TOWARD INNOVATIVE SPECTRUM SHARING TECHNOLOGIES:

A TECHNICAL WORKSHOP ON COORDINATING FEDERAL GOVERNMENT/PRIVATE SECTOR R&D INVESTMENT

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Table of Contents

1. Executive Summary

In June, 2010, the President issued a memorandum, *Unleashing the Wireless Broadband Revolution,*[1] which identified the importance of providing adequate spectrum "to support the forthcoming myriad of wireless devices, networks, and applications that can drive the new economy." To help "wring abundance from scarcity," the memorandum called upon the Secretary of Commerce to "create and implement a plan to facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies…"

In response to this charge, the National Information Technology Research and Development (NITRD) program created the Wireless Spectrum R&D Senior Steering Group (WSRD SSG), which brings together representatives of all of the federal agencies that conduct or support spectrum-related research. Upon its formation in November, 2010, and at the urging of the U.S. Chief Technology Officer, the WSRD group quickly recognized the importance of reaching out to private industry and academia as an avenue of coordinating national wireless R&D investments.

In July, 2011, the WSRD SSG held its first workshop to engage key representatives of the industrial and academic communities. The workshop was hosted by the National Institute of Standards and Technology at its Boulder, Colorado, facility, and was held in conjunction with the International Symposium on Advanced Radio Technologies. The workshop was structured as a roundtable discussion among technical experts and researchers from private industry, public safety, and academia to explore ongoing spectrum-related Federal Government R&D activities as listed in an inventory[2] created by the WSRD SSG members. The participants were asked to explore the inventory and offer their thoughts on a national-level wireless technology initiative. They were asked to suggest avenues of research that the participants believe are presently underrepresented in federal R&D and that are not being pursued in private industry research laboratories. The goal was to focus on identifying R&D that may have large potential payoffs for the national wireless industry and the nation's economy at large. In addition, it needed to be consistent with the Federal Government's role in sponsoring "high-risk high-reward" research.

The workshop was comprised of three interactive discussion sessions which built upon each other to achieve the final workshop objective.[3] Dr. Paul Kolodzy of DARPA convened the first session by asking the participants to consider current spectrum sharing opportunities. The results of that discussion included general agreement that:

- The current spectrum allocations and assignments require specific analysis for each band's potential for sharing and that grouping bands and services for sharing is impracticable

[1] http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution , June 10, 2010

[2] http://www.nitrd.gov/nitrdgroups/images/f/f0/WSRD_Project_Inventory_15.pdf and Attachment A (for additional explanation) http://www.nitrd.gov/nitrdgroups/images/b/bf/Wireless_Spectrum_R%26D_Inventory_Template_Attachments_-_Attachment_A_-_Topic_Areas.pdf

[3] The WSRD Co-chairs, Mr. Byron Barker of the National Telecommunications and Information Administration, and Dr. Andrew Clegg of the National Science Foundation, instructed the participants to please limit their comments to technical and R&D-related facets. They acknowledged that the policy questions surrounding this issue are critically important, but asked that they be reserved for a different venue.

- Sharing needs to be broken into three levels: (a) sharing of similar legacy systems; (b) sharing of dissimilar systems; and (c) adaptive systems that enable systems to change dependent upon conditions (i.e. national emergency)
- Providers at both the federal and the commercial level consider shared use as an impediment to their quality of service (QoS) requirements. Incentives will be required to improve both sectors' willingness to share spectrum, and
- Currently there are many instances of spectrum sharing bands inclusive of primary, co-primary, and secondary spectrum allocations as well as unlicensed devices.

The second session was led by Dr. Rangam Subramanian of Idaho National Laboratory and covered the topic of perceived gaps in current technology development and ideas for future research emphasis. Participants felt the major gaps in current spectrum sharing research were:

- Technologies for broadband sensing and situational awareness
- Quantification of interference
- Technical and policy developments related to enforcement of rules
- Realistic testbeds for advanced spectrum sharing research
- End-to-end system-oriented analysis and integration
- Spectrum sharing protocols, and
- The lack of a sufficient talent pool for developing analog systems.

