Trends and Precedents Favoring a Regulatory Embrace of Smart Radio Technologies

J. Brad Bernthal, Timothy X Brown, Dale N. Hatfield,
Douglas C. Sicker, Peter A. Tenhula and Philip J. Weiser **

***Abstract*— Burgeoning demands for communications bandwidth stress the abilities of military and civil spectrum managers to provide needed access to spectrum resources while taking appropriate measures to avoid causing harmful interference to legacy users. Empirical analysis shows that radio frequency (RF) bandwidth is often available: measurement data indicate that while most channels are used at *some* times, most channels remain unused at any *given* time. Going forward, so-called "smart radio" technologies will be able to exploit these holes in the RF spectrum and will play a crucial role in achieving the core objectives of efficient spectrum management. The United States Defense Advanced Research Projects Agency's ("DARPA") NeXt Generation Communications Program ("XG") is on the vanguard of smart radio innovations. In particular, XG technology uses automated intelligence at a system's edges in order to navigate real-time fluctuations in spectral conditions that cannot be precisely predicted in advance. This dynamism will enable opportunistic use of intermittently available spectrum.**

This paper examines how the introduction of smart radio technologies fit within past precedents and current regulatory developments involving shared use of spectrum resources. The key finding is that implementation of smart radios in the near term would represent an incremental policy step that is consistent with policy trends and recent regulatory actions. Two perspectives militate in favor of this conclusion. First, smart radio systems enable regulators and spectrum managers to more efficiently achieve long-held policy and spectrum management objectives. And second, the regulatory prospects of smart radios are further buoyed by contemporary examples of approved technologies and sharing methods that are modest precursors to XG. Case studies are used to underscore that while smart radios promote vast gains in spectrum accessibility and interference avoidance, implementation of smart radio systems follows a lengthening line of precedents promoting flexibility and collaborative sharing techniques. Accordingly, in the face of sharp increases in demand from a wide assortment of spectrum users, it is clear that regulators and spectrum managers will— and, indeed, should— embrace smart radio systems as a tool to help resolve the spectrum access challenges of today and tomorrow.

***Index Terms*— Cognitive radios, dynamic spectrum policy, smart radios, software defined radios, spectrum regulation, XG program.**

I. INTRODUCTION

Methods of providing access to wireless spectrum resources are in the midst of a global revolution. Regulatory authorities around the world are re-orienting spectrum policy around principles of technological flexibility and market dynamism. "Smart radio" technologies – which can include cognitive radios, software defined radios and frequency agile radios – will further these principles and play a crucial role in achieving the core objectives of spectrum management: interference avoidance and spectrum access. In short, smart radios are poised to accelerate adoption of decentralized spectrum management and advanced sharing strategies.

The United States Defense Advanced Research Projects Agency's ("DARPA") NeXt Generation Communications Program ("XG") is on the vanguard of these efforts. Fundamentally, XG uses automated intelligence at a system's edges in order to navigate real time fluctuations in conditions that cannot be precisely predicted in advance. This enables opportunistic use of frequencies for which availability is intermittent. Significantly, empirical analysis shows that bandwidth is often available; spectrum tests indicate that on average while most channels are used at *some* times, most channels remain unused at any *given* time. XG's adaptive capabilities permit an unprecedented dynamism that facilitates use of spectrum by automating tasks that, when performed manually, are too information, labor and time intensive to be used on a wide scale. Notable among the adaptive capabilities of XG-enabled devices is that they are frequency agile. That is, such devices can change how and where they operate within the radio spectrum, moving among a set of frequency bands in response to interference or other constraints.

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Author affiliations and contact information: J. Brad Bernthal, University of Colorado Law School and Interdisciplinary Telecommunication Program, University of Colorado-Boulder (e-mail: Brad.Bernthal@colorado.edu); Timothy X Brown, Interdisciplinary Telecommunication Program, Electrical and Computer Engineering Department, University of Colorado-Boulder (e-mail: timxb@colorado.edu); Dale N. Hatfield, Interdisciplinary Telecommunication Program, University of Colorado-Boulder (e-mail: Dale.Hatfield@ieee.org); Douglas C. Sicker, Department of Computer Science, Interdisciplinary Telecommunication Program, University of Colorado-Boulder (e-mail: Douglas.Sicker@Colorado.edu*);* Peter A. Tenhula, Shared Spectrum Company, Vienna, VA (e-mail ptenhula@sharedspectrum.com); Philip J. Weiser, University of Colorado Law School, Interdisciplinary Telecommunication Program, University of Colorado-Boulder (e-mail: Phil.Weiser@colorado.edu).

Regulators face an expansion of spectrum-dependent services, introduction of new wireless technologies, and unintended and incidental emissions that demand valuable spectrum. All regulators must grapple with the challenges related to increasing demand for spectrum resources from all types of users whether they be the military, law enforcement and public safety, critical infrastructure, industrial, commercial operators, amateurs or individuals. Against this backdrop, today's regulatory trends favor adoption and promotion of smart radio systems such as XG. For example, in the United States and other countries, regulators have authorized secondary markets in spectrum licenses, enabling parties to broker access to spectrum with minimal regulatory processes. Similarly, regulators have set forth flexible licensed and unlicensed models that welcome the use of smart radio technology so that firms can deploy equipment that more flexibly adapts to the spectral and network environment. This paper argues that, upon examining regulatory trends and developments, regulatory barriers should not prevent the near or long term realization of gains from smart radio systems. In particular, our analysis shows that deployment of smart radio technologies such as XG may soon occur in certain commonly-controlled or pooled bands and that broader spectrum access represents an incremental and logical evolution of existing regulatory precedents. While this paper's primary focus is on regulatory developments and trends in the United States, future work may build on this paper by examining similar regulatory trends on an international scale.

Growing regulatory support for innovative technologies that promote spectrum sharing is an appropriate response to the increasing demand for spectrum. A compelling aspect of technologies enabled by the XG program is the ability to facilitate efficient spectrum use irrespective of the regulatory model approach applicable to a given band. "Regardless of the regulatory model – licensed, unlicensed, or other new models – [software defined and cognitive] technologies are allowing and will increasingly allow more intensive access to, and use of, spectrum than possible with traditional, hardware-based radio systems." [1] In bands governed by traditional "command and control" regulation, XG technology can also improve spectrum access opportunities while avoiding interference to legacy users without displacing such users. Accordingly, a valuable aspect of XG is that it presents efficiency gains for the range of regulatory models that govern different bands.

This paper explains how smart radios in general— and XG in particular—can be used to facilitate spectrum sharing and generate efficiencies in spectrum usage and management. Moreover, the paper provides a regulatory analysis showing that deployment of XG technologies is a near term likelihood, not a long term crusade. The paper proceeds in four parts. *First,* following this Introduction, Part II situates smart radio technologies against the backdrop of the traditional model of spectrum regulation and today's reform efforts. *Next,* Part III explains why regulatory trends bode well for the implementation of XG technologies and, further, that XG systems could prove to be regulatory enablers. *And finally,* Part IV details case studies of spectrum sharing methods already approved by regulators and in use today. These case studies serve as precedents favoring sharing strategies facilitated by smart radio systems and, equally important, underscore how smart radio technologies such as XG promise to improve existing spectrum sharing going forward. Each of these parts is addressed in turn below.

II. How XG Is Situated Vis-à-vis The Current Regulatory System and Its Ongoing Reform

Spectrum management continues to be reformed around the principle of managing interference and regulating access in flexible ways. Fundamentally, increasing support for cognitive radios, software defined radios and frequency agile radios (collectively, "smart radios") reflects the prospect of a third significant regulatory development favoring more flexible sharing of spectrum. The first two developments—trunking and increased flexibility in unlicensed use—introduced more dynamic efficiency into wireless communications and relaxed the rigid authority of the command-and-control model. A third spectrum sharing development—namely, the regulatory embrace of smart radio technologies— will be necessary to meet regulatory objectives of spectrum access and interference avoidance amid increasing spectrum demands.

The traditional model of spectrum management envisions four distinct steps for spectrum regulators. First, they must allocate spectrum for particular uses or services (such as commercial mobile radio services and air navigation systems). Second, they must establish the particular band plan that may include individual allotments of spectrum resources (e.g., channels) and, almost certainly, will include technical and other rules that apply to the service (e.g., maximum transmitter power limits). Third, they must grant licenses that assign users to particular channels or groups of channels. Fourth, they must enforce the relevant rules through monitoring and other activities.

Under the traditional system of spectrum management, government regulators—as opposed to the decisions of spectrum users— decided "what [uses of spectrum are] best for the public."[2] In practice, however, governmental decisions tended to restrict the possible uses of spectrum along the lines of rules misaligned with market forces. Such rules could be arbitrary and, as one commentator colorfully put it, in some instances were along the lines of a rule that a newly purchased truck could "be driven only on Sunday while carrying

[1] Report and Order, *In the Matter of Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies*, FCC 05-57, ET Docket No. 03-108, at ¶ 1 (March 11, 2005) ("CR Report and Order").

[2] Douglas W. Webbink, *Frequency Spectrum Deregulation Alternatives*, FCC Working Paper 10 (October 1980) (http:/www.fcc.gov/Bureaus/OPP/working_papers/oppwp2.pdf).

nonagricultural products."[3] To spectrum regulators, such rules were viewed as the best means of managing interference between rival users of spectrum.

Under classic regulatory doctrine, the threat (as opposed to the reality) of interference and a perceived need to ration the spectrum justified highly conservative assumptions about uses of the spectrum. Under this model, users limited freedom and, by design, large swaths of spectrum were left under-utilized, making it difficult for new services to access spectrum. Over time, however, increasing technological developments and marketplace experiments have demonstrated the virtues of allowing individual spectrum licensees to make their own decisions about how spectrum under their control is used. The most powerful case in point is probably the system of spectrum management now used by the cellular and PCS operators, many of whom obtained their licenses under a system of extraordinary flexibility. In particular, holders of PCS licenses could use the relevant spectrum for "any mobile communications service" as well as "fixed services" if provided in combination with mobile ones (other than broadcasting).[4] Empowered by such flexibility, over the years PCS licensees have shown an impressive ability to manage their own spectrum and, through a variety of techniques, to coordinate with those using adjacent spectrum. The FCC has deservedly highlighted this success in spectrum management and built upon it by adopting a *Secondary Markets Order*.[5] This order, which the Commission adopted in 2003, reversed the longstanding anti-leasing rule and encouraged the development of spectrum leasing mechanisms. In particular, it adopts the principle—now widely acknowledged among regulators—that win-win sharing and trading arrangements should be encouraged.

