Spectrum Sharing

The Promise and The Reality

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Introduction

As evidenced in recent comments and reports from government bodies such as NTIA at the Commerce Department, and The President's Council of Advisors on Science and Technology, there is increased interest in the concept of spectrum sharing. Three factors are driving this. First, there is the significant spectrum crunch faced by commercial mobile broadband consumers with the commensurate need to get additional spectrum into the hands of wireless broadband providers. Second is the awareness that many licensed frequency bands held chiefly by US governmental agencies are underutilized either over time or geography, yet complete relocation of these systems and reallocation of the spectrum to commercial use will take time and will be expensive. Finally, there has been some progress towards development of dynamic spectrum access (DSA) through approaches such as geolocation databases and cognitive radio (CR).

There is no question that spectrum sharing can and will eventually result in more efficient overall use of spectrum. There are already a number of spectrum sharing solutions in the market that can work under defined circumstances. But what must be understood is that spectrum-sharing approaches range from simple to extremely complex, from readily achievable and in use today to extremely difficult with technologies yet to be developed. The ones being used today solve relatively simple problems, e.g., geographic sharing or sharing between two types of fixed systems. More complex problems, such as how a carrier class mobile technology could share with multiple government systems will take many years to develop, test, and implement in an economically rational manner.

Making spectrum sharing a reality will mean identifying what types of systems can be shared, negotiating and stipulating access rights, determining the market for such shared systems, developing specifications and standards to allow sharing including spectrum-coordination systems, modifying existing networks to integrate with the new sharing architectures, developing infrastructure and devices to implement the sharing, certifying equipment using new test procedures and equipment for compliance, and finally enforcing compliance. This process could easily take ten years or possibly even much longer.

Certainly government and industry should collaborate and make the long-term investments in research and development to explore the potential of dynamic approaches to spectrum sharing. Given the technical, regulatory, and market complexities involved, however, the near-term spectrum capacity solutions such as making more spectrum available for commercial use from the 500 MHz identified in the National Broadband Plan should not be ignored in favor of these future and uncertain technologies.

The bottom-line reality is that there is no "magic bullet" spectrum-sharing technology currently in the pipeline that can adequately address the short-term and mid-term spectrum challenges faced by American consumers and our economy. Government, therefore, must continue to maintain its priority focus on rapidly clearing and reallocating as much spectrum as possible for commercial use even as longer-term technologies and sharing processes are developed.

Types of Sharing

Looking at sharing government spectrum, the Commerce Spectrum Management Advisory Committee (CSMAC) stated that, "DSA's promise is to improve spectrum utilization in three dimensions: frequency, location and time. It enables a network to opportunistically use any available channel (frequency) at points in time and space when and where they are not in use, and automatically move to another channel when policy demands it or a primary user/signal appears on the current channel. Because most RF channels are utilized only a small portion of the time and in a fraction of locations, DSA enables two or more applications/networks to share a given band."[1]

There are multiple ways that spectrum can be shared. The simplest way is to carve out geographic exclusion zones so that no two systems operate simultaneously in the same area. This is not DSA per se, but it is still spectrum sharing. For example, in the Advanced Wireless Service (AWS) bands, commercial licensees are required to protect from interference sixteen Department of Defense facilities located throughout the nation in the 1710-1755 MHz bands.[2] AWS licensees must do this by restricting the operation of their base stations from any locations that could potentially permit AWS mobile, fixed, and portable stations transmitting in the band to cause harmful interference within the radii of operation of the Federal government facilities.[3] This form of sharing is static, "wastes" spectrum because engineering calculations must be conservative, but it works. Another example is the FCC requirement for quiet zones in which wireless licensees must avoid interfering with radio astronomy and other sensitive government facilities.[4]

More complicated is DSA, in which the primary approaches are geolocation databases and CR. Sometimes the term CR is used synonymously with DSA, although strictly speaking, CR is a term that describes intelligence built into the radio itself so that it can react to the environment around it. One possible use of CR technology is DSA. When used for DSA, a CR senses the environment and adjusts its operation accordingly.[5] Sensing, for example, may involve detecting whether radios are already present

[1] Interference and Dynamic Spectrum Access Subcommittee, "Final Report," November 8, 2011.

[2] See 47 C.F.R. § 27.1134.

[3] Interference and Dynamic Spectrum Access Subcommittee, "Final Report," November 8, 2011.

[4] See 47 C.F.R. Sec. 1.924.