Drs. Subramanian and Kolodzy jointly lead the third session which focused on creating a capabilities development roadmap. Each participant was challenged to name two specific research topics that, based on their expertise, were the most valuable for the Federal Government to pursue. The following areas were recurring themes among the expert participants:

- Understanding spectrum utilization including dynamic spectrum inventory and databases
- Quantifying interference and the development of interference benchmarks
- Developing incentives for Federal/non-Federal sharing (including economic)
- Providing complete system deployment analysis for spectrum sharing techniques and technologies such as testbeds, and
- Establishing sharing protocols.

Toward Innovative Spectrum Sharing Technologies was the first in a planned series of workshops that will engage federal and non-federal communities in furthering the goal of moving toward a nation-wide shared spectrum environment. The input from this roundtable discussion was extremely valuable and the ideas expressed by the participants will shape the agenda for the next workshop (planned for January 2012) as well as the short and long-term goals of the group.

NITRD and its WSRD SSG thank the workshop participants for their time and effort in providing their valuable insight to the Federal Government R&D process, and we look forward to continued engagement with the private, public safety, and academic communities.

2. Introduction

The dramatic rise of radio frequency-based applications has sparked a new sense of urgency among federal users, commercial service providers, equipment developers, and spectrum management professionals on how best to manage and use the radio spectrum. While near-term solutions such as spectrum reallocations are critical to meeting national needs, so is the development of the next generation of technologies that can enable more efficient use of the radio spectrum.

The Wireless Spectrum Research and Development Senior Steering Group (WSRD-SSG) was created by the White House Office of Science and Technology Policy in late 2010. The committee was asked to identify current spectrum-related research projects funded by the Federal Government, and to work with the non-federal community, including the academic, commercial, and public safety sectors, to implement a plan that "facilitates research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies," in accordance with the Presidential Memorandum on Unleashing the Wireless Broadband Revolution. WSRD-SSG operates under the auspices of the Networking and Information Technology Research and Development (NITRD) program of the National Coordination Office (NCO), and has put together a preliminary inventory of federal R&D in the spectrum arena.

This workshop presented an opportunity for relevant interested parties, including technical experts and researchers from private industry, public safety, and academia, to explore ongoing spectrum-related R&D projects at the federal level, and offer their expert opinion. Participants were asked to suggest research projects that:

- Are currently underrepresented in federal R&D and private industry research laboratories,
- Have large potential payoffs for the wireless industry as well as the nation's economy, and
- Are consistent with the Federal Government's role in sponsoring "high-risk high-reward" research.

The workshop[4] was co-chaired by Mr. Byron Barker (National Telecommunications and Information Administration) and Dr. Andrew Clegg (National Science Foundation), co-chairs of WSRD-SSG. The workshop organizing committee was led by Dr. Rangam Subramanian (Department of Energy Idaho National Laboratory) and Dr. Paul Kolodzy (representing DARPA).

[4] The workshop was open to the public, webcast, and recorded to accommodate as many observers as possible. It was announced in the Federal Register on June 7, 2011 (see Appendix 4). A website described the event and allowed the public to access supporting details and materials as well as a link to the webcast.

3. Opportunities for Spectrum Sharing

The large number of systems that are being deployed by government and the commercial sector have diminished the potential for reallocating entire bands for new services. Therefore, allocations may need to be spatially and temporally fragmented to provide additional spectrum opportunities. The purpose of the spectrum sharing session was to discuss different spectrum sharing mechanisms, benefits, and opportunities for industry and government and to identify major challenges in exploiting spectrum sharing technologies that can be addressed by R&D.

This session explored all types of spectrum sharing, beginning with what types of spectrum sharing are currently possible. The following categories of sharing were discussed: between commercial operators; between public safety systems; between federal users to enable spectrum for commercial uses; and between commercial, federal, and public safety users. In addition, the benefits and challenges between sharing temporally or spatially.

A taxonomy for spectrum sharing was proposed:

- Similar legacy systems: systems whose ability to spectrum share is determined by a detailed coexistence analyses.
- Dissimilar systems: systems which will require new technologies to allow sharing.
- Adaptive systems: systems which can adapt to changing service conditions (i.e. national emergency) and enable federal/non-federal systems to share spectrum through either changing roles or allowing spectrum access dependent on service conditions

The need for incentives was introduced and participants agreed that there needs to be a motivation for the user community to find bands and mechanisms to share.