The development of smart radio technology is well suited to ensure effective sharing of spectrum rights and to provide the technological infrastructure that will support win-win sharing and trading solutions. Notably, the FCC has recognized that no approach "holds greater potential for literally transforming the use of spectrum in the years to come than the development of software-defined and cognitive, or 'smart,' radios."[6] A central premise of this technology is that, by building high processing capacity into receivers, "smart" wireless technologies can differentiate between the signals one wishes to receive from those that one does not wish to receive. Moreover, such technologies also promise to liberate spectrum users from equipment designed to work only with particular bands of spectrum—meaning that a transmitter and receiver can, in cooperation with one another, hop dynamically from frequency to frequency during the course of a call or data session, avoiding frequencies that are being used (or are noisy). In short, as Commissioner Jonathan Adelstein put it, "cognitive radios could play a key role in shaping our spectrum use in the future" and can "leapfrog the technical and legal problems that currently hamper many of today's spectrum opportunities."[7]

The use of smart radio technology is more common than often appreciated. Indeed, there are many existing systems and devices that incorporate some subset of smart radio innovations. For example, a typical Wi-Fi (802.11) card supports rudimentary cognitive and software defined radio characteristics inasmuch as they sense their environment (through listen-before-talk and channel sounding) and alter their frequency parameters (within a set of channels). Further, even most home cordless phones are in fact primitive cognitive radios. Phones first scan and detect an available channel. Once a channel is identified, the phone then has the ability to change channels.[8] Even this primitive form of dynamic spectrum access provides efficiency gains and suggests how cognitive radio technology can minimize interference. As these examples illustrate, commercial and residential users increasingly benefit from the introduction of smart radios and more efficient spectrum technologies. Currently deployed technologies, however, only provide a glimpse of the opportunities presented by next generation technologies, including the smart radio technologies in the XG program. As the FCC reported, "[r]egardless of the regulatory model—licensed, unlicensed, or other new models—these technologies are allowing and will increasingly allow more intensive access to, and use of, spectrum than possible with traditional, hardware-based system."[9]

In order to appreciate how the XG program is poised to assist efforts to reform the traditional command and control model of spectrum regulation, it is important to generally address how the XG program aims to enhance smart radio technologies. XG is often said to be a "smart radio." XG is better understood, however, as a catalyst that transforms existing radio platforms into smart radios that are capable of dynamic coordination and spectrum access. XG enhances the intelligence at the radio edges of a network. "As radios become more intelligent, they gain greater flexibility and are able to adapt their RF behavior to identify and use spectrum that otherwise would not be available for fear of causing interference."[10] Significantly, XG is an enabling suite of functionalities that can be integrated with existing and future radio platforms. Thus, XG is distinctive for its ability to enhance a range of transmitter and receiver devices, including hand-held and vehicle mounted radios, radios utilized in

[3] Greg Blonder, *American Needs Unchained Spectrum*, BUSINESS WEEK (January 4, 2004) (http://www.businessweek.com/technology/content/jan2005/tc2005014_6520.htm).

[4] 47 C.F.R. § 24.3.

[5] Report and Order, *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, 18 FCC Rcd 20,604 (2003); *see also See* Second Report and Order, *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, WT Docket 00-230 (2004) (http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-167A1.pdf).

[6] *CR Report and Order* at ¶ 1.

[7] Remarks of Jonathan S. Adelstein to Wireless Communications Association, WCA 2006, Washington, D.C. (June 27, 2006) (available at http://www.fcc.gov/Daily_Releases/Daily_Business/2006/db0628/DOC-266127A1.pdf).

[8] Additionally, some cordless phones dynamically adjust their transmissions so that they communicate between interfering microwave oven pulses.

[9] *CR Report and Order* at ¶ 2.

[10] *Id.* at ¶ 11.

aircraft/Unmanned Aerial Vehicles ("UAVs"), and radios used in submersibles.

XG's suite of functionalities leverages an unmistakable convergence of technology trends that are changing the operational and design characteristics of radio devices. The XG program includes software-defined, frequency agile and cognitive capabilities. A software defined radio ("SDR") is a device in which much of the physical layer is programmable and reconfigurable. In contrast to SDRs, traditional radios feature designs that are fixed in a radio's hardware. Notably, SDRs allow much of what was previously done with hardware— including signal processing, modulation/demodulation, and power control — to be accomplished in reconfigurable software. Accordingly, one of the chief virtues of a XG-enabled radio is that it may be reconfigured for various modulation schemes, frequency adaptation and portable waveforms. Further, XG-enabled devices are also frequency agile. That is, they can change how and where they operate within the radio spectrum, moving among a set of frequency bands in response to interference or other constraints. Finally, XG-enabled devices are cognitive. That is, they can autonomously make operational decisions in response to detected environmental conditions. Collectively, such capabilities enable devices where intelligence resides in individual radios operating at the edges of a network.

XG's development of a suite of smart radio capabilities yields sweeping promise: it could improve the spectrum sharing capabilities of a diverse range of radios across a variety of systems and networks. The so-called smart radio dimensions of XG facilitate significant advances in how spectrum can be accessed and shared. These improvements include the abilities to automate existing aspects of the spectrum coordination process that are currently handled manually, promote dynamic and opportunistic spectrum sharing arrangements, and permit reconfiguration of radios so as to permit updates in view of changing circumstances and revisions in regulatory policies over time.

III. Current Spectrum Management Policy Objectives: XG As An Enabling Tool For Regulators

Regulatory trends and precedents show that approval of smart radio technologies such as XG does not require a paradigm shift in spectrum management policy. Rather, approval of devices produced by the XG program would involve an incremental and logical evolution of existing regulatory precedents. Overall, the increasing willingness of regulators to embrace a variety of spectrum sharing techniques bodes particularly well for XG's adoption in military and commercial sectors, as well as in domestic and international arenas.[11] To illustrate this point, this Part III explains existing regulatory trends through the prism of three policy objectives that XG is poised to advance. In particular, the subsections below address objectives that spectrum managers have stressed as goals in contemporary spectrum regulation: (A) reduction in spectrum scarcity; (B) improved administrative efficiency; and (C) increased local autonomy concerning spectrum usage. Significantly, XG presents a set of tools that facilitate improved achievement of each of these three regulatory objectives.

While XG's sharing methods are more advanced than sharing by conventional radios, they are— from a policy perspective— conceptually similar to sharing methods approved by regulators over the past two decades. Indeed, recent spectrum sharing regulatory actions—including those that permit secondary markets and encourage decentralized trunking— provide several favorable precedents for the types of sharing promoted by XG. As explained below, there are ample spectrum sharing precedents and policy statements from the FCC, NTIA and international regulators which underscore the likelihood of regulatory support for XG technologies. In general, regulators acknowledge that in view of increased technological capabilities such as XG they "should strive, wherever possible, to eliminate regulatory barriers to increased spectrum access."[12] These trends must be emphasized in order to minimize the "regulatory lag" that often snags innovative services that "fall outside existing regulatory paradigms."[13] Moreover, considering the higher priority that spectrum managers today accord policy goals such as a reduction in spectrum scarcity, improved administrative efficiency, and better information collection, the regulatory embrace of novel sharing methods is a laudable trend that should be continued and even expanded with XG.

Burgeoning demand for services requiring spectrum access necessitates that regulators either refuse to allow such access to new applicants, relocate existing users, or find better methods to increase efficient use of the spectrum. XG represents the promise of this final alternative. As current FCC Chairman Kevin Martin previously observed:

> As more and more players vie to use the same frequencies, it is becoming increasingly difficult to find unencumbered spectrum. As a result, industry has been forced to respond with creative ways to enhance spectral efficiency. These more recent technological changes allow spectrum sharing to be taken to new levels. For example, . . . [The Department of Defense's] 'XG' program - which focuses on Next

[11] Notably, there is a feedback loop between federal, commercial and international sectors concerning the development and adoption of new technology such as XG. For example, XG's success in the federal or military sector would increase the probability of its commercial success. Meanwhile, commercial success would almost certainly result in increased federal adoption of XG-technology as it would allow for federal agencies to enjoy the "economies of scale that accrue to commercial service providers." *Federal Long-Range Spectrum Plan,* Working Group 7 of the Spectrum Planning Subcommittee, 43 (September 2000).

[12] *See* Spectrum Policy Task Force, Fed. Communications Comm'n, *Spectrum Policy Task Force Report* at 14 (2002) (*available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf) (herein, "SPTF"). "[T]the Commission's spectrum policies can and should remain technology agnostic, but they should not be technology antagonistic").

[13] Notice of Inquiry, *In the Matter of 1998 Biennial Regulatory Review—Testing New Technology*, 13 FCC Rcd. 21,879, 21882 (1998).

> Generation communications devices to support military deployment - seeks to produce even further advances in spectrum assignment technology through dynamic use of frequency, time and space.[14]

Importantly, XG presents a set of tools that are not just technological enablers, but regulatory enablers, too. This is explained in the subsections below.

A. Reduction in Spectrum Scarcity

Scarcity of spectrum emanates from two types of constraints: limitations related to the *physical* nature of the spectrum and limitations related to *administrative* barriers to access to the spectrum. Administrative scarcity arises from a host of factors related to regulation that results in underutilized spectrum. For example, administrative scarcity in the United States arises from unnecessary exclusive assignments engendered by coordination challenges between the NTIA, FCC and the State Department.[15] "The United States is unique in the world in that it lacks a mechanism to formulate a national spectrum policy that balances traditional national security and new commercial uses of frequency spectrum."[16] At least in some bands, regulators believe that physical scarcity is less of a problem than administrative scarcity for prospective spectrum users.[17] While resolution of physical scarcity challenges requires technological innovation that improves spectral efficiency (*viz.*, allows more information to be transmitted and received while using the same amount of the spectrum resource), resolution of administrative scarcity challenges requires improved access to spectrum for providers of spectrum-dependent services.

Problems of administrative scarcity cannot be over-emphasized in contributing to underutilized spectrum. For example, FCC measurements of spectral usage in 2002 showed "that significant spectrum capacity remains untapped."[18] "[T]emporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%."[19] Similarly, Shared Spectrum Corporation ("SSC") tests conducted in conjunction with the University of Kansas at six disparate locations in 2004-05 found "significant available spectrum in most bands," with an overall average spectrum occupancy rate of 5.2 percent.[20] Perhaps not surprisingly, 2001 measurements in Lichtenau, Germany also "showed that large chunks of potential spectral resources are used only sporadically."[21] Accordingly, alleviating administrative scarcity by facilitating greater access to spectrum is a viable way by which spectrum managers can mitigate the effects of physical scarcity.[22] Regulators are not impervious to this problem. In fact, over the past two decades regulators have laudably embraced innovative policies—ranging from "commons"-like unlicensed uses to encouraging property-like market based transactions —designed to facilitate greater access to spectrum by more users.[23]

Significantly, a compelling aspect of technologies enabled by XG is its ability to reduce administrative scarcity irrespective of the spectrum management approach used in a given band. The ability to opportunistically share spectrum with minimal risk of increased interference allows regulators to authorize more ambitious sharing strategies. Thus, no matter what type of regulatory regime is used, XG liberates spectrum managers from the narrow confines of worse case projections in their evaluation and approval of sharing methods. This is important because for the foreseeable future "[n]o single regulatory model should be applied to all spectrum" and it is likely that a hybrid of market-based mechanisms, open access to spectrum commons, and command and control will be used by spectrum mangers to allocate the spectrum resource.[24] Accordingly, a valuable aspect of XG is that it presents efficiency gains for the range of regulatory models that govern different bands.[25]

Regulators and policy-makers have unmistakably signaled a commitment to increased efficiency in spectrum use over the past 20 years. Among the most notable landmarks in contemporary spectrum sharing regulatory precedents are those liberalizing unlicensed uses, including the FCC's

[14] Remarks by Kevin J. Martin, Commissioner, FCC, to the FCBA Policy Summit & CLE, *U.S. Spectrum Policy: Convergence or Co-Existence?* (March 5, 2002).

