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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. It builds upon an earlier Presidential Memorandum, "Unleashing the Wireless Broadband Revolution," issued in 2010, which established the goal of re-purposing 500 megahertz of spectrum from existing Federal and non-Federal uses to wireless broadband use within 10 years.

In recognition of recent technological progress, the 2013 Presidential Memorandum advocates spectrum sharing as an important means of making more spectrum available. In doing so, it sustains the momentum of the 2012 President's Council of Advisers on Science and Technology (PCAST)[1] report, Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth, which made a case for advanced spectrum sharing and called for identifying 1,000 megahertz of Federal spectrum to be dedicated to pilot projects.

The first action specified in the 2013 Presidential Memorandum was the establishment of a Spectrum Policy Team, co-chaired by the U.S. Chief Technology Officer and the Director of the National Economic Council (or their designees) and including representatives from the Office of Management and Budget, the National Security Staff, and the Council of Economic Advisors. The Spectrum Policy Team is working with the National Telecommunications and Information Administration (NTIA) to implement the remaining actions called for in the memorandum.

Background

In the United States, the Federal Communications Commission (FCC) and the NTIA are responsible for managing the radio spectrum—that portion of the electromagnetic spectrum at frequencies between 3 kilohertz (kHz) and 300 gigahertz (GHz). The FCC and NTIA manage non-Federal (industry, state and local governments, and others) and Federal use of spectrum, respectively. The radio spectrum is divided into frequency bands

[1] PCAST is "an advisory group of the nation's leading scientists and engineers who directly advise the President and the Executive Office of the President" (PCAST web page). PCAST is co-chaired by the President's Science Advisor, who also serves as the Director of the White House Office of Science and Technology Policy, and a non-Federal member of the Council.

of varying sizes with each band allocated to one or more general classes of "radio services" (e.g., broadcasting, fixed, mobile, radiolocation, aeronautical radionavigation).[2]

Within this framework of frequency allocations, the FCC and NTIA authorize their constituents' use of frequencies at specified locations—the FCC generally through licenses and NTIA through frequency assignments for this purpose. The FCC dedicates bands of spectrum to specific services and technologies (e.g., amplitude modulated (AM) radio channels, very high frequency (VHF) television channels, advanced wireless services (AWS)). In general, the FCC partitions these bands along spectral, geographic, and temporal boundaries and grants licenses to commercial entities (e.g., radio stations, television stations, cellular carriers) for the exclusive use of the resulting coarse-grained partitions. Since 1993, many licenses have been granted through auctions. The FCC permits unlicensed users of certain devices (e.g., garage door openers, Wi-Fi) to share spectrum with licensed users in designated bands under specified conditions (e.g., low power, dynamic frequency selection), and on the basis of neither causing interference to, nor being protected from interference from, licensed devices.

Beyond the frequency allocations, NTIA maintains, in cooperation with the Federal agencies, frequency allotments and frequency plans for some types of systems to manage their use of spectrum. NTIA requires that the Federal agencies take all reasonable measures to ensure that their radio systems will neither cause nor receive harmful interference and mandates a multi-stage review of certain new systems toward this end. NTIA regulations also provide for Federal agency use of non-licensed devices. NTIA works with the Federal agencies to manage their use of the radio spectrum through the Interdepartment Radio Advisory Committee (IRAC). Although this approach is highly efficient, it sometimes results in many disparate systems sharing the same Federal bands.

Thus, spectrum sharing is not new. Spectrum has long been "shared" via frequency partitioning, meaning that some spectrum is assigned to a user and adjacent spectrum to another user, creating the possibility of interference and hence the need for sharing arrangements to limit that interference. The same has long been true for users in geographically adjacent bands; sharing arrangements are also employed to avoid interference in this case. What is new, and what has only recently become technologically possible, is more use of automated mechanisms to facilitate sharing arrangements. As

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[2] Title 47 §2.106 of the Code of Federal Regulations (CFR), part of the FCC rules, contains the United States and International Tables of Frequency Allocations and further refines these general frequency allocations through a system of footnotes to the United States Table that stipulate conditions for the use of frequency allocations in some frequency bands. The United States Table, consisting of separate "Federal" and "non-Federal" tables, designates these footnotes as applying either to "Federal" or to "non-Federal" frequency allocations, or to both (using a "United States" designation in this case). Section 4.1 of the NTIA Manual (NTIA 2014a), which CFR Title 47 §300.1 incorporates by reference, includes these same tables.

evidenced by the 2013 Presidential Memorandum, innovative spectrum sharing of both Federal and non-Federal bands is necessary as both government and commercial requirements for this finite resource are increasing.

Purpose

Section 1(b) of the 2013 Presidential Memorandum directs the Spectrum Policy Team to publish a report on how the NTIA and the FCC are incorporating spectrum sharing into their management practices. The Spectrum Policy Team asked the IDA Science and Technology Policy Institute (STPI) to support the development of the required report by identifying NTIA, FCC, and other related efforts to promote spectrum sharing. The purpose of this paper is to summarize the major spectrum sharing efforts examined by STPI researchers, and thereby provide essential information required in the Spectrum Policy Team's report.

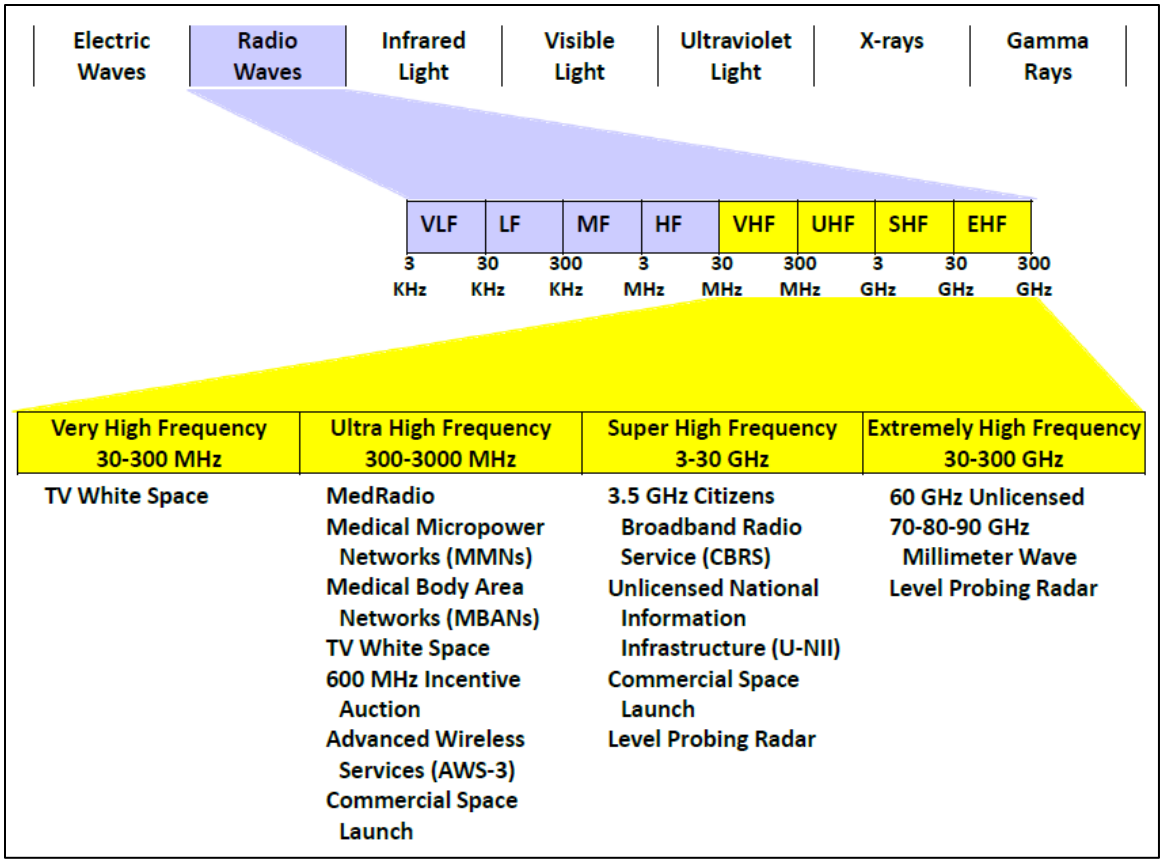
Selected NTIA and FCC Spectrum Sharing Initiatives

Through investigation and discussions with experts, STPI researchers identified 13 initiatives—representing both conventional and advanced sharing approaches—that are either completed or well underway. As shown in the figure below, the initiatives cover the higher end of the radio spectrum, from the TV white space initiative in the Very High Frequency (VHF) and Ultra High Frequency (UHF) bands to the 60 GHz unlicensed, 70-80-90 GHz millimeter wave, and level probing radar initiatives in the Extremely High Frequency (EHF) band.

The initiatives are summarized in the table on page ix in terms of primary sharing mechanism, target spectrum band, amount of spectrum under consideration for sharing, incumbent spectrum holders, licensing approach, and current status.[3]

- The **AWS-3** initiative is intended to meet wireless carrier demands for more licensed spectrum. The AWS-3 auction, concluded on 29 January 2015, raised a total of $41.3B in net bids, with 31 winning bidders winning a total of 1,611 licenses. Federal incumbents will either relocate to other bands or share with the incoming commercial systems, with sharing done on a geographical basis through the establishment of protection zones for the Federal users. In this way, spectrum is made available to carriers, while, at the same time, disruptions to Federal missions are prevented. Moreover, the reallocation of the 1755-1780 MHz band required compressing some Federal operations and relocating others to bands where a comparable capability could be assured.

[3] It should be noted that not all the initiatives advance mobile broadband sharing, and some predate the President's 500 MHz goal (e.g., the 70-80-90 GHz Millimeter Wave and Level Probing Radar proceedings).



Spectrum Sharing Initiatives by Radio Frequency Spectrum Band[4]

- The **3.5 GHz Citizens Broadband Radio Service** (CBRS) is intended to demonstrate the feasibility of the PCAST licensing scheme, which enables incumbent users and CBRS users to share spectrum via a dynamic Spectrum Access System (SAS). Incumbent users operate at the first tier, while CBRS users operate at the second and third tiers as priority access users and general authorized access users, respectively.
- **MedRadio**, **Medical Micropower Networks**, and **Medical Body Area Networks** are intended to meet the needs of wireless medical devices. These licensed-by-rule services are able to share spectrum with incumbent users through mechanisms such as low power and dynamic frequency selection, as well as through a certain level of manual coordination.
- Two of the initiatives are intended to promote a robust commercial space industry. Both initiatives embody conventional spectrum sharing approaches,

[4] LF, MF, and HF stand for "low frequency," "medium frequency," and "high frequency," respectively. The qualifiers V, U, S, and E stand for "very," "ultra," "super," and "extremely."

which entail careful manual analysis of the impact on the risk of harmful interference.

  - **Commercial Space Launch Services**. These services will provide spectrum for communications during commercial space launches. Such uses are already allowed today under special temporary authorizations, and the current proceeding would allow use in limited circumstances on a licensed basis.
  - **Federal Fixed Satellite Earth Stations using Commercial Satellites**. This is unique among the 13 initiatives in that its purpose is to gain Federal access rights to use non-Federal satellite capacity. It is included to make the point that Federal users, as well as non-Federal users, have unmet needs for spectrum.

- **Level Probing Radar** service is an example of a specialized service to determine the level of liquid. It accomplishes sharing through directional transmissions that are fixed, pointing downward and often contained within tanks.

- Several initiatives are intended to promote innovation in unlicensed wireless broadband communications services, which have spurred economic growth over the past 20 years. Two initiatives—the planned **600 MHz incentive auction** and **TV White Spaces**—are facilitating access to the TV bands for unlicensed use in certain geographic areas where the spectrum is not being used by the licensed users. The **U-NII** initiative is evaluating the expansion of the U-NII bands, which are already being used for Wi-Fi, by 195 MHz. The updated **60 GHz** Part 15 rules provide high-speed point-to-point broadband services. The **90 GHz** portion of the 70-80-90 GHz initiative, described below, is also proposed for unlicensed use.

- The **70-80-90 GHz** initiative, which is intended to stimulate innovation in millimeter wave communications, provides high-speed point-to-point broadband services. The 70 and 80 GHz portion of the initiative requires non-exclusive nationwide licenses that are coordinated with the NTIA.

With respect to spectrum below 6 GHz, NTIA and the FCC have been cooperating toward expanding wireless broadband use, increasing sharing, and meeting the 500 MHz goal of the June 2010 Presidential Memorandum. The NTIA's Fifth Interim Progress Report (NTIA 2015, 1) states, "Between October 2010 and September 2014, NTIA and the FCC formally recommended or otherwise identified for study for potential reallocation up to 589 megahertz.…" This total includes 335 megahertz in Federal or shared bands[5] and between 152-254 megahertz in non-Federal bands.[6] An additional 960

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[5] AWS-3 (40 of its 65 megahertz), 3.5 GHz (100 megahertz), and U-NII (195 megahertz), described herein. Note that the most recent proceeding on the 3.5 GHz band (FCC 15-47), released after the Fifth Interim Progress Report, adds an additional 50 megahertz (the 3650 to 3700 MHz band) to the non-Federal total here, bringing the overall total to 639 megahertz.

[6] Including AWS-3 (25 of its 65 megahertz) and 600 MHz Incentive Auction (42-144 megahertz), described herein.

megahertz[7] is slated for potential future study for repurposing. All together, the NTIA and the FCC have made available or are investigating for potential repurposing between 1,447 and 1,549 megahertz[8] of bandwidth under 6 GHz (NTIA 2015, Table B-1).

Other Recent Activities in Support of Spectrum Sharing

To meet escalating commercial and Federal demands for spectrum, the NTIA and the FCC are conducting spectrum band analyses to identify additional opportunities for spectrum sharing and repurposing. They are also developing publicly accessible spectrum inventories and conducting a number of measurement studies to gain a better understanding of spectrum use patterns. In addition, the NTIA has joined with Federal partners in launching research and development activities at new facilities in Boulder, Colorado, and the NTIA and FCC are developing the "RF Model City" concept.

Other Federal agencies, including the Department of Defense, the National Science Foundation, and the Department of Energy, have ongoing research and development activities in the area of spectrum sharing. For example, the Defense Advanced Research Projects Agency (DARPA) supported early research into cognitive radio and dynamic spectrum access through programs such as neXt Generation (XG), and it continues to address key problem areas in spectrum sharing for military systems.

The NTIA and FCC spectrum sharing initiatives have complementary relationships with a number of ongoing standards activities. For example, the Institute of Electrical and Electronics Engineers (IEEE) 802.11ac standard is being used to pursue Gigabit Wi-Fi for the 5 GHz U-NII spectrum bands, and several IEEE and Internet Engineering Task Force standards are being used to leverage TV white space and create a comprehensive TV white space ecosystem.

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[7] Counting 5 megahertz (1675-1680 MHz) listed in Table B-1 of the report as already being under study but not included in the 589 megahertz total.

[8] Or 1,497 to 1,599 megahertz, counting the 3650-3700 MHz band.

Summary of Selected Spectrum Sharing Initiatives

Spectrum Sharing Initiative	Primary Sharing Mechanism	Spectrum Band(s)	Shared Bandwidth	Incumbent Users	New Users	Status
Advanced Wireless Services (AWS-3)	Manual coordination of protection zones	1695–1710, 1755–1780, and 2155–2180 MHz	40 megahertz	Fed/Non-Fed (1695–1710); Fed (1755–1780)	Licensed	**Mar 2014**: Report and Order (R&O) **Nov 2014–Jan 2015**: Auction
3.5 GHz Citizens Broadband Radio Service (CBRS)	Spectrum Access System for 3-tiered access	3550–3700 MHz	150 megahertz	Fed	Licensed for priority access; Licensed by rule for general authorized access	**Apr 2015**: R&O and Second Further Notice of Proposed Rulemaking (FNPRM) **Jun 2015**: Public Notice
MedRadio	Listen before talk	401–406 MHz (402-405 already shared)	2 megahertz	Fed/Non-Fed	Licensed by rule	**Mar 2009**: R&O
Medical Micropower Networks	Dynamic frequency selection	413–419, 426–432, 438–444, and 451–457 MHz	24 megahertz	Fed/Non-Fed	Licensed by rule	**Nov 2011**: R&O
Medical Body Area Networks	Manual coordination	2360–2400 MHz	40 megahertz	Fed/Non-Fed	Licensed by rule	**May 2012**: First R&O and Further NPRM
Commercial Space Launch	Manual coordination	420–430, 2200–2290, 5650–5925 MHz	375 megahertz	Fed	Licensed	**May 2013**: NRPM and Notice of Inquiry (NOI)
Federal Earth Stations	Manual coordination	10 bands in the C, Ku, Ka, and V satellite bands	13.275 gigahertz	Non-Fed	Federal allocation	**May 2013**: NRPM and NOI
Level Probing Radar (LPR)	Directional, contained emissions	5.925–7.250, 24.05–29.00, 75–85 GHz	16.275 gigahertz	Fed/Non-Fed	Unlicensed	**Jan 2014**: R&O and Order
600 MHz Incentive Auction	TV white spaces database	512–698 MHz (42-144 megahertz to be repurposed)	20–34 megahertz	Non-Fed (Broadcast)	Unlicensed – guard bands	**Jun 2014**: R&O **Aug 2015**: Public Notice **Aug 2015**: R&O
TV White Spaces	TV white spaces database	54–60, 76–88, 174–216, 470–698 MHz	Varies (est. to average 107 megahertz)	Non-Fed (Broadcast)	Unlicensed – unused TV channels	**Apr 2012**: Third Memorandum Opinion and Order
U-NII Expansion	Dynamic frequency selection	5.350–5.470 GHz (U-NII-2B); 5.850–5.925 GHz (U-NII-4)	Additional 195 megahertz	Fed/Non-Fed	Unlicensed	**Apr 2014**: First R&O (under study)
60 GHz Unlicensed	Manual coordination of narrow beams, low power	57–64 GHz	7 gigahertz	Fed/Non-Fed	Unlicensed	**Aug 2013**: R&O
70-80-90 GHz Millimeter Wave	Manual coordination of narrow beams	71–76, 81–86, and 92–95 GHz (except 94.0–94.1)	12.9 gigahertz	Fed/Non-Fed	Licensed (70/80 GHz); Unlicensed (90 GHz)	**Mar 2005**: Memorandum Opinion and Order

Conclusion

Spectrum sharing is not new; the orderly sharing of spectrum has been the primary purpose of spectrum management since the beginning of the practical use of radio. But spectrum sharing is being reinvented due to the escalating demand for spectrum from both commercial and government users, the inability of conventional coarse-grained and manually-based spectrum sharing methods to meet the demand, and the advent of new technologies that enable automated and fine-grained sharing of spectrum along frequency, geography, time, and other dimensions. As stated in the 2012 PCAST report, advanced spectrum sharing has the potential to "transform spectrum scarcity into abundance

However, additional research and development is necessary to evolve advanced spectrum sharing technology to the point that it is a practical solution for the spectrum needs of both Federal and non-Federal users. The Federal Government could use the Model City concept, additional research and development, pilot studies, and support for related standards to advance these efforts to increase both Federal and non-Federal user access to spectrum sharing opportunities.