[5] As per the International Telecommunications Union (ITU), "ITU-R WP 1B defines the CR radio as a radio system employing technology that allows the system: to obtain knowledge of its operational and geographical

at that frequency, securing an open frequency, and switching to the vacant frequency. In contrast, a geolocation database, such as those now being developed to access TV white spaces, indicates via a database query what TV channels are available for data communication based on the geographical location of the radio.

Frequently appearing in discussions of CR systems is the term Software Defined Radio (SDR). This refers to radios in which physical layer functions (e.g., frequency range, modulation type) are implemented in software.[6] CR does not depend on SDR; however, future CR systems could employ SDR to increase their flexibility.[7]

To facilitate sharing of the same spectrum in the same location without interference and disruption, future systems are likely to employ some form of frequency coordination. For example, CSMAC states "We recognize that increased sharing between government and commercial users may necessitate greater government involvement in frequency coordination. Similarly, frequency coordination among disparate commercial enterprises may require a level of government oversight that is not necessary when coordinating among like services."[8]

Some current proposals, as reported by The New York Times[9], envision primary users with highest priority access, secondary users with more limited protections, and tertiary users who would use spectrum on an unlicensed basis using geolocation databases. This theoretical framework described seems promising, particularly in scenarios where the primary users only make limited use of the spectrum. However, the technology to accomplish this is only now being developed in the limited case of TV white spaces, in which the sharing case involves fixed, or at best, nomadic uses. More complex problems involving mobile networks have never been attempted.

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environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained." Source: IEEE Communications, "International Standardization of Cognitive Radio Systems," March 2011.

[6] See Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies, 25 FCC Rcd 587 n.3 (2010).

[7] For instance, an SDR could potentially adopt the medium-access protocols of the primary system, thus using the spectrum in a way similar to the primary system and thereby facilitating coexistence.

[8] Id.

[9] New York Times, http://www.nytimes.com/2012/05/26/technology/presidential-panel-urges-better-use-of-spectrum.html, May 25, 2012.

Beyond technical aspects, future sharing systems may also employ dynamic spectrum markets in which primary licensees can sell spectrum access to secondary users moment by moment. These market systems presume technical sharing issues are resolved, but they could add additional complexity that further delays the deployment of spectrum sharing approaches.

Examples of Sharing

Before discussing the technical issues involved in the sharing of spectrum, it is worth looking at some of the spectrum-sharing systems that are in use today, including their history and market situation.

One is TV white spaces, a DSA approach based on geolocation databases. The FCC issued final rules to allow low power unlicensed devices to operate on unused channels in the TV broadcast bands in September 2010, following a six-year process that began in May 2004 with the first Notice of Proposed Rulemaking (NPRM) in 2004.[10] So far, commercial deployment of TV white spaces has been extremely limited, partly because the available spectrum varies by market, and in the more highly populated areas, there are fewer broadcast channels with white spaces for unlicensed use.

Initially, developers considered spectrum sensing through CR approaches, but ultimately the FCC, concerned about the technical capabilities of sensing and the risk of interference, mandated a database-driven approach, attesting to the challenges of CR systems, even when employed with high-power, high-site and fixed transmissions.[11] The IEEE has developed two standards for communications in the TV white spaces, IEEE 802.22 and IEEE 802.11af. To date, the FCC has authorized two TV white space database systems for operation (one covering Wilmington, North Carolina and the other serving Nottoway County, Virginia), and manufacturers are only now beginning to obtain FCC certifications for this category of devices.[12] The lessons learned from TV white spaces is that it took six years for the spectrum to become available for use and that DSA technology to solve a relatively less complex sharing problem was not readily available.

[10] See Unlicensed Operation in the TV Broadcast Bands, Second Memorandum Opinion and Order, 25 FCC Rcd 18661 (2010); Unlicensed Operation in the TV Broadcast Bands, Notice of Proposed Rulemaking, 19 FCC Rcd 10018 (2004); IEEE Communications, “Emerging Cognitive Radio Applications: A Survey,” March 2011.

[11] See “Unlicensed Operation in the TV Broad. Bands,” 23 FCC Rcd 16807, 16386 ¶¶ 71-73 (2008) (“We also find that spectrum sensing, as currently presented in our measurement studies of prototype devices, is not sufficient by itself to enable unlicensed devices to reliably determine the TV channels that are available for use at a location.”).