[15] *Coping with Change: Managing RF Spectrum to Meeting DoD Needs,* Report of the Defense Science Board Task Force on DoD Frequency Spectrum Issues, Overview (November, 2000) (available at http://www.acq.osd.mil/dsb/reports/spectrum.pdf) ("DoD Frequency Spectrum Issues"); *see also* SPECTRUM POLICY FOR THE 21[ST] CENTURY – The President's Spectrum Policy Initiative: Report 2—RECOMMENDATIONS FROM STATE AND LOCAL GOVERNMENTS AND PRIVATE SECTOR RESPONDERS, Section 1 (June, 2004) (available at http://www.ntia.doc.gov/reports/specpolini/presspecpolini_report2_06242004.htm#_Toc75759593) (herein, "President's Spectrum Policy Initiative: Report 2").

[16] *DoD Frequency Spectrum Issues*, Overview.

[17] *See generally SPTF* at 3 ("In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential users to obtain such access.").

[18] *SPTF* at 14.

[19] Akyildiz, Lee, Vuran and Mohanty, *NeXt Generation/ Dynamic Spectrum Access / Cognitive Radio Wireless Networks: A Survey*, 1 (Science Direct) (Accepted for publication May 2006) ("Akyildiz *et. al.*") (available at http://www.ece.gatech.edu/research/labs/bwn/radio.pdf) (citing *Notice of Proposed Rulemaking and Order*, ET Docket No. 03-222 (Dec. 2003)).

[20] *See* Shared Spectrum Company Web-site, *Measurements* (available at http://www.sharedspectrum.com/?section=nsf_summary) (last checked July 13, 2006).

[21] *See* Timo A. Weiss and Friedrich K. Jondral, *Spectrum Pooling: An Innovative Strategy for the Enhancement of Spectrum Efficiency,* 58 (IEEE Radio Communications) (March, 2004).

[22] *SPTF* at 14.

[23] *See, e.g.,* Ellen Goodman, *Spectrum Rights in the Telecosm to Come*, 41 San Diego L. Rev. 269, 278 (2004) ("Goodman") (noting that in "recent years, the government has implemented changes in spectrum management that head in the precise directions (indeed, in both directions) of reform that have been urged by private property and commons advocates.").

[24] SPTF at 3.

[25] *See CR Report and Order* at ¶ 1: "Regardless of the regulatory model – licensed, unlicensed, or other new models – [software defined and cognitive] technologies are allowing and will increasingly allow more intensive access to, and use of, spectrum than possible with traditional, hardware-based radio systems."

authorization of spread spectrum techniques in 1985 followed by 1989 revisions increasing flexibility for unlicensed devises.[26] Contemporary changes to unlicensed rules—which were originally established in 1938—permit operation of devices with higher emissions in certain bands and, additionally, designate bands in which unlicensed devices can access more bandwidth. Indeed, one expert has suggested that the spread spectrum precedent may be viewed as "a form of secret sauce" that ushered in the modern era of increased spectrum sharing (and a concomitant reduction in administrative scarcity) through unlicensed services.[27] In the spirit of the spread spectrum precedent, Part 15 rules such as Section 15.209 have emerged which permit "unlicensed device operation at specified radiated emission levels, in almost any frequency band, other than the television broadcast and certain designated restricted frequency bands."[28] Indeed, the Commission changed the Part 15 rules in a recent proceeding on cognitive radio technologies "to allow certification of unlicensed transmitters capable of operation outside of permissible Part 15 bands" so long as devices incorporate an automatic frequency selection to ensure they operate only where permitted.[29]

Like XG, spread spectrum techniques were "originally developed for military applications" and soon presented "several interesting civil applications" that promised more efficient use of spectrum.[30] Also like XG, spread spectrum presents useful applications for both unlicensed and licensed bands. The wideband modulation technology utilized in spread spectrum permits low power uses that minimally affect primary users in utilized frequencies. Similar to spread spectrum, XG technology represents technological innovation that reduces administrative scarcity by facilitating spectrum access. In an important respect, however, XG-enabled devices are better at sharing than spread spectrum. While spread spectrum can cause interference in bands that it operates with,[31] XG's monitoring and agility capabilities allow it to co-exist with and present little increase in harm to prior existing services.

Additionally, more recent precedents underscore a shift away from prohibiting spectrum sharing (and thereby promoting administrative scarcity) in some bands based merely on the threat of some interference. For example, in the late 1990's the Commission considered whether terrestrial multichannel video distribution and data service ("MVDDS") proposed by Northpoint Technology, Ltd. ("Northpoint") would cause harmful interference with incumbent Direct Broadcast Satellite ("DBS") service in the 12.2-12.7 GHz bandwidth.[32] MVDDS access to this frequency range promoted efficiency since the "use of innovative spectrum sharing techniques [would] facilitate a high level of frequency reuse in the band . . . ."[33] The DBS incumbents, however, claimed that the new service would have a deleterious effect on the quality of their service. Significantly, the Commission found that adequate safeguards against harmful interference existed where parameters ensured that MVDDS operations such as Northpoint's would almost always cause less than a 10% increase in DBS signal outage.[34] On appeal, the Court of Appeals for the District of Columbia Circuit affirmed the Commission's determination that such effects would not constitute harmful interference.[35] In addition to Northpoint, a similar cost/benefit analysis is implicit in the Commission's approval of Ultrawideband ("UWB") uses.[36] In the UWB context the FCC determined that some interference—even for assigned licensees—is acceptable and, accordingly, the Commission "tr[ied] to balance costs and benefits" in determining what level of interference is permissible.[37] Echoing this approach in a third precedent, the FCC in 2003 articulated that an aggrieved party must accept the permitted spectrum uses of others which cause interference so long as the effects do not rise to pernicious levels constituting harmful interference.[38] In short, regulators have evinced an increased

[26] See Authorization *of Spread Spectrum systems Under Parts 15 and 90, First Report and Order*, Gen. Docket No. 81-413, 50 Fed. Reg. 25234 (June 18, 1985), (adopted May 9, 1985); *In The matter of Revision of Part 15 of the Rules Regarding the Operation of Radio Frequency Devices Without An Individual License, First Report and Order*, Gen. Docket 87-389, 4 FCC Rcd. 3493 (1989) (adopted Mar. 30, 1989).

[27] *See* Charles Jackson, *Dynamic Sharing of Radio Spectrum: A Brief History* at 453, n. 8 (September 5, 2005) (IEEE DySPAN 2005 Proceedings) ("Dynamic Sharing History"); *see generally* Philip Weiser and Dale Hatfield, *Policing the Spectrum Commons,* 74 Fordham L. Rev. 663, 672 (November 2005) (describing traditional Part 15 rules as "a paradigm of regulatory minimalism").

[28] *Comments of the National Telecommunications and Information Administration, In the Matter of Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies,* at 26 (ET Docket No. 03-108) (February 15, 2005) ("NTIA CR Comments").

[29] *CR Report and Order* at ¶ 72.

[30] *See In the Matter of Authorization of spread spectrum and other wideband emissions not presently provided for in the FCC Rules and Regulations*, Gen Docket No. 81-413, 101 F.C.C.2d 419 (1985).

[31] *See* Jackson, Pickholtz and Hatfield, *Spread Spectrum is Good—But it Does Not Obsolete NBC v. U.S.,* Vol. 58 Federal Comm. L. J. 245, 245 (2006).

[32] *See First Report and Order and Further Notice of Proposed Rulemaking*, In the Matter of Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range; Amendment of the Commission's Rules to Authorize Subsidiary Terrestrial Use of the 12.2-12.7 GHz Band by Direct Broadcast Satellite Licensees and Their Affiliates; and Applications of Broadwave USA, PDC Broadband Corporation, and Satellite Receivers, Ltd. to Provide A Fixed Service in the 12.2-12.7 GHz Band, ET Docket No. 98-206, ("*Northpoint First Order*"), 16 F.C.C. Rcd. 4096, 4160 ¶ 164, 2000 WL 1804138 (2000).

[33] *Northpoint First Order* at ¶19, 20.

[34] See *Memorandum Opinion and Order and Second Report and Order* ("*Northpoint Second Order* "), 17 F.C.C. Rcd. 9614, ¶ 67, 2002 WL 1041075 (2002) (*cited in Northpoint Technology, Ltd. v. F.C.C.*, 414 F.3d 61, 67 (Ct. App. D.C. 2005)).

[35] *Northpoint Technology, Ltd. v. F.C.C.*, 414 F.3d 61, 67 (Ct. App. D.C. 2005).

[36] R. Paul Margie, *Can You Hear Me Now? Getting Better Reception from the FCC's Spectrum Policy*, 2004 Stan. Tech. L. Rev. 5, 749 (2004) ("Margie")).

[37] *Margie* at 749.

[38] See *AirCell, Inc., Petition, Pursuant to Section 7 of the Act, for a Waiver of the Airborne Cellular Rule, or, in the Alternative, for a Declaratory Ruling*, 18 F.C.C.R. 1926, 1935 (2003) (cited by Goodman at 348 n. 249). Unfortunately, methods to determine what rises to "harmful interference" (and separates it from permissible levels of interference) remain underdeveloped. *See NTIA IPC Phase I Report* at Executive Summary and Section 2 ("The identification of [interference protection criteria such as harmful interference] is often a confusing, time-consuming step with no single reference source upon which to draw."); *see also* Timothy X Brown, *An analysis of unlicensed device operation in licensed broadcast service bands*, (Proc. IEEE DySPAN)

willingness to consider whether the benefits of efficient use of spectrum outweigh the costs of minimal increases in risk of interference.[39]

Moreover, regulatory efforts to diminish administrative scarcity help achieve objectives that go beyond considerations related solely to the spectrum's commercial significance. "Effective and efficient use of the spectrum underpins efforts to ensure homeland security, national defense, public safety, law enforcement, domestic and international transportation, and scientific exploration."[40] Challenges in coordinating federal/non-federal sharing of spectrum are a contributing factor to administrative scarcity.[41] While notable federal/non-federal sharing precedents exist— including the use of Dynamic Frequency Selection ("DFS") in the 5 GHz band (discussed in Part 4, *infra*) – overall coordination problems persist and result in underutilized spectrum. To mitigate this problem, NTIA and FCC regulators have committed to establish a test bed to promote more efficient sharing between federal and non-federal users.[42] In a recent step in support of this initiative, the FCC in June 2006 published a Public Notice soliciting comment on this idea.[43] One of the goals of the test bed may be to test dynamic spectrum access techniques such as those promoted by XG.[44] While implementation of certain XG techniques are not a large leap from existing precedents, new techniques may be identified that are more experimental. Particularly for unprecedented sharing techniques, the proposed federal/non-federal test bed may present a valuable opportunity to develop new technologies as well as demonstrate the effectiveness of cutting edge systems.