Spectrum sharing is moving ahead in Europe and Asia, as well as in the United States. Therefore, it is important for the United States to continue exploring the possibilities of advanced spectrum sharing, not only to provide additional wireless spectrum to meet the domestic demands for wireless broadband, but also to help U.S. industries sustain leadership roles in the evolving worldwide wireless markets.

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. At the same time, the memorandum cautions that Federal, state, local, tribal, and territorial governments must have assured, current and future, mission-critical capabilities that depend on spectrum. It builds upon an earlier Presidential Memorandum, "Unleashing the Wireless Broadband Revolution," issued in 2010, which established a goal of re-purposing 500 megahertz (MHz) of spectrum from existing Federal and non-Federal uses to wireless broadband use within 10 years.

In recognition of recent technological progress, the 2013 Presidential Memorandum advocates advanced spectrum sharing as an important emerging means of making more spectrum available. In doing so, it sustains the momentum of the 2012 President's Council of Advisers on Science and Technology (PCAST)[1] report, Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth, which made a case for advanced spectrum sharing and called for identifying 1,000 megahertz of Federal spectrum to be dedicated to pilot projects.

The first action specified in the 2013 Presidential Memorandum was the establishment of a Spectrum Policy Team, co-chaired by the U.S. Chief Technology Officer and the Director of the National Economic Council (or their designees) and including representatives from the Office of Management and Budget, the National Security Staff, and the Council of Economic Advisors. The Spectrum Policy Team is working with the National Telecommunications and Information Administration (NTIA) to implement the remaining actions called for in the memorandum.

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B. Purpose

The 2013 Presidential Memorandum directs the Spectrum Policy Team to publish a report on how the NTIA and Federal Communications Commission (FCC) are incorporating spectrum sharing into their management practices:

> *Section 1. Spectrum Policy Team*
>
> *(b) The Spectrum Policy Team shall monitor and support advances in spectrum sharing policies and technologies. Within 1 year of the date of this memorandum, the Spectrum Policy Team shall publish a report describing how NTIA and FCC are incorporating spectrum sharing into their spectrum management practices. The report shall include recommendations that enable more productive uses of spectrum throughout our economy and society and protect the current and future mission capabilities of agencies. The Spectrum Policy Team shall also assess national security, law enforcement, safety-of-life, economic, scientific, social, international, and other policy considerations related to licensed and unlicensed spectrum use, including standardization as well as the extent to which the revenue potential of spectrum auctions affects spectrum policy.*

The Spectrum Policy Team requested that the IDA Science and Technology Policy Institute (STPI) provide support in developing the required report. Specifically, the Spectrum Policy Team asked STPI researchers to identify and describe NTIA, FCC, and other related efforts to promote spectrum sharing. The purpose of this paper is to summarize the major spectrum sharing efforts examined by STPI researchers, and thereby provide essential information required in the Spectrum Policy Team's report.

C. Approach

For this project, the STPI team gathered information on spectrum sharing activities from key personnel at the NTIA and the FCC, and then met with them to seek their input on the most important activities. The STPI team also reviewed the recent literature on Federally sponsored research and development activities and related standards activities.

2. Evolution of Spectrum Management

America's future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum. ...

Few technological developments hold as much potential to enhance America's economic competitiveness, create jobs, and improve the quality of our lives as wireless high-speed access to the Internet. ...

Spectrum and the new technologies it enables also are essential to the Federal Government, which relies on spectrum for important activities, such as emergency communications, national security, law enforcement, aviation, maritime, space communications, and numerous other Federal functions. ...

This new era in global technology leadership will only happen if there is adequate spectrum available to support the forthcoming myriad of wireless devices, networks, and applications that can drive the new economy. To do so, we can use our American ingenuity to wring abundance from scarcity, by finding ways to use spectrum more efficiently. We can also unlock the value of otherwise underutilized spectrum and open new avenues for spectrum users to derive value through the development of advanced, situation-aware spectrum-sharing technologies.

The June 2010 Presidential Memorandum, "Unleashing the Wireless Broadband Revolution," called for the NTIA and the FCC to make 500 megahertz of spectrum available for wireless broadband use within 10 years. Significantly, he followed up this instruction with the statement, "The spectrum must be available to be licensed by the FCC for exclusive use or made available for shared access by commercial and Government users in order to enable licensed or unlicensed wireless broadband technologies to be deployed" (Presidential Memorandum 2010). In doing so, he gave impetus to greater spectrum sharing and increased support for unlicensed use of spectrum.

This chapter describes why and how spectrum management is evolving. It begins with an overview of the conventional approach to spectrum management, which entails granting access rights to individual and organizational entities for mutually exclusive, fixed, coarse-grained partitions of spectrum along frequency, geography, and time boundaries. It shows why this framework of exclusive-use access rights cannot meet the spectrum demands of government and commercial users. It then describes advanced

spectrum sharing—its methods, enabling technologies, and promise for relieving the perceived spectrum crunch.

Chapter 3 then examines specific spectrum sharing initiatives that have been undertaken by the NTIA and the FCC.

A. Conventional Spectrum Management

Spectrum management has, for most of its history, centered around three primary functions:

- *Allocating bands of spectrum for specific services*. The characteristics of the service demand (e.g., size of devices, throughput) and the available technology drive the selection of frequency bands. For example, radio transmissions at lower frequencies have longer ranges and higher ("building" or "structure") penetration capabilities; in contrast, higher frequencies are better contained by structure, require smaller antennas, and have historically been allocated to radio services in larger frequency bands and can thus support larger bandwidth requirements. Cellular carriers, and other industry and government mobile users and service providers, prefer the "beachfront" spectrum of 300 megahertz (MHz) to 3 gigahertz (GHz), so called because it is well-suited for mobile wireless technologies, including today's ubiquitous handheld devices.
- *Granting spectrum use rights* (e.g., licenses, frequency assignments, unlicensed access). Conventional spectrum management involves dividing the spectrum along the dimensions of frequency, space, and time. By limiting the transmission and resulting interference to geographic zones, it becomes possible to allow users to share the same frequency band when they are in different zones. Although not as prevalent, temporal sharing is accomplished by limiting the times at which a frequency band can be used. It is possible to share the same frequency band by allocating time slots to different users in the same zone, as in the limited case of the TV station channel sharing via the whitespace database. In frequency sharing, certain frequency bands are licensed or assigned to users via further partitioning of the frequency between users, i.e., frequency separation, and assigning a center frequency and bandwidth. Licensed users have protection against interference from other users. Both the FCC and NTIA also authorize the use of "unlicensed devices" in some frequency bands, but they may not cause harmful interference to systems with licenses or assignments, and they must accept interference from them. Partitions along these dimensions are not disjoint and may overlap necessitating guard bands or conservative zone sizes. As technology has advanced, it has become feasible to consider partitioning spectrum with finer granularity and precision (Matheson and Morris 2011, 2012).
- *Defining rules of use to protect against harmful interference*. Licenses and other authorizations to use spectrum typically require adherence to limits on the transmission power and bandwidth in a band, along with the power emitted

outside that bandwidth. Spectrum management also frequently involves creating guard bands between the frequency authorizations to further protect against interference.

The rules for authorizing use of a frequency band are based on the state of the art of the technology at the time the rules are made. For example, as receivers become more sensitive, the previously determined interference levels at zone boundaries may no longer be acceptable, or, with better clocks, the minimum time for temporal reuse can be smaller.

In the United States, as illustrated in Figure 2-1, the NTIA and the FCC jointly manage spectrum. They collaboratively decide which spectrum is allocated to Federal users, which to non-Federal users, and which to shared use. The NTIA is responsible for managing Federal use of spectrum, while the FCC is responsible for managing non-Federal use of spectrum. The NTIA and the FCC have to coordinate on spectrum shared among Federal and non-Federal users. Federal agencies provide input to NTIA and FCC deliberations through the Interdepartment Radio Advisory Committee (IRAC).

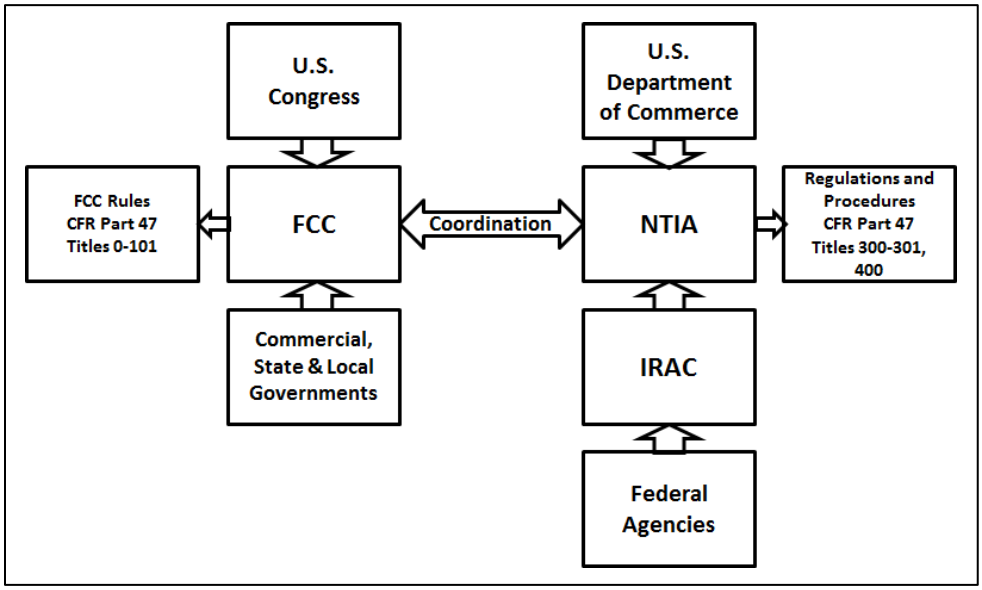

Figure 2-1. Spectrum Management in the United States

The international and U.S. allocations are published by the Federal Register in the Table of Frequency Allocation for frequencies ranging from 9 kHz to 275 GHz. For the U.S., the table gives the most current Federal and non-Federal allocations (in terms of purpose or use, e.g., fixed, aeronautical mobile, maritime mobile, broadcasting, radiolocation, radionavigation, amateur, land mobile, meteorological satellite, space research), as well as references to relevant rules. The table is codified in the Code of

Federal Regulations at Title 47 (Telecommunication), §2.106 (Table of Frequency Allocations).[2]

As of September 2012, about 18 percent of the high-value spectrum between 225 MHz and 3700 MHz was allocated to Federal users; 33 percent, to non-Federal users; and the remaining 49 percent, to shared use. Much of the shared-use spectrum is dominated by either Federal or non-Federal users, meaning that actual sharing is very limited. The NTIA estimates that about 43 percent of the high-value spectrum is predominantly used by Federal operations (GAO 2012).

1. Federal Communications Commission

Historically, the FCC has employed a licensing mechanism and regulations to assign spectrum and to control its use. In 1985, the FCC began to allow unlicensed access to specified spectrum bands, beginning with the industrial, scientific, and medical (ISM) bands. When making assignments, whether by granting licenses or authorizing unlicensed access, the FCC must consider the impact of new users on the incumbent users of the same and nearby bands.

Licensed Users. Licenses for spectrum partitions are granted to individual entities and, importantly, contain regulatory protections against interference from other users. The FCC manages a variety of spectrum and services including satellite, amateur radio, and public safety, as well as the fixed and mobile wireless broadband services, and employs different schemes for licensing decisions. Exclusive use licensing of bands with interference protection and geographic limitations is the most prevalent form of assignment in use below 3 GHz. For example, a cellular carrier may be granted a license for exclusive use of a 20 megahertz frequency band centered at a particular frequency within a certain Cellular Market Area (i.e., Metropolitan Statistical Area or Rural Service Area), while other carriers are granted licenses for exclusive use of the same band in other Cellular Market Areas.

Licenses are typically granted on a long-term basis, often for 10 or more years, with renewals possible. This is desirable from the commercial perspective to justify the large capital investment required to create cellular or other services infrastructure. In return for

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the license, the licensee must utilize the spectrum by building out the infrastructure or the license may be revoked.

Until the 1980s, the FCC administratively assigned cellular wireless licenses based on comparative hearings, sometimes referred to as "beauty contests," where the Commission weighed the relative merit of competing proposals (Copps 2002, Wynns 2004). As spectrum demand increased—making spectrum a scarce resource—the FCC began to explore new mechanisms for granting mobile wireless licenses, briefly experimenting with spectrum lotteries before auctions were implemented in 1993 for some terrestrial services where mutual exclusivity exists between competing spectrum proposals[3] (Crampton 2013, FCC 97- 353, Genty 1999, Salmon 2002).

Spectrum auctions are now generally accepted as a best practice for assigning wireless broadband spectrum where demand exceeds availability. Auctions are a market-based mechanism and, as such, are used to help assign the spectrum in optimal ways from an economic perspective. Auctions have tended to favor assignment of exclusive licenses, because they are deemed to have the highest value by terrestrial wireless carriers.

As of September 2015, the FCC had conducted 89 spectrum auctions, which together raised over $120 billion for the U.S. Treasury.[4]

Licensed by Rule Users. There is a special category of licensed services—known as "licensed by rule" services—which allow users to operate without acquiring individual licenses. The basis of license by rule services lies in 47 U.S.C. 903(e), which authorizes the citizens band radio service and certain other services to operate without individual licenses and, furthermore, gives the FCC discretion in defining the meaning of "citizens band radio service" and other relevant services. In 47 CFR §95.401, the FCC exercises its authority to define the scope of the term citizens band radio service and declares that the citizens band radio services include not only the original Citizens Band (CB) Radio Service, but also several other services such as Medical Device Radiocommunication Service (MedRadio).

Unlicensed Users. Under Part 15 of the FCC Rules, devices meeting certain technical specifications, administrative requirements, and other conditions are permitted to access spectrum in an unlicensed mode, i.e., without individual licenses. Part 15 applications include Wi-Fi, Bluetooth, cordless phones, wireless garage door openers, and wireless microphones.

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[3] The FCC had been seeking auction authority since 1985. Finally, driven in part by the large budget deficits of the late 1980s and early 1990s, Congress authorized the FCC to award licenses for rights to use the radio spectrum through competitive bidding, as part of the 1993 Budget Act (Omnibus Budget Reconciliation Act of 1993).

[4] FCC Auctions Summary web page

Unlicensed users are not granted the same kinds of rights and protections as licensed users. They, in fact, have no vested right to continue using any frequency. They must accept any interference generated by other users, and they may not cause harmful interference. If notified by the FCC that they are causing harmful interference, they must cease operation.

To reduce harmful interference, unlicensed users typically have restrictions placed on them, such as limited power levels, geolocation database controlled access, and/or sensing (e.g., to avoid radars in the 5 GHz Wi-Fi band).

Unlicensed use of spectrum cannot generate revenue from auctions, but it has been shown to have a positive effect on the country's economy and on innovation, as exemplified by the tremendous success of Wi-Fi. The Presidential Memorandum of 2013 calls for increases in the amount of spectrum available for unlicensed use.

2. National Telecommunications and Information Administration

The NTIA is primarily concerned with ensuring Federal agencies meet their mission requirements in areas such as public safety, national security, and transportation.

Although both the FCC and the NTIA authorize new use of frequencies in a way to protect the incumbent systems, the NTIA approaches allocation and assignment differently from the FCC, relying less on restricting the uses and technologies in a band. Instead, the NTIA makes allocations from a systems perspective in that applications for use of a spectrum band are analyzed to determine whether the new application can coexist with the other incumbent systems.

This has led to efficient use of the spectrum with the Federal bands being packed with many disparate systems, representing a wide range of uses and technologies. For example, NTIA reports that over 20 agencies use more than 3,100 individual frequency assignments—many covering multiple systems and operating areas—in the 1755–1850 MHz band alone. As shown in Figure 2-2, the assignments provide communications capabilities for a wide variety of important military and other systems, including point-to-point microwave communications, satellite operations, air combat training, precision guided munitions, unmanned aerial vehicles, and high-resolution law enforcement video links.

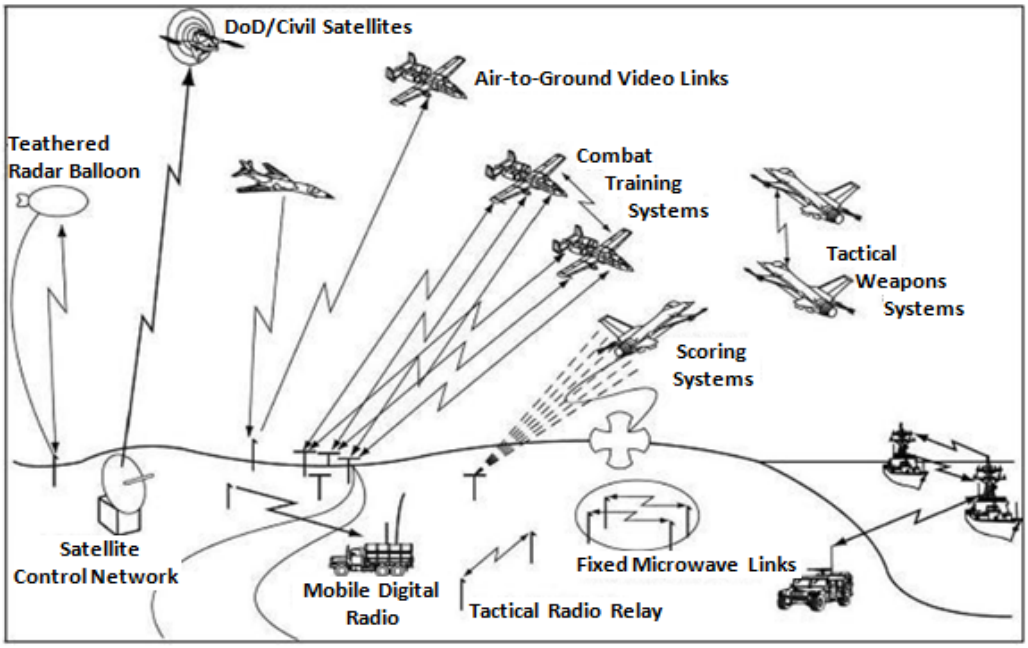

Figure 2-2. Major Systems in the 1755–1780 MHz Band (NTIA 2010b)

B. Challenges in Meeting the Spectrum Demand

In some cases, additional frequency bands have been made available for commercial use by relocating incumbent Federal systems to other frequency bands. As described below, this is an expensive and time-consuming process and is not sustainable in the long term.

1. Relocation Experience: The 1710–1755 MHz Band

In 2002, the NTIA and the FCC jointly reallocated the 1710–1755 MHz band from Federal use to non-Federal Advanced Wireless Service (AWS) use. In 2006 and 2008, the FCC auctioned the 1710–1755 MHz band, paired with the 2110–2155 MHz band (already allocated for commercial use), raising $13.7 billion in total, with $1 billion for the Spectrum Relocation Fund (SRF).[5] The paired bands are referred to as AWS-1.

