectrum Auditor proposals reviewed here are potentially complementary.

CSMAC's OMB proposal, which was included in the CSMAC Incentives Subcommittee Report (2011) and implemented by OMB in 2012, addressed spectrum use in the context of the procurement process. Specifically, the proposal outlined revisions to OMB Circular A−11 Section 33.4, "Radio spectrum-dependent communications-electronics systems,"[30] which at the time focused on consideration of spectrum costs in the agency capital planning process, but said little about spectrum efficiency, spectrum sharing, and trade-offs in spectrum use. CSMAC suggested that Circular A−11 consider these other issues by, for example, asking agencies to choose the spectrum efficient solution when choosing between procurement options that both meet operational requirements.[31] The Committee, however, did not propose that OMB take a role in auditing agency spectrum use on an ongoing basis.

Eisenach offers a proposal for OMB oversight that involves an annual review of agency spectrum holdings requiring agencies to justify their spectrum needs and pinpoint spectrum to be made available for sharing, lease, or auction. Eisenach's proposal would include the revenue from the auction of agency spectrum in the President's budget and in each congressional budget resolution, strengthening the incentives of OMB and the congressional committees to reallocate underutilized spectrum in order to promote fiscal responsibility (Eisenach 2011). It is designed to ensure that OMB takes seriously its role as an auditor.

Finally, Lenard, White, and Riso's proposal would ask OMB to draw on the research and recommendations of the National Academy of Sciences (NAS), the proposed Government Spectrum Reform Task Force (GSRTF), and the NTIA to encourage agencies to relinquish or share under-utilized spectrum. The NAS would

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[30] Due to a reorganization of OMB Circular A-11, the section on "Radio spectrum-dependent communications-electronics systems," formerly labeled 33.4 is now embodied in two separate sections: Section 31.12 and 51.18.

[31] See Section 2.E for additional details on the updates to OMB Circular A-11.

prepare a study detailing current allocation of government spectrum and opportunities for spectrum reallocation, as well as calculations of opportunity costs of Federal use. The GSRTF, composed of government officials and private-sector experts, would make recommendations for agency spectrum bands that should be relinquished. Finally, NTIA reports would keep inventory and opportunity cost information current on an annual basis, while identifying future likely sources of surplus spectrum (Lenard, White, and Riso 2010).

Under Lenard, White, and Riso's proposal, OMB would serve as a "skeptical auditor" requiring agencies to provide annual accounting of spectrum use, and be responsible for routinely searching for under-utilized spectrum that would be a good candidate for auction (Lenard, White, and Riso 2010). Like Eisenach, the authors do not detail how the OMB auditing process might work.

Implementation Variation—Spectrum Budgets. In a variant of the OMB Spectrum Auditor approach, Feld and Rose propose that agencies be required "to prepare a 'spectrum budget' in the same manner they prepare a Federal budget, assessing existing and future needs." In this variant, recommended by Feld and Rose as a follow-up to their Zero Base Spectrum Allocations proposal, the U.S. Chief Technology Officer (CTO) would serve as the designee of the OMB Director and work with NTIA in reviewing and approving agency spectrum budgets (Feld and Rose 2010b, 3). The key differences between this proposal and the others are that in this proposal (1) the CTO plays a leading role and (2) the focus is on spectrum budgets (i.e., allocations), with no discussion of tying spectrum budgets to monetary budgets.

c. Challenges and Issues

The proposals by Eisenach and Lenard, White, and Riso each face obstacles to successful implementation.

First, both proposals ask OMB to perform a role that it does not currently perform. Even though OMB is well-practiced in agency negotiations over budgetary issues, assuming the role of spectrum auditor would no doubt require significant institutional learning within OMB with regard to spectrum management. While not insurmountable, this challenge would take time to overcome.