One simple example of how federal/non-federal spectrum sharing arrangements that reduce administrative scarcity makes sense is Fort Irwin, California. At Fort Irwin, the military utilizes the television guard bands adjacent to channel four which, in view of Fort Irwin's remote location, poses low risk of increased interference to adjacent television channels. As former NTIA Assistant Secretary Michael Gallagher explained, "[c]ommanders use radio frequency identification (RFID) tags to monitor individual soldiers as they train in areas that simulate desert terrain. The tags operate in the TV band but apparently do not cause interference."[45] Going forward, in addition to reducing administrative scarcity, the ability to share spectrum in this manner is "of paramount importance for national defense purposes" because it provides military access to spectrum under circumstances where exclusive spectrum is not warranted.[46]

B. *Automation to Improve Administrative Efficiency*

In addition to mitigation of administrative scarcity, smart radio systems such as XG present additional value as a regulatory enabler that can automate existing spectrum management functions. Fundamentally, spectrum managers perform a coordination function to ensure that gains are realized from beneficial spectral uses while minimizing unnecessary interference between and among users. The spectrum manager's role is difficult: the command and control legacy demands that the manager constantly recalibrate uses of the spectrum in view of rapidly changing technology, fluctuating demands for existing services, and rising clamor for new services.[47]

Overall, spectrum use is coordinated through four tasks: allocation, establishment of the band plan (including the imposition of any service rules), assignment, and enforcement. Smart radio systems present the possibility of helping automate each of these functions, resulting in lower administrative costs through speedier decision-making and the ability to more nimbly alter and update service and technical rules. Regulators have taken steps in recent years to lower costs from both the perspective of the agency and of spectrum stakeholders. For example, the FCC has been willing to lower its costs and facilitate flexible spectrum use by delegating tasks such as frequency coordination to private guard band managers.[48] Additionally, the FCC has reduced costs and delays for spectrum users through streamlined automation such as permitting leasing approval applications to be submitted on-line and expediting approval of such applications.[49]

(November 2005) (analyzing different ways to approach how harmful interference could be measured); *Margie* at 17 ("the [harmful interference] definition includes several undefined terms and concepts that make it difficult to apply consistently").

[39] Overall, this policy direction is consistent with the sound argument originally articulated by Ronald Coase in 1959. "It is sometimes implied that the aim of regulation in the radio industry should be to minimize interference. But this would be wrong. The aim should be to maximize output . . . What has to be insured is that the gain from the interference more than offsets the harm it produces." R.H. Coase, *The Federal Communications Commission*, 2 J.L. & Econ. 1, 27 (1959) (cited in *Margie* at 70).

[40] *See President's Spectrum Policy Initiative: Report 2*.

[41] "Barriers to Federal/non-Federal sharing should be identified and reduced by NTIA and FCC cooperative actions." *NTIA Special Publication 94*-31, United States National Spectrum Requirements: Projections and Trends, Chapter 7 (Department of Commerce, March 1995) ("NTIA 1995 Projections") (available at http://www.ntia.doc.gov/openness/sp_rqmnts/sharing7.html).

[42] *See President's Spectrum Policy Initiative: Report 2* at Section 3, Recommendation 6.

[43] Public Notice, Federal Communications Commission Seeks Public Comment on Creation of a Spectrum Sharing Innovation Test Bed (ET Docket No. 06-89) (June 8, 2006) ("Test-Bed").

[44] *Test-Bed* at 3.

[45] *Policy Issues for Telecommunications Reform: Reports of the 2005 Aspen Institute Conferences on Telecommunications and Spectrum Policy*, 12 (Robert Entman, Rapporteur) (The Aspen Institute, 2006).

[46] *See NTIA 1995 Projections*, Chapter 7.

[47] At least according to one account, the nature of the job has always been challenging. *See* Howard Pyle, "Shake Hands with the 'R.I'", *Radio Broadcast,* pp. 289-94 (1924) (cited by Douglas Galbi, *Revolutionary Ideas for Radio Regulation,* 18 n.4 (2002) (available at http://129.3.20.41/eps/le/papers/0304/0304001.pdf). "[The spectrum manager] comes to the office, not refreshed by a restful night's sleep, but dog-tired from a four or five hour vigil the night before…. Not once in a while but every night, does he do this. . . The devotion to duty of the men in the service is remarkable . . . Much more has been tendered the inspectors by outside firms, but the majority prefer to stay and conquer your problems and to take such satisfaction as they may find in the fact that they are beyond a doubt doing more to give you better radio than any other individual or group in the art."

[48] *See* Report and Order, *In the Matter of Frequency Coordination in the Private Land Mobile Radio Services*, PR Docket No. 83-737, 103 F.C.C.2d 1093 (adopted April 3, 1986).

[49] *See* 2003 and 2004 *Secondary Markets* Orders discussed in note 5, *supra.*

For an example of prospective efficiency gains that could be realized, consider the opportunity for a radio's software to automate the United States Department of Defense's existing spectrum manager and coordination functions. At a basic level, the XG program uses software-based *policies* to control what radios can do and must not do. Commanders in military theaters have expressly recognized the costs associated with *not* having an automated spectrum management capability. Indeed, the recent Central Command statement to the Armed Services Committee noted that "***[b]ecause we lack automated capability to dynamically manage the spectrum at the tactical level, we must focus on training spectrum managers*** in all Services and equipping them with the right tools."[50] At present, each service has its own spectrum manager and is not well positioned to cooperate with one another (either at home or around the world). By adopting a flexible architecture that utilizes software-based policy controls enabled by XG systems, coordination of spectrum devices can be automated through downloadable, machine-readable policies. Such automated coordination would be highly valuable under exigent military circumstances involving rapid deployment. Moreover, even outside of war-time theater, automated policy-based controls would enable military branches to better coordinate spectrum sharing and thereby operate far more efficiently.

The administrative efficiencies facilitated by XG are closely tied to some of the distinctive technological capabilities of cognitive and software defined radios. XG's software defined capabilities include a policy engine that governs operation of the radio (that is, the circumstances when it can and cannot transmit). Significantly, the software defined policy engine is updateable so that a radio's operating parameters can be altered over time. From the view of a regulator, XG's potential to reduce administrative costs associated with service rules is apparent. Currently, regulators must tread cautiously in setting operating parameters for conventional radios that cannot be updated: an error results in the unhappy dilemma of either tolerating increased interference or the need to recall devices. The reconfigurable, flexible nature of XG, however, means that service rule stakes are much reduced: adjustments can be made through updates over time. As one proposal presented to the ITU-R explained:

> The magnitude of the spectrum management task of not only comprehending all of the dynamic or temporal and spatial or geographic sharing requirements, but also anticipating changes to all of these sharing arrangements in order to code them into the devices *ex ante,* makes a strong case for devices to have the ability to have their operating parameters modifiable via software in the field. ***Equally important is the need to be able to change the policies that dictate the radio's behavior***.[51]

A notable feature of a SDR such as XG is that it is reconfigurable.[52] "Reconfigurability is the capability of adjusting operating parameters for the transmission on the fly without any modification on the hardware components."[53] Two aspects of XG's reconfigurability are particularly promising: *transmission reconfigurability* and *policy reconfigurability*. Transmission reconfigurability allows a XG radio to alter its operating frequency, modulation and transmit power within the limits of the device's hardware capabilities.[54] Such transmission reconfiguration can occur at the beginning of a transmission or even during transmission.[55]

Additionally, software-based policy reconfigurability allows a XG radio to update the smart-radio policies that govern the device's operation. To appreciate this capability, however, it is critical to distinguish between *regulatory policies* and *smart radio policies.* Regulatory policies are rules provided by regulators that generally govern radio operation. In contrast, smart radio policies are a data set of machine readable rules that can be downloaded onto a radio. A smart radio policy is an instruction rendered when system inquires as to whether a specified transmission may be performed.[56] Of course, there is an important nexus between these two policy variants: in order to be effective, *smart radio* policies must incorporate the relevant *regulatory* policies into a machine-readable data set that can be downloaded to and understood by a XG device.

The potential value of XG's reconfigurability should not be overlooked. By way of analogy, consider the Voyager 2 spacecraft. When NASA launched Voyager 2 in 1977, it was designed to explore two planets, Jupiter and Saturn.[57] The success of the mission—combined with reprogrammable software features of Voyager 2— allowed NASA to direct the spacecraft to do far more than was originally expected. After completing its original mission, Voyager 2 was reprogrammed so that its travels were extended to exploration of Uranus and Neptune. Following that, the spacecraft was directed to explore the heliopause, which is the fringe of the Sun's magnetic field. Indeed, "[a]s the spacecraft [has flown] across the solar system, remote-control reprogramming has given the Voyagers greater capabilities than they possessed when they left the Earth."[58] Key to extending its range and lifetime was

[50] Statement of General John P. Abizaid, United States Army Commander, United States Central Command, Before the Senate Armed Services Committee on the 2006 Posture of the United States Central Command (March 14, 2006) (available at http://192.31.19.143/sites/uscentcom1/Shared%20Documents/PostureStatement2006.htm) (emphasis added).

[51] *Canada/New Zealand SDR Proposal* at 14 (emphasis added).

[52] Some experts conceive of reconfigurability as more of a cognitive than software defined aspect of a XG radio. *See, e.g., Akyildiz et. al.* at 5-6. It is not the purpose of this paper to focus on taxonomic categorization. Whether reconfigurability is characterized as a software defined element, a cognitive element, or both, the essential point for purposes of this paper is that a XG radio is reconfigurable.

[53] *Akyildiz et. al.* at 5.

[54] *Id.* at 6.

[55] *Id.*

[56] This is based on ideas first proposed by Steve Berger and John Chapin.

[57] *See* Jet Propulsion Laboratory, *Two Voyager Spacecraft Still Going Strong After 20 Years* (NASA Public Information Office, September 2, 1997) ("NASA Release") (available at http://www.jpl.nasa.gov/releases/97/vgrani97.html).