As shown in Table 2-1, 12 Federal agencies—representing 173 separate systems comprising thousands of pieces of radio equipment in hundreds of locations—have had to

[5] The SRF is a fund established by the Commercial Spectrum Enhancement Act (CSEA) of 2004 (Title II of Public Law 108-494) to reimburse Federal agencies for the cost of relocating from spectrum auctioned for commercial use.

relocate from the 1710–1755 MHz AWS-1 band to make way for commercial use of the spectrum band.[6] As of December 2013, the state of the relocation effort was as follows:

- *Cost—estimated at $1.5 billion:* The 12 Federal agencies have received approximately $1 billion from the SRF to pay relocation costs. The total cost to complete relocations is expected to reach about $1.5 billion.
- *Timeline for clearing spectrum—6 years:* The agencies came in under the projected cost and clearing timelines, facilitating the successful auction. In addition, the overall relocation costs were matched with budget numbers that were well within the CSEA 110% net revenue requirement. The 12 affected Federal agencies have ceased operations of their systems in the 1710-1755 MHz band, clearing the band for new commercial licensees.
- *Timeline for establishing comparable capability—still ongoing after 7 years:* Only five agencies have completed the relocation effort and achieved comparable capability of systems, either by relocating to new frequency assignments or by using alternative technology.

2. Outlook for Future Relocation Efforts: The 1755–1850 MHz Band

Any future relocation efforts may prove to be even more challenging and costly. An NTIA-led interagency group assessed the viability of accommodating commercial wireless broadband in the 1755–1850 MHz band and estimated that the cost of relocating Federal users from the band would be approximately $18 billion over 10 years (DOC 2012). The Department of Commerce report on the assessment states (DOC 2012, vi):

> *The variety of operations and number of systems in the 1755–1850 MHz band, as well as the length of the transition of those operations to other spectrum, will present greater coordination complexity and will require commercial providers to operate in the presence of continuing and transitioning federal operations. Over 20 agencies utilize more than 3,100 individual frequency assignments. In turn, there simply are few bands to consider for repurposing and few comparable bands to which federal agencies can relocate their operations.*

A DoD alternative proposal for the lower 25 MHz of this band (1755-1780 MHz), however, ultimately became a lynchpin of the FCC's AWS-3 auction rules, clearing the way for a successful auction through a combination of relocation, sharing, and limited compression at a lower cost ($3.5 billion).

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[6] See (NTIA 2002) for a detailed discussion on relocation options and plans. As it turned out, many Federal agencies relocated 1710–1755 MHz operations to the 1755–1850 MHz band (NTIA 2012).

Table 2-1. Relocation of Federal Systems from 1710–1755 MHz Band (DOC 2014)

Department/ Agency	Number of Systems[7]	Spectrum Vacated as Required?[8]	Dec 2013 Transition Status[9]	Feb 2007 Estimate of Relocation Cost	Dec 2013 Estimate of Relocation Cost
Dept. of Agriculture	27	Yes	Complete	$21,578,486	$21,578,486
Dept. of Housing & Urban Dev.	5	Yes	Complete	$21,115	$21,115
Dept. of Transportation	21	Yes	Complete	$58,062,020	$58,062,020
NASA	2	Yes	Complete	$740,000	$740,000
Tennessee Valley Authority	6	Yes	Complete	$10,687,857	$15,751,057
Dept. of Interior	5	Yes	2 Complete 3 Ongoing	$25,411,949	$34,441,134
Dept. of Defense	44	Yes	Ongoing	$355,351,524	$355,351,524
Dept. of Energy	36	Yes	Ongoing	$176,820,959	$212,200,959
Dept. of Homeland Security	12	Yes	Ongoing	$89,994,832	$282,239,840
Dept. of Justice	13	Yes	Ongoing	$262,821,000	$556,424,000
Dept. of Treasury	2	Yes	Ongoing	$5,301,000	$5,301,000
United States Postal Service	1	Yes	Ongoing	$1,761,760	$8,333,760
Total	**173**			**$1,008,552,502**	**$1,550,444,895**

C. Advanced Spectrum Sharing as an Alternative to Relocation

The challenges encountered in making more spectrum available for commercial use by clearing and relocating Federal users—especially given the unabated growth in Federal and non-Federal spectrum requirements—have provided the impetus for the consideration of advanced sharing methods. By employing advanced sharing methods, such as proposed in the PCAST report (PCAST 2012), there is the possibility that Federal agencies could make more spectrum available for commercial use without having to relinquish and relocate. Similarly, Federal agency sharing of bands with non-Federal incumbents could help to address growing Federal bandwidth requirements.

The PCAST report detailed several findings that motivate the movement toward advanced spectrum sharing, including (PCAST 2012, page x):

> *Finding 1.2: Clearing and reallocation of Federal Spectrum for exclusive use is not a sustainable basis for spectrum policy due to its high cost, lengthy time to*

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[7] A single system can represent hundreds of elements in dozens of locations. For example, the February 2007 Office of Management and Budget (OMB) Report to Congress listed the Department of Justice Bureau of Alcohol, Tobacco, Firearms and Explosives as having 1,641 "systems," but those 1,641 systems have since been determined to represent only 5 unique systems (each with multiple elements).

[8] As of December 2012, all 12 agencies had vacated the spectrum, where required to do so. Exceptions are specified areas around Federal facilities in Yuma, Arizona, and Cherry Point, North Carolina, which are protected indefinitely.

[9] "Complete" means that the agency has vacated the spectrum, where required, and established comparable capabilities. "Ongoing" means that the agency has vacated the spectrum, but is still in the process of establishing long-term comparable capabilities.

implement, and disruption to the Federal mission. Sharing of Federal spectrum, however, would provide the basis for economic and social benefits for the Nation.

Finding 1.3: The fragmented partitioning of Federal spectrum leads to inefficiency, artificial scarcity, and constraints on current and future Federal and non-Federal uses.

The FCC captured the sense of the evolution of spectrum sharing in a recent Notice of Proposed Rulemaking on an innovative sharing approach for the 3.5 GHz band (FCC 12-148, p. 3):

*Spectrum sharing in this context refers to the use of **automated techniques** to facilitate the **coexistence** of **disparate unaffiliated spectrum dependent systems** that would conventionally require separate bands to avoid interference.*

Despite the promise represented by the PCAST report, there are serious considerations that have slowed or prevented the rapid adoption of advanced spectrum sharing techniques. These include concerns on the maturity of the technology, the ability to share with safety-critical systems, the costs to provide these capabilities on expensive legacy systems, operational requirements, the information security implications, and much more. In order to gain acceptance the advanced sharing methods need to prove sufficiently beneficial to agencies that they can successfully compete with mission-driven performance requirements for a shrinking pool of Federal system development funding. Further, commercial developers have similar concerns from their business perspectives.

1. Foundational Concepts

Recent advances in spectrum sharing capabilities are based on several concepts,[10] notably:

- *Software-defined radio (SDR):* "A radio transmitter and/or receiver employing a technology that allows the RF [radio frequency] operating parameters including, but not limited to, frequency range, modulation type, or output power to be dynamically set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard" (ITU 2009).
- *Cognitive radio system (CRS):* "A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in

[10] Though ITU and IEEE definitions are provided here as examples, other industry and governmental groups, including the FCC and NTIA, use somewhat different definitions.

order to achieve predefined objectives; and to learn from the results obtained" (ITU 2009).

- *Dynamic spectrum access (DSA):"*The real-time adjustment of spectrum utilization in response to changing circumstances and objectives…. Changing circumstances and objectives include (and are not limited to) energy-conservation, changes of the radio's state (operational mode, battery life, location, etc.), interference-avoidance (either suffered or inflicted), changes in environmental/external constraints (spectrum, propagation, operational policies, etc.), spectrum-usage efficiency targets, quality of service (QoS), graceful degradation guidelines, and maximization of radio lifetime" (IEEE 1900.1-2008).
- *Spectrum sensing*: "The action of a radio measuring signal features…. For instance, a radio engaging in dynamic spectrum access may use spectrum sensing to determine whether a particular section of spectrum is occupied. Examples of some signal features that could be sensed include energy, bandwidth, periodic features (pilot signals, preambles, chip rates), identity of transmission source, interference tolerance capabilities, and expected duration of spectrum usage" (IEEE 1900.1-2008). Spectrum sensing can be performed by user devices or by infrastructure-based sensors.

2. Emerging Technologies

Many new technologies are being developed in support of the above concepts. Some of the technologies directly influencing spectrum sharing research and implementation as well as scalability experimentation, and/or increasing the intra-commercial mobile broadband throughput and data capacity of their networks, include:

- *Spectrum database management and signaling.* Techniques for management and operation of spectrum databases that are used to control access to the spectrum are already being deployed on a limited basis (i.e., the FCC whitespace database rules in the 700 MHz band). However, there are ongoing development efforts to evolve these capabilities to include features such as real-time or dynamic transactions, shorter-term access grants, better channel estimation, and better interference predictions.
- *Location capable devices*. Incorporation of GPS receivers or other location determination methods in the devices enables interactions with geolocation databases and greater precision in predictions of interference effects.
- *Heterogeneous networks (HetNets)*. HetNets (e.g., tiered cellular networks) can include wide area macrocells and smaller, lower-power cells such as picocells, femtocells, or unlicensed Wi-Fi local area networks (Damnjonovic et al. 2011, Landstrom et al. 2011, Qualcomm 2011). An example is the common practice of using Wi-Fi networks to offload cellular network traffic.
- *Wideband spectrum sensing.* Wideband spectrum sensing techniques can determine the state of a large collection of channels over wide frequency bands of up to several gigahertz. The methods are being investigated for user devices to

allow dynamic spectrum access or as distributed collections of sensors that cover a larger area (Sakarya et al. 2011, Sun et al. 2013).

- *Smart antennas*. Incorporation of multiple-antennas, as with Multiple-In Multiple-Out (MIMO) designs, is an integral part of many radio systems. More advanced antenna designs, also called adaptive array antennas, that support beam-forming are used to create directional transmissions and reception patterns that can narrow the volume of the interference areas, allowing finer-grained spatial reuse, are increasingly being incorporated into radio systems.
- *Mesh networks*. Wireless systems made of user devices that can also serve as relays hold promise for enabling longer distance communications through a series of shorter, low-power hops.
- *Micropayment schemes*. Automated or semi-automated algorithms on a user device can be used to negotiate and perform a low-cost transaction, such as for dynamic, short-term leases of spectrum blocks (Hu 2005, Peha 2009).
- *Improved interference detection and cancellation*. Technology developments in filters and receiver designs are improving the ability to detect and mitigate the effects of some types of interference. Smart antennas and cooperation between base stations are also used to detect and deal with interference from multiple users (Andrews 2005, Damnjonovic 2011).
- *Time/space/frequency coordination*. Improved clocks and synchronization protocols allow tighter coordination and often less communication to achieve cooperative goals.
- *Carrier aggregation*. Cellular system enhancements, such as in Long Term Evolution Advanced (LTE-A), enable the use of contiguous and non-contiguous spectrum allocations to increase bandwidth (Wannestrom 2013).
- *Infrastructure/radio area network sharing*. The cellular carriers are now investigating sharing infrastructure equipment to cut costs. Enhanced cooperation and coexistence methods will need to be developed to support this kind of sharing.

3. Advanced Spectrum Sharing Methods

The above concepts and emerging technologies, as well as the inclusion of greater computing power in radio systems, have led to the development of many advanced sharing methods, several of which have been implemented to increase intra-commercial mobile broadband throughput and data capacity of their networks (Akyildiz 2011, Marinho 2012). Applicability and scalability of these methods to Federal users or for Federal/non-Federal sharing requires further evaluation. These methods can be characterized in various ways according to the key properties they use to accomplish sharing (Bazelon 2014, Berg 2013, Buddhikot 2007, Peha 2009, Rysavy 2014, Wyglinsky 2009):

- *Cooperative or non-cooperative* (also called coexistence). Cooperative schemes have devices communicate with each other to avoid interference; non-cooperative

systems do not directly communicate with each other. An example of a cooperative scheme is an 802.11-like scheme that uses a "Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)" protocol to avoid simultaneous transmission. An example of coexistence is use of the unlicensed frequency band by both Wi-Fi and Bluetooth, which use a combination of low power and "Listen Before Talk" to share the band among many users from different organizations.

- *Centralized or distributed.* In a centralized system, access is granted by either a single or a small number of central authorities, such as a Spectrum Access System database. In a distributed system, multiple authorities, or even all user devices, have the ability to determine whether a device can access the spectrum (e.g., through spectrum sensing and dynamic spectrum access).
- *Overlay or underlay.* An overlay sharing method allows a secondary user device to access a band if the band is not being used by a primary device, such as for TV white space devices. An underlay method allows a device to access the network without regard for the primary user, providing it will not cause excessive interference to the primary user. An example is an ultra-wideband system that uses very low power and a specialized protocol to share across a large block of frequency allocated to primary users.
- *Equal or prioritized access*. Either all users have equal access rights to a band, or prioritized groups of users have preferential access. For example, the unlicensed ISM bands allow equal access to all users, typically on an opportunistic basis, while shared licensed schemes with primary and secondary users are priority based.
- *Short-, medium-, or long-term leases*. The time period for which access to a spectrum band is granted can vary from very short (e.g., a single packet) to hours, days, or even longer.

4. President's Council of Advisors on Science and Technology Report

In July 2012, the President's Council of Advisors on Science and Technology (PCAST) released its report "*Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth"* (PCAST 2012).[11] A key finding of the report is that spectrum clearing and relocation of users is no longer a sustainable way to increase the amount of

[11] PCAST is co-chaired by John Holdren, the Director of the White House Office of Science and Technology Policy, and Eric Lander, the President of the Broad Institute of Massachusetts Institute of Technology and Harvard. The PCAST Working Group that prepared the report was chaired by Mark Gorenberg, a venture capitalist and former Sun Microsystems manager. The Working Group included PCAST members S. James Gates of the University of Maryland, Craig Mundie of Microsoft Corporation, William Press of the University of Texas, Maxine Savitz of the National Academy of Engineering, and Eric Schmidt of Google, Inc., as well as 21 invited spectrum experts from academia, industry, and advocacy groups. Over 80 other spectrum experts, including several from Federal agencies, contributed to the report by participating in meetings and responding to requests for information.

spectrum available for commercial use. This leads to the report's conclusion that exclusive licensing is not the way forward and that advanced spectrum sharing should become the new norm. The report contends that spectrum sharing has the potential to turn the spectrum shortage into spectrum abundance by efficiently sharing spectrum that is often idle or lightly utilized.

The PCAST report proposes managing spectrum by dividing it into large blocks, called Spectrum Superhighways, and allowing users with compatible services to dynamically share that spectrum on a priority basis. The report recommends that the Secretary of Commerce identify 1000 megahertz of spectrum to create the first shared-use Spectrum Superhighways. In addition to ensuring that Federal agencies continue to have access to spectrum to meet their current requirements, the report also suggests enabling Federal access to additional spectrum (including non-Federal spectrum currently licensed for commercial use) on a shared basis to address their growing spectrum needs.

In the proposed PCAST licensing concept, users would be divided into three tiers (PCAST 2012, 23):

- ***Federal Primary Access*** users would register their actual deployments in a database, and in return would be guaranteed protection from harmful interference in their deployed areas, consistent with the terms of their assignment (by NTIA or by FCC).
- ***Secondary Access*** users would be issued short-term priority operating rights in a specified geographic area and would be assured of interference protection from opportunistic use (see below); however, they would be required to vacate when a user with Federal Primary Access registers a conflicting deployment in the database. There may be multiple levels of Secondary Access users of spectrum, with different assigned levels of priority, so that some Secondary Access users may be preferred over others, either because of payments (e.g., an auction or user fees), or because of a public interest benefit such as being a Federal user or public safety user.
- ***General Authorized Access (GAA)*** users would be allowed opportunistic access to unoccupied spectrum if no Federal Primary or Secondary Access users are registered in the database for a given frequency band, specific geographical area, or time period.

All users would be required to register in the Spectrum Access System (SAS) database, which would control dynamic access to the spectrum. Secondary Access and GAA users would be required to query the SAS to gain permission to access the spectrum.

The PCAST report also addresses several other key issues for realizing advanced sharing including:

- Incentivizing Federal agencies with Spectrum Currency and a Spectrum Efficiency Fund to cover costs of implementation

- Setting standards for receivers
- Increasing support for research and development
- Establishing a Test City for operational testing of the methods in a large-scale realistic environment
- Harmonizing frequency band allocations internationally

The scheme outlined in the PCAST report is a centralized, overlay scheme that depends on several emerging technologies, such as dynamic spectrum access using a geolocation database.

These proposed methods present a promising potential to evolve the way spectrum is managed and increase spectrum sharing, but are still largely unproven, and would require significant changes to many of the regulations governing spectrum access, and the spectrum governance structure. Much work is needed to define the implementation details. There are also views that this form of spectrum sharing is not practical from a technical and business perspective (Goldstein 2012, Marsh 2012). Other recent studies have claimed that spectrum sharing will reduce the value of the spectrum versus exclusive licensing in any auction (Deloitte 2014).

Since the release of the PCAST report, the Federal Government has been taking steps to study and explore these methods, to advance the maturity of the technologies, to incentivize Federal agencies to share spectrum, and to explore the feasibility with the business community.

Authorized Shared Access and Licensed Shared Access (ASA/LSA). The investigation of advanced spectrum sharing is not confined to the United States but is spreading worldwide. For example, a spectrum sharing scheme—similar in concept to the PCAST scheme and known as ASA/LSA—is being pursued by the European Union and several other countries (GSMA 2013). The ASA/LSA scheme, which was initially proposed by Qualcomm, differs from the PCAST scheme in that it has just two levels of users and supports a finer level of temporal granularity in the granting of access (Qualcomm 2013). A potential advantage of the ASA/LSA approach is that with only two levels, the system may be better able to guarantee the quality of service. ASA/LSA technology is being standardized by the European Telecommunications Standards Institute (ETSI) and the Electronic Communications Committee (ECC), and it is under consideration by European carriers (ECC 2014).