Second, for the proposals to succeed, OMB would need to approach the role of spectrum auditor as an important part of its core mission. By ensuring that every dollar of auction revenue enters the Federal budget as revenue, Eisenach's proposal is designed to ensure that OMB is incentivized to fulfill its spectrum auditor duties in this way. Lenard, White, and Riso are quiet on the allocation of auction proceeds, though allocating revenue in this fashion is not inconsistent with their proposal. Eisenach does not address whether the costs of agency relocation should be taken from auction revenues, as the current arrangement of the Spectrum Relocation Fund allows for.

Third, as with other administrative mechanisms, information asymmetries may present a significant challenge to the proposals by Eisenach and Lenard, White, and Riso,

because agencies will be reluctant to reveal information to NAS, GSRTF, NTIA, or OMB that might lead to the identification of opportunities for vacating or sharing spectrum. Doing so is not necessarily in the agencies' interest. While Eisenach fails to address this concern, Lenard, White, and Riso's proposal may mitigate the challenge somewhat by employing multiple different avenues of data collection and analysis. These independent analyses also would calculate the opportunity costs of Federal spectrum use—a necessary step for determining efficient allocations that Eisenach neglects to address.

It is worth noting that Lenard, White, and Riso nonetheless present the OMB Spectrum Auditor approach as only an interim solution, to which a modified spectrum use fee approach is preferred in the long run. The justification for this preference is that the latter incorporates incentives for agencies to economize on their spectrum use, while the former does not (Lenard, White, and Riso 2010). Without agency incentives, efficient spectrum allocations are less likely because of the information asymmetry challenge.

Finally, the OMB Spectrum Auditor plans considered here, with the exception of the CSMAC revision of OMB Circular A−11, are lacking in implementation specifics with regard to everything from audit details (what would agencies be asked to provide?) to the calculation of NTIA's assessment of likely sources of surplus spectrum. A more definite assessment of their feasibility would require more implementation details.

The Feld and Rose Spectrum Budgets proposal, like the Eisenach proposal and the Lenard, White, and Riso proposal, lacks implementation specifics and so cannot be readily assessed. However, it is worth noting that this Feld and Rose proposal brings the CTO onboard as the OMB Director's designee for collaborating with NTIA in spectrum budget review and approval. This addresses, in part, the concerns about OMB performing a role outside the scope of its expertise and primary mission.

d. Conclusion

In spite of the challenges outlined above, the OMB Spectrum Auditor approach presents the advantage of relying primarily on existing institutional relationships to boost the efficiency of Federal spectrum use. For this reason, the proposals by Eisenach and Lenard, White, and Riso may be more immediately implementable than several of the other approaches outlined in this report, even if their lack of reliance on agency incentives could result in sub-optimal Federal spectrum allocations.

3. Administrative Relocation with Overlay License Negotiation

As formulated by Skorup, administrative relocation with overlay license negotiation involves modifying the administrative approach that was used to clear the Advanced Wireless Services-1 (AWS-1) 1710 MHz to 1755 MHz spectrum of government users and auctioning it to commercial users. Clearing AWS-1 relied on the newly created Spectrum Relocation Fund to facilitate the handoff of spectrum identified as lightly used by Federal entities and appropriate for FCC auction of overlay licenses.

While the AWS-1 approach presents agencies with administrative directives—rather than incentives—to relocate, it nonetheless offers the advantage of being a feasible option

that has been already tried with moderate success. In his discussion of overlay licenses, Skorup outlines a more incentive-laden variant on the AWS-1 approach that is the subject of this section: allowing overlay licensees to negotiate directly with agencies over the timeline of their spectrum relinquishment (Skorup 2013).

a. Problems Addressed

Administrative relocation with overlay license negotiation addresses two primary problems thwarting efficient spectrum allocation. First, administrative relocation circumvents the problem of agency reluctance to vacate underutilized spectrum through a centrally planned administrative process. Second, overlay license negotiation is designed to shorten the long timeframe that has been a challenge plaguing past Federal relocation efforts, including the AWS-1 clearance process.