While regulatory agencies seek intensive use of the spectrum to provide commerce (non-federal use) as well as security (federal use), the user community has to consider balancing the costs for smarter systems (that enable sharing) with the uncertain impact on quality-of-service. Unencumbered spectrum remains the most straightforward and least risky (technical, policy, deployment, etc.) solution for the commercial user. What became clear from the discussion is that spectrum sharing will remain undesirable for both the federal and non-federal users until there are more powerful incentives to do so. Incentives will most likely come from policy/regulatory directives or when there is a significant lack of unencumbered spectrum available.

The discussion moved on to the question of technical impediments for sharing spectrum. It was agreed that a short range goal would be to focus on spectrum sharing between similar systems. A band used primarily for short range communications can be more readily shared with another short range communication system because the technologies and the interference issues are quite similar and highly symmetric (interference between the services are similar in spatial and temporal extent). When the systems that are sharing the spectrum are dissimilar, research is still required to address interference and legacy system (less sophisticated technology) issues. Despite the fact that radar spectral bands provide a significant opportunity, there was general agreement that dissimilar system sharing should be seen as a long-term goal.

When asked what was still needed to determine which bands and which services/applications can benefit most (from a spectrum utilization perspective) through sharing, the panel suggested a "Google-like" search engine for spectrum, and the means to maintain security. Maintaining security in a shared environment was seen as an important factor not only for national security but for commercial proprietary information as well. Adequate security would need to include both the ability to maintain the accuracy and precision of information as well as the ability to characterize the sensitivity of the systems involved.

The session concluded by asking for support for several additional key challenges:

- Characterizing the “front-end” components (such as Low-Noise Amplifiers, Power Amplifiers and filters) and how they impact the shared uses of a band
- Identifying the new range of latency and capacity requirements as services move increasingly away from voice to various forms of data
- Establishing methods for sharing spectrum usage data between parties
- Examining the differences between service-sharing and spectrum-sharing with regards to like-services/systems and dissimilar services/systems
- Developing a quantitative understanding of the impact of interference including relevant statistical measures
- Exploring opportunities for sharing in the higher frequencies
- Development of clear enforcement protocols, and
- Better technologies for identifying users and providing location awareness (security)

4. Technology Development Gap Analysis

Spectrum sharing, especially sharing that is secure, will force the development of new and complex technologies that will impact players across all the technical and business layers of communication systems and networks. Investors, entrepreneurs, researchers, service providers, product developers, application developers, national policy and rule making agencies, and consumers will all be affected. As summarized in the WSRD SSG First Interim Report[5], the federal agencies have invested in spectrum sharing related research in multiple areas. Only about 6% of these projects have matured to the demonstration stage and most of the testing has been done using simulators and emulators. Barriers to advancing technology research, development, experimentation and deployment need to be identified and addressed. The Federal government's decision to invest in this research needs to be informed by all the stakeholders.

Industry participants identified the following major gaps in current spectrum sharing research:

- Technologies for broadband sensing and situational awareness, quantification of interference, and enforcement of rules
- Realistic testbeds for advanced spectrum sharing research
- End-to-end system oriented analysis and integration
- Spectrum sharing protocols, and
- The lack of a sufficient talent pool for developing analog systems.

Participants felt that the Federal Government should focus on research that challenges the status quo. For example, bands below 3.7GHz are extremely crowded and yet little research is focused on using the higher frequencies, such as 5GHz frequencies and millimeter wave, for broadband. Fundamental communication theories like the Shannon bandwidth limit theory need to be challenged as well.

Both industry and academia expressed dissatisfaction with the usual "laundry list" of radio frequency (RF) research as inadequate for real innovation. They would like an increased focus on related devices such as broadband antennas and new materials for development of RF filters. They also cited research in Europe on wideband devices and associated technologies that are underrepresented in U.S. labs.

While avoiding discussing spectrum policy directly, they expressed the need for improving situational awareness technologies to assist policymakers and enforcement agencies. This was cited as a key area where federal funds could be used. They envision a system where spectrum reports from various users are collected and used to make efficient spectrum decisions at the network core as well as the handset. Unlike 802.x, where multiple bands are available, coexistence assurance is needed to be able to shift bands while the radio is up and running, and standards are needed to ensure minimal interference to other users of the bands. Efficient spectrum brokerage was seen as key. To develop technology that will scale, research must provide proof of concept and provide the necessary level of trust between primary and secondary users.

