Before the
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Boulder, Colorado 80305

In the Matter of	)	
	)	
Research and Development Priorities for Desirable Features of a Nationwide Public Safety Broadband Network	)))	Docket No. 110727437-1433-01

COMMENTS OF SHARED SPECTRUM COMPANY

Peter A. Tenhula
Vice President, General Counsel
Mark A. McHenry, Ph.D
President, Chief Technology Officer
Shared Spectrum Company
1593 Spring Hill Road, Suite 700
Vienna, VA 22182
Telephone: (703) 462-6949

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I. INTRODUCTION

Shared Spectrum Company ("SSC") respectfully submits these comments in response to the *Notice and Request for Comment*[1] published by the National Institute of Standards and Technology ("NIST"), which seeks input on various possible features of a new nationwide interoperable public safety broadband wireless network for purposes of determining research and development priorities that will help drive innovation of next-generation network technologies. SSC applauds the Administration's efforts to help drive wireless innovation through research, experimentation, testbeds, and applied development through the proposed Wireless Innovation ("WIN") Fund and the Public Safety Innovation Fund ("PSIF"). These initiatives, if adequately funded, will spur the continued development of cutting-edge wireless technologies. SSC looks forward to working with NIST and other public safety stakeholders to drive technological progress by demonstrating the near-term capabilities of SSC's dynamic spectrum access ("DSA") solutions that meet many of the key requirements outlined in the *RfC*.

SSC is a small, entrepreneurial business that, since 2000, has been inventing and implementing a

[1] "Soliciting Input on Research and Development Priorities for Desirable Features of a Nationwide Public Safety Broadband Network , *Notice and Request for Comment*, Docket No. 110727437-1433-01, 76 Fed. Reg. 56165 (Sept. 12, 2011) ("*RfC*").

broad range of innovative DSA capabilities that enable wireless devices to access or share multiple frequency bands for all types of applications, including those that are critical to first responders. The company developed DSA over the past 11 years on several military projects, building prototype devices, developing software and conducting field tests. As the Federal Communications Commission ("FCC") recently recognized, SSC performed successful tests in 2006 at Fort A.P. Hill, Virginia, demonstrating core spectrum access and efficiency objectives of the Defense Advanced Research Projects Agency ("DARPA") NeXt Generation ("XG") Communications program.[2] These objectives included the ability to access ten times more spectrum capacity with near-zero setup time; the simplification of spectrum planning, management and coordination; and the automatic resolution of conflicts in operational spectrum usage. Some of SSC's follow-on DSA projects since the "XG program ended successfully a few years ago" are referenced below. One of these projects, which is summarized below, was supported in part by the National Institute of Justice ("NIJ")[3] and involved the successful development and demonstration of an end-to-end, Cognitive Radio Access Management ("CRAM") subsystem that could securely control DSA-enabled public safety devices. SSC has published several papers on DSA, some of which are referenced herein.[4]

In these comments, SSC recommends that NIST dedicate a significant portion of its anticipated research and development ("R&D") funds for demonstration projects aimed at fulfilling important goals of the WIN Fund and the PSIF by focusing on key features that achieve first responders' most crucial

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[2] FCC, "Promoting More Efficient Use of Spectrum Through Dynamic Spectrum Use Technologies," *Notice of Inquiry,* ET Docket No. 10-237, 25 FCC Rcd 13711 at ¶ 10 (Nov. 30, 2010) ("*DSA NOI*"). *See also*, M. McHenry, E. Livsics, T. Nguyen, N. Majumdar, "XG Dynamic Spectrum Access Field Test Results," IEEE Communications Magazine, Vol. 45, no. 6, pp. 51-57 (June 2007), available at http://www.sharedspectrum.com/wp-content/uploads/2007-02_SSC_Description_Demonstrations_Ft_AP_Hill.pdf.

[3] Office of Justice Programs, U.S. Department of Justice, Award No. 2007-DE-BX-K008. The views, opinions, and/or findings contained in these comments and the papers referenced herein are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the United States Department of Defense or the Department of Justice.

[4] SSC's published papers are available at http://www.sharedspectrum.com/papers/.

requirements while, at the same time, ensuring efficient and more dynamic use of limited radiofrequency ("RF") spectrum resources. The next section provides additional background on SSC's state-of-the-art DSA technology. We then highlight some important overarching policy objectives that will guide wise investment of grant funds and we provide responses to certain key questions in the *RfC* surrounding the promising potential of DSA-enabled public safety radios to ensure resiliency, availability and reliability, security, and affordability/commercial alignment.

