



## New Approaches to Private Sector Sharing of Federal Government Spectrum

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### Abstract

Radio spectrum is a key input to today's information technology society and economy. In the United States today, some spectrum is shared between federal government users and users regulated by the Federal Communications Commission (FCC). However, the potential for such sharing is limited by traditional spectrum sharing techniques that require an extremely high confidence level of interference protection for Federal users. This unique bifurcated spectrum policy system in the U.S. has made only modest progress in this area. However, if future federal systems were designed to affirmatively facilitate sharing by letting private sector users have real-time information about spectrum use, then high-reliability sharing and efficient spectrum use would be enabled. This paper describes scenarios using radar systems and public mobile radio systems.

### I. INTRODUCTION

As the U.S. economy and society becomes more and more information-centric and mobile, wireless systems are becoming a major factor in the efficient functioning of our society. Radio spectrum is a key economic input into wireless systems that power our information society and economy and enhance public safety and national security. Since the earliest days of radio regulation in the United States; federal government use of spectrum has been handled independently of other users' access to spectrum. Thus, the FCC controls spectrum use by private parties and states and local governments while the Department of Commerce's National Telecommunications and Information Administration (NTIA) controls federal government spectrum use.<sup>1</sup>

Until recently all spectrum was distributed to possible users by administrative means. Spectrum access has generally been seen as a "zero sum game" in which spectrum was available either to one party or another mutually exclusive party. However, "green field" spectrum is now almost nonexistent in the populated areas of the United States, meaning growth in wireless technology use must come from more efficient use of spectrum resources. This efficiency could come from traditional efficiency improvements like modulation and coding advances and more intensive spatial reuse of spectrum (as in cellular communications). Although there have been significant advances in these areas<sup>2</sup> in the past two decades, for many types of systems large (order of magnitude) increases in effi-



*There are real limitations to first and second generation spectrum sharing with respect to how much spectrum can be shared with a negligible risk of interference to critical federal government systems. However, if future federal systems are designed to enable and actively facilitate spectrum sharing, then more efficient sharing is possible.*

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ciency through these techniques are no longer achievable. Therefore, we must look to new means to more efficiently utilize spectrum. Advances in new types of spectrum sharing that allows underutilized spectrum to be used by more than one user, subject to interference and availability constraints that preserve access for the first user, offer the most promising means to maximize efficient use of spectrum resources.

In the following discussion, I will review the special case of federal government spectrum in the United States and possible new sharing mechanisms that would spur access for other users to this valuable spectrum. The current federal spectrum management system provides little incentive to allow sharing of existing federal spectrum and thus limits any such sharing to extremely conservative criteria to protect systems that were designed with no consideration of sharing. The focus here is not on sharing with existing federal systems, but rather how the next generation of federal systems could be designed with the goal of simultaneously implementing advanced federal agency wireless use, while also facilitating, interference free private sector sharing.

## **II. FEDERAL GOVERNMENT SPECTRUM USE**

The federal government is a large user of wireless systems for both military and civil systems. Some of these uses are uniquely governmental in nature, *e.g.* law enforcement and air traffic control, while others parallel private sector spectrum users, *e.g.* the electric power systems of the Tennessee Valley Authority and Bonneville Power Authority and the medical system operated by the Department of Veterans Affairs.

The U.S. bifurcated spectrum management, mandated by Sections 301 and 305 of the Communications Act of 1934, as amended,<sup>3</sup> is unusual compared to other countries. Under Section 301, the Federal Communications Commission (FCC), an independent regulatory commission, is responsible for assigning all frequency bands use by private parties and state and local governments. Under Section 305, though, the president is responsible for assigning all frequencies used by federal government users.

Throughout most of the history of radio regulation in the U.S. the president's Section 305 authority was implemented by a White House entity. However, President Nixon began and President Carter completed the migration of this function to the Commerce Department – ironically, just before spectrum policy became of critical importance due to our emerging information technology economy. Now it is executed by NTIA, an agency of the Department of Commerce.<sup>4</sup> NTIA is “advised” by the Interdepartmental Radio Advisory Committee (IRAC) which is composed of representatives of the federal agencies that have significant spectrum use.<sup>5</sup> In practice, the independence of NTIA and IRAC and their relative dominance in spectrum policy making varies from year to year. However, it is fair to say that most of the spectrum policy decisions of the past two decades have been made by the IRAC since NTIA does not have the political power to dictate policy to major cabinet agencies that fund and operate their own radio systems.