Creation of test beds to perform outdoor, realistic experimentation, which have become increasingly important for next generation of wireless innovation, was seen as another key area where the Federal

[5] http://www.nitrd.gov/nitrdgroups/images/f/f0/WSRD_Project_Inventory_15.pdf and Attachment A (for additional explanation) http://www.nitrd.gov/nitrdgroups/images/b/bf/Wireless_Spectrum_R%26D_Inventory_Template_Attachments_-_Attachment_A_-_Topic_Areas.pdf

government could take the lead. Industry participants emphasized that widespread adoption of spectrum sharing technologies will be very difficult without access to appropriate national testbeds. These testbeds, while too expensive for the private sector alone to build, would benefit all the stakeholders by bringing together different vendors, network service providers, application developers, system integrators, and importantly, the rule making and standardization agencies.

End-to-end system engineering analysis and design was also mentioned as a basic issue that needs to be addressed in a spectrum sharing environment. As system components are integrated, new algorithms will be necessary to understand their functions. Shared Spectrum Company noted that system integration companies are looking for general research funding to build end-to-end system prototypes to demonstrate and prove spectrum sharing technology concepts.

Software industry participants went on to emphasize the need to better adapt the wireless network protocols to the content needs. Maintaining quality of service for various broadband applications is difficult when the bandwidth levels are constantly changing. Therefore, research on adapting channel agility to the software and application delivery was seen as another key gap.

And finally, broadband chip entrepreneurs felt that the limited availability of domestic foundries is hampering the growth of new analog based semiconductor chip development. This, combined with the lack of academic programs to develop the necessary analog skill sets, is affecting the pace of innovation in the U.S. They pointed out that this is not a factor in countries like China and Europe.

5. A National Research Roadmap

Drs. Subramanian and Kolodzy jointly led the third session which focused on creating a capabilities development roadmap. It is important to focus on federal R&D efforts to maximize innovation in all sectors. Understanding and supporting the synergy between the public and private R&D process is critical to establish an effective national research strategy. Considering the opportunities and gaps identified in the preceding sessions, participants discussed the development of a national research strategy or roadmap.

Each participant was challenged to name two specific research topics that, based on their expertise, were the most valuable for the Federal Government to pursue, in the near-term and/or the long-term, to help develop such a roadmap. The following areas were recurring themes among the expert participants:

- Understanding spectrum utilization including an up-to-date, accurate and comprehensive spectrum inventory
- Quantifying interference and the development of interference benchmarks
- Developing incentives for Federal/non-Federal sharing (including economic)
- Providing complete system deployment analysis for spectrum sharing techniques and technologies such as testbeds
- Establishing sharing protocols

Participants were adamant that the lack of understanding of spectrum utilization and the absence of quantifiable interference standards are major impediments in both determining spectrum sharing opportunities and in the development of technologies that can turn those sharing opportunities into additional spectral capacity. These two specific areas were considered “low hanging fruit” and precursors to developing effective incentives and protocols. Due to the dynamic nature of a shared environment where many systems need to interact, it was also concluded that testbeds of reasonable scale and complexity will be required to accomplish system-wide verification, validation, and accreditation (VV&A) of these technologies.

a. Near-term Goals

Some of the near-term technology needs that were identified included:

- Development of tunable RF filters and antennas that would enable the inclusion of more spectral bands
- Signal processing tools and strong academic program foundation for the development of innovative air interface technologies research on higher software layer protocols to exploit better understandings of the channel characteristics, and hence tune application performance
- Better modeling of the spectrum sharing environment

Industry felt that there was little incentive for private research on key spectrum sharing issues like enforcement, spectrum mapping, spectrum brokering tools, and a spectrum inventory. These were identified as prime areas for government research with the development of a data representation schema and standardization of reporting suggested as a possible near-term goal.

b. Mid-term Goals

Defining and quantifying interference criterion and developing benchmarks for interference in spectrum sharing environments was mentioned as a mid-term need. Protocols for spectrum sharing with federal systems and databases was identified as possibly lying outside the scope of private industry research, yet, given the amount of radar spectrum in use, the ability to share it with the communications industry was deemed an important area for further development.

c. Long-term Goals

Looking long term, industry participants felt that current compliance testing of devices and applications is insufficient and suggested a systems approach to testing be required. The need for realistic testbeds for experimentation and systems integration both in the near term and the long term was stressed once again as a way to bring together the equipment builders, federal stakeholders, and investors in spectrum technology.