Licensed-Assisted Access (LAA) and LTE-Unlicensed (LTE-U). Recently, LAA and LTE-U technologies and specifications have emerged as mechanisms to allow LTE use of the unlicensed spectrum in the 5 GHz band currently used by Wi-Fi. In the United

States, the LTE-U Forum,[12] formed by Verizon in cooperation with Alcatel-Lucent, Ericsson, Qualcomm Technologies, and Samsung, has generated technical specifications for LTE operation in the 5 GHz UNII-1 and UNII-3 bands to boost downlink capacity. LTE-U, which is compatible with 3rd Generation Partnership Project (3GPP)[13] LTE Releases 10/11/12, is seen as a U.S.-focused competitor to the more internationally-focused LAA, which is based on a 3GPP LTE Release 13. According to the Chairman of the 3GPP Radio Access Networks (RAN) Technical Specification Group:

> *The focus of the Release 13 work is on the aggregation of a primary cell, operating in licensed spectrum to deliver critical information and guaranteed Quality of Service, with a secondary cell, operating in unlicensed spectrum to opportunistically boost data rate. A key objective of the project is to ensure fair coexistence between LTE LAA and Wi-Fi.*

The Chief of the FCC Office of Engineering and Technology has expressed concern about the divergence of the LTE-U and LAA specifications, and in particular about the Carrier Sensing Adaptive Transmission (CSAT) protocol of LTE-U as compared to the Listen Before Talk (LBT) access procedures of LAA (Knapp 2015).

5. Developments since the Release of the PCAST Report

Under the three-tier system laid out in the PCAST report, licenses in the middle (Secondary Access) tier present an allocation problem. There is no such problem in the top (Federal Primary Access) tier, because those rights reside with Federal incumbents; and there is no such problem in the bottom (General Authorized Access) tier, because those rights have no interference protection and are open to all. However, the Secondary Access tier involves a scarce right—that is, the right to be protected from General Authorized Access users—which will need to be specified in the service rules.

The PCAST report does not dictate how that right is to be allocated. On one hand, it seems to indicate that the right should be allocated by a usage fee, rather than by an auction. For example (PCAST 2012, 12):

> *Transitioning to the new spectrum architecture described in this report also implies a transformation of the way that spectrum use yields Federal revenue. This report argues that the United States should shift to a spectrum management model that makes possible a continual stream of revenue instead of one-time auction returns. The revenues would derive from wireless services eager to pay modest fees under a*

[12] LTE-U Forum webpage.

[13] 3GPP webpage.

variety of leasing arrangements to obtain spectrum access with varying levels of quality of service and lease lengths, appropriate to their business needs.

On the other hand, in discussing alternatives to long-term licenses, the report suggests the possibility of auctions to determine leasing fees:

- Medium-term licenses (e.g., 1- to 3-year): "Leasing fees could be set by auction, and there would be no automatic right of renewal when the lease expires, although users would be able to compete for renewal by bidding against other potential users" (PCAST 2012, 43).
- Short-term licenses (potentially as short as a few days or even a few minutes): "Because the feasibility of the short-term access model may be sensitive to the transaction costs, the SAS should be designed to allow dynamic bidding for brief periods among devices registered in the database" (PCAST 2012, 44).

a. Preference for Auctions

The 3550-3700 MHz band (now referred to as the 3.5 GHz band) is the first spectrum band the FCC is considering for the SAS approach.[14] In the original Notice of Proposed Rulemaking (NPRM) for that band, the middle-tier "Priority Access Licenses" (PALs) were not to be allocated by auction, but rather were to be "designated for small cell use by certain critical, quality-of-service dependent users at specific, targeted locations" (FCC 12-148, 5). However, this approach was subsequently abandoned (FCC 13-144; FNPRM 14-49).

The Report and Order and Second Further Notice of Proposed Rulemaking (R&O and Second FNRPM), designated FCC 15-47 and released on 21 April 2015, upholds the decision to allocate PALs by auction. Specifically, PALs would authorize use of a 10 megahertz channel in a single census tract for three years,[15] and be assigned in up to 70 megahertz of the 3550-3650 MHz band. Mutually exclusive applications for PALs would be subject to competitive bidding, albeit by an auction with properties quite different from those of a traditional FCC spectrum auction. With this change, the ambiguity in the original PCAST report regarding how middle-tier rights should be assigned appears to have been resolved in favor of auctions.

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[14] The 3.5 GHz Citizens Broadband Radio Service (CBRS) is one of the 13 spectrum sharing initiatives described in Chapter 3 of this paper (see 3.B.2).

[15] PALs are non-renewable, but can be aggregated for up to two consecutive three-year terms at the first application window. In addition, PALs can be aggregated in the frequency dimension; i.e., licensees can hold up to four PALs in one census tract at one time (i.e., 40 megahertz out of 70 megahertz allocated to PALs in one census tract at a time). Note that if there is only one applicant seeking PALs in a given geographic area, there will be no auction and no PALs for that license area. Instead, access to spectrum in the area will be provided via shared GAA use.

In the 2015 proceeding (FCC 15-47), General Authorized Access (GAA) users are allowed, by rule, throughout the entire 150 megahertz of the 3.5 GHz band. The SAS would be expected to serve as an advanced, highly automated frequency coordinator, protecting higher-tier users from lower-tier users and facilitating efficient use of the spectrum.

b. Different Rights in Different Bands

The auctions proposed in the R&O and Second FNPRM (FCC 15-47) for the 3.5 GHz band are quite different from traditional FCC auctions. The biggest difference is that that the licenses proposed for the 3.5 GHz band are for a short term (three years), and are non-renewable (but aggregatable for up to two consecutive terms up front). This is in contrast to traditional FCC auctions in which licenses are long and are usually automatically renewed, essentially becoming a perpetual right. Which approach is preferred depends on the extent to which using a particular band requires costly investment in band-specific capital equipment. In general, corporations are unwilling to make costly band-specific investments without assurance that they will control the band long enough to recoup the investment, so long-term licenses are necessary for bands whose use requires such investments.

The 3.5 GHz band is different in that the capital equipment required to exploit the band is based on relatively inexpensive small-cell technology. Since the investment costs are lower for this band than for bands using macrocells for wide-area cellular coverage, shorter-term licenses become feasible. These licenses have the considerable advantage of allowing frequent refreshment of the rights and continuous reallocation of them to their highest valued use. If technology were to progress in a way that reduces band-specific investment costs more generally, short-term licenses might become appropriate for additional bands.

6. Selected Regulatory Factors Affecting Spectrum Sharing

Any actions taken by the FCC and the NTIA to embrace advanced spectrum sharing must conform within the existing regulatory and legal environment, unless the latter is also changed. Recent law and administrative guidance updates that impact spectrum sharing are described below.

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

Title VI of the Middle Class Tax Relief and Job Creation Act (MCTRJCA) of 2012 (Public Law 112-96), which is commonly referred to as the Spectrum Act, includes provisions in support of spectrum sharing, but, at the same time, places certain constraints on sharing, as described below.

Changes to the Spectrum Relocation Fund (SRF) in Support of Sharing. The Spectrum Act made important changes to the SRF:[16]

- The Act makes SRF funds available to reimburse Federal agencies not only for relocation costs, but also for costs associated with spectrum sharing.
- Federal agencies are authorized to receive reimbursement for costs associated with the *planning* of spectrum relocations or *sharing*.

To date, however, there has been no action on applying the SRF to sharing with unlicensed users. Currently, SRF funds can be used only to reimburse expenses related to a spectrum band that is either being *auctioned* by the FCC or has been previously identified by statute. 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*. This generalization of SRF funds did not make it into the Spectrum Act.

Prioritization of Relocation over Sharing. In evaluating a band of frequencies for possible reallocation for exclusive non-Federal use or shared use, the Spectrum Act requires the NTIA to give *priority to options involving reallocation of the band for exclusive non-Federal use*. The NTIA may only choose options involving shared use when it determines, in consultation with the Director of the Office of Management and Budget (OMB), that relocation of a Federal entity from the band is not feasible because of technical or cost constraints.

Constraints on Guard Bands and Unlicensed Use. The Spectrum Act allows the FCC to implement band plans with guard bands and, furthermore, to permit unlicensed use in the guard bands. However, the Act states, "Such guard bands shall be no larger than is technically reasonable to prevent harmful interference between licensed services outside the guard bands."

b. OMB Circular A−11

The most recent update of the OMB Circular No. A−11 (OMB 2013) 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. Specifically, it requires agencies to indicate whether the system being procured is the most spectrum "efficient" among those that met specified mission/operational requirements. In that regard, the Circular provides an example methodology for determining the spectrum "efficiency" of a system under

[16] The SRF is a fund established by the Commercial Spectrum Enhancement Act (CSEA) of 2004 (Title II of Public Law 108-494) to reimburse Federal agencies for the costs of relocating from spectrum slated to be auctioned for commercial use.

procurement, based on three factors: (1) a weighting factor based on the frequency band used by the system, (2) the population of the area in which the system will operate and use spectrum, and (3) the amount of bandwidth utilized. According to the Circular, the product of these factors—a weighted MHz-pops[17] value—yields a baseline that can be used in evaluating spectrum efficiency improvements. The guidance also gives the agencies the option of coming up with their own methodology on a case-by-case basis. 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."

There is concern that this metric does not capture the efficiency in spectrum sharing. Recognizing that better guidance in assessing spectrum efficiency is needed, the Presidential Memorandum of June 14, 2013, called for the Director of OMB, in consultation with the NTIA, to develop spectrum efficiency guidelines and incorporate them into budget and procurement processes.

[17] 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. Selected FCC and NTIA Spectrum Sharing Initiatives

This chapter briefly describes the regulatory change process and then summarizes selected spectrum sharing initiatives, all of which involve changes to Federal regulations.

A. FCC and NTIA Process for Regulatory Change

As indicated in Figure 3-1, the process for changing the FCC rules governing non-Federal use of shared spectrum involves a series of documents, reviews, and coordination activities. In the case involving Federal/non-Federal sharing, illustrated in the figure, a need for regulatory change is identified by a stakeholder; for example, a company may file a petition, Congress may pass a law, or the President may launch an initiative.

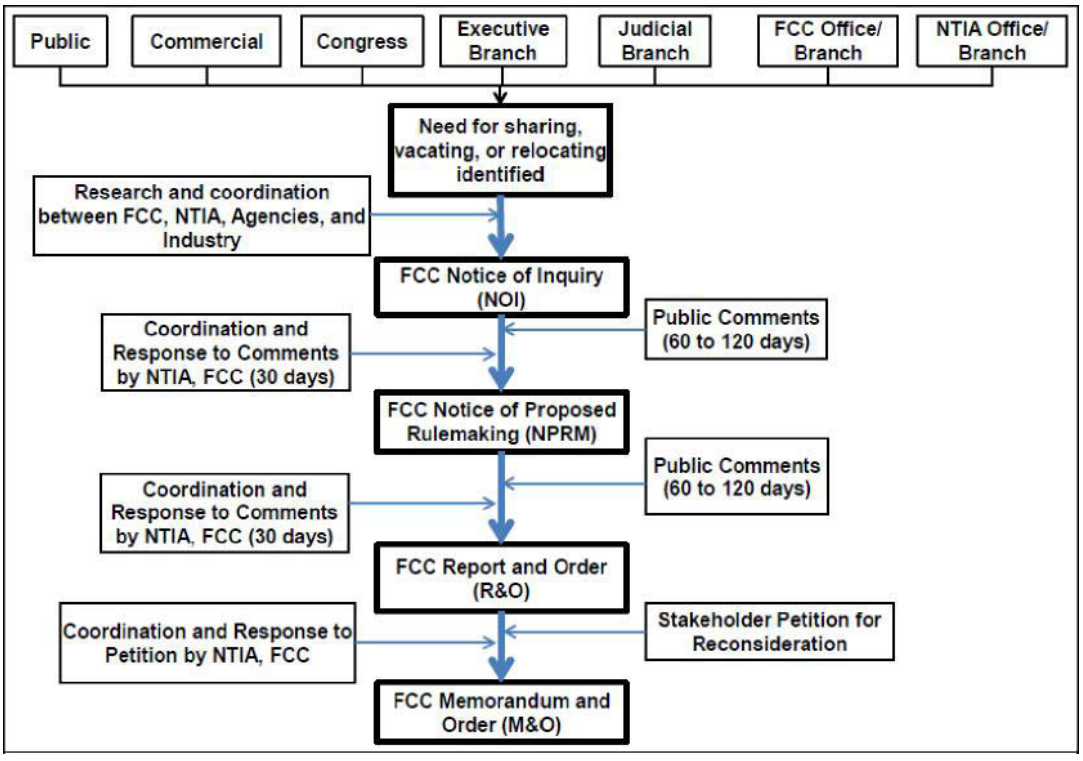


Figure 3-1. Typical FCC Process for Regulatory Change for Federal/non-Federal Sharing[18]

[18] Adapted from (Nebbia undated), (GAO 2002), and (Wellenius and Stern 1994).

Once the need has been identified, the FCC may issue a Notice of Inquiry (NOI). This is the first in a series of documents that are prepared by the FCC in coordination with the NTIA and then reviewed by the public. After the comments on the NOI are considered by the FCC and the NTIA, the FCC may release a Notice of Proposed Rulemaking (NPRM). The NPRM is, in turn, subjected to public review and subsequent FCC and NTIA coordination, and typically leads to a Report and Order (R&O), which directs changes to Federal regulations governing spectrum management.

B. Spectrum Sharing Initiatives

This section presents one-page tabular summaries of 13 spectrum sharing initiatives—representing both conventional and advanced sharing approaches—that have been undertaken by the FCC and the NTIA. The initiatives fall into four general categories, as shown in Table 3-1. Each summary begins with a brief description of the sharing initiative—giving the spectrum band(s) that are the focus of the initiative, the rules governing the new use of the band(s), and the intended application of the new use—and then follows up with (1) a timeline detailing actions taken with respect to the initiative, (2) a list of primary and secondary users of the spectrum band being shared, and (3) a list of mechanisms used to facilitate sharing.

Table 3-1. Spectrum Sharing Initiatives

Federal Incumbents (plus some non-Federal Incumbents, in a few cases)	**Sharing with Licensed Users**[19] 1. Advanced Wireless Services (AWS-3) 2. Citizens Broadband Radio Service (CBRS) at 3.5 GHz 3. MedRadio 4. Medical Micropower Networks (MMNs) 5. Medical Body Area Networks (MBANs) 6. Commercial Space Launch Services 7. 70-80-90 GHz Millimeter Wave Service[20]	**Sharing with Unlicensed Users** 8. Unlicensed National Information Infrastructure (U-NII) 9. 60 GHz Unlicensed Service 10. Level Probing Radar (LPR)
Non-Federal Incumbents	**Sharing with Federal Users** 13. Federal Fixed Satellite Earth Stations using Commercial Satellites	**Sharing with Unlicensed Users** 11. 600 MHz Incentive Auction 12. TV White Spaces

[19] The following services are license by rule services: MedRadio, MMNs, MBANs, and the General Authorized Access tier of CBRS. As described in Section 2.A.1 of this paper, users of these services do not require individual licenses.

[20] A portion of the 90 GHz Millimeter Wave Service is unlicensed.

These initiatives are shown in Figure 3-2 to illustrate the extent of the spectrum that is being considered for spectrum sharing efforts. The initiatives cover the higher end of the radio spectrum, from the TV white space initiative in the Very High Frequency (VHF) and Ultra High Frequency (UHF) bands to the 60 GHz unlicensed, 70-80-90 GHz millimeter wave, and level probing radar initiatives in the Extremely High Frequency (EHF) band.

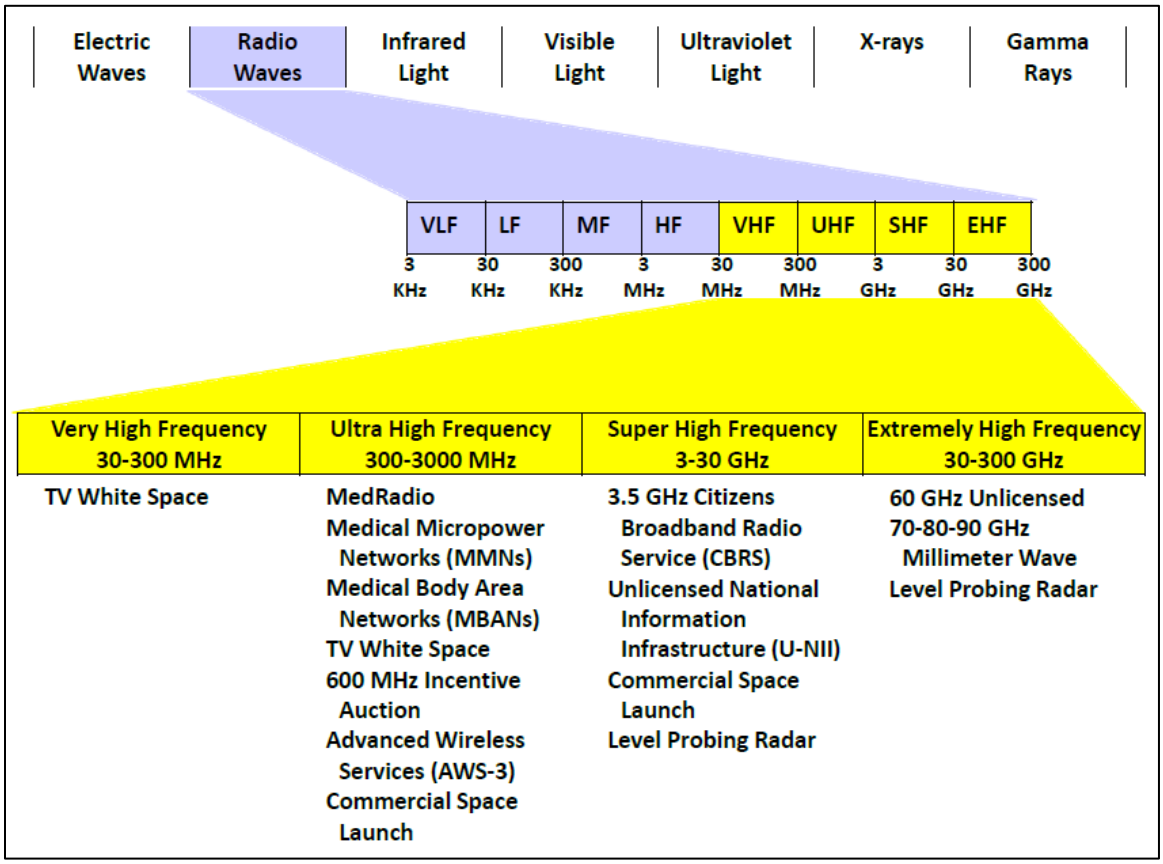


Figure 3-2. Spectrum Sharing Initiatives by Radio Frequency Spectrum Band[21]

[21] LF, MF, and HF stand for "low frequency," "medium frequency," and "high frequency," respectively. The qualifiers V, U, S, and E stand for "very," "ultra," "super," and "extremely."