II. BACKGROUND ON SSC'S DSA TECHNOLOGY

The concepts and terminology surrounding "dynamic spectrum access", "cognitive radio," "opportunistic radio", "policy radios" and similar references have distinct and sometimes varying meanings in industry standards and other venues. These terms can often be used interchangeably and basically describe radios and radio networks that can react and self-adjust to local changes in spectrum use or environmental conditions, to obtain access to spectrum without causing harmful interference to other users.[5] The radios and software developed by SSC were originally designed and tested for the military and, therefore, by definition are resilient and reliable.

Fundamentally, a DSA-enabled cognitive radio ("CR") device dynamically adapts to its RF environment to maintain reliable communications with other DSA-enabled devices across a wide swath of shared and exclusive bands, and it does so without causing harmful interference to protected "non-cooperative" or legacy systems in shared bands and without being hindered by jammers and rogue emitters in exclusive bands. Furthermore, a DSA-enabled device operates only in accordance with prescribed "policy" constraints, which may vary depending upon the devices' geographic locations, authorized and available frequency bands, times of day, other spectrum activity, deployment scenarios and user roles, spectrum leasing costs, and a wide range of anticipated or unanticipated factors.

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[5] *See DSA NOI*, n. 2 *supra* . at ¶ 6.

Therefore, they are capable of safely and reliably operating over many broadband frequencies by rapidly detecting protected non-cooperative emitters and adjusting their operating frequencies and other transmission parameters in real time.

SSC's DSA technology is centered around software tools that enable the automated and secure reconfiguration of each radio device's transmission and reception parameters. These include state of the art methods and techniques to detect and classify available unused spectrum. However, modern radio hardware and software development encompasses very difficult and expensive system engineering tasks that are themselves implementing amazing innovations at a rapid pace. For example, while there are many user and system-level requirements to satisfy, it is difficult to reliably analyze or simulate the performance of a wide range of radio platforms and air interfaces. Additionally, there is a need to continually evolve and upgrade radios to meet new requirements while minimizing total lifecycle costs. At the same time, the uncertainty and complexity of the RF environment is increasing, especially as a result of the wide variety of emitters and emissions from any number of new and legacy wireless systems, most of which cannot be found in any database. Moreover, elevated levels of man-made noise (including impulse noise and spurs) from everyday "unintentional" emitters such as car engines, power lines, computers and power supplies impact not only localized radio performance, but the ability of DSA-enabled devices to accurately sense signals from protected intentional emitters.

SSC's policy-based, modular software approach to DSA enables wireless systems to accurately sense their RF environment and deliver robust, uninterrupted connectivity across multiple and diverse spectrum bands. As mentioned above, SSC's technology was initially developed and demonstrated for the DARPA XG program. Several military radio platforms are currently being extended to integrate the technology and SSC continues to improve the spectrum sensing capabilities of DSA-enabled radios to

overcome "hidden node" and man-made noise issues.[6] SSC's DSA technology and software enables users of virtually any radio device to deploy cognitive radio techniques and thereby dramatically improve spectrum efficiency, communications reliability, and deployment time.

Based on the success of the XG program, the objective of SSC's follow-on work has been to develop a common DSA architecture and design so that the software could be integrated with the vastly different hardware platforms and protocols used to operate the various networks, including emerging public safety and commercial software defined radios ("SDR") and networks. SSC has achieved this objective for several military customers by developing, testing and deploying a modular software application that resembles commercial solutions. This approach precludes many problems by abstracting reconfigurable radio components into a set of device classes and includes an open application programming interface ("API") for interacting between the device classes and the DSA modules. In addition, an open management interface allows for consistent spectrum management across all platforms. As a result, SSC's DSA technology supports a scalable proliferation of DSA-enabled wireless devices, enables future enhancements and upgrades across platforms and provides compatible spectrum management capabilities for a wide range of military, civil and commercial applications – from tactical radios to public safety cognitive radios to femtocells and TV Band Devices.

SSC's DSA software development and integration experience and results to date show that this approach performs well across heterogeneous military radio platforms with varied hardware and software features. The resulting improvements in radio performance and spectrum efficiency from this software

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[6] These integration efforts have included the Wireless Network after Next ("WNaN") radio platform, the Enhanced Position Location and Reporting System -- eXtended Frequency ("EPLRS-XF") radios, the Mobile Ad hoc Interoperability Network GATEway ("MAINGATE") platform and several radios developed for the Joint Tactical Radio System ("JTRS"). *See* F. Perich, E. Morgan, O. Ritterbush, M. McHenry, and S. D'Itri, "Efficient Dynamic Spectrum Access Implementation," IEEE Military Communications Conference (MILCOM 2010), pp.1887-1892 (Oct. 2010), *available at* http://www.sharedspectrum.com/wp-content/uploads/Perich-et-al-on-Efficient-DSA-Implementation-MILCOM-2010.pdf. Additional information on our other government projects involving improved detection and classification techniques, spectrum management and planning, and communications in extreme environments is available to NIST staff upon request, subject to applicable security and disclosure restrictions.

extension is achieved through adaptively collecting, analyzing, and responding to the radio's spectral environment at runtime. In the Appendix, we describe how the technology is designed and provide more details of some of the lessons learned from the challenges with network and waveform integration.