Other topics mentioned that would help increase their willingness to participate in shared spectrum environments included the design of economic incentives, improvements in risk mitigation, and clear definitions of ownership policies and rights.

6. Conclusion

Although a one-day session is insufficient time to make meaningful progress on actually coordinating federal and non-federal R&D in the spectrum sharing arena, the workshop discussions were helpful in meeting the following objectives:

- Identifying and focusing on the technical issues involved in this type of R&D
- Connecting the R&D communities across the federal government with the private, public safety, and academic sectors
- Raising awareness of current R&D within the federal government
- Identifying R&D areas that, due to their potentially broad impact, may be particularly good investments for the federal government
- Re-emphasizing the need to make positive progress on spectrum sharing

Because of the importance of spectrum sharing to all wireless innovators, and consistent with the views expressed by the participants, the WSRD-SSG will continue to actively engage the non-governmental community on these important topics. The next workshop, scheduled for January 2012, will explore the concept of a national testbed(s) to help build, prove, and deploy efficient and secure spectrum sharing technologies.

Appendix 1 - Participants

Invited participants were chosen to represent stakeholders from industry and academia including: service providers, device and component manufacturers, companies that could be considered “new comers” to this market, investors, and those working in public safety. You can find a copy of the workshop invitation in Appendix 3 and biographies of many of the participants in Appendix 2. The list of participants included:

Jennifer Bernhard, University of Illinois
Vanu Bose, Vanu, Inc.
Joseph Evans, Kansas University
Behrouz Farhang, University of Utah
John Grosspietsch, Motorola Solutions
Amer Hassan, Microsoft
Dale Hatfield, Colorado University Silicon Flatirons
James Kimery, National Instruments
Bruce Kraemer, Marvel Semiconductor
Robert Kubik, Samsung
Joohwan Lee, Electronics and Telecommunications Research Institute, Korea
Kevin Lo, Google
Emer Marchetti, Sprint Clearwire
Preston Marshall, University of Southern California, Information Sciences Institute
Abbie Mathew, Newlans
Mark McHenry, Shared Spectrum Co.
Jon Peha, Carnegie Mellon
Robert Pepper, Cisco Systems
Jerry (Zhouyou) Pi, Samsung
Ravi Prakash, University of Texas, Dallas
Steve Sharkey, T-Mobile
Tod Sizer, Alcatel-Lucent

NITRD and its WSRD SSG thank the workshop participants for their time and effort in providing their valuable insight to the Federal Government R&D process, and we look forward to continued engagement with the private, public safety, and academic communities

Appendix 2 – Biographies

Byron Barker:

Byron Barker serves within the Department of Commerce's National Telecommunications and Information Administration (NTIA) Office of Spectrum Management as Chief of its Strategic Planning Division. His office has the responsibility to develop the long range strategic plans, policies and comprehensive strategies that will provide for a continuous, ongoing regulatory transition to a future architecture envisioned to ensure spectrum access for our nation's vital interests of national security, public safety and economic opportunity, now and in the future. Previous to coming NTIA, Mr. Barker served in Defense Information Systems Agency's (DISA) Defense Spectrum Organization (DSO). His responsibilities were concentrated on the development of the department's long-term spectrum strategies and comprehensive plans to include the development of the department's first enterprise architecture for spectrum management, serving as the framework in transforming spectrum management to support the Department's future vision on net-centric operations and warfare. Mr. Barker, originally an Oklahoma native, has spent the last ten years within the Washington DC area. He earned a Bachelor of Science Degree in Electrical Engineering from the University of Oklahoma and completed his post-graduate studies at Webster University, St. Louis, MO. Mr. Barker began government service in 1987 serving as an electronics engineer for the Air Force located at Tinker AFB, OK where he worked on various communications projects and programs that included the MILSTAR Air Force Ground Command Post Satellite Terminal program.