1. Advanced Wireless Services (AWS-3)
Shared Spectrum: 65 megahertz (40 megahertz to be shared) subject toauction • 1695–1710 MHz and 1755–1780 MHz (to be shared with Federal incumbents); 2155–2180 MHz (already allocated for commercial use) **Governing Rules:** March 2014 Report and Order making additional spectrum available for commercial use via auction of geographic areas under long-term leases, specifying rules for sharing with Federal incumbent users, and use of the Spectrum Relocation Fund (47 CFR Parts 1, 2, and 27 are amended) **Application:** Commercial wireless broadband
Timeline
Jun 2011–Jan 2013: NTIA conducted several studies and requested CSMAC to study commercial use in the 1695–1710 MHz and 1755–1850 MHz bands **Feb 2012:** Spectrum Act (MCTRJCA 2012, Title VI) established deadline for AWS-3 auction **Jun 2013:** Presidential Memorandum (2013) called for sharing where feasible **Jul 2013:** DOD (Takai 2013) proposed relocating some systems in 1755–1780 band to 2025–2110 MHz band and other bands. Remaining systems would operate on shared basis in 1755-1780 MHz band. **Jul 2013:** NPRM and Order on Reconsideration (FCC 13-102) **Nov 2013:** NTIA endorsement (Nebbia 2013) of DOD Proposal and CSMAC recommendations **Mar 2014:** Report and Order (FCC 14-31) makes 65 megahertz available for commercial use via auction **Jul 2014**: Public Notice describes coordination required between incumbent Federal users and commercial entrants (FCC DA 14-1023), in support of auction and as follow up to March 2014 R&O **Sep 2014**: Public Notice announces DoD workbook, greatly facilitating commercial coordination with DoD systems without the release of classified data (FCC DA 14-1314) **Nov 2014–Jan2015**: AWS-3 Auction raised $41.3B, with 31 winning bidders winning 1,611 licenses
Users (as specified in March 2014 Report and Order)
Primary (AWS-3 licenses will be allocated following the auction): • 1695–1710 MHz: AWS-3 Mobile/Uplink operations (unpaired); Federal Meteorological Satellite (MetSat) (space to earth) in 27 protection zones • 1755–1780 MHz: AWS-3 Mobile/Uplink (paired), protection zones for Joint Tactical Radio, Air Combat Training, and Space Operation (earth to space) • 2155–2180 MHz: AWS-3 Fixed and Base/Downlink (paired) **Secondary:** • 1695–1710 MHz: Federal MetSat earth stations outside protection zones • 2155–2180 MHz: Non-AWS authorizations after 1992
Sharing Mechanisms
Coordination: AWS-3 licensees must agree on transmission rules with incumbent Federal users within protection zones prior to operation. All AWS-3 Mobile/Uplink devices must be controlled by base stations that implement coordination rules for a protection zone • 1695–1710 MHz: Low power AWS-3 devices share with MetSat in 27 protection zones. Higher power AWS-3 devices share with incumbents in nationwide protection zone • 1755–1780 MHz: AWS-3 devices share with all Federal incumbents in default nationwide protection zone. NTIA and FCC will be refining protection zones and coordination procedures through a planned joint FCC and NTIA public notice • Mobile devices must minimize transmit power to reduce interference • Federal users are developing monitoring stations for 1695-1710 MHz to help with coordination • AWS-3 mobile devices in paired bands are required to interoperate across specified bands **Conditional AWS-3 licenses:** Licensee must not cause harmful interference to incumbent Federal entities relocating from these bands under an approved Transition Plan

2. Citizens Broadband Radio Service (CBRS) at 3.5 GHz
Shared Spectrum: Up to 150 megahertz at 3.5 GHz (3550–3700 MHz) **Governing Rules:** New rule part (47 CFR, Part 96) **Application:** "Innovation Band" for exploring spectrum sharing and technologies such as small cells • "3.5 GHz band properties are ideal to explore methods of spectrum sharing and small cells for relatively low-powered applications. If successful, the spectrum sharing model proposed for this band could ultimately be expanded to other spectrum bands and transform the availability of a precious national resource—spectrum—from scarcity to abundance" (PCAST 2012, vi) • Small cells (microcells, picocells, metrocells, femtocells) add cellular capacity in congested areas (both outdoors and indoors) and coverage in areas with weak or non-existent cellular service, such as indoors, in remote rural locations, and on cruise ships (with satellite backhaul)
Timeline
Nov 2010: NTIA Fast Track Report (NTIA 2010a) recommended reallocating 100 MHz of 3.5 GHz band (3550–3650 MHz) for wireless broadband use, subject to large coastal exclusion zones to protect shipborne radars (assumed macrocell use) **Jul 2012:** PCAST Spectrum Report (PCAST 2012) advocated three-tiered sharing model and called for 1000 MHz of spectrum to be used to establish "spectrum superhighways" with initial implementation in 3550–3650 MHz band (anticipated small cell use) **Dec 2012:** NPRM and Order (FCC 12-148) proposed implementing PCAST scheme in 3550–3650 MHz band and sought comment on extending band to 3650–3700 MHz **Apr 2014:** FNPRM (FCC 14-49) proposed allocation of Priority Access Licenses (PALs) by auction **Apr 2015**: R&O and Second FNPRM (FCC 15-47) establishes rules for CBRS and SAS **Jun 2015**: Public Notice (FCC DA 15-750) provides an approximate schedule for upcoming FCC actions to which the R&O and Second FNPRM refers
Users (as proposed in April 2015 R&O and Second FNPRM)
Primary (Incumbent Access): Protected from harmful interference from lower tiers by SAS • Authorized Federal users (e.g., radars) and grandfathered Fixed Satellite Service (FSS) earth stations • 3650–3700 MHz: Incumbent wireless broadband providers are grandfathered for a finite transition period (at least 5 years) as primary users; afterwards, they could shift operations to 2nd or 3rd tier **Secondary (Priority Access):** Licensed and protected from interference from tier 3 (GAA) by SAS • Priority Access License (PAL) terms: (1) broad eligibility, (2) 3 year (non-renewable), 10 megahertz channel (not fixed, but dynamically assigned by the Spectrum Access System), single census track, (3) aggregatable with limits, (4) subject to competitive bidding • Up to 70 megahertz of the 3550–3650 MHz band in a census tract reserved for PALs **Tertiary (General Authorized Access (GAA)):** Licensed by rule • Can opportunistically access unused PAL channels • Floor of GAA spectrum availability in a census tract: Up to 80 megahertz (50 in 3650–3700 band and up to 30 in 3550–3650 MHz band) of spectrum not encumbered by Incumbent Access
Sharing Mechanisms
Three-Tiered Access Model **Spectrum Access System (SAS):** a proposed control mechanism modeled on TV White Spaces database, dynamically assigns PAL channels and GAA bandwidth **Small Cells:** • Minimize harmful interference to incumbents due to low power • Increase spectrum efficiency by geographic "reuse" of spectrum **Exclusion Zones:** • Large zones along coastal areas based on macrocell assumptions in Fast Track report; to be reassessed based on move from macrocells to small cells

3. MedRadio
Shared Spectrum: Additional 2 megahertz for wireless medical devices • MedRadio adds 401–402 and 405–406 MHz "wing" bands to 402–405 MHz "core" band **Governing Rules:** 47 CFR, Part 95, Subpart I, Medical Device Radiocommunication Service (MedRadio) • MedRadio is a Part 95 license-by-rule service within scope of Citizens Band Radio Service **Application:** Wireless medical devices—implanted and body-worn—used for diagnostic and therapeutic purposes, e.g., pacemakers, glucose monitors, vagus nerve stimulators for controlling epilepsy • Implanted and body-worn devices use MedRadio service to communicate with nearby external programmer/control unit, which can connect to wired/wireless LAN for further communication • To be classified as "implanted" device or transmitter, transmitting antenna must itself be implanted wholly within body (below skin, or more deeply within body); to be classified as "body-worn" device or transmitter, antenna must be placed upon or in very close proximity to body (e.g., within a few centimeters)
Timeline
Nov 1999: FCC established Medical Implant Communications Service (MICS) as a license-by-rule service at 402–405 MHz to accommodate implantable wireless medical devices on a secondary basis **Jul 2005:** Medtronic, Inc., Petition for Rulemaking (Medtronic 2005) for the allocation of additional spectrum to accommodate growing variety of wireless medical devices **Jul 2006:** NPRM and NOI and Order (FCC 06-103) proposed allocating further shared spectrum (401–402 MHz and 405–406 MHz bands) for implantable, as well as body-worn, medical devices and establishing new MedRadio service in 401-406 MHz band **Mar 2009:** Report and Order (FCC 09-23)
Users
Primary (vary by sub-band; only selected users are listed): • 401–406: Federal and non-Federal meteorological aids (weather balloons) • 401–403: Federal meteorological-satellite services—uplinks supporting Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellites (POES) systems • 401–403 MHz: Federal Earth exploration-satellite services—uplinks supporting scientific exploration of Earth **Secondary (vary by sub-band; only selected users are listed):** • 401–403 MHz: Non-Federal meteorological-satellite and Earth exploration-satellite services • 403–406 MHz: Military tactical fixed and mobile operations **Secondary (introduced in March 2009 Report and Order—MedRadio):** • 401–406 MHz (core MICS band plus wing bands): Listen-before-talk (LBT) implanted medical devices now have secondary access to the entire band • 401–402 MHz and 405-406 MHz (wing bands only): (1) LBT body-worn devices may now be used, but only in wing bands (2) Non-LBT devices (implanted and body-worn) with lower power and duty cycle limits may now be used, but only in wing bands
Sharing Mechanisms
Listen Before Talk (LBT): LBT devices sample the available spectrum and select an open channel before commencing operation **Low power:** Minimize harmful interference. Power and duty cycle limits for non-LBT devices in the 401–402 MHz and 405–406 MHz bands are 250 nanowatts and 0.1%, respectively **Rules of use:** (1) Device certification, (2) Operation under supervision of authorized health care professional

4. Medical Micropower Networks (MMNs)
Shared Spectrum: Additional 24 megahertz for wireless medical devices • Four MMN bands: 413–419 MHz, 426–432 MHz, 438–444 MHz, 451–457 MHz **Governing Rules:** 47 CFR, Part 95, Subpart I, Medical Device Radiocommunication Service (MedRadio) • MMNs are a Part 95 license-by-rule service defined under MedRadio • MMN Report and Order extended MedRadio to the four MMN bands **Application:** Medical Micropower Networks (MMNs) • Use functional electric stimulation to restore sensation, mobility, and other functions to limbs and organs • MMN: "An ultra-low power wideband network consisting of a MedRadio programmer/control transmitter and medical implant transmitters, all of which transmit or receive non-voice data or related device control commands for the purpose of facilitating functional electric stimulation, a technique using electric currents to activate and monitor nerves and muscles" (47 CFR Part 95, Appendix 1 to Subpart E)
Timeline
Sep 2007: Petition for Rulemaking by Alfred Mann Foundation **Mar 2009:** NPRM (FCC 09-20) **Nov 2011:** Report and Order (FCC 11-176)
Users
Primary: • 413–419 MHz: Federal fixed, mobile, and space research services • 426–432 MHz and 438–444 MHz: Federal radiolocation services • 451–457 MHz: Non-Federal land mobile communications services throughout, plus non-Federal fixed services in 454–455 MHz and 456-457 MHz bands. Heavy use in this band is for public safety and private one- and two-way radio systems **Secondary (Incumbents):** • 426–432 MHz and 438–444 MHz: Non-Federal amateur users **Secondary (introduced in November 2011 Report and Order—MMNs):** • All four bands: Medical Micropower Networks, a new licensed-by-rule MedRadio service (devices must be certified; operators must be authorized health care providers)
Sharing Mechanisms
Dynamic Frequency Selection (DFS): • Uses only one of four bands at any time; automatically shifts to another band if interference is sensed; if all four bands are unusable, system enters "graceful shutdown" that begins pre-programmed sequence of actions allowing implants to operate independently of programmer/controller for short time **Ultra-low power wideband network:** • Minimizes harmful interference to incumbents • Filters out narrowband interference when detected within a band

5. Medical Body Area Networks (MBANs)
Shared Spectrum: Additional 40 megahertz for wireless medical devices • 2360–2400 MHz band for MBANs **Governing Rules:** 47 CFR, Part 95, Subpart I, Medical Device Radiocommunication Service (MedRadio) • MBANs are a Part 95 license-by-rule service defined under MedRadio and CB Radio Services. • MBAN Report and Order extended MedRadio to 2360–2400 MHz band **Application:** Medical Body Area Networks (MBANs)—used by healthcare facilities to monitor vital patient health information with wireless sensors • Wireless sensors use MBAN to communicate with nearby MBAN programmer/controller (hub), which in turn relays information via Ethernet or Wireless Medical Telemetry Service (WMTS) to central station in a healthcare facility
Timeline
Jul 2006: As part of its MedRadio proceeding, FCC issued a *Notice of Inquiry* (FCC 06-103) regarding future spectrum needs for wireless medical technologies **Dec 2007:** GE Healthcare (GEHC) filed a response that became a *Petition for Rulemaking* (FCC DA 08-953) proposing that 2360–2400 MHz band be used by MBANs on secondary basis **Jun 2009:** NPRM (FCC 09-57) proposed MBAN service based on GEHC Petition **Jan 2011:** "Joint Proposal"—ex parte filing developed by incumbent Aeronautical Mobile Telemetry (AMT) licensees and MBAN proponents—on how to approach AMT-MBAN sharing **May 2012:** First Report and Order and Further NPRM (FCC 12-54)—based closely on "Joint Proposal"—extended MedRadio to MBANs **Outstanding Issue:** Selection of MBAN Coordinator
Users
Primary: • Predominant: Federal and non-Federal aeronautical mobile telemetry (AMT) at 2360–2395 MHz (but very sparsely used in 2390–2395 MHz band, due to risk of interference from amateurs) • Others: Federal radiolocation at 2360–2390 MHz (supporting radio astronomy operations in Arecibo, Puerto Rico) and non-Federal amateur radio at 2390–2400 MHz **Secondary (Incumbents):** • Federal fixed service at 2390–2400 MHz **Secondary (as of May 2012 First Report and Order—MBANs, a new *license-by-rule* MedRadio service):** • 2360–2390: Registration and coordination; indoor use only • 2390–2400: No registration and coordination; any location
Sharing Mechanisms
Low power: Minimizes harmful interference to incumbents **Rules of use:** (1) Device certification, (2) Operation under supervision of authorized health care professional **Additional rules to protect incumbent AMT licensees in 2360–2390 MHz band:** • Registration and coordination of MBAN operations with MBAN Coordinator • Use restricted to indoor operation within healthcare facility • Lower power levels than 2390–2400 MHz band • Use in Puerto Rico requires prior notification to protect operations at Arecibo Observatory, in accordance with existing CB radio service rules **Additional mitigating factors in 2390–2400 MHz band:** (1) Lack of geographic proximity between MBANs and amateurs, (2) Frequency agility capabilities built into MBAN devices

6. Commercial Space Launch Services
Shared Spectrum: Up to 375 megahertz to support space launch operations • 420–430 MHz, 2200–2290 MHz, and 5650–5925 MHz **Governing Rules:** 47 CFR §2.106, the Table of Frequency Allocations, is amended **Application:** Used for communication and tracking during launch phase and in particular, self-destruct messages; intent is to provide spectrum for the expanding use of commercial space launches and additional future needs of the commercial space industry
Timeline
Nov 2008: NASA awards commercial space station resupply contracts **May 2012, October 2012, March 2013:** Special Temporary Authority (STA) was issued to two commercial space companies to support launches on case-by-case basis **May 2013:** NPRM and NOI (FCC 13-65)
Users
Primary: • 420–430: Federal Radio Location and non-Federal land mobile service at three locations. Proposed commercial use for self-destruct messages during launch • 2200–2290 (launch telemetry): Primary for Federal space operation, earth exploration-satellite, fixed, mobile, and space research services. Proposed commercial use for self-destruct messages during launch (2207–2219 MHz, 2270.5–2274.5 MHz, and 2285–2290 MHz portions) • 5650–5925 (radar tracking during launch): Federal Radio Location, non-Federal primary Fixed Satellite Service (FSS) allocation for international, non-Federal mobile primary allocation for Intelligent Transportation System radio service **Secondary:** • 420–430: Non-Federal amateur radio • 5650–5925: Non-Federal amateur radio, non-Federal amateur satellite service
Sharing Mechanisms
Coordination: Proposal to either (1) allocate non-Federal launch uses on a co-primary basis with Federal users in the Allocation Table, or (2) create a rule (Allocation Table footnote) to allow non-Federal launch uses with interference protection • Use of the bands by non-Federal users require coordination with Federal users to avoid interference • Details to be worked out based on responses to the NPRM

7. Federal Fixed Satellite Earth Stations using Commercial Satellites
Shared Spectrum: 13.275 gigahertz of spectrum in parts of 10 satellite bands • Provide interference protection for Federal earth stations that communicate with commercial Fixed-Satellite Service (FSS) and Mobile-Satellite Service (MSS) space stations • Governing Rules: 47 CFR §2.106, the Table of Frequency Allocations, is amended • Application: Improve government use of commercial satellite capabilities as directed by the National Space Policy; the FSS services are used for video, voice, and data
Timeline
Aug 2006: NTIA files petition for protection of Federal earth station use of commercial satellites **May 2013:** NPRM and NOI (FCC 13-65)
Users
Primary: • 3700–4200 MHz downlink and 5925–6425 MHz uplink: FSS and Fixed Service (FS) and Mobile Service (MS) • 19.7–20.2 GHz downlink and 29.5–30.0 GHz uplink: Overlapping FSS, MSS, MS, and FS allocations; also a Federal co-primary FSS allocation in 18.3-20.2 GHz in three locations • 10.7–11.7 GHz downlink and 12.7–13.25 GHz + 13.75–14.0 GHz uplink: FSS shares spectrum as co-primary with terrestrial services and with Federal radars and NASA's Tracking and Data Relay Satellite System (13.75–14.0 GHz uplink) • 40–41 GHz and 48.2–50.2 GHz: Co-primary Federal FSS allocations already exist **Proposed:** Co-primary or protection for Federal Earth stations operating with commercial satellites is proposed for the following ten bands • Fixed Satellite (space-to-Earth): 3700–4200 MHz, 10.7–12.2 GHz, and 37.5–39.5 GHz • Fixed Satellite (Earth-to-space): 5850–6725 MHz, 12.7–13.25 GHz, 13.75–14.5 GHz, 27.5–30 GHz, and 47.2-48.2 GHz • Mobile Satellite (space-to-Earth): 19.7–20.2 GHz • Mobile Satellite (Earth-to-space): 29.5–30 GHz
Sharing Mechanisms
Coordination: Proposal to either (1) allocate Federal Earth stations to above bands on a co-primary basis with non-Federal users in the FSS and MSS bands creating shared spectrum in the Allocation Table, or (2) create a rule (Allocation Table footnote) to provide interference protection for Federal earth stations, maintaining FCC control. • Earth stations are generally coordinated with commercial satellite operators • Federal earth stations in these bands would operate under FCC rules of operation (Part 25) and receive interference protection (rules dependent on approach adopted) • In the bands shared between terrestrial and satellite users, coordination between terrestrial licensees and earth stations is required