In the U.S., spectrum is divided into three basic categories for management purposes: Federal Government, non-Federal Government, and shared.<sup>6</sup> Generally the three categories are comparable in size throughout the spectrum. However, determining the relative size of the three categories is complicated by assumptions that have to be made about what spectrum is under consideration. For example, depending upon the starting and ending points, you can get a different ratio. Spectrum

above 20 GHz is generally shared, thus if you include that in the accounting the shared proportion is substantially increased. Further, basically adding block sizes measured in Hz or kHz over a large range of spectrum, say from 0.1 MHz to 10 GHz is generally meaningless. What is important is the size of a band compared to its center frequency; otherwise you are comparing apples to oranges. For example, 7 GHz for unlicensed at 57-63 GHz is not necessarily greater than the 40 MHz at 2450-2490 MHz that is available for Wi-Fi. It is also important to note, that a given band size, say 1 kHz, is far more valuable at low frequencies (particularly below 3 GHz) than at high frequencies.

A relatively precise accounting was completed by FCC staffer John Williams in 2002 (see Table 1 below) of the spectrum usually of most interest,<sup>7</sup> 300-to-3000 MHz. (Since the spectrum considered in this accounting covers only a decade of frequencies the direct addition of bandwidths is more meaningful than when larger blocks are considered.)

Table 1. Spectrum Categories in U.S.

Category	Fraction
Federal Government	22.4%
Non-Federal Government	34.7%
Shared	34.7%
In transition from Federal to Non-Federal	2.5%
Unlicensed and managed by FCC	5.6%

*Source:* John Williams, FCC, 2002

Federal government spectrum is exclusively managed by NTIA and Non-Federal Government spectrum is managed exclusively by FCC. The shared spectrum is managed jointly under an interagency agreement.<sup>8</sup> Federal government spectrum use generally differs from the private sector in terms of spatial distribution, in peak-to-average usage ratio, and in the large scale use of radar systems with rotating narrow beam antennas and large occupied bandwidths.<sup>9</sup> A significant fraction of federal spectrum use is military related and tends not to be in the large urban areas where private sector spectrum use is high. San Diego is a notable exception to this spatial distribution in that it has a large naval base adjacent to the central city area. Of course, emergencies can result in large increases in military use in urban areas and any change in spectrum sharing must allow for this contingency.

### III. CONTEMPORARY CHANGES IN SPECTRUM USAGE

Traditionally, most spectrum use was either, broadcasting, a simplex (one way) service, or full duplex real-time communications often involving voice such as cellular telephone services. Because voice services needed to accommodate simultaneous, two-way communication, Commercial Mobile Radio Service (CMRS) spectrum is auctioned (or otherwise assigned) as “paired” bands with enough separation to avoid interference within the handset (which can be simultaneously transmitting and receiving). However, in contemporary spectrum usage, packetized information with asymmetrical traffic flows is the area undergoing the most growth and full duplex voice usage is relatively stable.<sup>10</sup> Thus, there is a growing need for spectrum that can be used for new packetized applications (such as mobile Internet, video and other high-bandwidth data services) and less need for the traditional paired spectrum for full duplex systems.

The record in the FCC’s pending AWS-3 proceeding,<sup>11</sup> dealing with the reallocation of an unpaired band at 2155-2175 MHz, demonstrates a growing interest in using spectrum for packetized applications that was of little interest only a decade ago. Major cellular companies have proposed to use the band for asymmetrical supplements to existing paired bands or for time division asymmetrical duplex (TDD) usage. Potential users have stated that the band can be used for asymmetrical traffic associated with Internet usage, music and video downloads, and real time or near real time video distribution to mobile terminals.