[58] *See NASA Release*.

the ability to reprogram the spacecraft communication software to match new communication technology on Earth that did not exist when the spacecraft was launched. In short, the ability to update the device's operational directives enabled accomplishments that would have been difficult to conceive of when the Voyager 2 hardware was launched almost 30 years ago.

Similarly, there exists great potential to take advantage of the reconfigurable nature of XG. Like Voyager 2, an essential characteristic of a policy-defined SDR is that it partitions the device's physical *capabilities* from its operational *directives*. Thus, the radio's operating directives, which are expressed in the smart radio policies that govern the radio's operation, can be used to limit or liberate how the device is used. This is important. As regulatory policies and spectrum rules change over time—even in ways not anticipated at the time of a radio's release—the XG radio's policies can be adapted and updated as necessary. Reconfigurability is also particularly valuable when a radio is moved from one jurisdiction to another. For example, if a XG radio is moved from one country to another, the radio's geolocation capabilities will detect its new location and then adapt its operations to the new country's directives as expressed in smart radio policies. Moreover, as networking advances allow for improved coordination between XG nodes over time—again, even in ways not currently anticipated— XG's operating directives can be adapted and updated. Notably, this means that changes in regulatory policies or advances in networking techniques can be accommodated and even automatically assimilated by XG radios without requiring wholesale replacement of hardware devices.[59]

Accordingly, the reconfigurable nature of SDRs could eventually make possible significant spectrum management changes without requiring wholesale replacement of devices. This would represent a significant development. Consider, for example, some instances of military acquisitions where frequency supportability was not properly accounted for prior to building out such systems. Unfortunately, these failures led to devices that are effectively inoperable in places where the frequency that such systems are designed to use is unavailable. For example:

- "The B-2 Bomber's radar has a high probability of interfering with primary users in the radar's frequency band. It is currently being redesigned.
- "The Enhanced Position Location Reporting System (EPLRS) Situational Awareness Data Link (SADL) cannot be used in Germany or Korea.
- "The Global Hawk SATCOM data links use exclusive non-government bands, which means the Global Hawk can only be employed in the U.S. and its Possessions (US&P) if it can operate in a non-interference mode with primary users of that spectrum.
- "COTS Radio Frequency Identification (RF ID) systems were acquired that operated in frequencies that precluded their use in some European countries."[60]

A significant advantage of SDRs is that much of what was previously done with a device's hardware— including signal processing, modulation/demodulation, and power control — can be accomplished in reconfigurable software. Combined with frequency agility, this permits adjustment in the operating parameters of a device. For example, if a certain frequency is unavailable or a certain amount of power is causing interference, a highly flexible device would be able to adapt use without wholesale redesign. Alternatively, if a spectrum manager adjusted relevant rules or regulations governing operation—for example, a foreign government conducts a reallocation of frequencies—again a highly flexible device would be able to adapt its uses without wholesale redesign. While such SDR capability is not yet available, this is among the promising directions in which smart radio research and the XG program are going.

Moreover, one of the most important consequences of the reconfigurability insight is that it should facilitate less costly and possibly speedier approval for new devices and services. For a simple example of the value of reconfigurable radios, consider the recent development of the dynamic frequency selection ("DFS") rules designed to facilitate sharing between Unlicensed National Information Infrastructure ("U-NII") devices and military radar systems.[61] Implementations of DFS rules as a technical matter were complicated because of difficulties in detection flowing from the secret nature of the radar's signal attributes.[62] These difficulties were compounded, however, by the fact that changes to the DFS rules needed to be incorporated into the hardware rather than a reconfigurable device such as XG. All told, the process of revising the DFS rules took almost three years[63] and required millions of dollars in expenditures. Access based on

[59] Additionally, in one respect the Voyager II analogy actually *understates* the upshot of a SDR. While Voyager II effectively underscores the value of reprogramability in repurposing a device, it does not fully capture the reconfigurable dimension of an SDR that enables fundamental changes in functionality (not just repurposing).

[60] John Stine and David Portigal, *Spectrum 101: An Introduction to Spectrum Management,* 6-8 (Mitre Technical Report) (available at http://www.mitre.org/work/tech_papers/tech_papers_04/04_0423/04_0423.pdf#search=%22mitre%20spectrum%20101%20an%20introduction%20to%20spectrum%20management%22).

[61] DFS is discussed in more detail in Part 4(B), *infra.*

[62] *In the matter of Revision to Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure devices in the 5 GHz Band*, at ¶ 4 (ET Docket No. 03-122) (February 23, 2005) ("*February 23 U-NII Order*"). Note that the sensing difficulties in DFS, however, are valid and underscore that a challenge for future cognitive radios relates to improved detection of non-cooperative signals.

[63] Memorandum Opinion and Order, *In the matter of Revision to Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure devices in the 5 GHz Band* at ¶ 3 (ET Docket No. 03-122) (June 30, 2006) ("*June 30, 2006 U-NII Opinion*").

reconfigurable hardware would have eased introduction since there would be a ready path to ease or tighten the rules as field experience was gained. This would focus discussion more on the modifiable "introduction process" and less on the irrevocable "introduction launch."

In addition to reconfigurability, another characteristic of XG devices, high detection aptitude in radios at the network's edges, also promotes administrative efficiency through automation. "[T]he novelty characteristic of a cognitive radio transceiver is a wideband sensing capability of the RF front-end." [64] Further, XG features "location awareness" cognitive capability whereby a device can use geo-location technology (such as GPS) to determine where it is and, based on this information, discern the relevant parameters for operation in that environment.[65] Notably, the NTIA has agreed with the assessment of the Institute of Electrical and Electronics Engineers (IEEE) 820.18 Radio Regulatory Technical Advisory Group that the geo-location capability can be combined with an on-line database of the fixed site locations so that a cognitive radio will know whether or not it may operate at a given place and time.[66] Additionally, XG's high detection and geolocation capabilities can be leveraged to increase administrative efficiencies in assisting enforcement efforts. For example, XG nodes can conduct sensing operations and identify signals that are not supposed to be in a particular band. Detection of users that do not comply with existing policies could be reported to regulators in order to assist in identifying rogue users.

Finally, the geolocation capability of XG should further lower administrative costs by helping automate spectrum coordination across jurisdictions. There are two respects in which XG may save cross-jurisdiction coordination costs: (i) sharing across geographic areas within an organization, and (ii) sharing across different agencies or organizations. For example, it will help mitigate coordination problems between the United States Department of Defense ("DoD") and commercial users so that military applications can be used with the knowledge that such applications are *not* interfering with other spectral uses. In this respect, DoD can mitigate significant types of misbehavior and interference through the functionality made possible by XG's policy engine combined with a wide-band front end and high detection capability. Accordingly, XG presents a significant opportunity to help mitigate and resolve existing dilemmas and disputes facing the NTIA, DoD and FCC while achieving improved efficiency in spectrum use.

C. *Increased Local Autonomy*

A final regulatory trend advanced by XG is increased local autonomy. Decentralized information collection and decision-making is advanced as spectrum management moves away from the command-and-control regulatory model outlined in Part II above. The move away from "wise-man" regulation leverages two powerful forces: (i) the general technological trend of greater intelligence at the "edge" of a network; and (ii) the recognition that decentralized decision-making is better informed as it uses more localized information than centralized regulators can collect and assimilate. In short, decentralized mechanisms allow for more nimble and tailored uses and decision-making.[67]

For example, a noteworthy instance of regulator commitment to decentralized decision-making is exemplified in the Secondary Markets proceeding. [68] In 2003, the Commission jettisoned the antiquated *Intermountain Microwave* standard which had stymied efforts by licensees to sublease available spectrum to secondary users. The Secondary Markets proceeding instead adopted new standards to promote spectrum markets and help decentralize access for new spectrum users. In so doing, the Commission explicitly cited an "end goal" of making spectrum more available to third parties by removing barriers to spectrum leasing so that "underutilized or fallow spectrum" could be put to more efficient use.[69] Not surprisingly, XG enables decentralized regulatory approaches such as secondary markets. As noted in the Spectrum Policy Task Force report:

> Because new, smart technologies can sense the spectrum environment and because they have the agility to dynamically adapt or adjust their operations, increasing access to the spectrum for smart technologies, such as software-defined radios, can improve utilization, through more efficient access, of the radio spectrum without detriment to existing spectrum users.[70]

Moreover, it should be observed that the same intelligent attributes that allow XG to enhance secondary markets also favor better decentralized sharing in the "commons" space. For example, Canada's Milton system is a cognitive radio network that opportunistically identifies spectrum in providing wireless broadband access in unlicensed frequencies.[71] As a cognitive network, Milton works well within a commons space because it can "identify poor quality radio links and adapt its own signal transmission characteristics to improve performance."[72] Similarly, the cognitive capabilities of XG

[64] Akyildiz *et. al.* at 4.
[65] *CR Report and Order* ¶ 11.
[66] *NTIA CR Comments* at 19.

[67] Moreover, these mechanisms help overcome the informational handicaps of a centralized agency which is disadvantaged in its ability to value the spectrum resource, assimilate relevant business information, and track consumer preferences for goods and services. *See, e.g.,* Ronald Coase, *The Federal Communications Commission*, Journal of Law & Economics, at 18 (October, 1959).
[68] Report and Order And Further Notice of Proposed Rulemaking, *In the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets,* ¶ 3 (WT Docket No. 00-230) (October 6, 2003) ("2003 Secondary Markets Order"); *CR Report and Order* at ¶¶ 80-90.
[69] 2003 *Secondary Markets Order* at ¶¶ 7, 32.
[70] *SPTF* at 15.
[71] *MILTON (Microwave-Light Organized Network)*, Communications Research Centre Canada (June 29, 2005) (available at http://www.crc.ca/en/html/milton/home/home).
[72] *Broadband Access in Canada: Luxury or Civil Right?,* Link Magazine: Vol 52, 2005, at 10-11 (available at

can facilitate opportunistic sharing in a commons environment typified by changing conditions.