III. DISCUSSION

A. IMPORTANT OVERARCHING POLICY OBJECTIVES

SSC recommends that NIST dedicate a significant portion of its anticipated R&D funds for demonstration projects that address first responders' most crucial requirements while, at the same time, ensuring efficient and more dynamic use of limited spectrum resources. While including DSA and spectrum sharing demonstration projects in this portfolio would be expected in light of Administration and Congressional policy directives, they will also show how public safety's needs can be served beyond what can be provided by the current generation of broadband technology. Specifically, the ultimate goal of Section 3 of President Obama's June 2010 spectrum memorandum is to "facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies, including those that are secure and resilient."[7] That provision directed the Secretary of Commerce to consult with NIST on this spectrum-sharing research plan, which can be implemented immediately for public safety broadband applications as a result of previous investments by NIJ and the Department of Defense ("DoD").

Moreover, while Congress will ultimately guide the broad parameters of NIST's public safety R&D program, NIST should be commended for anticipating these (apparently based on pending

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[7] *See* Memorandum for the Heads of Executive Departments and Agencies, "Unleashing the Wireless Broadband Revolution," released June 28, 2010, 75 Fed. Reg. 38387, 38388 Sec. 3 (July 1, 2010), *available at* http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution. As the President stated last summer, "[w]e can . . . unlock the value of otherwise underutilized spectrum and open new avenues for spectrum users to derive value through the development of advanced, situation-aware spectrum-sharing technologies" and "wring abundance from scarcity by finding ways to use spectrum more efficiently." *Id.*

legislation) by identifying the "core components" of the program, including the establishment of "a roadmap that seeks to capture and address public safety's needs beyond what can be provided by the current generation of broadband technology and driving technological progress in that direction."[8] It is also apparent that Congress and the Administration will continue to scrutinize how scarce R&D funds are expended and how public safety spectrum can be used more efficiently.

In light of the fiscal crisis facing Congress and the Administration – and the spectrum crisis anticipated by commercial, public safety and Federal users all needing more bandwidth – a wise investment of grant funds should include near-term projects that will facilitate commercialization of DSA-enabled systems for the National Public Safety Broadband Network. As noted in the *RfC*, the Administration originally proposed a $3 billion WIN Fund to help drive innovation through research, experimentation, testbeds, and applied development. Of the $3 billion in this proposal, $500 million would be devoted to public safety R&D.[9] In the *Public Safety Spectrum and Wireless Innovation Act*, the Senate Commerce Committee's bill would also authorize $100 million per year for each of fiscal years 2012 through 2016 ($500 million total) for NIST public safety R&D.[10] The *American Jobs Act of 2011* would create a $300 million fund for NIST to carry out the research program established under section 296 of the bill, subject to approval of NIST's spend plan by the Office of Management and Budget

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[8] *RfC* at 56165.

[9] *See* Office and Management and Budget, "The Budget for Fiscal Year 2012," Appendix – Other Independent Agencies at 1231, available at http://www.whitehouse.gov/sites/default/files/omb/budget/fy2012/assets/oia.pdf. In addition, $1 billion would go to the National Science Foundation ("NSF"), $500 million would be for DARPA, $500 million would be appropriated for the spectrum relocation fund and another $500 million would be spread among various agencies including the Departments of Energy, Education, Transportation and Commerce. *Id.*

[10] *See* S.911, "Public Safety Spectrum and Wireless Innovation Act," 112th Cong., 1st Sess., §§ 223-225, 401(b)(5) (June 1, 2011) (amendment in the nature of a substitute by Sens. Rockefeller and Hutchison); *see also* H.R. 2482, "Public Safety Spectrum and Wireless Innovation Act," 112th Cong., 1st Sess., §§ 223-224, 304, 401(b)(5) (July 11, 2011) (as introduced in the U.S. House of Representatives), available at http://thomas.loc.gov/cgi-bin/bdquery/z?d112:h.r.2482:#. S.911 would also authorize a total of $650 million and $350 million for NSF and DARPA, respectively, for fiscal years 2012 through 2016. *See* S.911 at §401(b)(6). On the other hand, H.R. 2482, would authorize $350 million only for DARPA, without any provision for NSF funding. H.R. 2482 at §401(b)(6).