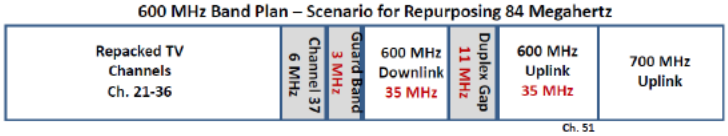
8. Level Probing Radar (LPR)
Shared Spectrum: Comprehensive rules for unlicensed level probing radar (LPR) • 16.275 gigahertz in three spectrum bands: 5.925–7.250 GHz, 24.05–29.00 GHz, 75–85 GHz **Governing Rules:** 47 CFR §15.256, Operation of level probing radars within the bands 5.925–7.250 GHz, 24.05–29.00 GHz, and 75–85 GHz • Existing LPR technology has primarily operated inside tanks on an unlicensed basis at 6 GHz, 24 GHz, and 26 GHz bands under Rule §15.209 • New Rule §15.256 establishes a new LPR band (75–85 GHz), higher LPR emissions limits for better device measurement accuracy, and allows for certification measurement of main beam emissions rather than reflected emissions, simplifying the certification process **Application:** Unlicensed Level Probing Radar • LPR devices are downward-looking low-power radars that measure the height level of a substance in containers (tank LPR) or open-air environments; applications include sewer tanks, coal piles, and water level measurement devices installed on bridges • New rules designed to streamline product development process, and spur introduction of new LPR applications, including for open-air applications, which have been difficult to certify under strict requirements of §15.209
Timeline
Jan 2010: NPRM and Order (FCC 10-14) **Mar 2012:** Further NPRM (FCC 12-34) **Jan 2014:** Report and Order and Order (FCC 14-2)
Users
Primary: • 5.925–7.250 GHz: Federal fixed and space research (7.125–7.250 GHz) and non-Federal fixed, fixed satellite and mobile (5.925–7.125 GHz) • 24.05–29.00 GHz: Federal and non-Federal radiolocation, Earth exploration satellite, amateur, fixed, inter-satellite, radionavigation, radiolocation satellite, fixed satellite, mobile, standard frequency and time signal satellite, space research • 75–85 GHz: Federal and non-Federal radio astronomy, fixed/mobile/fixed satellite, mobile satellite, broadcast, broadcast satellite, radiolocation, space research, amateur and amateur satellite; sparsely used **Unlicensed (in addition to newly authorized LPR use under §15.256):** • 5.925–7.250 GHz: Permitted under §15.209, under stricter radiation limits; wideband systems permitted under §15.250 including LPR; not permitted for toys, onboard aircraft or satellites, or for outdoor area networks • 24.05–29.00 GHz: Permitted both under §15.209 (general) and §15.252 (vehicular), except in the 23.6–24.0 GHz band, where only vehicular use is permitted • 75–85 GHz: Permitted only for vehicular radar use under §15.253 (76–77 GHz)
Sharing Mechanisms
Certification of LPR devices: Compliance with emission limits **Characteristics mitigating potential interference:** • Interference from LPR is unlikely, given downward-looking, fixed location setup, and existing LPR or vehicular radar use in all three bands without interference • In 75–85 GHz band, interference is mitigated because propagation losses are significant and the band is otherwise little used

9. 600 MHz Incentive Auction

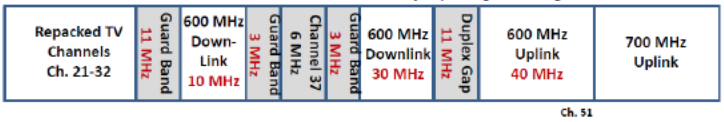
Shared Spectrum: 20-34 megahertz of unlicensed spectrum (guard bands, duplex gap, Channel 37)

- Repacking and clearing of UHF TV broadcast channels (512-698 MHz) to free spectrum for cellular use in geographic areas through 2 stage incentive auction for broadband wireless on geographic basis
- New significant amount of unlicensed spectrum available on a nationwide basis

600 MHz Band Plan – Scenario for Repurposing 84 Megahertz



600 MHz Band Plan – Scenario for Repurposing 108 Megahertz



Governing Rules:

- New 600 MHz band licensees flexible use service rules under 47 CFR Parts 1, 27, and 73 with technical rules similar to those governing the adjacent 700 MHz band
- Changes to Part 15 rules for 600 MHz band unlicensed users (FCC 15-99)

Application:

- Increased commercial wireless broadband spectrum (see FCC 15-78 on incentive auction)
- Additional spectrum for applications such as Wi-Fi and Super Wi-Fi—unlicensed use of (1) the guard bands separating TV channels and new broadband uses, (2) the duplex gap, and (3) Channel 37
- Continued use of unused TV channels by TV white space (TVWS) devices

Timeline

2006–2012: Rules and Orders for unlicensed operation in the TV broadcast bands (TV white space)

Feb 2012: Spectrum Act (MCTRJCA 2012, Title VI) authorizes incentive auction for Broadcast TV and specifies use of reasonable guard bands

Oct 2012: NPRM (FCC 12-118) proposes rulemaking for TV spectrum incentive auction

Jun 2014: Report and Order (FCC 14-50) announces incentive auction

Aug 2015: Public Notice (FCC 15-78) addresses procedures for competitive bidding for (1) reverse auction, scheduled to begin 29 March 2016, and (2) forward auction, which will follow reverse auction

Aug 2015: Report and Order (FCC 15-99) proposes rulemaking for unlicensed operations

Users

Primary:

- Wireless Medical Telemetry Service (WMTS), Radio Astronomy Service (RAS) on Channel 37
- Licensed wireless microphones in Duplex Gap

Secondary:

- Licensed Fixed Broadcast Auxiliary Service (BAS) in post-auction TV bands
- Unlicensed devices and wireless microphones permitted in guard bands
- Unlicensed use of Channel 37 where not used by incumbents
- Unlicensed TVWS devices can operate on remaining channels assigned to Primary TV

Sharing Mechanisms

Guard bands and coordination:

- Guard bands to separate service types
- On Channel 37, coordination with existing RAS by new broadband operators

TV white space database:

- Regulate access by unlicensed TVWS users to unused TV Channels
- Protect wireless microphones from TVWS users

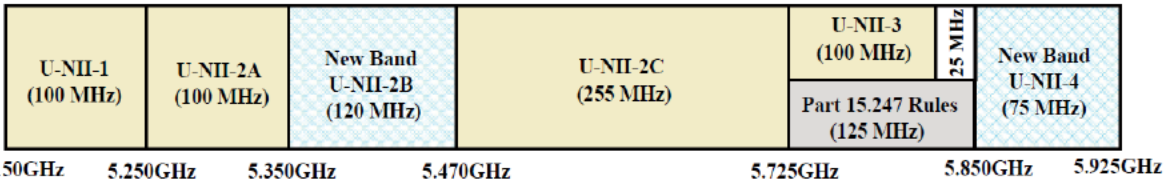
Low power restrictions: For unlicensed devices

10. TV White Spaces
Shared Spectrum: Average of 107 megahertz, with at least 96 megahertz available in most of the United States (Spectrum Bridge 2010) • Unlicensed operation in the TV broadcast bands below 900 MHz and in the 3 GHz band • Database controlled access to unused 6 megahertz TV channels in a geographic area • TV Band Devices (TVBD) can be (1) Fixed devices that operate on channels 2–51, excluding channels 3, 4 and 37, or (2) Portable devices that operate on channels 21–51 except 37. **Governing Rules:** • Unlicensed device certified under a new Part 15 Subpart H – Television Band Devices **Application:** • Wi-Fi, Super Wi-Fi, Rural Broadband
Timeline
Dec 2002: Notice of Inquiry (FCC 02-328) to consider operation of devices in TV white spaces **May 2004:** NPRM (FCC 04-113) **Oct 2006:** First Report and Order and Further NPRM (FCC 06-156) **Nov 2008:** Second Report and Order and Memorandum Opinion and Order (FCC 08-260) requires database access control and sensing of spectrum **Jun 2009:** Conversion to Digital TV started **Sep 2010:** Second Memorandum Opinion and Order (FCC 10-74) removing sensing requirement **Dec 2011:** FCC (2011) announces approval of first TVWS database system and devices **Apr 2012:** Third Memorandum Opinion and Order (FCC 12-36)
Users
Primary: • Broadcast TV (full power TV, Class A stations, low power TV, TV translator, wireless microphones, fixed broadcast auxiliary service (BAS), multichannel video programming distributors (MVPD), public safety, private land mobile operations, Offshore radio telephone service, specified radio astronomy sites • Registered unlicensed wireless microphones (e.g., for large events) **Secondary:** • TVBDs can opportunistically access unused channels after contacting TVWS database
Sharing Mechanisms
Low Power Operation: • Certification of fixed and portable TVBDs. Fixed devices may have higher power **Separation:** Fixed devices may not operate adjacent to occupied channel **TV White Space Database:** Protect incumbent users, through automated access to channel data • Operated by FCC designated administrators (e.g., Spectrum Bridge, Telcordia, and Google) • Contains Information on TV, other services, registered wireless microphones for large events • TVBDs must periodically submit geolocation to the database and receive information on available channels prior to use; devices can only use received channels • Portable devices—geolocation required or must communicate with another device with geolocation

11. Unlicensed National Information Infrastructure (U-NII)

Shared Spectrum (5 GHz band): Additional 195 megahertz of unlicensed spectrum

- Since 2003, U-NII devices have operated in 555 MHz of spectrum in 5 GHz band: U-NII-1, U-NII-2A, U-NII-2C, and U-NII-3. IEEE 802.a, 802.n, and 802.ac Wi-Fi standards use U-NII bands (FCC 13-22)
- Near-term achievement: Enhanced utility of 100 MHz (U-NII-1) of currently shared spectrum
- Goal: Proposed sharing of additional 195 MHz (U-NII-2B and U-NII-4) of Federal spectrum



Governing Rules: 47 CFR, Part 15, Subpart E, Unlicensed National Information Infrastructure (U-NII) Devices (supersedes 47 CFR, Part 15, Subpart C (§15.247) rules as they pertain to U-NII)

Application: Wi-Fi, including new Gigabit Wi-Fi (IEEE 802.11ac), which can be used to relieve congestion at Wi-Fi hot spots, provide broadband to rural areas, and off-load cellular traffic

Timeline

Feb 2012: Spectrum Act (MCTRJCA 2012, Title VI) required FCC and NTIA to move toward expanding U-NII sharing into U-NII-2B band U-NII-4 bands

Feb 2013: NPRM (FCC 13-22) proposed expanding sharing into additional 195 MHz of Federal spectrum (U-NII-2B and U-NII-4); also proposed changes to enhance utility of existing U-NII bands

Apr 2014: First Report and Order (FCC 14-30) (1) enhanced utility of U-NII-1 band by removing restriction on indoor-only use and increasing permissible power to that of U-NII-3 band, (2) extended upper edge of U-NII-3 band by 25 megahertz and harmonized the rules for operation in the band, and (3) postponed rulemaking for U-NII-2B and U-NII-4 bands, pending additional technical analyses

Aug 2014: ANPRM and Research Report (NHTSA 2014a, 2014b) addressed sharing of the U-NII-4 (DSRC) band, in terms of protecting vehicle-to-vehicle (V2V) communications from harmful interference from U-NII devices

Mar 2015: Final Report of DSRC Coexistence Tiger Team summarizes sharing issues and recommends further analysis and field/lab testing

Selected Users

(vary by sub-band) (See FCC Online Table of Frequency Allocations)

Primary (selected only; see above references for details):

- All U-NII bands except U-NII-1: Federal radars
- U-NII-2A, U-NII-2B, and U-NII-2C: Federal earth exploration and space research
- U-NII-2C: Federal and non-Federal meteorological aids (e.g., Terminal Doppler Weather Radar)
- U-NII-4: Intelligent Transportation System (ITS) Dedicated Short-Range Communications (DSRC)

Secondary (selected only; see above references for details):

- U-NII-2C, U-NII-3, and U-NII-4: Non-Federal amateur radio

Unlicensed: U-NII, as specified in 47 CFR, Part 15, Subpart E

Sharing Mechanisms

Dynamic frequency selection (DFS): Required in U-NII-2A and U-NII-2C bands: U-NII devices detect radars and shift to alternative frequencies to avoid causing harmful interference

Transmit power control (TPC): Also required in U-NII-2A and U-NII-2C bands: U-NII devices transmit at less than maximum power when doing so can maintain quality of service; intended to protect Earth Exploration Satellite and Space Research Services

U-NII device certification: Compliance to rules

U-NII device software integrity: Manufacturers must secure devices against illegal modification (such as disabling DFS in device certified for operation in U-NII-2A or U-NII-2C bands)

12. 60 GHz Unlicensed Service
Shared Spectrum: 7 gigahertz in the 60 GHz Region • New rules for previously shared 57–64 GHz frequency band **Governing Rules:** 47 CFR §15.255, Operation within the band 57–64 GHz • Since 1995, Part 15 of the FCC's rules has permitted unlicensed operation of devices in the 57–64 GHz band; Part 15 now permits higher emission limits for outdoor devices, simplifies power limit measurement and compliance, and eliminates the requirement that devices must broadcast a transmitter ID **Application:** Unlicensed devices, such as point-to-point broadband services • Primary users of unlicensed 57–64 GHz spectrum are (1) outdoor short-range point-to-point systems that extend broadband networks between buildings or provide broadband backhaul between cellular network base stations, and (2) indoor wireless personal area networks (WPANs) that connect consumer electronic devices • Rule changes designed to facilitate cost-effective development of broadband transmission links with longer operating distances
Timeline
Sep 2004: Petition for Rulemaking (WCA 2004) filed by Wireless Communications Association **Jun 2007:** NPRM (FCC 07-104) **Aug 2013:** Report and Order (FCC 13-112)
Users
Primary: • Federal fixed, inter-satellite and radiolocation, and non-Federal fixed, mobile, and radiolocation; very few primary users of any type **Unlicensed:** • Access is unrestricted except not permitted onboard aircraft or satellite
Sharing Mechanisms
Certification of devices: Compliance with emission and RF exposure limits **Characteristics Mitigating Potential Interference:** • Outdoor point-to-point links produce a narrow beam unlikely to interfere with indoor WPAN systems • WPAN systems operate behind walls that attenuate signals from higher-powered outdoor devices • Significant geographic separation of outdoor point-to-point links and indoor WPAN networks

13. 70-80-90 GHz Millimeter Wave Service
Shared Spectrum: 12.9 gigahertz of shared spectrum • 71–76 GHz, 81–86 GHz, and 92–95 GHz shared between Federal and non-Federal users **Governing Rules:** 47 Parts 15 (RF Devices for indoor use), 97 (Amateur Radio), and 101 (Fixed Microwave) **Application:** High-speed, point-to-point wireless local area networks and broadband Internet access. Due to the highly directional, "pencil-beam" signal characteristics, systems in these bands can co-exist in close proximity to one another without causing interference
Timeline
Sep 2001: Proposal by Loea Communications Corporation (Loea 2001) for rules on the licensed use of the 71–76 GHz and 81–86 GHz bands **Jun 2002:** NPRM and NOI (FCC 02-180) on allocations and service rules for the 71–76 GHz, 81–86 GHz and 92–95 GHz bands **Nov 2003:** Report and Order (FCC 03-248) **Sep 2004:** Order (FCC 04-3151) designating link registration system managers **Mar 2005:** Memorandum Opinion and Order (FCC 05-45) to modify some operating parameters based on a petition by the Wireless Communications Association
Users
Primary: • 71–76 GHz: Federal and non-Federal mobile, fixed, and fixed satellite (71–75.5), and mobile satellite (71-74), and non-Federal broadcasting and broadcasting-satellite services(74–76) • 81–86 GHz: Federal and non-Federal fixed, fixed-satellite, mobile-satellite (81–84), mobile, and radio astronomy services • 92–95 GHz: Federal and non-Federal fixed, mobile, radio astronomy, radiolocation services, and Federal Earth exploration satellites and space research (94.1–95) **Secondary:** • 71–76 GHz: Space research (74–76) and an existing primary allocation for amateur radio (75.5–76) • 81–86 GHz: Space research (81–84) • 94-94.1 GHz: Radio astronomy (94–94.1) for space communications • 92-95 GHz: Unlicensed indoor use
Sharing Mechanisms
Narrow Beams: Highly directional, pencil beam transmissions are used to allow multiple concurrent users (indoor-use only for unlicensed 92-95 GHz) **Coordination (70 and 80 GHz):** Unlimited non-exclusive nationwide licensing for non-Federal fixed and mobile use; a licensee will not be authorized to operate a link under its nationwide license until the link is both coordinated with the NTIA (to protect classified information) and registered as an approved link in a third-party-managed registration database • NTIA checks registration requests against incumbent Federal (and non-Federal radio astronomy) uses using an automated mechanism that reports a "green light," resulting in near-instantaneous registration, or a "yellow light," which requires the licensee to further coordinate with the IRAC for approval • Non-Federal active users are protected against future interference from later Federal users

4. Other Recent Activities in Support of Spectrum Sharing

This chapter describes various activities that have been undertaken in recent years to promote the development, acceptance, and use of advanced spectrum sharing methods, and that have, in many cases, laid the foundation for the specific spectrum sharing initiatives covered in the previous chapter. First, it discusses important steps that the NTIA and the FCC have taken in support of the President's call for making more spectrum available for commercial wireless broadband use. Next, it summarizes Federal research and development efforts related to advanced spectrum sharing technologies and methods. Finally, it identifies standards activities that are closely related to ongoing spectrum sharing initiatives, such as unlicensed use of TV white spaces.

A. NTIA and FCC Activities to Advance Spectrum Sharing

1. Spectrum Band Analyses

The NTIA and the FCC have been working collaboratively to identify additional spectrum for commercial use, all entailing some level of sharing, in response to the National Broadband Plan (FCC 2010) and the subsequent Presidential Memorandum (2010) calling for 500 megahertz of spectrum for expanded wireless broadband use. In addition, the Spectrum Act (MCTRJCA 2012, Title VI) called for additional study and analysis of the 5350-5470 MHz and 5850-5925 MHz bands for unlicensed use. As a result, several important studies have outlined the possibilities.

FCC National Broadband Plan (FCC 2010). The FCC, mandated by Congress, started the process of creating the National Broadband Plan with a Notice of Inquiry in April 2009. At that time, the FCC had only 50 megahertz in its inventory, not enough to meet the expected demand. The Plan's recommendations on spectrum policy included the following:

- Make 500 MHz of spectrum newly available for broadband use within 10 years, of which 300 MHz should be made available for mobile use within 5 years.
- Provide incentives and mechanisms to repurpose spectrum to more flexible uses.
- Expand options for opportunistic and unlicensed use of spectrum and support research into new spectrum technologies.
- Ensure greater transparency of spectrum allocation, assignment, and use.

NTIA Response to Presidential Memorandum. In October 2010, the NTIA issued a Plan and Timetable (NTIA 2010a) to achieve the President's 500 megahertz goal over the next 10 years and identified over 2,200 megahertz of Federal and non-Federal spectrum bands as candidates for evaluation. The NTIA also released a Fast Track Report (NTIA 2010b) on an evaluation of four candidate bands. The Report identified 15 megahertz in the 1675–1710 MHz band and 100 megahertz in the 3550–3650 band that could be made available for wireless broadband use within 5 years, but concluded that the 1755–1780 band and the 4200–4220 and 4380–4400 bands needed further investigation.