[12] See “Innovation in the Broadcast Television Bands: Allocations, Channel Sharing and Improvements to VHF, ET Docket No. 10-235, Report and Order,” FCC 12-45 ¶ 6 (rel. Apr. 27, 2012).

Another example of spectrum sharing is IEEE 802.11 wireless LAN (Wi-Fi) systems that must avoid radar and other government systems at certain 5 GHz frequencies in what is called Dynamic Frequency Selection (DFS). Again, this is a relatively simple problem because radar transmissions are usually continuous and at high power.[13] The DFS feature in the 802.11 system monitors the spectrum and selects a frequency for 802.11 operation that is not being used by a radar system. Nevertheless, the process of designing workable DFS proved to be significantly more involved and complicated than originally anticipated.[14]

Though 802.11 (Wi-Fi) itself is not considered a form of DSA, it is an instance of spectrum sharing in that multiple unlicensed users can share the same spectrum. The 802.11 protocols employ spectrum sensing: they only permit transmission when the medium is quiet, and then only after waiting for a random back-off interval to prevent multiple simultaneous transmissions.

It is worth noting that it took over eight years to develop the initial 802.11 protocols, and the standard only became popular several years later after the 802.11b version was developed. Thus it took over ten years to popularize a sharing approach that employs a *homogenous* approach. Sharing across disparate networks, as envisioned with DSA, is inherently more complex. It is easier to communicate when everybody is speaking the same language.

There have been efforts to develop CR systems for unlicensed bands, such as the 902 to 928 MHz band.[15] These CR radios can choose the clearest available channel to minimize interference. Note, however, that systems already operating in this band are designed to withstand a certain level of interference. This is inherent to unlicensed bands in which there are never any assurances about other entities using or not using the band. Consequently CR systems designed for unlicensed bands are unlikely to be suitable for systems operating in licensed bands, such as cellular networks, which are much more sensitive to interference, and are designed with the expectation that any interference present is from the cellular system itself.

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[13] *See* 47 C.F.R. § 15.407(h)(2).

[14] The FCC initially authorized DFS in the 5 GHz bands in 2003, but it took another three years before the FCC released final rules allowing certification of DFS-equipped devices. For a discussion of some issues, see "Dynamic Frequency Selection (DFS) and the 5GHz Unlicensed Band," http://www.elliottlabs.com/documents/dynamic_frequency_selection_combined.pdf

[15] For example, xMax from xG Technology and work by WINLAB at Rutgers University described in "High Performance Cognitive Radio Platform with Integrated Physical and Network Layer Capabilities."

Issues and Considerations

The issues and considerations for implementing spectrum sharing between disparate systems are multifold. First, access rights have to be negotiated and stipulated for primary, secondary, and possibly tertiary users. This includes determining under what circumstances different categories of users each could have access. Possible considerations include geographical location, frequency, bandwidth, spectral masks, power level, duration, and degree of mobility. Given the many different government systems in operation, this alone will be an involved process.

Then, as discussed below, there are technical challenges that will necessitate entirely new sharing technologies, as well as certification and enforcement considerations. Longer term, there are concerns about how sharing schemes will constrain the evolution of technology.

Technical Challenges

The technical complexity of spectrum sharing stems from the inherent difficulty of coordinating transmissions of different systems and the difficulty of accurately sensing radio environments. For instance, TV white spaces depend on the ability to broadcast in unused TV channels in a way that does not interfere with that TV channel being used some distance away. Given that TV towers transmit at power levels up to a million watts one might think that it would be relatively easy to sense TV transmissions and to avoid those frequencies. Yet, even this is considered a difficult problem. Imagine how much more difficult it would be to properly sense transmissions that are at much lower power levels, that are intermittent or that are mobile.

Sensing a radio environment to accurately determine whether it is in use is difficult because first, the sensing system may not be able to hear active nodes if their signals are weak due to distance or obstructions such as buildings and terrain (referred to as the hidden node problem). Second, the nodes may be temporarily inactive. Thus sensing a radio environment to determine whether a particular frequency is in use provides no assurance that any subsequent transmission won't interfere with existing systems.

Even with TV white space systems using database approaches, the issue of how multiple white space networks might co-exist and coordinate with each is only now beginning to be explored. The databases inform the radios which TV channels are available – they say nothing about other data networks that might be trying to use the available TV channels.

Need for New Frequency Coordination Systems

It is for these reasons that any form of robust DSA will require some combination of cooperation between systems, including databases, and transmissions or other information that distributes information about the environment. For example, the primary licensees might inform secondary users about parameters that indicate for each location what frequencies are available, and at what power over what time.