("OMB").[11]

In addition, most of the spectrum bills being considered by Congress this year contain a provision requiring regular reports from the FCC, in consultation with the National Telecommunications and Information Administration ("NTIA") and NIST, on the use and efficiency of spectrum allocated for public safety use.[12] These studies must also consider the feasibility of public safety entities relocating from other bands to the 700 MHz public safety broadband spectrum so that any spectrum made available could be reassigned through auctions. Accordingly, in light of the risks facing public safety agencies of potentially losing access to currently dedicated spectrum bands, DSA technology demonstrations would show how resiliency, reliability and availability across multiple bands can be ensured during an emergency. Next, we address how DSA can meet these and other first responder requirements in the near term in response to the *RfC*'s key questions.

B. RESPONSES TO KEY QUESTIONS/ISSUES

The *RfC* lists several possible technical features and requirements of the nationwide public safety broadband network and seeks comment on the extent to which these can be satisfied through existing commercially available technology or though technology that could become available in the relative short-term, assuming appropriate research and development.[13] It then seeks input on a number of questions and issues concerning, among other things: the importance of each feature; existing gaps that are preventing the realization each feature and what R&D efforts could close such gaps. While SSC

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[11] *See* S. 1660, "American Jobs Act of 2011," 112th Cong., 1st Sess. §§ 296, 297(b)(5) (Oct. 5, 2011) (as placed on calendar in Senate), available at http://thomas.loc.gov/cgi-bin/query/z?c112:S.1660.PCS:/; *see also*, H.R. 12, American Jobs Act of 2011, §§ 296, 297(b)(5) (Sept. 21, 2011) (as introduced in the House of Representatives), available at http://thomas.loc.gov/cgi-bin/query/z?c112:H.R.12.IH:/). There is no funding for NSF and DARPA in the American Jobs Act. Section 296 appears to be identical to Section 223 of S.911 and H.R. 2482.

[12] *See, e.g.,* S. 1660 and H.R. 12 at § 298, S. 911 and H.R. 2482 at § 304.

[13] *See RfC* at 56166.

addresses some of these questions/issues in the context of our DSA technology solutions for public safety, we note that the comments of the Wireless Innovation Forum in response to the *RfC* provide a comprehensive response based on the results of projects it has undertaken to determine how advanced wireless technology such as software defined radio, reconfigurable radios, and cognitive radios could enhance public safety communications. SSC is a member of the Forum and endorses its comments filed in this proceeding.

Resiliency in an Emergency

Multi-band, reconfigurable cognitive radios offer key solutions to ensure resiliency in an emergency. Major incidents and disasters are often beyond the scope of planning, involve teams of responders from different organizations and jurisdictions, and may likely occur where there is minimal or no communications infrastructure. Disparate agencies are equipped with radio devices that are configured to their current operational specifications or some minimal pre-planning, but are likely incompatible to the particular incident area's needs. The challenges are to quickly set up and efficiently maintain a network spanning the entire incident and integrate heterogeneous devices to establish an effective incident command system that is not distracted by spectrum availability or reliability issues.

As described in the *RfC*, self-organizing networks can dynamically manage their own configuration by automatically making changes to ensure messages reach their destinations. The adaptability and flexibility of DSA-enabled cognitive radio network architectures provide a network design framework where many different kinds of networks and devices can adapt to real-time conditions encountered in specific places on the network or at the scene of an emergency incident. Under this framework, the network nodes are smart enough to allocate resources dynamically when needed, in real time, but not all the time in every place. This framework includes features such as ad hoc and mesh networking configurations, DSA functionality across multiple frequency bands, nodes that sense the RF environment and change their operating policies based on real time conditions, and the ability for network

managers to send policy updates to specific portions of the network and network nodes.

The most important aspect of this resiliency, is the trust and control that first responders and incident commanders have in self-organizing networks of adaptable devices. Remote, over-the-air configuration or reprogramming of conventional Public Safety radios or even newer software defined radios does not necessarily allow the appropriate and necessary control over the devices. This is because, despite the best incident command structure and leadership, multiple stakeholders at various levels may have different, sometimes conflicting requirements and objectives. Once those requirements are manually converted into configuration values, the values cannot be translated back into the original requirements very easily. Therefore, the configuration loses transparency and flexibility. Remote configuration can be only done by a single party otherwise multiple parties may overwrite settings required by other stakeholders.