Commerce Spectrum Management Advisory Committee (CSMAC) Studies. NTIA created working groups under the auspices of the Commerce Spectrum Management Advisory Committee (CSMAC) to develop recommendations on approaches to sharing, transition, and/or relocation for the 1695–1710 and 1755–1850 MHz bands. The main purpose of the working groups was to facilitate interaction among Federal agencies, industry experts, and other interested stakeholders, in order to further refine the NTIA's Assessment of these bands. Working Group 1 focused on the 1695–1710 MHz band, while the other four working groups were organized by application area (e.g., Law Enforcement, Satellite Control, Ground-based, Airborne) in the 1755–1850 MHz band. The 1755–1850 MHz band working groups were primarily concerned with compatibility of commercial LTE systems and Federal systems. The CSMAC working group reports, completed in 2013, indicated that some systems could be relocated, some required coordination and protection zones, while others, such as military airborne systems, required hundreds of kilometers of separation. Some of the reports concluded that additional studies of sharing methods were required (CSMAC WG1 2013, CSMAC WG2 2013, CSMAC WG3 2013, CSMAC WG4 2013, and CSMAC WG5 2013).[22]

NTIA 3.5 GHz Analysis. In response to the 2012 FCC NPRM on spectrum sharing between radar and non-radar systems in the 3550–3650 MHz band, the NTIA Institute for Telecommunication Sciences (ITS) (in collaboration with the NTIA Office of Spectrum Management and U.S. Navy electronics engineers) is performing focused measurement studies to assess the compatibility of broadband communication systems and radar systems operating in the band. In one study, a series of tests was conducted to assess the effects of pulsed radar signals on the performance of LTE in time division duplex mode. The test results measured broadband LTE receiver performance (data throughput rates, block error rates, and internal receiver noise levels) when exposed to various radar waveforms at varying power levels (Sanders, F., et al. 2013). Another study examined the effects of various radar waveforms on LTE in frequency division duplex mode and a

[22] See Spectrum Sharing Initiative 1, Advanced Wireless Services (AWS-3), in Section 3.B of this report for background and current information on the status of the 1755–1780 band.

client device (Sanders, G., et al. 2014a). In a third study, the effect of LTE signals on current and anticipated radar systems was measured (Sanders, F., et al. 2014b). In these three studies, significant impacts on both LTE and radar performance were observed. The reports concluded that additional studies were needed to better understand the interactions and possible mitigations to achieve effective band sharing.

A fourth NTIA study in the 3.5 GHz spectrum band examined the emission spectrum characteristics of selected naval radars (Sanders, F., et al. 2014c). The fifth and most recent study examined the emission spectrum characteristics of a 3.5 GHz LTE hotspot (Sanders, G., et al. 2015). The results of these studies will provide valuable input to electromagnetic compatibility analyses for future 3.5 GHz spectrum sharing between LTE-based devices and incumbent radar systems.

NTIA 5 GHz Analysis. As required by the Spectrum Act (MCTRJCA 2012, Title VI), the NTIA investigated the potential use of 195 megahertz of spectrum in the 5350–5470 MHz and 5850–5925 MHz bands by U-NII devices (DOC 2013). These bands currently support a variety of Federal systems, such as radar and airborne communications. The NTIA examined the effects of various types of advanced spectrum sharing on these systems and identified risks and mitigations. The NTIA concluded that further quantitative analysis was needed to ensure that Federal operations would not be overwhelmed by large numbers of U-NII devices.[23]

Progress on Ten Year Plan. The NTIA's Ten Year Plan (NTIA 2010) identified 2,200 megahertz of spectrum for possible repurposing. According to the NTIA's Fifth Interim Progress Report (NTIA 2015, Table B-1), 80 megahertz has already been made available for repurposing or sharing; between 207 and 309 megahertz (depending on the outcome of the upcoming incentive auction) is in the process of being repurposed or shared; and 205 megahertz in being actively studied for repurposing or sharing.

Moreover, additional spectrum bands totaling 960 megahertz are slated for quantitative assessments of actual Federal usage to help determine which bands are the best candidates for future study for repurposing and/or sharing. These assessments were called for in Section 3(a) of the 2013 Presidential Memorandum (Sec. 3(a)), and a plan for conducting the assessments was laid out in Appendix A of the NTIA's Fourth Interim Progress Report. The plan identified five specific bands for quantitative assessments, as shown in Table 4-1.

[23] See Spectrum Sharing Initiative 8, Unlicensed National Information Infrastructure (U-NII), in Section 3.B of this report for further information and current activities related to the U-NII bands.

Table 4-1. Spectrum Bands for Quantitative Assessment (NTIA 2014b, A-2)

Frequency Band (MHz)	Amount (megahertz)	Current Allocation/Usage	Federal Agencies with Assignments in the Frequency Band
1300-1390	90	Federal	Air Force (AF), Army (AR), DHS, FAA, Marine Corps (MC), Navy (N), NASA
1675-1695[24]	20	Federal/non-Federal shared	AF, AR, DOC, DOE, MC, N, NASA
2700-2900	200	Federal	AF, AR, DOC, DOE, FAA, MC, N, NASA, NSF
2900-3100	200	Federal/non-Federal shared	AF, AR, Coast Guard, DHS, DOC, DOE, EPA, FAA, N, NASA, DOT
3100-3550	450	Federal/non-Federal shared	AF, AR, N

The plan requires agencies to detail the characteristics (e.g., transmitter and receiver operating parameters, time of use parameter) of the systems associated with their frequency assignments, in order to produce a more accurate approximation of the extent to which each system uses its assigned spectrum. The plan also requires agencies to provide information "on their projected increases in spectrum usage as well as detailed information regarding any non-federal bands in which agency operations could be performed to aid in fulfilling their missions" (NTIA 2014b, 17).

2. Spectrum Inventories

The NTIA and the FCC each maintain publicly accessible websites of current spectrum allocations, assignments, and licenses:

- *NTIA Federal Government Spectrum Compendium.* This new website (referred to as Spectrum.gov) was announced by NTIA in April 2014 (Nebbia 2014). The website is aimed at providing greater transparency regarding how Federal government agencies utilize spectrum. It describes Federal spectrum use in the 225 MHz through 5 GHz bands. For each band, it gives the following information: (1) a narrative summary of Federal use, (2) a table showing the number and type of frequency assignments, and (3) major applications and systems.
- *FCC Spectrum Dashboard.* The FCC's Spectrum Dashboard (http://reboot.fcc.gov/reform/systems/spectrum-dashboard), launched in 2010, provides information on allocations and licenses for spectrum between 225 MHz

[24] The NTIA's Fifth Interim Progress Reports shows the 1675-1680 band as having already been selected for study; its 5 megahertz is included in the 205 megahertz cited in the report as being currently under study (NTIA 2015, Table B-1).

and 3700 MHz, the most desirable for mobile broadband services. The information can be browsed by frequency range, radio service (e.g., AWS-1, radiolocation), or frequency purpose (e.g., broadband, radar). The Spectrum Dashboard provides a graphic depiction of the spectrum allocation table, through which users can explore particular bands of interest, as well as a map giving ready access to information on all the licenses in a given location (e.g., a county).

3. Spectrum Monitoring

The NTIA Institute for Telecommunication Sciences (ITS) has conducted measurement studies to better understand the spectrum use patterns in certain bands based on specific assumptions. To date, broadband spectrum surveys have been reported for three large metropolitan areas: Denver, Colorado; San Diego, California; and Chicago, Illinois. The measurements were done using the NTIA's fourth-generation mobile sensor measurement system. The Denver study (Hammerschmidt 2013) and the Chicago study (Hammerschmidt 2014) measured frequency data spanning spectrum from 108 MHz to 10 GHz. The San Diego study examined the Maritime Radar Band in the 3550– 3650 MHz frequency range (Cotton 2014a). The spectrum measurements provided data on expected signal levels and probability of occurrences of signals, which are difficult to obtain without doing field measurements, based on the specific methodology and assumptions applied for each effort.

The 2013 Presidential Memorandum (Section 3(c)) directed the NTIA to go beyond these broadband spectrum surveys: "The NTIA shall design and conduct a pilot program to monitor spectrum usage in real time in selected communities throughout the country to determine whether a comprehensive monitoring program in major metropolitan areas could disclose opportunities for more efficient spectrum access, including via sharing." In August 2013, the NTIA issued a Notice of Inquiry (NTIA 13b) on a proposed spectrum monitoring pilot program that would, if fully funded, develop and deploy a prototype system to monitor spectrum usage in up to ten metropolitan areas throughout the United States. A key component of the program is the design, implementation, and deployment of a federated Measured Spectrum Occupancy Database (MSOD) architecture. The MSOD architecture would allow organizations to host sensors and MSOD instances (where an MSOD instance is a database and an associated web server) and contribute data to the overall program. It is envisioned that authorized users could query the real-time spectrum usage data through web browsers (Cotton 2014b; Cotton, et al. 2015).

4. Center for Advanced Communications

The National Institute of Standards and Technology (NIST) and the NTIA have established a national Center for Advanced Communications (CAC) (Boehm 2013, NIST

2013) in Boulder, Colorado, as called for in the Presidential Memorandum (2013). The Center's mission is to advance the fundamental understanding of spectrum and spectrum usage to promote spectrum sharing approaches and innovation. The Center will leverage NIST and NTIA research and engineering capabilities to address a wide range of advanced communications challenges and increase the impact of existing efforts already under way in both agencies. A key focus of the Center will be to promote interdisciplinary research, development, and testing in radio frequency technology spectrum sharing for public safety and commercial broadband applications. The laboratory will be located at the U.S. Department of Commerce Boulder Labs and is a collaboration between the new NIST Communications Technology Laboratory and the existing NTIA ITS. In May 2015, the Assistant Secretary of Commerce for Communications and Information announced that the CAC leadership—a NIST Co-Director and an NTIA Co-Director—would soon be in place and that the Center was expected to be fully operational by the end of the year (Strickling 2015).

5. National Advanced Spectrum and Communications Test Network

In March 2015, the NTIA, the NIST, and the Department of Defense (DoD) signed a Memorandum of Agreement (MOA) to support the National Advanced Spectrum and Communications Test Network (NASCTN) capability, an adjunct of the Boulder CAC. The NTIA, NIST, and DoD will share laboratories, test ranges, and modeling and simulation facilities. As stated in the NIST announcement of the MOA (NIST 2015), the NASCTN's key functions are to:

- Facilitate and coordinate spectrum sharing and engineering capabilities
- Create a trusted capability for evaluating spectrum-sharing technologies
- Perform outreach activities to identify spectrum-related testing and modeling needs
- Protect proprietary, classified and sensitive information while facilitating maximum dissemination

6. RF Model City

The PCAST Report (2012) introduced the concept of a Test City and a Mobile Test Service to address the need for more opportunities to test spectrum sharing systems in large-scale and realistic environments having a complex mix of existing services. The Test City was envisioned as providing "essential operational test data to establish the dependability of both the technology and the management techniques supporting the new spectrum architecture" (PCAST 2012, Appendix G). The Mobile Test Service was envisioned as providing measurement capabilities that could be relocated to rural and other areas of interest. An FCC Technological Advisory Council (TAC) Working Group on Advanced Sharing and Enabling Wireless Technologies also prepared

recommendations on an "RF Model City" concept. Issues considered included the scope and definition of the RF Model City, the practical logistics (e.g., location, systems, frequency bands, operational constraints, timelines/phases/objectives), and possible sharing technologies to be tested (FCC 2014a).

In July 2014, the NTIA and FCC released a Joint Public Notice requesting comments on establishing a public-private partnership to facilitate the creation of an urban test city environment which would be used for interdisciplinary research, development, testing and demonstration of advanced spectrum sharing technologies (FCC/NTIA DA 14-981). The Model City notice pointed to the FCC's recently modified rules of experimental licenses and sought comments on the potential relevance of "innovation zones" that permit multi-use geographic areas to be designated for experimental purposes (FCC 13-15). The Model City notice called for comments from all stakeholders on various aspects of the concept, including the organizational strategies, operating rules and possible regulatory changes, feasible locations, solicitation of participants, promotion of the facility, technology goals, funding sources, necessary equipment/facilities, use of government facilities such as NTIA/NIST CAC, interference limitation, and other concerns.

More recently, in April 2015, the FCC and the NTIA held a national workshop[25] with Model City stakeholders from industry, government, and academia to further explore the development of, and alternatives for, the Model City concept, the scope of the effort, a governance framework, and technical considerations. The results of the workshop will be used in moving the Model City concept to reality.

B. Federal Research and Development Activities in Support of Spectrum Sharing

In addition to NTIA and FCC regulatory actions and supporting activities, research and development (R&D) efforts and test bed developments are being pursued at several Federal agencies. In conjunction with the release of the 2013 Presidential Memorandum, the White House detailed steps to advance $100 million in funds for spectrum sharing and advanced communications R&D. The funds are to be disbursed through the National Science Foundation, Defense Advanced Research Projects Agency (DARPA), NTIA, and NIST (White House 2013).

Several Federal agencies have long recognized the potential of advanced sharing methods and related emerging technologies to address their own spectrum needs in terms

[25] A video record of the workshop, along with links to other materials including presentations given at the workshop, is available on the FCC website at https://www fcc.gov/events/fcc-and-ntia-announce-workshop-model-city-program.

of improved efficiency, better resilience, and additional capacity. In addition, the National Science Foundation (NSF) has invested in radio spectrum R&D at academic institutions for many years, due in part to the enormous potential benefits to the national economy.

Network and Information Technology Research and Development Program (NITRD) Wireless Spectrum Research and Development (WSRD). The WSRD Senior Steering Group[26] is tasked with coordinating Federal spectrum-related R&D activities and to advance the goals of the 2010 Presidential Memorandum. The group maintains a current list of government-supported, spectrum-related R&D projects, and an inventory of wireless test facilities in the U.S.[27] In addition, the group holds workshops, makes recommendations on research priorities, and coordinates with private industry and academia.

National Science Foundation (NSF) Enhancing Access to the Radio Spectrum (EARS).[28] Since 2012, The EARS program (EARS 2014) has been funding research projects aimed at "significant improvements in the efficiency of radio spectrum utilization, and in the ability for traditionally underserved Americans to benefit from current and future wireless-enabled goods and services." The EARS projects (66 awarded to date) are aimed at cross-disciplinary approaches that span the traditional boundaries of the technical, policy, and economic disciplines.

Department of Defense (DOD). The DOD has been involved in spectrum research in support of its many missions involving communications, intelligence, surveillance, reconnaissance, and electronic warfare for many years through Defense Advanced Research Projects Agency (DARPA), DOD laboratories, and collaborations with industry and academic institutions.

In February 2014, the DOD Chief Information Officer released the "Department of Defense Electromagnetic Spectrum Strategy" (DOD 2013). The report states that the DOD's demand for spectrum is growing due to the increasing demand for timely information at every echelon of operation, and due to the increasingly complex communication needs of modern military systems. The report directs DOD programs to "focus on developing systems that are efficient, flexible, and adaptable in their use of the spectrum; increasing our operational agility in use of the spectrum; and participating in the development of national and international policies and regulations needed to enable

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[26] WSRD web page. (For readers viewing hard copies of this document, links to web pages and portals are provided in the reference list.)

[27] WSRD maintains a map-based listing of test beds and labs at the WSRD Testbed Information Portal.

[28] NSF EARS web page.

these improvements" (DOD 2014). Two of the top four objectives listed in the report are related to spectrum sharing.

DARPA Advanced Sharing R&D. DARPA supported early research into cognitive radio and dynamic spectrum access through programs such as neXt Generation (XG), and it continues to research key problem areas in spectrum sharing for military systems (Fette 2013):

- *XG Program (2002–2008)*. The XG program was an early effort to automatically and dynamically access available spectrum and to develop and demonstrate these techniques (Marshall 2004). Initial versions of a wideband sensor were developed, and a policy layer was defined separately to allow experiments with varied sets of policies for spectrum sharing. The XG program laid the groundwork for future DARPA programs in dynamic spectrum allocation and cognitive radio techniques such as the Wireless Network after Next (WNaN) (Redi 2011) and the Advanced Wireless Networks for the Soldier (AWNS).[29]
- *Shared Spectrum Access for Radar and Communications (SSPARC)*.[30] The SSPARC program, started in 2013, seeks to improve radar and communications capabilities through spectrum sharing in spectrum below 6 GHz. It is pursuing *cooperative* sharing methods, where information is exchanged between systems in real time to facilitate sharing and avoid interference. The program is examining military/military and military/commercial sharing needs.
- *Advanced RF Mapping (RadioMap)*.[31] The RadioMap program, started in 2012, is developing real-time spectrum awareness as a function of frequency, terrain, and time to provide a dynamic map of the complex spectral environment to enable more responsive spectrum management. The environment information is obtained using radios as sensors, with minimal impact on the primary communication functions of the radios.
- *Spectrum Challenge* (DARPA 2014). A competition was held in March 2014 to develop adaptive techniques to use software-defined radios to communicate in the presence of interference and congestion. Fifteen teams—12 representing academic institutions and the remaining 3 composed of individual radio enthusiasts—participated in the competition, with the three winning teams earning a total of $150,000 in prize money.
- *Communications under Extreme RF Spectrum Conditions (CommEx)*.[32] The CommEx program, started in 2011, is developing adaptive techniques to enable communications in the presence of spectrum congestion and interference, such as

[29] DARPA AWNS web page.

[30] DARPA SSPARC web page.

[31] DARPA RadioMap web page.

[32] DARPA CommEx web page.

from jamming. The program employs various methods, including cognitive radio and spectrum sensing techniques (DARPA 2014e).

DOD Network Communications Capability Program (NCCP). The NCCP is an umbrella R&D program that has funded network research, including relevant spectrum-related activities, at DOD laboratories and universities since 2008 (for example, Boksiner 2010, Mai 2011, McGuffin 2010, Robertson 2012, Sakarya 2011). The program has investigated technologies such as cognitive radios and methods for DOD to share radio spectrum with commercial users and among other DOD users. Areas that have been investigated include sharing between cognitive radios and WiMAX networks, demonstration of an airborne- and ground-based spectrum sensing network, radar coexistence testing, spectrum sensing metrics, and proactive tactical cognitive radio networks. The program has also supported a number of test beds.

National Spectrum Consortium.[33] The recently formed National Spectrum Consortium (NSC)—whose spectrum industry members come from large businesses, small businesses, non-traditional government contractors, academic research institutions, and not-for-profit organizations—stems from a DoD initiative (announced in a March 2014 FedBizOpps.gov Solicitation Number W15QKN14Z1000) to "seek collaboration with industry on research and development (R&D) to advance better use of the electromagnetic spectrum." The initiative leverages the Spectrum Relocation Fund, a fund administered by the Office of Management and Budget (OMB) and financed by auction proceeds of eligible frequencies (47 U.S.C. § 928).