Traditionally, only spectrum that was paired and constantly available “1000 ms/s”<sup>12</sup> (that is, without interruption) was of interest since most usage was analog two-way voice. But with packetized information and frequency agile radios it is possible to produce practical wireless systems that use spectrum with intermittent availability.<sup>13</sup> Indeed, much of the anticipated wireless usage growth in the near future will be in applications with asymmetric spectrum use that can be implemented with packetized technology. While the commercial wireless industry has traditionally searched for paired full-time availability spectrum as the foundation of their systems, unpaired spectrum with intermittent availability can readily be used for many applications that are currently in demand.

#### **IV. PREVIOUS SPECTRUM SHARING WITH FEDERAL GOVERNMENT USERS**

As the information in Table 1 showed, private sector sharing of federal government spectrum is not a new idea. Actually there have been two generations of sharing approaches to date.<sup>14</sup> What both generations of federal band sharing have most in common is that government users are entirely passive; they do nothing to facilitate private sector use of these lightly-used bands. Shared use is permitted, but only to a very limited degree that places the entire burden on private industry to ‘work around’ federal systems to avoid interference.

The first generation of government spectrum sharing systems was based on worst-case interference scenarios that severely limited options for sharing. There has been low-power sharing of government bands, including Wi-Fi and Bluetooth in the 2450-2490 MHz band,<sup>15</sup> and site-based licensing of private stations in government bands based on case-by-case agreement on the availability of a specific frequency at a specific location by both the government and private users.<sup>16</sup> The second generation of government spectrum sharing started in 2004 with cognitive radio-based sharing of the 5.25 – 5.35 and 5.47 – 5.725 GHz radar bands by unlicensed Wi-Fi like systems. This sharing is called Dynamic Frequency Selection (DFS) in regulatory and standards publications. The Department of Defense permits the shared use of these radar frequencies by fixed devices that have the capability to scan, detect and rapidly hop off frequencies when a radar transmission is detected. Although DFS enables sharing of the spectrum, the technical criteria to facilitate use by other parties was very conservative due to the fact that the military radar systems were not designed for sharing and the fact that interference to these radar systems had to be kept to a very insignificant likelihood. This resulted in the very-low permitted power levels and required very high detection sensitivity for DFS devices.<sup>17</sup>

With this type of rigorous DFS precedent, there will be few additional opportunities for access to government spectrum based on purely passive sensing of channel use. The basic issue is illustrated in Figure 1. The plot shows the fraction of idle spectrum that can be used as a function of the required confidence of no or negligible interference to the original primary user. If the primary system was not designed with any anticipation of sharing with other users then interference protections have to con-

sider all possible worst case scenarios, including rare, but problematic issues such as the “hidden node problem.”<sup>18</sup> This is what resulted in the very conservative DFS sharing at 5 GHz. However, if the primary system is designed with sharing in mind and can cooperate with the new user so that most sharing opportunities can be realized, then a significantly higher fraction of idle spectrum can be used.