By introducing DSA-enabled CR wireless devices, the planning period in anticipation of major emergency incidents and disasters can be shortened or eliminated. DSA-enabled CR devices automatically find available frequencies and then quickly establish and maintain a network. There also must be assurance that these CR devices are using only authorized frequency bands or otherwise operating in a manner required by the incident command structure and applicable regulations. A policy-based approach of controlling radios overcomes these limitations. Such an approach defines the spectrum access, environmental sensing and other operational behaviors of wireless systems in a high-level machine language. The specifications and functionalities are transparent to all stakeholders. Multiple sources can define multiple restrictions and permissions, which are combined together and enforced by each device locally at runtime. High-level policies are also defined independently of hardware or software characteristics and are, thus, applicable to heterogeneous systems.

In a project that was supported in part by NIJ, SSC developed and demonstrated an end-to-end, Cognitive Radio Access Management ("CRAM") subsystem that securely controls DSA-enabled public

safety devices.[14] The primary objective of this research was to gather information on how trust can best be established in DSA-enabled CR devices and networks. SSC has done this by not only showing the benefits of DSA technology, but by developing command, control and communications requirements for the design and operation of a policy-based control system for varied communications needs and applications, with a focus on incident area broadband use cases. However, additional work is necessary to demonstrate in field tests how DSA-enabled broadband CR systems can be tailored, safely managed and effectively controlled in real-world situations.

While each of the tools developed for or used in the CRAM subsystem are being used and tested by SSC on a variety of CR devices, the subsystem and devices should be tested in progressively advanced live field demonstrations. Existing multi-band radio platforms can be leveraged for an incident area network ("IAN") test and evaluation of broadband applications. Such demonstrations can show CR device interference avoidance and coexistence with legacy systems while ensuring link range and quality of service under a number of compelling use cases. Resiliency to out-of-band interference and denial of service attacks (intentional jamming) should also be shown in such demonstrations. For example, in the event of harmful interference, the demonstrations could show how DSA systems can quickly determine what the issue is and swiftly modify and distribute the spectrum access rules to eliminate the problem.

Reliability, Availability and Security

DSA-enabled cognitive radio networks and policy-based control systems enable prioritization, quality of service controls and secure access through role-based approaches and tools. High-level functionalities and features of the CRAM subsystem consoles and their respective software tools and

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[14] *See* R. Foster, P. Tenhula, M. McHenry, and F. Perich, "Cognitive Radio Access for Public Safety," SDR '09 Technical Conference (Dec. 2009), *available at* http://groups.winnforum.org/d/do/2445; *See also*, Shared Spectrum Company, "An End-to-End, Multi-Band Cognitive Radio System for Public Safety Communications," Draft Final Technical Report, Version 1.0, NIJ Grant No. 2007-DE-BX-K008 (December 2009) (available upon request).

modules are described in SSC's final report to NIJ and summarized in a paper cited above.[15] To limit unauthorized access and minimize potential conflicts among stakeholder roles, the subsystem is separated into three main consoles: Authoring, Administration and User consoles. The User console has some or all of the features as the Administration console and would be used by the Communications Unit Leader ("COML") during an incident. The CRAM Policy Authoring Tool allows regulators, frequency coordinators and spectrum/network managers to write spectrum access policies, validate them, and push them to secure data repositories. Administration and User consoles enable local spectrum/network managers and Incident Commanders (through the COML) to effectively manage policies and CR devices. The Validation Simulator modules enable policy authors and administrators to visualize and validate the correctness of policies with their intended effect and to debug faulty policies. The subsystem uses a standard form of public-key cryptography to ensure secure policy dissemination.

Again, these tools require and are ready for field demonstrations which will yield additional insights into stakeholder requirements and issues surrounding reliability, availability and security. With further development and demonstrations, public safety practitioners and other stakeholders will be more confident that a public safety broadband CR system utilizing DSA technology can safely, efficiently and effectively share spectrum resources for a range of applications. SSC's spectrum occupancy measurements conducted during the NIJ project show that there are plenty of spectrum holes in the lower UHF spectrum bands with a minimum 2 MHz contiguous bandwidth, which can be used when the 700 MHz capacity is constrained or infrastructure is unavailable.

Affordability/Commercial Alignment

DSA software technology is compatible with commercial infrastructure and devices enabling the use of commercial services as well as network and spectrum sharing for any applications that the devices

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[15] *See* n. 14, *supra*.

and networks allow. SSC is currently working on a project for DARPA that will build on commercial standards and practices with military-specific modifications in order to produce secure, affordable, and rapidly deployable solutions for warfighters.[16] The program will leverage existing commercial handheld devices for initial development efforts and subsequent evaluations. The end goal will result in the handheld devices and applications being broadly available to the lowest military echelons, a user base comprising of hundreds of thousands of individuals.