IV. Case Studies Underscoring Important Regulatory Precedents for XG

Spectrum sharing reaches back to the early uses of the radio spectrum and is hardly a new development accompanying smart radio programs such as XG.[73] Traditional maritime radio, for example, "always used shared channels" to keep watch.[74] As noted in Part II, well over half of the spectrum between 9 kHz and 3.1 GHz is already shared by federal and non-federal users.[75]

Of course, XG technology facilitates much more dynamic and sophisticated sharing methods than those used by traditional radio systems. In particular, XG enhances capabilities for dynamic spectrum sharing over shorter time intervals (facilitating arrangements such as interruptible spectrum leasing) and increases sharing between diverse services across different systems. Indeed, the Commission has characterized XG as a "catalyst for many further developments in cognitive radio technology" which could help "initiate a new era in radio frequency spectrum utilizations."[76]

In some respects, the innovations represented by XG should make approval of spectrum sharing less contentious than previous sharing proceedings insofar as XG enables technological improvements to sharing practices already approved for less advanced devices. Significantly, illustrations of three regulatory precedents provide a conceptual foundation for sharing methods promoted by XG. *First,* Section A explains that XG can be understood as decentralized trunking writ large: bands where spectrum is shared by XG form the common pool from which XG draws on an "as needed" basis using advanced interference avoidance strategies so as not to degrade primary user services. *Second,* Section B details that regulators have recognized that decentralized intelligence such as that presented by XG permits a shift to more dynamic sharing over short time intervals.[77] Dynamic Frequency Selection ("DFS") in the 5 GHz band provides an illustrative precedent of approval of dynamic sharing across diverse systems. *And third,* Section C considers the precedent of Automatic Link Establishment ("ALE"), which implements automation and frequency agility in order to improve communication in high frequency ("HF") or "shortwave" bands. Such methods have much in common with automated XG systems: fundamentally, both ALE and XG embrace technological solutions to surmount interference and communications difficulties caused by unpredictable spectrum environments. Each of these three precedents is discussed in turn.

A. Pooling and trunking precedents[78]

XG presents the potential for dramatic improvement to a sharing method known as *trunking.* Trunking is the technique of pooling channels and then allowing users to temporarily draw from the pool to carry conversations on an as needed basis. In contrast to trunking, the conventional approach assigns users to individual channels. Notably, the efficiency advantages of a trunking method over a conventional approach stem from the fact that trunking reduces the chances of encountering a channel-busy condition and permits utilization of otherwise unused channels by allowing access to all channels on an as needed basis. Opportunistic uses of spectrum through XG can be understood as an advanced version of decentralized trunking: the spectrum hole selected by a XG radio is simply part of the common pool from which XG draws on an as needed basis.

Trunking systems are premised on the insight that pooling a group of channels together and giving the users access to all channels on an as needed basis provides better service by reducing the likelihood of a channel-busy condition. The upshot of this technique is that it provides for higher utilization of the spectrum resource— *viz.,* more conversations in a given amount of spectrum— than conventional systems. Accordingly, trunking provides better quality (*e.g.,* there is lower blocking probability) and much higher average utilization of the resource (*i.e.,* increased spectral efficiency).

To appreciate the trunking insight in practice, consider the example of the Alaska Land Mobile Radio System. As a general matter, a major contributor to public safety interoperability woes in the United States is the predominant stove-pipe paradigm of public safety frequency assignment and use under an inflexible arrangement where spectrum is seldom shared. In a stove pipe regime, disparate fragments of spectrum are used by federal, state and local agencies and the relevant agencies rely on equipment that is specialized for

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http://www.dlink.ca/link/2005vol2/2005vol2_article2.pdf). The article quotes Veena Rawat of the Communications Research Centre as stating that Canada hopes that a commercially available Milton cognitive radio network could be available in 2006.

73 *See generally* C. Jackson, *Dynamic Sharing History*.

74 *Id.* at 3. This strategy has historically provided two benefits: (i) sharing promotes spectrum efficiency as there are not enough channels for each ship to have a separate channel; and (ii) sharing promotes human resource efficiency as ship operators would need additional people to monitor many radio channels or risk missing an important call such as a distress signal.

75 About 55.6% of spectrum between 9 kHz and 3.1 GHz was shared by federal and non-federal users as of fall, 2002. United States General Accounting Office, *Better Coordination and Enhanced Accountability Needed to Improve Spectrum Management* (September 2002). Additionally, "[f]rom an allocation point of view in the 0 to 30,000 MHz range, the government exclusive allocation is 7% (2271 MHz), non-government users have 30% (8961 MHz), and the remainder (63%) (18768 MHz) is shared." NTIA Web-Page, *NTIA Myths vs. Reality* (available at http://www.ntia.doc.gov/ntiahome/myths.html) (last checked August 7, 2006).

76 *CR Report and Order* at ¶¶ 35, 36.

77 "Because such smart devices are agile and can change frequencies nearly instantaneously, they can operate for short periods of time in temporarily unused spectrum, making possible multiple dynamic and opportunistic uses of spectrum." 2003 *Secondary Markets* at ¶ 231.

78 The pooling concept as utilized in trunked radio systems explains much about why smart radio systems such as XG can yield great efficiency gains in spectral use. This concept, especially as evidenced in decentralized trunking systems, is summarized in this section as a salient precedent to XG. This section, however, represents only an abridged version of an idea more fully developed and detailed in a paper by Dale Hatfield and Peter Tenhula. *See* D. Hatfield and P. Tenhula, *The Potential Value of Decentralized Trunking as Regulatory Precedent for the Introduction of Dynamic Spectrum Access Technology*, Proceedings of DySPAN 2007, Dublin, Ireland, April 2007.

particular tasks (*viz.,* the reality of segmented spectrum allocations and specialized equipment gives rise to the stove-pipe analogy). Moreover, even within a single jurisdiction such as a municipality, it is common that additional fragmentation occurs as different services—police, fire, ambulance, etc.—each has their own system operating on different channels. Even small, rural agencies typically get a full channel which can remain fallow at most times of the day. The costs of such a stove-pipe system of public safety frequency usage include a lack of interoperability and severely underutilized spectrum.

Significantly, interoperability is enhanced by leveraging the pooling insight. "Far fewer channels are needed to serve multiple agencies if those channels are shared by all agencies, or equivalently, the same number of channels can support far more mobile users when channels are shared among agencies . . . ."[79] Indeed, the ALMR system offers a glimpse of how a shared system can utilize this insight to help transform public safety communications. ALMR partners federal, state and local governments in a cross-jurisdictional arrangement that shares frequencies using trunking technology.[80] Under the arrangement, which is the first statewide sharing agreement of its kind, federal high-band VHF channels are used for communications from mobile units while state spectrum is used for fixed infrastructure transmissions.[81] All entities have "access to all spectrum employed in the system for daily intra-agency use as well as inter-agency interoperability use" when necessary.[82] Significantly, the ALMR communications system received "rave reviews" following a 2005 military exercise in which state and local first responders participated with federal agencies such as the FBI and the Federal Emergency Management Agency.[83] Such a trunked system promotes not just interoperability, but efficient use of spectrum as it represents a significant shift away from the stove-pipe paradigm in which individual channels go underused. Moreover, the trunked approach promotes economic efficiency because, for a given quality of service, more traffic can be handled over the same number of channels (or, alternatively, the same among of traffic can be handled over fewer channels).[84]

A simple analogy illustrates efficiencies gained through trunking.[85] Consider a parking lot with many "reserved" signs. While each reserved parking space is used at some time, assume that only half of the reserved spaces are filled at any given time (since some users telecommute on certain days, other users are sick, and other users go on vacation, etc.). Instead of *reserved* parking spaces dedicated to designated users, an XG system would instead give *priority* parking spaces to designated users while allowing other users to use the parking spots on an as needed basis. Through automated agility, XG systems ensure access for designated users while increasing access to others when designated users are not occupying their spots. In short, a trunked system enhances (i) access by permitting more users to use the same number of spaces; and/or (ii) efficiency as the same number of users can be accommodated with fewer parking spaces.

Smart radio systems like XG can perform an important role as public safety agencies follow the ALMR lead and find solutions that overcome the spectrum and economic efficiency limitations (and greater expense) of the stove-pipe paradigm. To be sure, while laudable, technology and techniques utilized in the ALMR solution works in a sparsely populated state and is not a silver bullet that can be easily duplicated throughout the United States. Nonetheless, the XG program presents a technological leap forward that will enable advanced versions of the trunking techniques which ALMR used to achieve more efficient use of the spectrum. As the FCC has noted, "trunked operations on shared spectrum [ ] allow[s] licensees to construct systems that are more efficient than conventional systems, thereby *allowing licensees to use fewer channels to provide the same communications capability*."[86] Indeed, a XG-type system could conceivably provide an overlay of existing public safety systems. Such an arrangement would not require radical re-arrangement of frequency assignments but, nonetheless, would facilitate sharing across existing assignments to individual agencies. Accordingly, a XG-enabled system would help minimize some of the costs of the stove-pipe paradigm.

A particular version of a trunked system which closely resembles an XG system involves *decentralized* trunking. Like a decentralized trunking architecture, individual radio units at the edge of the network in an XG system are responsible for determining – through monitoring – the busy or idle status of what amount to pooled channels. "In a decentralized trunked system, which is also a system of dynamic channel assignment, the system continually monitors the assigned channels for activity both within the trunked system and outside the trunked system, and transmits only when an open channel is found."[87] Decentralized trunking systems do not store information on the status of the pooled channels on a centralized basis and no dedicated control channel is involved. Instead, in a decentralized system the

[79] Jon M. Peha, *Protecting Public Safety With Better Communications Systems*, IEEE Communications Magazine at 9 (March 2005) (http://www.comsoc.org/ci1/Public/2005/Mar/cireg.html) (citations omitted).

[80] *In the Matter of Applications of STATE OF ALASKA Request for Waiver of Sections 2.102(c), 2.103(a), 90.20, and 90.173(c) of the Commission's Rules*, ¶ 1 (DA 03-2612) (August 7, 2003) ("State of Alaska Waiver").

[81] Donny Jackson, *Trailblazers* (MRT Magazine) (April 1, 2006) (available at http://mrtmag.com/mag/radio_trailblazers/index.html) (last checked July 19, 2006) ("Trailblazers").

[82] *See State of Alaska Waiver* at ¶ 5.

[83] *See Trailblazers,* note 81 *supra.*

[84] Although there is some increase in the cost of the logic necessary to enable trunking, those costs are often more than offset by the cost efficiencies realized through trunking. This is particularly true if each agency otherwise builds its own antenna sites and/or brings in its own power.

[85] This analogy was provided to us by Hilary Darby, who ascribes credit to Edward Rocksvold, a current employee of Alion Science and Technology.

[86] *See State of Alaska Waiver* at ¶ 18 (*citing* 12 FCC Rcd 14307 (1997)) (emphasis added).

[87] *In re 1998 Biennial Regulatory Review-47 C.F.R. Part 90-Private Land Mobile Radio Services*, 15 FCC Rcd. 16,673 at n. 64, 2000 WL 958893 at *19 (Adopted: June 28, 2000).

mobile and/or fixed radio units can be said to continuously scan or monitor all of the pooled channels in the system.[88]

Significantly, there is regulatory precedent for spectrum sharing utilizing decentralized trunking techniques that avoid harmful interference with incumbent users operating with conventional systems. Specifically, beginning with a Notice of Proposed Rulemaking in 1992, the FCC started on a course that ultimately approved of decentralized trunking in ranges between 150 and 450 MHz whereby Private Land Mobile Radio ("PLMR") users follow a Listen Before Talk ("LBT") protocol before using frequencies already heavily occupied with multiple licensees operating on conventional systems.[89] Based upon trunking's history and, in particular, the Commission's more recent efforts to facilitate the introduction of decentralized trunking, there is strong policy and regulatory precedent to facilitate and even promote the introduction of advanced XG technology going forward.