Jennifer Bernhard:

Prof. Jennifer Bernhard has been a faculty member in the Electromagnetics Laboratory in the Department of Electrical and Computer Engineering at the University of Illinois since 1999. Her research group focuses on the development and analysis of multifunctional reconfigurable antennas and their system-level benefits as well as the development of antenna synthesis and packaging techniques for electrically small, planar, and integrated antennas for wireless sensor and communication systems. In addition to the NSF CAREER Award, the IEEE Antennas and Propagation Society H. A. Wheeler Prize Paper Award, and other research recognitions, she has been honored with a number of teaching and advising awards. In 2008-2009, Prof. Bernhard was a member of the Defense Science Study Group, sponsored by DARPA. She is a Fellow of the IEEE, and in 2008, she served as the President of the IEEE Antennas and Propagation Society. She also was one of the organizers for the 2010 NSF Enhancing Access to the Radio Spectrum Workshop.

Vanu Bose:

Vanu Bose is the President and CEO of Vanu, Inc. Vanu earned all of his degrees from MIT, receiving his Ph.D. in Electrical Engineering and Computer Science (EECS) in 1999, his Master's degree in EECS in 1992, and two Bachelor's degrees, one in EECS and one in Math, in 1988. As a graduate student, Vanu worked on the MIT SpectrumWare project at the MIT lab for Computer Science, an effort to bring a software oriented approach to wireless communication and distributed signal processing. There he performed the software radio research that would later evolve into Vanu, Inc. Prior to graduate school, Vanu developed a technical teaching curriculum and onboard medical, computer and satellite communications systems for a DC-10 flying hospital for Project Orbis, a private, non-profit organization dedicated to fighting world blindness. Vanu is a member of the Board of Trustees for the Boston

Museum of Science, as well as the Bernard M. Gordon-MIT Engineering Leadership Program Industry Advisory Board. He has moderated several panels in the wireless industry, including, most recently, a panel at the Center for Strategic and International Studies in Washington DC in September 2010; the aim was to increase appreciation of the Electro-Magnetic Spectrum (EMS) conditions that threaten US prosperity and to develop a basic framework for a national strategy to better posture the United States for the future.

Andrew Clegg:

Andrew Clegg is the program director for the Enhancing Access to the Radio Spectrum (EARS) program at the National Science Foundation. He holds a PhD in radio astronomy and electrical engineering from Cornell University, and a BA in physics and astronomy from the University of Virginia. Since 1990, he has been involved in spectrum-related regulation and R&D in the commercial and government (civilian and military) sectors. He has represented the U.S. at the 2007 ITU World Radio Communication Conference, and is the alternate representative to the IRAC for the National Science Foundation. He has also served two terms as president of the National Spectrum Managers Association. He has been with the National Science Foundation since 2003.

Joseph Evans:

Joseph B. Evans is the Deane E. Ackers Distinguished Professor of Electrical Engineering & Computer Science at the University Of Kansas (KU). Most recently, he has been developing TIGR, a tactical information system that has been extensively deployed in Iraq and Afghanistan for DARPA and the US Army. From 2008 to 2010, he served as Director of the Information & Telecommunication Technology Center and from 2005 to 2008 as Director of Research Information Technology at KU. From 2003 to 2005, he served as a Program Director at the National Science Foundation and he is currently serving as a member of the IEEE Communications Society Board of Governors. He has been a researcher at the Olivetti & Oracle Research Laboratory, Cambridge University Computer Laboratory, USAF Rome Laboratories, and AT&T Bell Laboratories. He has co-founded several technology companies, including a network gaming company acquired by Microsoft in 2000 and a defense-oriented venture acquired by General Dynamics in 2010. His research interests include cognitive radio networking, spectrum-related issues, sensor networking, adaptive systems, and network testbeds. He received the B.S.E.E. degree from Lafayette College in 1983, and the M.S.E., M.A., and Ph. D. degrees from Princeton University in 1984, 1986, and 1989, respectively.

John Grosspietsch:

John Grosspietsch received his BSEE degree from the Illinois Institute of Technology in 1978. He received his MSEE degree in 1979 and his Ph.D. in 1984 also from the Illinois Institute of Technology. Prior to joining Motorola he designed low power mixed signal CMOS adaptive filter signal processing systems for hearing aid applications. He joined Motorola in 1989 in the IC Design Research Laboratory within the Chicago System and Technology Laboratory of Motorola Labs. He has worked on many mixed-signal CMOS IC design projects for Motorola's cellular telephone products. After 1997 he led a variety of research projects in Software Defined Radio and Cognitive Radio technologies. From 2004 to 2007 he chaired the SDR Forum Working Group on Cognitive Radio. Currently, he is a member of the Enterprise Mobility Solutions Research group of Motorola Solutions where he is involved in research of advanced communications systems technologies for mission critical applications.