For this project, SSC is implementing DSA in cellular mobile base stations. The goal is to demonstrate improvements to cellular communication for military users by indentifying and adapting to interference that causes dropouts that reduce scalability and resilience. SSC is integrating DSA software onto commercial base stations to give them sensing and adaptive capabilities. Field demonstrations are planned for 2012. Similar efforts could be tested for public safety scenarios under DARPA, NIJ or NIST programs.[17]

IV. CONCLUSION

As recognized in the FCC's National Broadband Plan and by several commenters in the FCC's *DSA NOI* proceeding, additional funding is required for wireless testbeds and demonstrations for DSA technology.[18] From SSC's perspective, such demonstrations are a near-term possibility. We therefore

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[16] *See* DARPA, "Transformative Apps," BAA 10-41 (March 2010), available at https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-BAA-10-41/listing.html.

[17] The American Jobs Act, referenced *supra.* n. 11, contains a provision in Section 296(c) that would grant NIST "transfer authority" if another Federal agency is better suited to carry out and oversee any R&D activity to be carried out in accordance with the requirements of this section.

[18] *See* Federal Communications Commission, *Connecting America: The National Broadband Plan*, at Recommendation 7.6 (Mar. 16, 2010) ("*National Broadband Plan*") ("Wireless test beds can permit empirical assessment of radio systems and the complex interactions of spectrum users, which are nearly impossible to assess through simulation or analytical methods. As a result, they can reveal a great deal about how sharing can best be facilitated, how spectrum rights might be established, and the impact of dynamic spectrum access radios on existing and future communications services.") *See also* Motorola Solutions Comments in ET Docket No. 10-237 at 24 (Feb. 28, 2011); Wireless Innovation Forum Comments in ET Docket No. 10-237 at 17 (Feb. 28, 2011).

urge NIST to dedicate a significant portion of its anticipated R&D funds for demonstration projects aimed at ensuring efficient and more dynamic use of limited public safety spectrum resources.

It is also crucial that NIST remain aware of and support DoD and other cognitive radio and DSA development activities. As a recent report of the Wireless Innovation Forum concluded, "CR has emerged as one of the principle technologies researched for wireless networks across all user domains, with real empirical work now being published. [CR and DSA have] transitioned from a laboratory curiosity to a practical, beneficial, deployable technology as part of a larger trend to incorporating artificial intelligence into information processing systems and will continue to evolve in surprising ways."[19]

Respectfully submitted,

Peter A. Tenhula
Vice President, General Counsel

Mark A. McHenry, Ph.D
President, Chief Technology Officer

October 12, 2011

[19] Wireless Innovation Forum, "Quantifying the Benefits of Cognitive Radio," WINNF-09-P-0012 at pp. 112-113 (Dec. 2, 2010), available at http://groups.winnforum.org/d/do/3839.

APPENDIX: SSC's DSA Modules and Interfaces

In the context of military and commercial radio communication applications and platforms, modular hardware architectures have evolved as an excellent way to support radio development.[1] A good design for a specific application may be significantly different than the design for another application. Therefore, there is no single frequency range, medium-access-control ("MAC") design, transmit power level, or other physical ("PHY") layer requirement for emerging military radios. This observation also applies, if not more so, with regard to the wide array of wireless devices, applications and services across thousands of megahertz of spectrum governed by many different rules and regulations adopted over a long period of time. At the same time, most modern radio devices are actually used for the same simple goal: to provide an un-tethered means to exchange information/data with other devices. From an end-user perspective, especially a first responder, the device's basic operations appear to be the same and are just expected to work.

The core challenge for innovators that arises from this combination of complex system designs and simple user expectations is that cognitive radio devices must be able to rapidly reconfigure themselves at the PHY layer and throughout the protocol stack[2] to satisfy future spectrum bandwidth needs, application diversity and interoperability requirements.[3] Additional challenges involve the need to internally process the information and decisions that lead to a reconfiguration event based on inputs from spectrum access control policies, the sensed RF environment and coordinated messages exchanged with DSA-enabled neighbors. Because the processing capability of onboard computing resources varies widely while performance expectations do not, creative solutions are required to satisfy the heterogeneity of devices, applications and systems.

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[1] *See, e.g.*, J. Neel and J.H. Reed, "Case Studies in Software Radio Design," in *Software Radio*, Ch. 9 (J.H. Reed, ed.), Prentice Hall PTR (2002); Modifications of Parts 2 and 15 of the Commission's Rules for Unlicensed Devices and Equipment Approval, *Second Report and Order* in ET Docket No. 03-201, FCC 07-56 (Apr. 23, 2007) (establishing rules under Part 15for approval of modular transmitters).

[2] For example, depending on the application and environment, parameters may need to be reconfigured as fast as once per frame in a time division multiplexing (TDM) context or once per packet in other MAC implementations.