b. Key Features

Rights and Benefits. Under Skorup's approach, after the initial administrative relocation decision, agencies facing spectrum relocation would see their existing exclusive use rights (or, if spectrum is shared between agencies, shared use rights) converted to primary use rights. Though not required for overlay licenses, a deadline or timeline for agency relocation would likely accompany the conversion of rights.[32]

Upon this conversion from exclusive to primary use rights, FCC would auction overlay licenses for commercial use. Overlay licenses give holders primary rights to any unused spectrum and secondary rights to spectrum that is used by an agency incumbent until the deadline arrives for the incumbent agencies to vacate the spectrum bands (Skorup 2013).

The benefits of overlay licenses would be twofold. First, rather than waiting for agencies to vacate completely, auction winners could immediately gain secondary rights to their spectrum, with attendant economic benefits. Nonetheless, Skorup points out that overlay licenses fetch less at auction than corresponding exclusive use licenses for the same bands (Skorup 2013). While this is certainly true, overlay licenses would also net a sum at least as large as the discounted present value of an exclusive license starting at the future deadline for agency relinquishment, because an overlay license holder gains additional, albeit encumbered, use between the present and the future deadline.

Second, Skorup points to a significant benefit of overlay licenses: overlay holders gain the right to negotiate with incumbent spectrum holders to compensate them to move before the deadline (if such deadline exists), or to otherwise engage in a voluntary spectrum transfer. Negotiation was first deployed when overlay licenses were used for Personal Communications Service PCS auctions in 1995, but to date, negotiation has not been implemented when government agencies are the incumbent holders. The justification supporting negotiation is that the potential economic gains from transacting

[32] Without a deadline, the approach more closely resembles agency property rights, as agencies would be free to negotiate the lease or sale of their spectrum on their own terms, though they would possess only primary, not exclusive, use rights.

for an earlier vacancy are enormous because the spectrum is far more valuable to the overlay license holder than the incumbent (Hazlett 2011). Among private actors, the two parties will find an efficient solution, with the overlay license holder only compensating the incumbent for relocation if the gains to the licensee from relocation exceed the incumbent's moving costs.

Implementation. While Skorup's proposal does not include implementation specifics, he does point to the AWS-1 relocation, begun in 2006, as a prior example of using overlay licenses in conjunction with a plan to relocate Federal spectrum users. That plan involved congressional action, in the form of the Commercial Spectrum Enhancement Act of 2004 (CSEA), which facilitated NTIA relocation of Federal spectrum users in the AWS-1 band, and created the Spectrum Relocation Fund to facilitate the process by reimbursing agencies with auction proceeds for their relocation expenses (47 U.S.C §§ 151, 301, 302, 303). The CSEA required annual NTIA progress reports on agency relocation efforts and NTIA/FCC coordination, so that holders of overlay licenses, won at auctions in 2006 and 2008, could be notified when agencies vacated the spectrum to which they held secondary rights (NTIA 2013).

Missing from the AWS-1 example is the opportunity for the overlay license holder to negotiate voluntary incumbent relocation—a central justification for using overlay licenses in past settings involving commercial incumbents. While the Spectrum Relocation Fund would seemingly make negotiation unnecessary, Skorup does not articulate how the negotiation process he proposes might be implemented in the agency context.

c. Challenges and Issues

The proposed approach faces several significant challenges.

First, in any negotiation between multiple parties, strategic behavior may cause holdout problems: one or more incumbent parties on a given band may refuse to move until the offering price rises. But because the marginal benefit to the overlay license holder from attaining unanimous rather than near-unanimous relocation is small, the holdout problem is likely to be unimportant in the overlay license setting (Hazlett 2011). Skorup believes that the same would hold true even when agencies are the incumbent spectrum users, resulting in successful negotiations (Skorup 2013). But there is at least reason to suspect that the standard critiques of overlay licenses—including the high transaction costs of piecemeal negotiations and other bargaining problems—might apply especially when one party is a Federal agency acting under the constraints of Federal administrative law.[33]