Amer Hassan:

Amer Hassan received his BSEE and MSEE from the University of Kansas in 1983 and 1984, respectively, with emphasize on digital communications. He received his Ph.D. in Electrical Engineering Systems from the University of Michigan, Ann Arbor, in 1988, where his research focused on radio communications and information theory. Since then Amer worked at the GE R&D Center in Schenectady as a Researcher in radio communications and signal processing, then at Ericsson Mobile Research in North Carolina as a Research Manager for emerging wireless systems. He was an Adjunct Professor at North Carolina State University. Amer joined Microsoft as an Architect and Program Manager in June 2000 as part of Windows Devices and Networking Technologies. His activities include in depth analyses of high speed wireless and cognitive radio systems, and how these technologies integrate with the operating system; he is also a program manager for wireless features being developed in next generation Windows. Amer is holder of over 60 issued patents, 50 technical publications, and keynote presenter in over 20 recent conferences and forums. Amer co-founded several industry alliances focusing on high speed wireless and on the Board of Directors for: White Spaces Alliance, High Speed Wireless Center (Sweden), and Wi-Fi Alliance, Wireless Gigabit Alliance, and Technical representative for Microsoft on the Broadband Internet Technical Advisory Group (BITAG). Amer is currently an adjunct professor at the University of Washington.

Dale N. Hatfield:

Dale N. Hatfield is currently the Executive Director of the Silicon Flatirons Center for Law, Technology, and Entrepreneurship and an Adjunct Professor in the Interdisciplinary Telecommunications Program – both at the University of Colorado at Boulder. Prior to joining the University of Colorado, Hatfield was the Chief of the Office of Engineering and Technology at the Federal Communications Commission (FCC) and, immediately before that, he was Chief Technologist at the Agency. He retired from the FCC and government service in December 2000. Before joining the FCC in December 1997, he was Chief Executive Officer of Hatfield Associates, Inc., a Boulder, Colorado based multidisciplinary telecommunications consulting firm. Before founding the consulting firm in 1982, Hatfield was Acting Assistant Secretary of Commerce for Communications and Information and Acting Administrator of the National Telecommunications and Information Administration (NTIA). Before moving to NTIA, Hatfield was Chief of the Office of Plans and Policy at the FCC. Hatfield has over four decades of experience in telecommunications policy and regulation, spectrum management and related areas. Hatfield holds a BS in electrical engineering from Case Institute of Technology and an MS in Industrial Management from Purdue University. In May, 2008, Hatfield was awarded an Honorary Doctor of Science degree by the University of Colorado for; *inter alia*, his commitment to the development of interdisciplinary telecommunications studies. Hatfield is also the Executive Director of the Broadband Internet Technical Advisory Group (BITAG) and is currently serving on the FCC's Technology Advisory Council (TAC). Until recently, he served as co-chairman of the Commerce Spectrum Management Advisory Committee (CSMAC)

James Kimery:

James Kimery is RF and Communications Group Manager for National Instruments. In this role, James is responsible for the defining the hardware and software roadmaps for the company's software radio strategy. He also leads the RF and Communications academic programs for research and education. Prior to joining NI, James was the Director of Marketing for Silicon Laboratories' wireless division which is now a subsidiary of ST-Ericsson. As Director, the wireless division grew to over $250M in revenue and produced several industry firsts including the industry's first CMOS RF synthesizer for cellular communications, the first completely integrated RF transceiver for cellular communications, the first digitally controlled crystal oscillator, and the first completely integrated single chip phone which was voted by the IEEE as one of the top 40 innovative ICs ever developed. James also worked at National Instruments before transitioning to Silicon Labs and led many successful program initiatives including the PCI eXtensions for Instrumentation (PXI) specification, product definition and introduction; and various VXI and instrument control products. James was also a founding member of the VXIplug&play Systems Alliance, VISA working group, and PXI System Alliance. James holds degrees from the University of Texas at Austin (MBA) and Texas A&M University (BSEE).