[3] *See, e.g.*, Service Rules for the 698-746, 747-762 and 777-792 Bands; Implementing a Nationwide, Broadband, Interoperable Public Safety Network in the 700 MHz Band, WT Docket No. 06-150, PS Docket No. 06-229, *Third Report and Order and Fourth Further Notice of Proposed Rulemaking*, FCC 11-6 at ¶ 16 (Jan. 26, 2011); *see also,* W. Lane, "Cognitive Radio Potential for Public Safety", FCC Public Safety and Homeland Security Bureau Tech Topic No. 9, *available at* www.fcc.gov/pshs/techtopics/techtopic9.html.

Based on its several years of experience and lessons learned, SSC's DSA software solutions have evolved (and continue to evolve based on our customers' needs) into a set of modular components and APIs. SSC's DSA system architecture consists of the DSA engine, a policy module, an environmental sensing subsystem, and a communications subsystem (*i.e.*, the radio transceiver). The DSA engine is the heart of SSC's system and is made up of three principal subcomponents: spectrum manager; rendezvous-related functions; and the high-level scheduler. On each DSA-enabled device, the scheduler manages the operation of the detectors, the spectrum manager maintains a list of candidate channels, and the rendezvous process uses channels ranked by the spectrum manager (in the channel manager) for network discovery and frequency negotiation with other DSA-enabled network nodes.

SSC has developed several DSA detection algorithms that can be easily tailored to the specific signal types and were designed to work on low-cost digital signal processing ("DSP") chips. For example, SSC's wideband detector is a fast Fourier transform ("FFT") based detector that is optimized for execution speed and limited dynamic range. It many cases, however, when higher dynamic range is needed due to the fact that most of the spectrum is empty or contains very low level signals, narrowband detectors are used. In addition, SSC is developing application-specific detectors such as those configured to specifically detect TV, wireless microphone, radar or other specific signal types.

Depending on the existing capabilities and limitations of the customer's radio hardware platform, any combination of the modular components can be integrated onto the platform. The newest devices are likely to have sufficient resources and computing bandwidth to support all of the components. Other modern software defined radio platforms, including those currently in the field, that may not have much extra processing capacity may delegate some of the components off-board or implement less-complex approaches.[4] The DSA functionality from the user and device perspective remains the same (other than slight timing differences). From the control perspective, the DSA engine accepts policies, status control commands, and configuration load-sets regardless of what modules are implemented on the radio itself and what modules are deployed on other network nodes (*e.g.*, base stations).

There are two levels of APIs in SSC's DSA architecture. The upper level API allows manufacturers, radio operators, service providers or other authorized stakeholders to distribute spectrum access control policy updates and monitor the performance of the DSA modules on each radio. This API

[4] For example, some radios may use frequency-range-based DSA Policy Control whereas others may use a full declarative policy support. Other radios may implement several detector types whereas some may implement a basic FFT detector.

enables, together with SSC's policy tools, the addition, removal, activation and deactivation of policies.[5] The lower level API supports the integration of the DSA software into the underlying radio device and its hardware and software components. This API enables, for example, the configuration of the RF front-end for sensing purposes, the exchange of network signaling and control messages with other DSA-enabled nodes, and instructions to the MAC layer to change transceiver configurations.

In light of SSC's more recent experience with integrating its DSA software onto various military radio platforms, the benefits of the modular design has been validated. For example, in the DARPA Wireless Networking after Next ("WNaN") project, the challenge involved the implementation of DSA on a MIMO (multiple-input/multiple-output) radio devices that operates over four channels with a complex MAC. With this configuration, the DSA detector module was tightly integrated into the radio platform, but the responsibility for selecting the proper transmit/receive configuration for the MAC was delegated to other components. The result is a robust policy-controlled DSA radio that continuously identifies available channels based on sensing knowledge, time of the day information, and location information.[6]

SSC's other ongoing integration activities for military radios include Small Business Innovation Research ("SBIR") projects to integrate the DSA software with the Joint Tactical Radio System ("JTRS") soldier radio waveform ("SRW") and wideband networking waveform ("WNW"). In addition to our military projects, we are also working with our commercial partners to incorporate SSC's DSA sensing and policy modules onto femtocells and TV band device platforms.

SSC's Spectrum Sensing Technology

As the FCC has recognized, spectrum sensing is an "important component of dynamic spectrum use," but several issues are typically raised by those not steeped in the technology's current capabilities.