A more formidable challenge is that administrative relocation of Federal spectrum users can be extremely slow and cumbersome, as was the case for AWS-1 (NTIA 2013). Skorup acknowledges that "relocation was not carried out perfectly," but even 4 years after the initial auctions, the winning bidders for the AWS-1 spectrum were unable to

[33] For a critique of FCC overlay licenses, see FCC (2010, 82).

make full use of the spectrum they had bought because agencies had not been totally cleared (Skorup 2013, 22, footnote 92; Eisenach 2011, 115). The clearing effort appears to have eventually been completed within 6 years of commencement (NTIA 2013). The long and unpredictable nature of the administrative relocation process presents a significant planning and investment challenge for a commercial purchaser of an overlay license, making an overlay license for Federal spectrum significantly less valuable.

Would overlay license negotiation accelerate the relocation process? Answering the question would first require a determination of how much faster agency relocations might feasibly be achieved. Agency relocation is cumbersome and slow in part because of technological challenges inherent in maintaining nearly uninterrupted government services that rely on spectrum.

Even if technological challenges were not a significant timing barrier, agency negotiation with overlay license holders might not necessarily be practical or result in a more efficient relocation process. It is not clear that agencies could accept payments in exchange for their (interim) spectrum rights, nor how such payments might be allocated to the agency in the context of the budget appropriation process (i.e., would the fees simply be offset by a decrease in budget appropriations?). Agencies are not profit-maximizing entities, so even if negotiation was made feasible, it is not clear how they would respond to financial incentives for speedy relocation. There is also the problem of protecting an agency from undue pressure to speed up clearing from aggressive commercial purchasers.

d. Conclusion

The administrative relocation and overlay license approach is a "status quo" approach in the sense that it has been used before and could again work to liberate agency spectrum. While overlay licenses may give commercial users useful secondary rights during Federal efforts to clear the auction spectrum bands, the AWS-1 experience suggests that the biggest challenge confronting this approach is the slow pace of administrative relocation. Unfortunately, given the implementation challenges, Skorup's proposal to use negotiation between license holders and agencies to address this problem may not be equal to the challenge. Instead, the approach might yield long-term sharing if relocation is excessively delayed or never fully accomplished. Given that possibility, administration relocation with overlay license negotiation seems to fit within the continuum between immediate agency relinquishment and a Federal spectrum sharing arrangement with tiered licenses.

C. Beyond Sharing and Relinquishment: Guiding Economic Principles for Spectrum Reallocation

The rationale behind the various proposals to encourage Federal agencies to economize on spectrum usage is that spectrum is a scarce and highly valuable resource, and that it is important it be put to its most socially valuable use. In some cases, achieving an economically efficient allocation of spectrum will require that it simply be

shifted from government uses to private commercial use, with agencies relocating out of some spectrum bands entirely. In other cases, it will involve agencies and private commercial users sharing spectrum with each other, and many ideas have been suggested about how this could be accomplished. When spectrum is to be shared, economic efficiency requires that those rights that are, under a spectrum sharing arrangement, reserved for private users be allocated to the users who can put those rights to their most valuable private use. While this is not the primary subject of this report, it is important enough to merit a brief discussion here.

Traditionally, when Federal agencies have made spectrum available for private commercial use, they have done so by vacating particular spectrum bands, licenses for which were then auctioned by the FCC. The rationale for allocation via auction was that the highest bidder for the spectrum would be the one that could put it to the most privately profitable use, which would in turn likely be close to the most socially valuable use. This arrangement also generates government revenue, meaning that the proceeds from the sale of this public natural resource can be used for public purposes.

This same principle applies in the context of spectrum sharing as well. Except for the rare special case where all non-government use of a particular spectrum band were to be allocated on an unlicensed basis, the private entity that receives rights under a spectrum sharing arrangement will possess a scarce and valuable resource. It is important for that resource to be allocated efficiently, and this will usually mean allocating it to the private user willing to pay the most for it. That is, any spectrum sharing arrangement will require some sort of mechanism to play the role that traditional FCC spectrum license auctions have played and continue to play.