B. Dynamic Frequency Selection in the 5 GHz band

Recent regulatory efforts in the 5 GHz band represent an important precedent signaling increasing support of automated, dynamic spectrum sharing. These regulatory actions generally aim to expand use of Unlicensed National Information Infrastructure (U-NII) devices in the 5 GHz band. Like decentralized trunking, the recent spectrum sharing course followed by regulators in 5 GHz is relevant to XG. Four dimensions of the 5 GHz precedent are particularly noteworthy: (i) decentralized sensing by U-NII devices; (ii) cognitive decision-making by U-NII devices concerning whether transmission is permitted; (iii) involvement by multiple regulatory bodies culminating in adoption of dynamic frequency selection ("DFS"); and (iv) an embrace of flexible technical standards that relies on outside expertise. Each of these dimensions is discussed below.

The adoption of a signal detection and interference avoidance method known as DFS is perhaps the most significant aspect of regulatory action in the 5 GHz band. Fundamentally, DFS is a means to enable greater spectrum access for unlicensed U-NII devices in the 5 GHz band where military radar is a primary user.[90] U-NII devices are one of five types of "Intentional Radiators" permitted under the FCC's Part 15 Rules.[91] U-NII devices were originally authorized to operate in 1997 but the available spectrum was deemed "insufficient to support the long-term growth for unlicensed wireless broadband devices and networks."[92] Accordingly, in November 2003, the FCC made an additional 255 MHz available to U-NII devices.[93] Notably, this increase represented an 80% expansion in the range of available bandwidth for U-NII uses.[94] Regulators favor U-NII devices because they present opportunities for applications such as wide area networks that could promote roll-out of wireless broadband access in rural areas.

DFS is a cognitive radio technology (albeit an early-stage one) "that *monitors* the spectrum and *selects* for operation a frequency that is not in use."[95] Accordingly, adoption of DFS is unmistakably a regulatory vote of confidence for a decentralized strategy of interference avoidance such as that proposed by XG: cognitive capabilities at a network's edges are relied upon to collect and process information to determine if operation is permitted.[96] Moreover, based on information collected by U-NII devices, appropriate levels of transmission power are determined through a method known as transmit power control ("TPC"). "TPC is a feature that adjusts a transmitter's output power based on the signal level present at the receiver."[97] TPC promotes improved spectrum sharing because it facilitates a *use-what-you-need* approach: devices operate at maximum power only when lower signal levels would be inadequate to transmit information. Accordingly, use of DFS and TPC push two significant spectrum coordination functions away from centralized control and toward automated and intelligent network edges: (1) monitoring and sensing; and (2) decision-making concerning whether transmission is permitted and, if so, what level of power should be used.

Significantly, DFS is not the product of a single regulatory body's initiative. Rather, DFS is the product of the combined

[88] When a dispatch call is initiated by a mobile unit or dispatcher, the unit immediately stops at the next idle channel in the pool. The radio unit initiating the call sends out a signaling message on the selected idle channel identifying the group to be contacted. The resulting signaling message is of sufficient duration that it is certain to be picked up by the remaining units that are continuously scanning all channels. The radio unit initiating the call waits on the channel. When the scanning radios encounter the signaling message on the selected channel the pause briefly to determine if the message is for them and, if not, they resume scanning. On the other hand, if the message is for them, they remain on the selected channel and with the calling and called units gathered on the selected channel, the conversation is begun. When the call is completed, a signaling message releasing the channel is sent and the gathered units then resume their scanning of all channels in the pool.

[89] *See* 1998 Biennial Regulatory Review – 47 C.F.R. Part 90 - Private Land Mobile Radio Services, WT Docket No. 98-182, Report and Order and Further Notice of Proposed Rule Making, 15 FCC Rcd 16,673 (2000) (available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-00-235A1.pdf) (1998 Biennial Regulatory Review Report and Order); *Third Memorandum Opinion and Order*, 14 FCC Rcd 10,922 (1999) (*Refarming Proceeding*).

[90] *June 30, 2006 U-NII Opinion* at ¶ 3.

[91] Kenneth Carter, Ahmed Lahjouji and Neal McNeil, *Unlicensed and Unshackled: A Joint OSPOEt paper on Unlicensed Devices and Their Regulatory Issues,* OSP Working Paper Series No. 39 (May 2003)("Unlicensed and Unshackled"). The five types of Part 15 Intentional Radiators are: (1) General Low Power Devices; (2) Spread Spectrum and Digitally Modulated Devices; (3) Unlicensed PCS Devices; (4) Unlicensed NII Devices; and (5) Ultra-Wideband (UWB) Devices.

[92] *See* Report and Order, *In the matter of Revision to Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure devices in the 5 GHz Band* at ¶¶ 10 (ET Docket No. 03-122) (November 18, 2003) (*"November 18, 2003 U-NII Report").*

[93] *Id.* at ¶ 1.

[94] *See* Gregory Staple and Kevin Werbach, *The Coming Spectrum Explosion—A Regulatory and Business Primer,* 21-FALL Comm. Law. 23, 25 (Fall, 2003).

[95] *See* Memorandum Opinion and Order, *In the matter of Revision to Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure devices in the 5 GHz Band* at ¶ 3 (ET Docket No. 03-122) (June 30, 2006) ("*June 30, 2006 U-NII Opinion*") (emphasis added).

[96] Use of DFS is not the only way that U-NII devices can use the 5 GHz bands. Remote stations that are centrally controlled are exempt from the DFS capability obligations. *See November 18, 2003 U-NII Report* at ¶¶ 27, 31.

[97] *June 30, 2006 U-NII Opinion* at ¶ 4.

efforts of international and domestic regulatory bodies, as well as concerted cooperation between federal and non-federal stakeholders within the U.S. Indeed, DFS is "an ITU accepted mechanism" and the FCC's 2003 adoption of DFS was consistent with resolutions previously adopted at the World Radiocommunication Conference 2003 in the 5 GHz bands.[98] The alignment of United States and international DFS policies promotes innovation and allows users to benefit from economies of scale since manufacturers can build devices that can be used and sold on a global scale.[99] Such coherence between domestic and international regulatory approaches to use of cognitive radios bodes well for the prospects of future regulatory acceptance of XG.

Moreover, within the United States, the development of DFS featured the type of federal/non-federal sharing efforts which reform proposals often advocate as a strategy to reduce administrative scarcity. As noted above, DFS enables U-NII devices to utilize 5 GHz bands where military radar is a primary user. As a secondary user, however, U-NII devices manufactured by commercial providers must avoid causing harm to the military radar systems. Devising a mechanism to detect and separate military radar from other unlicensed devices was difficult because of the secret nature of the radar's signal attributes.[100] Nonetheless, industry, the FCC, NTIA and the military collaborated to resolve these difficulties and, as a result, make available additional shared spectrum for U-NII use. "Much credit for [DFS] goes to the joint efforts of industry and Government representatives" who "worked tirelessly" to develop equipment authorization guidelines for U-NIII devices.[101]

Finally, it is notable that in implementing DFS the FCC embraced flexible technical standards that sensibly incorporated outside expertise. In particular, the DFS precedent provides two significant examples in which the FCC eschewed a centralized prescription of technical DFS operations. First, the FCC refused to prescribe an algorithm to govern the TPC function of U-NII devices.[102] Observing that locking in a particular algorithm would likely "hinder innovation," the FCC left it to industry to find workable solutions and then explain to the FCC why equipment authorization is warranted using those solutions.[103] Second, the FCC declined to delineate specific detection requirements—such as the required minimum number of pulses and observation times— for U-NII devices prior to a time in which compliance testing procedures could be completed.[104] Significantly, while the FCC provided *interim* compliance testing procedures, it relied upon a joint industry/U.S. Government team to help establish the revised measurement procedures. The FCC adopted the "consensus agreement of industry and government participants" in June, 2006.[105] Again, this approach sensibly reflects a move away from static and centralized regulation and a movement towards increasingly decentralized decision-making.

C. Automatic Link Establishment

Automatic Link Establishment ("ALE") provides a third illustrative precedent that underscores important elements of the XG program. ALE standards prescribe automated techniques to select the optimum frequency for transmission in high frequency bands. These standards reflect government, industry and academic cooperation and are international in scope. Significantly, like XG, ALE enables automated frequency agility to help realize improved efficiencies in spectrum bands where fluctuating communication environments previously required labor and time-intensive adjustments which limited use of such bands. XG and ALE systems make more efficient use of pooled frequencies where the availability of individual channels within the pool is uncertain in advance. Accordingly, both ALE and XG embrace technological solutions to surmount interference and communications difficulties caused by unpredictable environments to realize improvements in spectrum availability. The success of ALE systems is reflected by the adoption and use of a variety of governmental and military entities today, including the DoD and NATO.[106]

The essence of ALE is a family of standards that, among other things, set forth how ALE-enabled systems automatically determine the optimum frequency for a high frequency ("HF"— also known as *shortwave*) link. HF radio involves transmission between 3 and 30 MHz. HF radio has long been used and is particularly valuable for its ability to transmit over long distances. HF communications can cover up to 4,000 km in one hop, 4,000-7,000 km in two hops, and 7,000-12,000 km with three hops.[107] Before the advent of communications satellites and high capacity undersea cables, HF radio was the backbone of intercontinental communications and communications with ships and aircraft outside line of sight ranges. Moreover, HF radio is still attractive to military users as it can function under stressful conditions such as global conflict as a redundant back-up or alternative to other means of radio transmission such as satellite, microwave, and terrestrial systems.[108] Significantly, HF is a "medium that can be deployed quickly [ ] with

[98] *November 18, 2003 U-NII Report* at ¶ 29; Order, *In the matter of Revision to Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure devices in the 5 GHz Band*, at ¶ 4 (ET Docket No. 03-122) (February 23, 2005) ("*February 23 U-NII Order*").

[99] *June 30, 2006 U-NII Opinion* at ¶ 2.

[100] Note that this underscores a challenge for the sensing capabilities of cognitive radios—namely, that detection of non-cooperative signals is far more difficult than detection of known signals.

[101] *June 30, 2006 U-NII Opinion,* Statement of Commissioner Jonathan S. Adelstein.

[102] *November 18, 2003 U-NII Report* at ¶ 36.

[103] *Id.*.

[104] *Id.* at ¶ 32.

[105] *June 30, 2006 U-NII Opinion* at ¶ 26.