The complexity of such frequency cooperation, and of CR in general, should not be underestimated, and is in fact acknowledged by proponents of the technology. For example, CSMAC references a report of the Aspen Institute Communications and Society Program about a recent spectrum conference that evaluated the state of CR: “Participants agreed that the technology is still evolving and it is not where it needs to be at the moment. Some suggested a timeline of 10 to 12 years for significant improvements. In addition, the participants agreed that a critical enabler for increased use of this technology is the development and implementation of appropriate enforcement mechanisms to protect incumbent authorized users.”[16]

There are virtually no off-the-shelf technologies or systems that implement spectrum coordination or cooperation between disparate networks, such as a government network as a primary user and a commercial mobile network as a secondary user.[17] As mentioned previously, commercially available CR systems have been designed for unlicensed bands in which interference may already be present and do not address the more complicated sharing schemes required for systems designed to operate without external interference. Meanwhile the geolocation databases used for TV white spaces have been designed specifically for that spectrum and is based on the assumption that TV transmissions are from static fixed locations. In contrast, the coordination needed for government and commercial sharing would likely be much more dynamic in both location and time. There will need to be entirely new specifications and standards developed to address this much more complex form of sharing.

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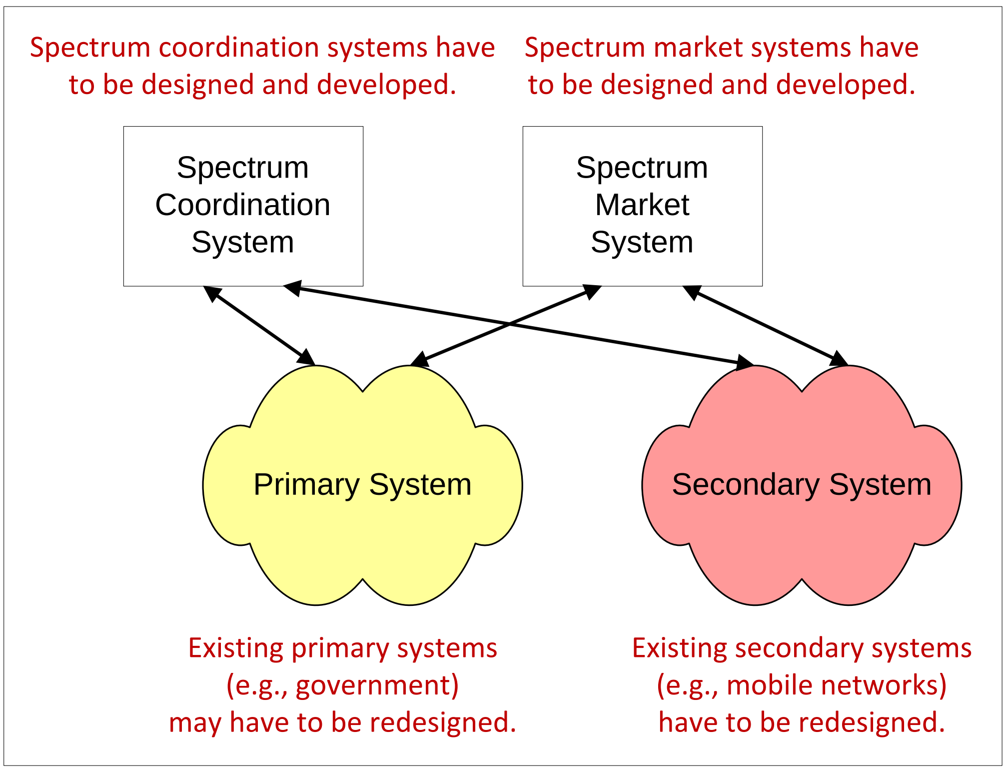
[16] See also “Comments of the Wireless Innovation Forum to the FCC,” February 28, 2011. “For example, CR implementations can potentially be complex, in some cases significantly reducing potential benefits. The coexistence of many CR systems may pose new issues as systems react to one another’s decisions.”… “When primary and secondary cognitive radio systems coexist, it is the responsibility of the secondary system to ensure that it does not significantly impact the primary system. However, the coexistence of multiple cognitive radio systems introduces an element not seen in traditional wireless networks – interactive decision processes. In an interactive cognitive radio decision process, an adaptation by a cognitive radio (or network or system) alters the operating environment changing the observations of other cognitive radios (or networks or systems) and influencing their adaptations. This interaction can easily spawn an infinite sequence of adaptations that never converge, yield an unstable network whose behavior radically changes with small changes in the environment, or produce a network with decidedly suboptimal performance (e.g., a tragedy of the commons). The analysis and design of these networks is further complicated by the expected vendor-specific implementations of the radio platforms as well as the observation, orientation, decision, and learning processes.”