Some ideas for allocating partial rights under spectrum sharing arrangements have been proposed in the works reviewed in this report. Another possibility is a traditional FCC auction of licenses for pre-defined packages of partial rights. There are surely others. The precise modality for allocating packages of partial rights under a spectrum sharing arrangement is beyond the scope of this report. Here we merely wish to emphasize that in all of the discussion of how spectrum will be shared between the government and private entities, and of how to ensure successful participation in these arrangements by Federal agencies, we must not lose sight of the fact that any such arrangement must also take heed of the requirement that the private rights be allocated in ways that are economically efficient and (secondarily) that generate government revenue.

4. Summary of Approaches

The previous chapter described nine approaches identified from the recent literature for improving spectrum efficiency of government-allocated spectrum. The approaches are categorized as either market based or government directed, and they give agencies different degrees of decision-making power. Table 2 provides a summary of the salient features of each approach to facilitate comparison. The columns included in the table are as follows:

- *Approach*: title of the approach and the key references
- *Problem(s) Addressed*: major issues or barriers to be solved
- *Key Idea*: method and goals of approach
- *Spectrum Rights Summary*: spectrum rights of an agency in terms of access, flexible use, and ownership
- *Role of Central Authority*: main responsibilities of the Federal regulators
- *Legal/Regulatory Issues*: main legal or regulatory authorities required
- *Primary Challenges*: impediments to realizing this approach
- *Relationships to Other Approaches*: similarities and dependencies among the approaches
- *Primary Agency Incentives*: main incentives for an agency to increase spectrum efficiency, relinquish spectrum, or adopt sharing
- *Benefits to the Government:*[34] specific benefits to the Federal Government associated with the particular approach

Although the approaches represent diverse incentives for achieving their objectives, several broad themes frequently emerge:

- *Revenue Generation*. The increased emphasis on spectrum sharing is intended to result in a package of spectrum rights that can be leased or auctioned to prospective bidders, such as for Secondary Access users. The value of shared spectrum may initially be less than that of exclusive rights; however, there is still potential for revenue generation. In some cases, the spectrum may be shared with unlicensed users, but that can be viewed as the exception to the norm.
- *Reimbursement Funds*. In order to initiate and sustain agency efforts to improve spectrum efficiency by relocating, relinquishing, or sharing spectrum, a funding mechanism is needed that will cover two objectives: (1) funds could be made

[34] All of the identified approaches seek to increase spectrum efficiency, make more spectrum available for commercial uses, and improve the national economy. These common benefits are not specifically called out in the table.

available to cover any and all costs involved with enhancing, relinquishing, or sharing an agency's spectrum allocation, whether or not that spectrum has been previously identified for auction or lease, and (2) agencies could continue to realize benefits from past spectrum enhancements beyond their initial action to sustain continual improvements and discourage hoarding.