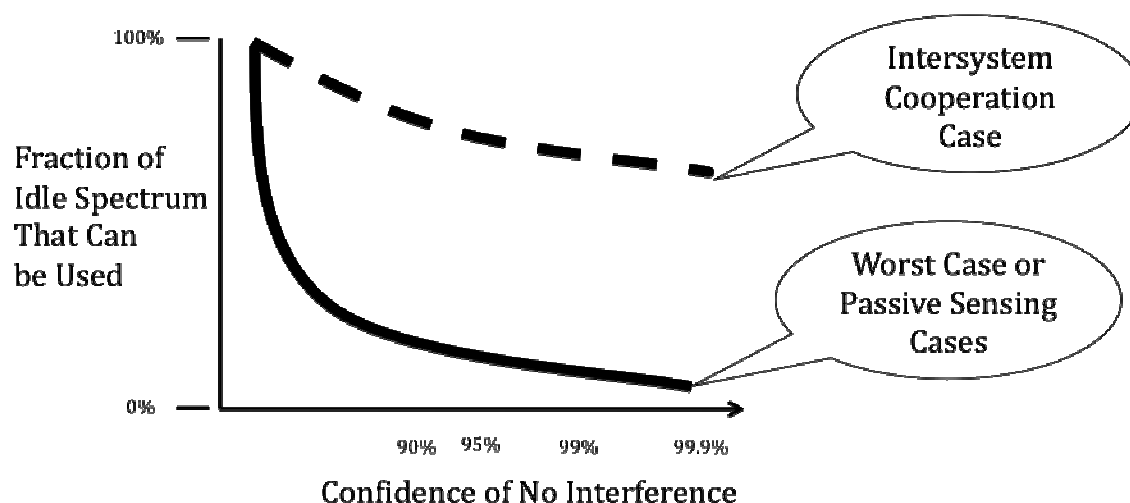


Figure 1: Fraction of idle spectrum that can be used under different cases

There is an intrinsic technical tradeoff between requiring a high-confidence level for detecting incumbent users and limiting the number of device false positives, where a DFS device incorrectly detects an incumbent user and unnecessarily vacates the spectrum. With the current system, government users will demand a high-detection threshold for worst case, passive sensing scenarios that will inevitably lead to a high number of false positives – thereby limiting the functionality of the technology while also undermining the actual goal of utilizing the spectrum more intensively. The 5 GHz case dealt with continuously operating radars with fixed locations. Sharing spectrum with mobile federal users with intermittent spectrum use raises different DFS issues about how quickly a new government user can be identified and the spectrum vacated for that user based on DFS passive sensing. All of these factors limit the fraction of idle spectrum that can be used in a DFS-like system based on passive sensing of federal spectrum use.

However, a third generation of sharing could be based on new technologies for federal government radio systems that are designed with sharing in mind and that can actually *facilitate* sharing. The remainder of this paper will deal with two options for designing such systems to facilitate sharing. The first deals with radar spectrum, a distinctive large scale usage of federal government spectrum with important safety and security implications – although one that at a given moment usually results in intermittent interference-free spectrum sharing opportunities. The second example deals with federal mobile radio systems, which are channelized and therefore offer opportunities for sharing of unused capacity on an as-available basis. While these opportunities are of little interest to many classical private sector communications systems, they could be used with innovative designs for meet present and future spectrum needs.

## V. “RECYLING” RADAR SPECTRUM

A significant use of federal government spectrum is radar for air traffic surveillance and weather monitoring. Almost all of these systems are the traditional monostatic design (collocated transmitter and receiver) and use rotating antennas (vice phased arrays) with constant rotation rates.

Today Global Positioning System (GPS) technology is widely available at costs affordable to consumers. While GPS is widely known for its ability to determine location quickly and accurately, it is less well known that the underlying technology can also be used to establish precise time and precise frequency at a location.<sup>19</sup> This precise distribution of timing and frequency references can be used to synchronize radar systems rotations.

Radar systems designated for spectrum sharing could have published rotation rates and rotation phasing that is synchronized with precise timing (for example, a 5s rotation with the antenna pointed due North at all times where the second count is of the form  $I \times 5$ , where  $I$  is an integer). Low-power shared spectrum users could then use the radar spectrum when they determine that through knowing their location, the radar’s location, and the radar’s rotation phasing, that the beam is at least  $X$  degrees away from them, where  $X$  might be in the order of  $30^\circ$ . Knowing the location and precise rotation phasing of surveillance radars would allow intermittent sharing of the spectrum during part of the rotation cycle.

Due to national security constraints it is unlikely that all surveillance radars will have publicly available location and rotation phasing information. But even sharing parts of the band would be productive.

## VI. “RECYLING” MOBILE RADIO SPECTRUM

The federal government also uses a variety of mobile radio systems throughout the spectrum. In general, individual agencies operate their own systems although the general policy has been towards shared systems.<sup>20</sup> While many of these systems use spectrum comparable to the commercial cellular systems, for a variety of reasons they are implemented with different technology. Yet this spectrum could be used for a variety of commercial applications if a reliable sharing mechanism was implemented.