[17] The limited exception is 70/80/90 GHz database sharing with government for fixed-to-fixed communications.

Moreover, existing systems would have to integrate with this spectrum coordination function. For example, if LTE networks were to take advantage of other spectrum as a secondary user, protocols and interfaces would need to be developed and specified to implement the coordination functions. Primary systems would also have to be modified to advertise their spectrum availability following the protocols of this spectrum coordination system. Developing this coordination system and modifying primary and secondary networks could easily be a process that takes ten years or longer.

Figure 1 depicts the architecture of an approach that employs some form of spectrum coordination.

Figure 1: Shared Spectrum Architecture



Certification and Enforcement

In addition to developing new technical approaches for spectrum sharing, there will need to be means of certifying that new equipment is in compliance with the access rights that have been defined. This will potentially require new test equipment, new test procedures, and new certification bodies. Beyond certification, monitoring will be needed to ensure that deployed systems are in compliance, and when they are not, enforcement procedures will be needed to remedy the problems.

Constraints on Evolution of Technology

Another concern is that once access rights are defined and technologies developed to coordinate access to spectrum, this will place constraints on how technology can evolve in the future. Innovation in technology depends on having as much latitude as possible. Any technology that is tightly integrated with other systems simply will not have the degrees of freedom available in clear spectrum. This concern applies to both the primary and the secondary users.

Value of Spectrum

There is finally the question of whether the potential seller even has spectrum of value. If for instance the primary system is used only a portion of the time, it might appear a tantalizing resource. But if the primary system needs arbitrary access to its spectrum such that a secondary system cannot predict when the capacity is actually going to be available, the spectrum might be of little value to the secondary user. This would especially be the case for cellular operators that have to manage capacity extremely carefully. It would be like trying to manage traffic and congestion on a highway where the number of lanes changes randomly.

Conclusion

The spectrum sharing implementation timeline is going to be long and involved. Other than sharing on a geographic basis, there is no sharing technology “magic bullet” already developed or even in the pipeline to adequately address short-term spectrum-shortage challenges.

Spectrum sharing will entail a multi-faceted process that requires identifying what types of systems will be shared and how, determining the market for shared systems, developing specifications and standards to allow sharing including spectrum coordination systems, modifying primary and secondary systems to integrate with the new sharing architectures, and developing infrastructure and devices to implement the sharing. In addition, there may also need to be new spectrum- market systems.

Given this extreme complexity, and given the widespread agreement about rising demand for commercial mobile broadband services, government must maintain focus on all available solutions. In the short term this means placing priority on the rapid clearing and reallocation of spectrum, even as it works in parallel with industry to develop and deploy sharing technology over the long term.

About Rysavy Research

Peter Rysavy is the president of Rysavy Research, LLC, a consulting firm that has specialized in wireless technology since 1993. Projects have included reports on the evolution of wireless technology, spectrum analysis for broadband services, evaluation of wireless technology capabilities, strategic consultations, system design, articles, courses and webcasts, network performance measurement, and test reports. Clients include more than seventy-five organizations.

Peter Rysavy is a leading international authority on the capabilities and evolution of wireless technology. He has written more than a hundred and twenty articles, reports, and white papers, and has taught forty public wireless courses and webcasts. He has also performed technical evaluations of many wireless technologies including municipal/mesh Wi-Fi networks, Wi-Fi hotspot networks, mobile browser technologies, cellular-data services and wireless e-mail systems.

From 1988 to 1993, Peter Rysavy was vice-president of engineering and technology at LapLink where projects included LapLink, LapLink Wireless, and connectivity solutions for a wide variety of mobile platforms. Prior to that, he spent seven years at Fluke Corporation where he worked on touch screen and data acquisition products.

Peter Rysavy is also the executive director of the Portable Computer and Communications Association (PCCA, http://www.pcca.org), a group that evaluates wireless technologies, investigates mobile communications architectures, and promotes wireless-data interoperability. Peter Rysavy graduated with BSEE and MSEE degrees from Stanford University in 1979. More information is available at http://www.rysavy.com.

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