- *Legal/Regulatory Modifications*. The current legal and regulatory environment is often an inhibitor to adopting new approaches. The Miscellaneous Receipts Act, for example, effectively prevents agencies from directly benefiting from any economic returns on their spectrum changes. The ability of agencies to negotiate with potential commercial users is also limited by regulations that are restrictive and time consuming. Modifications to the rules that would streamline adoption of additional property rights and more flexible access, such as short-term leases for Secondary Access users, have been suggested.
- *Governance and Enforcement*. All the methods will rely on cooperation from agencies and commercial users to be successful. Agencies need to provide accurate data on their spectrum use and requirements. Better spectrum efficiency definitions and metrics that can be applied to communications and other applications could be developed to guide evaluation and gauge progress. Rules for interference levels and methods of enforcement are a concern in most approaches, particularly as the frequency bands become more crowded.
- *Trust in Technologies*. The trend toward increased sharing is partly based on employing new technologies that have not been validated in the real environment or the market. Commercial providers have not enthusiastically adopted spectrum sharing as a viable approach, partly because there is no spectrum available for this purpose. Several approaches identify the need for government to foster R&D and to make spectrum available for sharing with a real expectation of making sufficient spectrum available.
- *Balance between Relinquishment and Sharing*. The strong preference of the commercial sector is for exclusive access to spectrum bands and for agencies to relocate out of those bands. However, this approach may not be sustainable in the long run, because demands by both commercial and Federal users are growing exponentially faster than spectrum can be cleared. Two-way sharing has potential in that Federal agencies could acquire shared access to commercial spectrum, thereby gaining additional capacity. The identified approaches are divided between emphasis on relinquishment, reallocation, or sharing, with few supporting all three objectives. It is likely that an evolutionary path that starts with the existing regulatory innovation fund framework and encompasses more sharing over time will be adopted.

Table 2. Summary of Approaches for Sharing or Relinquishing Agency-Assigned Spectrum (additional columns on next page)

Approach	Problem(s) Addressed	Key Idea	Spectrum Rights Summary	Role of Central Authority
Spectrum Use Fees "GSA for Spectrum" (Lenard, White, and Riso 2010) NTIA-Administered Fees (FCC 2010)	Agencies do not bear opportunity costs of inefficient use	Incentivize efficiency and relinquishment by charging agencies spectrum use fees	• Exclusive (or primary) access rights • Flexible use not addressed • No change in ownership rights	Either GSOC (Lenard) or NTIA (FCC) "owns" spectrum and manages fees
Generalized Spectrum Relocation Fund (CSMAC 2011; PCAST 2012)	Cost of innovations aimed at efficiency and sharing are not in budget	Provide funds to agencies for efficiency, sharing, and relinquishment	Spectrum rights not addressed	NTIA manages Innovation Fund, OMB manages Efficiency and Incentive Funds
Spectrum Property Rights Licensed Electrospace Regions (LERs) (Matheson and Morris 2011, 2012)	Unclear way forward for flexible use due to lack of technical foundation for spectrum property rights	Grant agencies spectrum ownership and flexible use, thus incentivizing efficient use	• Access is by licenses based on LERs • Flexible use: Simplify interference rules • Ownership rights granted: LERs can be aggregated, subdivided, bought, sold, leased	Partition spectrum into LERs, devolve LER rights to licensees, manage public database of rights, enforce, mediate
Dynamic Federal Spectrum Secondary Markets (Feld and Rose 2010a)	Non- and anti-competitive auction practices (e.g., hoarding by largest companies, inability of small companies to compete)	Allow shared access to Federal spectrum by short-term leases via real-time auctions	• Prioritized access rights (Federal or commercial) • Flexible use permitted • No change in ownership rights	Manage sharing (similar to TV Whitespace) and maintain spectrum access system (SAS) database
Flexible Access Rights (Cave and Webb 2011; Rosston 2013; PCAST 2012; Berg et al. 2013)	Current licensing schemes are barriers to innovative sharing and efficient use of spectrum	Implement flexible licensing regimes and prioritized access for shared use	• Access by flexible licensing regimes • Flexible use • No change in ownership rights	Defining regulatory framework, granting of licenses
Shared-Use Spectrum Superhighways with Federal sharing incentivized by **Spectrum Currency/Spectrum Efficiency Fund (SEF)** (PCAST 2012)	• Inability of relocation to meet commercial demands • Challenges of vacating spectrum • Agencies do not bear opportunity cost of inefficient use	• Target 1000 megahertz of Federal spectrum for prioritized shared use • Incentivize sharing investment via Spectrum Currency and SEF	• Prioritized access rights (Federal Primary, Secondary, General Authorized Access) • Flexible use (transmitter and receiver technical standards to address harmful interference) • No change in ownership rights	• Identify Federal spectrum for shared use • Establish standards • OMB manages Spectrum Currency and SEF • Maintain SAS database
BRAC the Spectrum (Kirk and Kinzinger 2011; Skorup 2013) **Zero Base Spectrum Allocations** (Feld and Rose 2010b)	Agency intransigence, political stalemate, lack of transparency and accountability	Mandate broad-based reallocation leading to relinquishment	Regulators retain spectrum rights in the Federal Spectrum Reallocation Commission (FSRC)	FSRC evaluates Federal spectrum use and proposes reallocation plan
OMB Spectrum Auditor (Lenard, White, and Riso 2010)	Lack of budgetary pressure to improve efficiency	Use budget authority to achieve broad-based reallocation	Spectrum rights controlled by OMB and regulators	OMB has authority over allocations, and NTIA has advisory role in audits.
Administrative Relocation with Overlay License Negotiation (Skorup 2013)	Lengthy, costly, and unpredictable relocation process	Facilitate case-specific relocation (overlay is temporary)	Spectrum rights controlled by regulators	Regulators have final approval of process