I first proposed private sector sharing of public safety land mobile spectrum several years ago during the deliberations of the FCC’s Spectrum Policy Task Force.<sup>21</sup> At the time the concept was generally criticized by state and local public safety users. However, over time this concept has become more acceptable and the FCC’s 700 MHz D block proposals entail a similar type of sharing between private sector and public safety users in adjacent blocks with a movable boundary. The draft of the Spectrum Policy Task Force Report mentioned D block-like sharing might be possible between federal government users and those regulated by the FCC.<sup>22</sup> NTIA reviewed this draft pursuant to normal FCC-NTIA coordination of spectrum policy issues and objected so strongly to even the mention of such sharing that the section was removed. Thus, there has never been a parallel proposal to allow private sector users to share with federal users. As in the case of D block new land mobile systems with be needed public safety users for such a system to work.

The limitations of second generation passive sharing could be avoided if new government mobile systems use base stations for control of spectrum access, similar to land mobile trunking systems or the ubiquitous cellular systems. It is interesting to note that sharing based on spectrum use knowledge from a base station can go beyond a “realizable system,”<sup>23</sup> in that the resulting DFS system essentially *can predict the future*. This is because the government base station knows:

1. Exactly what frequencies are being used at a given moment,
2. Whether channel demand is growing or decreasing at that moment, and,
3. Precisely in what sequence new channels will be used when additional channels are needed for use.

Thus, in a third generation sharing system with cooperative sharing of spectrum use information, there is no question of making errors in deciding whether a channel is being used for government communications, and one could maintain a buffer of unused channels between the primary government users and the opportunistic private sector users.

The resulting private sector channel use could have large fluctuations in available capacity as government use peaks from time to time, but this could be moderated statistically by using such shared spectrum in conjunction with spectrum permanently assigned to the private sector. The growing trend towards packetized mobile communications with asymmetric traffic flows is consistent with such spectrum use as they do not require continuous use of one radio frequency. Packetized systems can move information among frequencies based on their real time availability.

## VII. CONCLUSION

There are real limitations to first and second generation spectrum sharing with respect to how much spectrum can be shared with a negligible risk of interference to critical federal government systems. However, if future federal systems are designed to enable and actively facilitate spectrum sharing, then more efficient sharing is possible. This increased sharing could in turn stimulate new economic growth among both the manufacturers and operators of radio systems, but also among other enterprises that use improved communications to improve their own efficiency and to offer new non-communications products and services to the public that would not be practical without new communications services.

## AUTHOR’S BIOGRAPHY

Michael Marcus is a native of Boston and received S.B. and Sc.D. degrees in electrical engineering from MIT. Marcus retired from the FCC in March 2004 after servicing a senior technical advisor to the Spectrum Policy Task Force and co-directing the preparation of the FCC’s cognitive radio rule-making. At the FCC his work focused on proposing and developing policies for cutting edge radio technologies such as spread spectrum/CDMA and millimeterwaves. WiFi is one outcome of his early leadership. He also participated in complex spectrum sharing policy formulation involving rulemakings such as ultrawideband and MVDDS.

He is now Director of Marcus Spectrum Solutions LLC, an independent consulting firm based in the Washington DC area and focusing on wireless technology and policy. Marcus has been recognized as a Fellow of the IEEE “for leadership in the development of spectrum management policies” and received IEEE-USA’s first Electrotechnology Transfer Award in 1994.

## ENDNOTES

<sup>1</sup> In practice a committee of agencies that use spectrum, the Interdepartmental Radio Advisory Committee (IRAC) has authority over policy issues related to federal government spectrum.

<sup>2</sup> For example, see Alouini & Goldsmith, “Areas Spectral Efficiency of Cellular Mobile Radio Systems,” *IEEE Trans. Vehic. Tech.*, Vol. 48, No. 4, July 1999, p. 1047-66. Martin Cooper has observed that “Wireless capacity has doubled every 30 months over the last 104 years” *IEEE Communications Magazine*, 9/08, p. 59.

<sup>3</sup> 47 U.S.C. 301,305.

<sup>4</sup> Reorganization Plan Number 1 of 1977; Executive Order 12046; 47 U.S.C. 101,105.

<sup>5</sup> See <http://www.ntia.doc.gov/osmhome/irac.html>.