On 3 April 2015, the NSC entered into a five-year, $1.25 billion, Section 845 Prototype Other Transaction ("OT") Agreement with the Office of the Deputy Assistant Secretary of Defense ("ODASD"), Emerging Capabilities and Prototyping ("EC&P"). On 7 April 2015, the NSC adopted its Articles of Collaboration (NSC 2014), which state that the principal goals of the NSC are:

- Maturing technologies that assist in improved electromagnetic spectrum awareness, sharing, and use
- Experimentation to better inform the optimal allocation of those technologies for both public and private objectives
- Demonstration of new technologies to increase trust among spectrum stakeholders
- Policy development to ensure technologies don't outpace the appropriate guidance for their best use

The NSC now has a management firm, SCRA Applied R&D, in place. Next steps are to develop an assessment process, issue solicitations, make awards, and conduct research.

[33] http://www.nationalspectrumconsortium.org.

Department of Energy, Wireless Research Center, Idaho National Laboratory (INL).[34] Since 2003, the INL has operated a large wireless test bed for research into areas such as cognitive communications, dynamic spectrum allocation, multiband systems, and location-based services. The lab is situated on Federal property in a remote, low-noise environment and is equipped to conduct experiments and field tests of high-frequency (HF), ultra-high-frequency (UHF), satellite, microwave, second- and third-generation cellular networks with fixed and mobile towers, and standalone WIMAX (mobile and fixed) networks. The lab is authorized by the NTIA to operate as an experimental radio station on a noninterference basis with local spectrum users.

C. Standards Related to NTIA and FCC Actions

The need for technical standards for spectrum sharing systems has been recognized by many standards organizations as necessary for commercial adoption and product development. In some cases the standards have preceded government actions related to spectrum sharing, and in others they are closely following regulatory developments such as for the TV white space bands (Sum 2013, Mody 2013). However, all spectrum-dependent systems and devices must operate in conformance with the national rules and regulations. Several recent standards activities addressing sharing issues related to the United States are described below.[35]

1. TV White Space Standards

Several standards are leveraging TV white space and coming together to create a comprehensive TV white space ecosystem:

- *IEEE 802.11af TV White Space Band Devices*. This standard defines cognitive radio-based spectrum sharing between unlicensed TV white space band devices (WSBDs) and licensed TV services, where sharing is coordinated by a geolocation database that depends on the regulatory domain proposed by different countries (Flores 2013).
- *IEEE 802.22 Wireless Regional Area Networks (WRANs)*. This suite of standards, adopted by the WhiteSpace Alliance into its Wi-Far specification, leverages TV white space to provide cost-effective, reliable, secure, high-speed broadband access to rural and remote communities. The standards use cognitive radio features such as spectrum sensing, spectrum management, and geolocation, along with security mechanisms, to share TV white space and achieve intra-system coexistence (Mody 2010).

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[34] INL Wireless Research Center web page.

[35] Full bibliographic entries for the standards documents referenced herein are provided in the References section of this report.

- *IEEE 802.15m-2014 Low Rate Wireless Personal Area Networks (WPANs), Amendment for Use of TV White Spaces*. This standard specifies how 802.15.4 low power, unlicensed devices use TV white space to support indoor/outdoor applications such as device control and smart utilities in differing regulatory domains (Sum 2013).
- *IEEE 802.19.1 TV White Space Coexistence Methods*. This standard addresses radio technology independent methods for coexistence among dissimilar TV band devices and dissimilar or independently operated networks that access TV white space. The standard defines an architecture framework and services such as discovery of neighboring systems and management of the interactions with the white space database (Filin 2011).
- *IEEE DySPAN Standards Committee (DySPAN-SC)* (formerly the IEEE Standards Coordinating Committee 41 (SCC41)). DySPAN-SC has produced the IEEE 1900.X suite of standards[36] that covers cognitive radio technologies to improve spectrum efficiency, reduce interference, and coordinate networks deploying different wireless technologies. The DySPAN-SC has working groups on definitions and concepts for dynamic spectrum access (DSA), recommended practices, architectures, policies for cognitive radios, spectrum sensing interfaces and data structures, and dynamic spectrum access networks for TV white space and other spectral environments (Harada et al. 2011, Murroni et al. 2011).
- *Internet Engineering Task Force (IETF) Protocol to Access White Space (PAWS) Databases*. The proposed IETF PAWS Databases standard defines an Internet-based protocol for discovering and communicating with TV white space geo-location databases to acquire information on available channels (Chen 2014).

2. Gigabit Wi-Fi (5 GHz Spectrum)

- *IEEE 802.11ac High Speed Wireless Local Area Network (WLAN)*. This standard defines the medium access protocol and physical layer for a high-speed WLAN using smart antennas to achieve multi-user throughput of up to 7 Gbps and dynamic spectrum sensing to share with Federal systems (Aruba 2014).

3. Ultra-wide Band

- *IEEE 802.15.4a Ultra-wide band (UWB) for Low Rate Wireless Personal Area Networks (LR-WPANs)*. This amendment to the 802.15.4 standard for low-data-rate, low-power, and low-complexity, short-range radios adds an UWB capability that operates in any of three bands: (1) A sub-gigahertz band, (2) a low band, which is between the 2.45 GHz industrial, scientific, and medical (ISM) band and the 5 GHz unlicensed National Information Infrastructure (U-NII) band, and (3) a

[36] For further information on DySPAN-SC activities and products, see the DySPAN-SC web page.

high band, which is above the U-NII band and differs per country. It supports a mandatory data rate of 851 Kbps with optional data rates of 110 Kbps, 6.81 Mbps, and 27.24 Mbps. The standard also defines a spread spectrum capability at 2.45 GHz (Ahmadian 2009).

4. 60 GHz WLAN

- *IEEE 802.11ad Very High Throughput WLAN in 60 GHz*. This standard, also called WiGig, defines the medium access protocol and the physical layer for a high speed WLAN that operates in the 57.05–64.00 GHz band in the United States. The standard supports short-range communications at up to 7 gigabits per second using 2.16 gigahertz channels, and beam-forming by antenna arrays with 16 to 32 elements. The MAC layer is compatible with other current 802.11 standards and supports multi-mode operations (Schulz 2013, Zhu et al. 2011).

5. Conclusion

The Federal Government has been actively examining advanced spectrum sharing methods as a means of making more spectrum available for commercial purposes without the burden of relocating incumbent users. A 2012 report from PCAST outlined concepts, and there have now been a number of initiatives, studies, trials, standards activities, and regulatory changes designed to facilitate the research, development, and testing necessary to prove the feasibility of new spectrum sharing technologies.

Emerging technologies may permit automation of coordination functions that are currently being done manually. New techniques such as dynamic spectrum access and cognitive radios hold the promise of allowing the management of spectrum with much finer granularity than previously possible. These methods have the potential to enable better utilization of spectrum that is exclusively allocated but often idle. Overall, this can increase the available spectrum for many purposes and avoid the cost and delay of relocating incumbent users to new bands.

This study has identified 13 specific spectrum sharing initiatives that are either completed or well underway. The initiatives, summarized in Table 5-1, employ different sharing mechanisms but have the same ultimate goal—to make more spectrum available for commercial as well as Federal use:

- The **AWS-3** initiative is intended to meet wireless carrier demands for more licensed spectrum. Federal incumbents will either relocate to other bands or share with the incoming commercial systems, with sharing done on a geographical basis through the establishment of protection zones for the Federal users. In this way, spectrum is made available to carriers, while, at the same time, disruptions to Federal missions are prevented. Moreover, the reallocation of the 1755-1780 MHz band required compressing some Federal operations and relocating others to bands where a comparable capability could be assured.
- The **3.5 GHz Citizens Broadband Radio Service** (CBRS) is intended to demonstrate the feasibility of the PCAST licensing scheme, which enables incumbent users and CBRS users to share spectrum via a dynamic Spectrum Access System (SAS). Incumbent users operate at the first tier, while CBRS users operate at the second and third tiers as priority access users and general authorized access users, respectively.

Table 5-1. Summary of Selected Spectrum Sharing Initiatives

Spectrum Sharing Initiative	Primary Sharing Mechanism	Spectrum Band(s)	Shared Bandwidth	Incumbent Users	New Users	Status
Advanced Wireless Services (AWS-3)	Manual coordination of protection zones	1695–1710, 1755–1780, and 2155–2180 MHz	40 megahertz	Fed/Non-Fed (1695–1710); Fed (1755–1780)	Licensed	**Mar 2014**: Report and Order (R&O) **Nov 2014–Jan 2015**: Auction
3.5 GHz Citizens Broadband Radio Service (CBRS)	Spectrum Access System for 3-tiered access	3550–3700 MHz	150 megahertz	Fed	Licensed for priority access; Licensed by rule for general authorized access	**Apr 2015**: R&O and Second Further Notice of Proposed Rulemaking (FNPRM) **Jun 2015**: Public Notice
MedRadio	Listen before talk	401–406 MHz (402-405 already shared)	2 megahertz	Fed/Non-Fed	Licensed by rule	**Mar 2009**: R&O
Medical Micropower Networks	Dynamic frequency selection	413–419, 426–432, 438–444, and 451–457 MHz	24 megahertz	Fed/Non-Fed	Licensed by rule	**Nov 2011**: R&O
Medical Body Area Networks	Manual coordination	2360–2400 MHz	40 megahertz	Fed/Non-Fed	Licensed by rule	**May 2012**: First R&O and Further NPRM
Commercial Space Launch	Manual coordination	420–430, 2200–2290, 5650–5925 MHz	375 megahertz	Fed	Licensed	**May 2013**: NRPM and Notice of Inquiry (NOI)
Federal Earth Stations	Manual coordination	10 bands in the C, Ku, Ka, and V satellite bands	13.275 gigahertz	Non-Fed	Federal allocation	**May 2013**: NRPM and NOI
Level Probing Radar (LPR)	Directional, contained emissions	5.925–7.250, 24.05–29.00, 75–85 GHz	16.275 gigahertz	Fed/Non-Fed	Unlicensed	**Jan 2014**: R&O and Order
600 MHz Incentive Auction	TV white spaces database	512–698 MHz (42-144 megahertz to be repurposed)	20–34 megahertz	Non-Fed (Broadcast)	Unlicensed – guard bands	**Jun 2014**: R&O **Aug 2015**: Public Notice **Aug 2015**: R&O
TV White Spaces	TV white spaces database	54–60, 76–88, 174–216, 470–698 MHz	Varies (est. to average 107 megahertz)	Non-Fed (Broadcast)	Unlicensed – unused TV channels	**Apr 2012**: Third Memorandum Opinion and Order
U-NII Expansion	Dynamic frequency selection	5.350–5.470 GHz (U-NII-2B); 5.850–5.925 GHz (U-NII-4)	Additional 195 megahertz	Fed/Non-Fed	Unlicensed	**Apr 2014**: First R&O (under study)
60 GHz Unlicensed	Manual coordination of narrow beams, low power	57–64 GHz	7 gigahertz	Fed/Non-Fed	Unlicensed	**Aug 2013**: R&O
70-80-90 GHz Millimeter Wave	Manual coordination of narrow beams	71–76, 81–86, and 92–95 GHz (except 94.0–94.1)	12.9 gigahertz	Fed/Non-Fed	Licensed (70/80 GHz); Unlicensed (90 GHz)	**Mar 2005**: Memorandum Opinion and Order

- **MedRadio**, **Medical Micropower Networks**, and **Medical Body Area Networks** are intended to meet the needs of wireless medical devices. These licensed-by-rule services are able to share spectrum with incumbent users through mechanisms such as low power and dynamic frequency selection, as well as through a certain level of manual coordination.
- Two of the initiatives are intended to promote a robust commercial space industry. Both initiatives embody conventional spectrum sharing approaches, which entail careful manual analysis of the impact on the risk of harmful interference.
  - **Commercial Space Launch Services**. These services will provide spectrum for communications during commercial space launches. Such uses are already allowed today under special temporary authorizations, and the current proceeding would allow use in limited circumstances on a licensed basis.
  - **Federal Fixed Satellite Earth Stations using Commercial Satellites**. This is unique among the 13 initiatives in that its purpose is to gain Federal access rights to use non-Federal satellite capacity. It is included to make the point that Federal users, as well as non-Federal users, have unmet needs for spectrum.
- **Level Probing Radar** service is an example of a specialized service to determine the level of liquid. It accomplishes sharing through directional transmissions that are fixed, pointing downward and often contained within tanks.
- Several initiatives are intended to promote innovation in unlicensed wireless broadband communications services, which have spurred economic growth over the past 20 years. Two initiatives—the planned **600 MHz incentive auction** and **TV White Spaces**—are facilitating access to the TV bands for unlicensed use in certain geographic areas where the spectrum is not being used by the licensed users. The **U-NII** initiative is evaluating the expansion of the U-NII bands, which are already being used for Wi-Fi, by 195 MHz. The updated **60 GHz** Part 15 rules provide high-speed point-to-point broadband services. The **90 GHz** portion of the 70-80-90 GHz initiative, described below, is also proposed for unlicensed use.
- The **70-80-90 GHz** initiative, which is intended to stimulate innovation in millimeter wave communications, provides high-speed point-to-point broadband services. The **70 and 80 GHz** portion of the initiative requires non-exclusive nationwide licenses that are coordinated with the NTIA.

With respect to spectrum below 6 GHz, NTIA and the FCC have been cooperating toward expanding wireless broadband use, increasing sharing, and meeting the 500 MHz goal of the June 2010 Presidential Memorandum. The NTIA's Fifth Interim Progress Report (NTIA 2015, 1) states, "Between October 2010 and September 2014, NTIA and the FCC formally recommended or otherwise identified for study for potential

reallocation up to 589 megahertz.…" This total includes 335 megahertz in Federal or shared bands and between 152-254 megahertz in non-Federal bands (202-304 megahertz counting the 3650-3700 MHz band, bringing the total to 639 megahertz). An additional 960 megahertz (counting 5 megahertz listed in in the report as already being under study but not included in the 589 megahertz total) is slated for potential future study for repurposing. All together, the NTIA and the FCC have made available or are investigating for potential repurposing between 1447 and 1549 megahertz (or between 1497 and 1599 megahertz counting the 3650-3700 MHz band) of bandwidth under 6 GHz (NTIA 2015, Table B-1).

More still needs to be done to prove the feasibility and utility of the technologies and to gain acceptance by the commercial or non-Federal and Federal communities. The Model City concept, additional R&D, experimental test beds, pilot studies, and field trials could be used to demonstrate the performance, reliability, and cost effectiveness of advanced sharing methods. At the same time, new technologies are emerging that hold promise to further increase efficiency and effectiveness of sharing as part of these efforts.

This report has detailed efforts that are ongoing in the U.S., but there are activities in Europe and Asia. It is important for the United States to continue exploring the possibilities of advanced spectrum sharing, not only to enable more spectrum access to meet the demands for wireless broadband, but also to enable shared access for Federal agencies to address their growing spectrum requirements.

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Abbreviations

AJA	American Jobs Act
AMT	Aeronautical Mobile Telemetry
ANPRM	Advance Notice of Proposed Rulemaking
ASA	authorized shared access
AWS	Advanced Wireless Services
BAS	Broadcast Auxiliary Service
CAGR	compound annual growth rate
CB	Citizens Band
CBRS	Citizens Broadband Radio Service
CFR	Code of Federal Regulations
CRS	cognitive radio system
CSEA	Commercial Spectrum Enhancement Act of 2004
CSMA/CA	carrier sense multiple access with collision avoidance
CSMAC	Commerce Spectrum Management Advisory Committee
DFS	dynamic frequency selection
DOD	Department of Defense
DSA	dynamic spectrum access
DSRC	Dedicated Short-Range Communications
ECC	Electronic Communications Committee
ENG	Electronic News Gathering
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FS	Fixed Service
FSS	Fixed Satellite Service
FNPRM	Further Notice of Proposed Rulemaking
GAA	general authorized access
GAO	Government Accountability Office
GE	General Electric Company
GEHC	GE Healthcare
GHz	gigahertz (frequency or spectrum band)
GOES	Geostationary Operational Environmental Satellites
HetNet	heterogeneous networks
IDA	Institute for Defense Analyses
IEEE	Institute of Electrical and Electronics Engineers
IRAC	Interdepartment Radio Advisory Committee
ISM	Industrial, Scientific, and Medical
ITS	Institute for Telecommunication Sciences
ITS	Intelligent Transportation System
ITU	International Telecommunication Union
kHz	kilohertz (frequency or spectrum band)

LBT	listen before talk
LPR	level probing radar
LSA	licensed shared access
LTE	Long Term Evolution
LTE-A	LTE-Advanced
LTE-U	LTE-Unlicensed
MBAN	medical body area network
MCTRJCA	Middle Class Tax Relief and Job Creation Act of 2012
MedRadio	Medical Device Radiocommunication Service
MetSat	meteorological satellite
MHz	megahertz (frequency or spectrum band)
MICS	Medical Implant Communications Service
MIMO	multiple-in multiple-out
MMN	medical micropower network
MS	Mobile Service
MSS	Mobile Satellite Service
MVPD	multichannel video programming distributor
NITRD	Networking and Information Technology R&D
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rulemaking
NSC	National Spectrum Consortium
NTIA	National Telecommunications and Information Administration
OMB	Office of Management and Budget
PAL	priority access license
PCAST	President's Council of Advisors on Science and Technology
POES	Polar Operational Environmental Satellites
QoS	quality of service
R&D	research and development
R&O	Report and Order
RAS	Radio Astronomy Service
RF	radio frequency
SAS	Spectrum Access System
SDR	software-defined radio
SRF	Spectrum Relocation Fund
STA	Special Temporary Authority
STPI	Science and Technology Policy Institute
TPC	transmit power control
TVBD	TV band device
TVWS	TV white space(s)
U-NII	Unlicensed National Information Infrastructure
UWB	ultra-wide band
WCA	Wireless Communications Alliance
WLAN	Wireless Local Area Network
WMTS	Wireless Medical Telemetry Service
WPAN	wireless personal area networks
WSRD	NITRD Wireless Spectrum R&D Senior Steering Group

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14. ABSTRACT

The Presidential Memorandum of June 14, 2013, "Expanding America's Leadership in Wireless Innovation," called for the newly established Spectrum Policy Team (SPT) to prepare a report on how the National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC) are incorporating spectrum sharing into their spectrum management practices. This paper, prepared in support of the SPT's efforts, summarizes 13 spectrum sharing initiatives, some completed and others in progress, in terms of target spectrum band, amount of spectrum being shared, incumbent spectrum holders, major regulatory actions, sharing mechanisms, licensing approach, and current status. The paper also describes important foundational activities related to the advancement of spectrum sharing, including Federal research and development efforts as well as international standards activities.

15. SUBJECT TERMS

spectrum, spectrum sharing, spectrum management, spectrum policy, frequency allocations, wireless broadband, unlicensed spectrum, advanced wireless service, citizens broadband radio service, incentive auction, TV white spaces, standards, NTIA, FCC

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