Table 2. Summary of Approaches for Sharing or Relinquishing Agency-Assigned Spectrum (continued from previous page)

Approach	Legal/Regulatory Issues	Primary Challenges	Relationships to Other Approaches	Primary Agency Incentives	Benefits to the Government
Spectrum Use Fees	Authority to impose use fees, establishment of GSOC	• Determining value of spectrum, phasing in costs • Succeeding in context of appropriation process	Final step in Lenard, White, and Riso's approach, following OMB as Spectrum Auditor	• *Economic*: cost, i.e., reduced spectrum use reduces fees	Revenue from resulting auctions
Generalized Spectrum Relocation Fund	Authority to expand scope of Spectrum Relocation Fund	Methods of distributing funds, maintaining self-supporting status	Component of PCAST Superhighways approach	• *Economic*: funding for efficiency, relocation, or RDT&E	Incentivizes agencies to relinquish or share spectrum
Spectrum Property Rights	Establishment of property rights, including mechanism for agencies to accrue benefits from sale/lease of spectrum	• Initial partitioning into LERs • Setting thresholds for power levels • Enforcement	Technical foundation for defining units of spectrum sharing in all the sharing-focused approaches	• *Operational*: flexible use • Economic: funds from selling, leasing, or sharing spectrum	Upon transfer of spectrum ownership to agencies, spectrum allocation is left to market forces
Dynamic Federal Spectrum Secondary Markets	• Proposed regulations need finalization • Units of spectrum allocation to be defined	• Unproven technology • Market-based interference resolution untried • Real-time auctions unproven	• Similar to PCAST tiered scheme and short-term leases	• *Operational*: continued access to assigned spectrum, prioritized sharing	Revenue from leases
Flexible Access Rights	Defining flexible licensed/ unlicensed regimes beyond exclusive access (priority, sharing open-licensed)	Agreement on interference conditions, enforcement	Component of PCAST Superhighways approach	• *Operational*: continued access, prioritized sharing, access to additional spectrum	• Revenue from secondary users • Accommodates unlicensed users
Shared-Use Spectrum Superhighways/ Spectrum Currency/ Spectrum Efficiency Fund	• Authority to share spectrum • Authority for Spectrum Currency • Authority to impose secondary use fees and to certify tertiary use	• Unproven technology • Receiver standards • Spectrum valuation	Builds on aspects of other approaches: use fees, efficiency fund, generalized access rights, property rights, dynamic secondary markets	• *Operational*: continued access, prioritized sharing, access to additional spectrum • *Economic*: SEF funding	• Revenue from secondary users • Accommodates unlicensed users
BRAC the Spectrum Zero Base Spectrum Allocations	Establishment of FSRC to make binding recommendations	• Potential for using skewed metrics to "game the system" • Sufficient expertise in decision making	Transition via overlay licenses and sustainment via use fees	• *Legal/regulatory*: compliance	• Revenue from resulting auctions • Visibility into agency holdings
OMB Spectrum Auditor	Establish OMB and NTIA roles	Gaining expertise, developing audit metrics, and educating agencies	Intermediate step in Lenard, White, and Riso's approach, following: (1) NAS study and (2) GSRTF recommendations. Ultimate step is use fees	• *Legal/regulatory*: compliance	• Revenue from resulting auctions or leasing • Visibility into agency holdings
Administrative Relocation with Overlay License Negotiation	Allowed under current regulations	Maintaining schedules, given complexities of relocation	Possible implementation method for BRAC the Spectrum or OMB Spectrum Auditor	• *Legal/regulatory*: compliance • *Operational*: Negotiated relocation process	Revenue from auctions