[106] *See generally* Eric Johnson, *Analysis of Third-Generation HF ALE Technologies,* 1139 (Proceedings of 2000 IEEE Military Communications Conference (MILCOM 2000) Los Angeles, CA, October 2000) (herein, "E. Johnson, *Third-Generation HF ALE Technologies*").

[107] *See* NTIA, Institute for Telecommunication Sciences, *High Frequency Radio Automatic Link Establishment (ALE) Application Handbook, Draft version,* 1 (1998) (available at http://www.its.bldrdoc.gov/pub/oa-rpt/hf-ale/handbook/) ("NTIA ALE Handbook Draft 1"). A *hop* in this context is understood as the number of times a transmission is bounced off the ionosphere and returned to earth.

[108] *See NTIA ALE Handbook Draft 1* at 15.

flexibility to restore a link that has been rendered out of service."[109]

A central challenge of HF communications, however, involves the ionosphere. HF waves are said to be sky-wave communications because they hit the ionosphere, are bent or refracted, and then return to the earth.[110] These patterns of sky-wave travel enable HF waves to travel long distances (*i.e.,* beyond the horizon). Changes in ionospheric conditions frustrate HF transmissions and are sufficiently variable so as to often elude predictive propagation models. In order to respond to difficult-to-predict variations affecting wave propagation, HF radios traditionally required highly trained radio operators to manually readjust HF systems.[111] Operators constantly had to adjust the parameters of the system since "[o]ptimum HF propagation can vary by location, frequency, season, time of the day; can have cyclic variations; and can be affected by unexpected ionospheric disturbances."[112]

Notably, advances in technology and a renewed interest in HF radio combined in the mid to late 1980's to create an *automated* solution to the adjustments required for HF communications. Because of the labor intensive nature of manual HF adjustments, HF systems were "an easy target for justifying adding automation and adaptive techniques."[113] These so-called "second generation" HF automations[114] successfully provided "robust, reliable and interoperable HF links."[115] In particular, integrated circuits, high-density random access memory ("RAM") and digital processors facilitating improved modulation/demodulation capabilities made technical solutions possible that did not previously exist.[116]

Originally developed with the active involvement of NTIA's Institute for Telecommunications Sciences ("ITS"), ALE-related standards[117] provide technical guidance and protocols for automation of features such as frequency selection/management, link establishment, link maintenance, and networking protocols.[118] The upshot of ALE-related automations is that robust intelligence at the edge of a network now enables even unskilled radio users to overcome fluctuations in HF operating environments and successfully communicate on the best available channel at a particular time. For example, HF radios can be used by medics in battle zones to communicate patient information needed to support care for wounded or sick individuals in need of treatment.[119] Such capabilities are particularly critical where other forms of communications such as satellites are unavailable. To users such as medics, the automated adaptive ALE mechanisms make radios "appear to be 'push-to-talk on the best channel,' while actually the radio is a multichannel communication device performing many underlying functions."[120]

A simplified version of ALE's operations can be understood as involving a combination of *scanning* and *sounding* activities.[121] ALE radio stations sense real-time conditions, share and analyze collected information, and then use adaptive techniques responsive to real-time conditions. "The key to achieving significant benefits . . . is to ensure that an adequate supply of real-time data is available for decision-making purposes."[122] ALE stations *scan* a prescribed range of frequencies at a certain rate. For example, a system's stations may scan 10 frequencies at a rate of two frequencies per second so that each frequency is scanned every five seconds.[123] Additionally, second-generation ALE systems use ionospheric *sounding* to test channels' propagation characteristics.[124] Sounding entails emission of self-identifying signals by sounding stations— such as brief broadcast of pulses by cooperative radios— in order to probe available HF propagation paths. ALE-enabled receivers score such tests and ALE stations record a Link Quality Analysis ("LQA") which ranks the quality of potential links. Based on this information, when initiating a call, ALE systems first attempt to use the channel with the highest LQA score and, if such channel is unavailable, move to the second best channel, and so on.

ALE's success presents many parallels relevant to XG. Both XG and ALE radio systems autonomously perform information collection and analysis from decentralized locations. Similar to group behavior techniques available to XG systems, LQA techniques in ALE systems share information collected by various stations to provide a more accurate picture of the communications environment. Moreover, XG and ALE systems are modular and can be added as an appliqué to existing radio foundations.[125] Such

[109] Robert Adair and David Peach, *A Federal Standard for HF Radio Automatic Link Establishment,* 3 (QEX) (January, 1990) (available at http://www2.arrl.org/tis/info/pdf/9001qex003.pdf) ("Adair and Peach").
[110] Waves at frequencies above 30 MHz increasingly penetrate the ionosphere and are less likely to be bounced back to receivers on the earth's surface.
[111] Adair and Peach at 4.
[112] *NTIA ALE Handbook Draft 1* at 4.
[113] *Id.* at 4-5.
[114] Current ALE developments are generally known as "third generation" HF technologies.
[115] E. Johnson, *Third-Generation HF ALE Technologies*
[116] Adair and Peach at 4.
[117] ALE standards increasingly are international in scope; specifically, many current efforts relate to NATO's STANAG standards. *See generally* E. Johnson, *Third-Generation HF ALE Technologies*. The first ALE standard that ITS helped develop, FED-STD-1045, is nearing obsolescence. Today, the significant ALE standards include MIL-STD-188-141B (governing second-generation ALE) as well as NATO's STANAG 4538 and MIL-STD-188-141B (standards for third-generation ALE technology).
[118] *See NTIA ALE Handbook Draft 1* at 2.
[119] *See* Harris Corporation brochure, *Improved long-range communications enhance combat readiness* (available at http://www.rfcomm.harris.com/products/tactical-radio-communications/improved-comm.pdf#search=%22improved%20long-range%20communications%20enhance%20combat%20readiness%20harris%22).
[120] *See NTIA ALE Handbook Draft 1* at 5.
[121] It should be noted that third generation ALE standards support operation in a so-called "synchronous mode" that renders sounding unnecessary. While it is beyond the scope of this paper to describe this in detail, the 3G synchronous mode utilizes other automated techniques to monitor traffic.
[122] *See NTIA ALE Handbook Draft 1* at 15.
[123] *See* Robin Moore, *Automatic Link Establishment (ALE) An Overview* (October, 1996) (available at High Frequency Industry Association Web-site: http://www.hfindustry.com/ale.html).
[124] *See NTIA ALE Handbook Draft 1* at 15.
[125] *Id.* at 20.

modularity enables use of these technologies across diverse radio systems.

Finally, and perhaps most significantly, both XG and ALE use automated intelligence at a system's edges in order to navigate real time fluctuations in conditions that cannot be precisely predicted in advance. In ALE, environmental variability is largely caused by ionospheric changes; in XG, environmental variability is caused by radio users who utilize frequencies intermittently. Notably, neither XG nor ALE utilize previously unused frequencies; rather, such systems make more efficient use of pooled frequencies where the availability of individual channels within the pool is uncertain in advance. Like ALE, XG's adaptive capabilities permits a dynamism that facilitates unprecedented use of spectrum by automating tasks that, when performed manually, are labor and time intensive.

V. Conclusion

Insufficient spectrum access looms as a prospective hindrance to innovation, a constraint on military capabilities, and an obstacle that could prevent realization of significant welfare gains. The expansion of wireless services today is sufficiently dramatic that it is often referenced in near-hyperbolic terms such as *explosion* and *exponential growth*. Such breathless terminology reflects the reality that people on a global scale increasingly rely on the ability to move more and more information without wires. Wireless innovations present tantalizing possibilities but, collectively, conspire to stress the abilities of spectrum managers to provide access to spectrum without causing harmful interference to existing users.

The confluence of (i) smart radio advances in technology, and (ii) increasingly limited spectrum availability, will likely— and, indeed, should— figure prominently in the calculus of regulators in weighing approval of smart radio systems like XG. Significantly, the cost of failing to promote spectrum sharing enabled by such devices is already high and, furthermore, such costs associated with insufficient spectrum access will only increase going forward. Moreover, as spectrum becomes more valuable, the spectrum access benefits that will be achieved from smart radios in general, and XG radios in particular, increasingly outweigh the costs of developing such technologies.

XG systems represent a noteworthy leap forward in spectrum sharing. XG's automated sensing and adaptive capabilities promote an unprecedented dynamism in allowing users to share spectrum while minimizing harmful interference. In general, XG permits a move away from rigid and static systems where underutilized spectrum is reserved simply because a user might need to communicate using the spectrum. Instead, XG facilitates a move toward flexible and dynamic systems where a XG-enabled user can operate on underutilized spectrum just so long as it vacates when a primary user wants it. This shift introduces precisely the type of efficiencies needed to respond to rising spectrum demands.

Nowhere are spectrum constraints and challenges felt more acutely than in the military today. Already, commanders are faced with circumstances in which potentially valuable technologies are hamstrung by a shortage of spectrum access. Bandwidth shortages are reportedly grounding UAVs today in Iraq that would otherwise be able to relay valuable surveillance information. Sharing techniques facilitated by XG systems that increase spectrum availability could help mitigate such shortages. In addition to sharing, the dynamism of XG systems is potentially valuable in other military contexts. For example, current operations in Iraq underscore the value of frequency agile XG systems which enable continued communication even where a particular channel is rendered inoperable during a transmission. Upon sensing new activity in a channel, rather than suffering interference that debilitate communications, frequency agile devices instead find another channel on which to operate.

Against the backdrop of rising challenges inherent in providing spectrum access while minimizing interference, this paper's regulatory analysis concludes that approval of XG technologies is a near term likelihood— not a long term crusade— and that regulators will support spectrum access gains from XG systems. Two perspectives militate in favor of this conclusion. First, XG systems enable regulators to achieve spectrum management objectives that have been repeatedly emphasized over the past 20 years. In particular, at least three spectrum management objectives are strongly promoted by XG systems: (i) increase spectrum access by reducing administrative scarcity; (ii) promote administrative efficiencies in spectrum management; and (iii) increase spectrum flexibility by taking advantage of decentralized intelligence. Second, XG's regulatory prospects are further buoyed by contemporary examples of approved technologies and sharing methods that are conceptually similar to XG. Illustrations such as decentralized trunking, DFS and ALE underscore that while XG promotes vast gains in spectrum accessibility, regulatory approval of XG follows a line of precedents.

Not long ago the introduction of smart radio technologies such as XG systems was widely perceived as a radical regulatory step into an unknown sphere of spectrum management. Our findings, however, indicate that this is not the case. Indeed, approval of XG systems would represent an incremental step that builds upon regulatory precedents that already embrace flexible spectrum uses enabled by technological advances such as improved sensing, digital processor improvements and automation. In radio systems, as with other areas of technology, the intelligence at the edges of the network is increasing. This change makes possible a paradigm shift that regulators, in the face burgeoning demand from spectrum users, will embrace as a tool to resolve the spectrum management demands of tomorrow.