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[5] *See* F. Perich, R. Foster, P. Tenhula and M. McHenry, "Experimental Field Test Results on Feasibility of Declarative Spectrum Management," 3rd IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2008), pp. 198-207 (Oct. 2008), *available at* http://www.sharedspectrum.com/publications/papers/2008-10_SSC_Declarative_Spectrum_Management.pdf; *see also* R. Foster, P. Tenhula, M. McHenry, and F. Perich, "Cognitive Radio Access for Public Safety," SDR '09 Technical Conference (Dec. 2009), *available at* http://groups.winnforum.org/d/do/2445.

[6] *Id. See also*, B. Fette, Remarks at National Broadband Plan Spectrum Workshop, "Panel 3: Innovating in Spectrum Access-Technological Advances and Other Approaches to Facilitate More Productive Spectrum Use," Transcript at p. 157-159 (September 17, 2009), *available at* http://www.broadband.gov/docs/ws_25_spectrum.pdf ("XG has subsequently been integrated into other defense radios of, in fact, multiple vendors. And so it's been clearly demonstrated that the technology can be integrated into a variety of platforms.").

These issues include ways to determine the appropriate detection threshold, avoiding so-called "hidden nodes" or detecting changes to the noise floor. As mentioned above, a key component of SSC's DSA system involves spectrum sensing through several types of detectors. SSC has also been a pioneer in addressing the hidden node problem by developing cooperative sensing (or "group behavior") solutions. The company's engineers are currently focusing on difficult noise floor and man-made noise issues to improve the capabilities of our detector algorithms.

With regard to detection thresholds for spectrum sensing and avoiding interference with hidden nodes, DSA detection thresholds depend on several statistical parameters including multi-path, blockage, body loss, as well as interference to non-cooperative nodes from man-made noise and other co-channel and out-of-band emissions.[7] In calculating the required sensing threshold level, the total probability of such parameters should be considered together instead of combining the worst case of each of the individual factors. In addition, the hidden node's receiver characteristics (signal margin) should also be considered. To further avoid the "hidden node" problem and to minimize false alarms, a simple cooperative sensing approach can work effectively at reasonable detection thresholds, which could vary depending on the DSA-enabled devices' output powers.[8] Specifically, when sensors are paired as indoor and outdoor nodes, the combined information increases the probability of successful detection, ensuring that if one sensor is affected by shadowing or local propagation loss the other sensor is able to provide a more accurate picture.

SSC has also implemented and demonstrated the effectiveness of cooperative sensing with its "group behavior" method, which enables DSA-enabled radios to learn where spectrum holes in their vicinity are located and to share this information among themselves. The objective of the group behavior algorithm is to find the highest power level at which each DSA-enabled node can transmit to

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[7] T. Erpek, M.A. McHenry, A. Stirling, "Dynamic Spectrum Access Operational Parameters with Wireless Microphones," IEEE Symposium on New Frontiers in Dynamic Spectrum (DYSPAN 2010), pp.1-11 (April 2010), *available at* http://www.sharedspectrum.com/wp-content/uploads/SSC-DySPAN-2010-PMSE-protection-reqts.pdf. Similar analysis performed by SSC was submitted into the record of the TV White Spaces proceeding by Microsoft Corporation. *See* Letter to Julius P. Knapp from Edmond Thomas, ET Docket No. 04-186 (Oct. 26, 2009).

[8] M. McHenry, K. Steadman, M. Lofquist, "Determination of Detection Thresholds to Allow Safe Operation of Television Band 'White Space' Devices", 3rd IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DYSPAN 2008), pp. 144-155 (Oct. 2008), *available at* http://www.sharedspectrum.com/publications/papers/2008-10_SSC_White_Space_Devices.pdf. This paper was also submitted into the record of the TV White Space proceeding. *See* SSC Letter to Chairman Kevin J. Martin, *Unlicensed Operation in the TV Broadcast Bands*, ET Docket No. 04-186 (Oct. 23, 2008).

both maximize communication range and protect non-cooperative radios from interference.[9] The main components of the group behavior algorithm and a description of the successful field demonstrations are described in SSC's 2008 DySPAN paper on the DARPA XG system.[10]

[9] At maximum interference free transmit power ("MIFTP"), the DSA-enabled radio's signal is at a specified interference-to-noise ratio ("INR") value at the non-cooperative radio. *See* A. Leu, M. McHenry, B. Mark, "Modeling and Analysis of Listen-before-Talk Spectrum Access Scheme," Int. J. of Network Mgmt., Vol. 16, Issue 2, pp. 131-147 (March 2006).

[10] *See* M.A. McHenry, K. Steadman, A. Leu, E. Melick, "XG DSA Radio System, 3rd IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2008), pp. 497-507 (Oct. 2008), *available at* http://www.sharedspectrum.com/wp-content/uploads/2008-DySPAN-XG-DSA-Radio-System.pdf.