- *Maintaining the Agency Mission*. The requirement to not harm the conduct of the mission of an agency is the underlying constraint on all of the approaches. This constraint has many facets that the approaches often do not explicitly consider. For example, operations in international areas, accommodating evolving technologies (e.g., new radars), or need for increased spectrum capacity can present challenges. None of the approaches describe how a satisfactory reallocation or sharing mechanism can be assured in every case, in a reasonable time, and at reasonable cost.

The nine approaches described in this paper represent a variety of paths to satisfying the increasing demands for spectrum capacity from both government and commercial users. No single approach is likely to be the final answer. There are many possible combinations, modifications, and offshoots of these approaches that may be used to best adapt to the evolving economic, political, and technological environment.

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Abbreviations

AIP	Administrative Incentive Pricing
AJA	American Jobs Act
ComReg	Commission for Communications Regulation (Ireland)
CSEA	Commercial Spectrum Enhancement Act of 2004
CSMAC	Commerce Spectrum Management Advisory Committee
CTO	Chief Technology Officer
DACA	Digital Age Communications Act
DOD	Department of Defense
FCC	Federal Communications Commission
FSRC	Federal Spectrum Reallocation Commission
FSS	Fixed Satellite Service
GAA	General Authorized Access
GAO	Government Accountability Office
GHz	gigahertz
GSA	General Services Administration
GSOC	Government Spectrum Ownership Commission
IDA	Institute for Defense Analyses
LER	licensed electrospace region
MCTRA	Middle Class Tax Relief and Job Creation Act of 2012
MHz	megahertz
NAS	National Academy of Science
NPRM	Notice of Proposed Rulemaking
NTIA	National Telecommunications and Information Agency
Ofcom	Office of Communications (UK)
OMB	Office of Management and Budget
PCAST	President's Council of Advisors on Science and Technology
R&D	research and development
SEF	Spectrum Efficiency Fund
SIF	Spectrum Innovation Fund
STPI	Science and Technology Policy Institute
SPT	Spectrum Policy Team
SRF	Spectrum Relocation Fund
SURs	Spectrum Usage Rights
UK	United Kingdom
UWB	ultra-wideband
WIN	Wireless Innovation

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14. ABSTRACT

The Presidential Memorandum of June 14, 2013, "Expanding America's Leadership in Wireless Innovation," called for continued efforts to make more spectrum available for commercial use. It established a Spectrum Policy Team (SPT) and directed the SPT to publish a report on "market-based or other approaches that could give agencies greater incentive to share or relinquish spectrum, while protecting the mission capabilities of existing and future systems that rely on spectrum use." This paper, prepared in support of the SPT's efforts, reviews the regulatory framework governing spectrum allocation and describes nine approaches for incentivizing agencies to share or relinquish spectrum. Six of the approaches are market-based approaches, which leave considerable decision-making authority with the agency, but attempt to influence the decision to share or relinquish in a variety of ways. The other three approaches—referred to as directed reallocation and sharing approaches—rely on a central authority to make decisions. No single approach is likely to be the final answer. Many possible combinations, modifications, and offshoots of these approaches could be used to best adapt to the evolving economic, political, and technological environment.

15. SUBJECT TERMS

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