<sup>6</sup> In some documents, these categories are called: government, nongovernment, and shared.

<sup>7</sup> U.S. Spectrum Allocations 300 - 3000 MHz, Federal Communications Commission, November 2002, [http://www.fcc.gov/Bureaus/OPP/working\\_papers/oppwp38chart.pdf](http://www.fcc.gov/Bureaus/OPP/working_papers/oppwp38chart.pdf).

<sup>8</sup> “Memorandum of Understanding Between the Federal Communications Commission and the National Telecommunications and Information Administration,” available at [http://hraunfoss.fcc.gov/edocs\\_public/attachmatch/DOC-230835A2.pdf](http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-230835A2.pdf).

<sup>9</sup> While FCC licenses some radar systems, *e.g.* on privately owned vessels, federal government use of radar is dominant with respect to the spectrum occupied.

<sup>10</sup> Thus it is ironic that the major cellular carriers, despite having spent billions of dollars to acquire cellular, PCS, and 3G spectrum are buying access to additional spectrum through Qualcomm’s MediaFLO service because their own full duplex paired spectrum can not efficiently handle the services that have the most growth at present.

<sup>11</sup> WT Docket 07-195; Service Rules for Advanced Wireless Services in the 1915-1920 MHz, 1995-2000 MHz, 2020-2025 MHz, and 2175-2180 MHz bands, Federal Communications Commission, [http://fjallfoss.fcc.gov/prod/ecfs/comsrch\\_v2.cgi](http://fjallfoss.fcc.gov/prod/ecfs/comsrch_v2.cgi).

<sup>12</sup> “1000 ms/s” is a cute variant of “24/7” and means full time availability, but emphasizes it on a microscope scale. Thus normal spectrum is available both 24/7 and 1000 milliseconds every second. But one can build practical systems for packetized communications with say, 850 ms/s availability. Also, for example XM/Sirius does not have 1000ms/s availability due to overhead obstructions, but they have designed their system to cope with this without gaps in the final audio.

<sup>13</sup> The XM and Sirius satellite broadcasting systems used buffering that was invisible to the user to achieve near continuous service to cars even though the radio path access from the satellite to car was intermittent due to overhead obstacles.

<sup>14</sup> M.J. Marcus, Sharing Government Spectrum with Private Users: Opportunities and Challenges, *IEEE Wireless Communications*, April 2009

<sup>15</sup> 47 C.F.R. 15.247.

<sup>16</sup> 47 C.F.R. 101.1523(b) is an example of such coordination.

<sup>17</sup> For example for a 200 mW to 1 W EIRP unlicensed transmitter, the DFS system must avoid a frequency for 30 minutes if it detects -64 dBm average power even for 1  $\mu$ s. See 47 C.F.R. 15.407(h)(2).

<sup>18</sup> See “Hidden node problem,” Wikipedia, [http://en.wikipedia.org/wiki/Hidden\\_terminal\\_problem](http://en.wikipedia.org/wiki/Hidden_terminal_problem).

<sup>19</sup> For example, see “Global Positioning System,” <http://www.gps.gov/applications/timing/index.html>.

<sup>20</sup> GAO, Radio Communications: Congressional Action Needed to Ensure Agencies Collaborate to Develop a Joint Solution, GAO-09-133 December 12, 2008 (<http://www.gao.gov/products/GAO-09-133>).

<sup>21</sup> Mark M. Bykowsky and Michael J. Marcus, Facilitating Spectrum Management Reform via Callable/Interruptible Spectrum, 2002 Telecom. Policy Res. Conf., <http://intel.si.umich.edu/tprc/papers/2002/147/SpectrumMgmtReform.pdf>.

<sup>22</sup> Spectrum Policy Task Force Report, ET Docket No. 02-135, Federal Communications Commission (November 2002), [http://hraunfoss.fcc.gov/edocs\\_public/attachmatch/DOC-228542A1.pdf](http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf).

<sup>23</sup> In the technical literature, “realizable” refers to a system that produces outputs based only on *past* information not on future information. While some mathematic models don’t have such a limitation, real physical, hence “realizable”, systems do.