Paul Kolodzy:

Dr. Paul Kolodzy has 25 years of experience in technology development for advanced communications, networking, electronic warfare, and spectrum policy for government, commercial, and academic clients. He is currently a Communications Technology Consultant in Advanced Wireless and Networking Technology based near Washington DC. Current areas include advanced technology development for communications, electronic warfare, and ISR with DARPA, the radio and policy for broadband radio access, 700 MHz commercial and public safety spectrum policy and interference mitigation technology, Advanced Wireless Service (AWS), TDD/FDD Coexistence, Fourth Generation (4G) radio technology inclusive of intelligent antenna and adaptive spectrum resource allocation. He is active in technology development for wireless components and new wireless networks and architectures as well as spectrum policy as impacted by new technology. Prior to being a consultant, Dr. Kolodzy has been: at Stevens Institute of Technology; during 2002, the Senior Spectrum Policy Advisor at the Federal Communications Commission (FCC) and Director of Spectrum Policy Task Force; Program Manager at the Defense Advanced Projects Agency (DARPA); Director at Sanders, A Lockheed Martin Company; and a Group Leader/Staff Member at MIT Lincoln Laboratory.

William Lehr:

Dr. William Lehr is an economist and research associate in the Computer Science and Artificial Intelligence Laboratory (CSAIL) at the Massachusetts Institute of Technology (MIT) and participant in the Communications Futures Program (CFP). The CFP is a joint industry-academic multidisciplinary research effort focused on the technical, economic, and public policy challenges confronting the Internet infrastructure industries. Dr. Lehr's research focuses on the economic and policy implications of broadband Internet access, next generation Internet architecture, and the evolution of wireless technology. In addition to his academic research, Dr. Lehr provides consultancy services on matters related to the information technology industries to public and private sector clients in the U.S. and abroad. Dr. Lehr has over twenty years of telecommunications industry experience as a researcher and industry consultant. Dr. Lehr holds a PhD in Economics from Stanford, an MBA in Finance from the Wharton School, and MSE, BA, and BS degrees from the University of Pennsylvania.

Kevin Lo:

As the General Manager of Google Access, Mr. Lo is responsible for day-to-day operations of Google's access businesses (wireline and wireless), including the recently announced Gigabit Fiber to the Home Network. From 2006-2010, Mr. Lo was the COO of M2Z Networks Inc., a wireless telecom service provider working to deploy a wireless broadband service to compete with fixed line cable and DSL. Previously, Mr. Lo was the founder and CEO of two software companies, one acquired by IBM (NYSE: IBM) in 2006 and the other acquired by Progress Software (NASDAQ: PRGS) in 2000. In between those ventures, he was CFO and COO of NaviSite (NASDAQ: NAVI) where he led the successful turnaround of the managed telecom services company and the stock price from $0.80/share to over $8.00 at the end of his tenure. Prior to that, Mr. Lo was a strategy consultant at Bain & Co. and got his start in software programming as a research assistant at the Jet Propulsion Laboratory. Mr. Lo received is AB from Harvard University where he was also a Harvard National Scholar. Mr. Lo is board member of several technology companies; he has an active interest in technology-in-education initiatives and is also an avid triathlete.

Mark McHenry:

Mark A. McHenry is the President and Chief Technical Officer of the Shared Spectrum Company in Vienna, VA. Mark has extensive experience in military and commercial communication systems design, including research on the next generation of advanced wireless networks. He founded two high-tech wireless research and development companies. In 2000, he founded Shared Spectrum Company (SSC), which is developing automated spectrum sharing technology. Shared Spectrum Company develops advanced technologies for Government and industry customers with challenging radio frequency and networking needs. It specializes in dynamic spectrum management applications. McHenry was also a co-founder of San Diego Research Center, Incorporated (SDRC) that focused on DoD test and training systems. SDRC was acquired by Argon ST in 2006. McHenry was a Program Manager at DARPA, where he managed multiple tactical wireless related programs. McHenry received the Office of Secretary of Defense Award for Outstanding Achievement in 1997 and the Office of Secretary of Defense Award for Exceptional Public Service Award in 2000. McHenry was an engineer at SRI International, Northrop Advanced Systems, McDonnell Douglas Astronautics, Hughes Aircraft and Ford Aerospace. McHenry was named Engineer of the Year by the District of Columbia Council of Engineering and Architectural Societies in February, 2006. McHenry was appointed by Secretary of Commerce, Carlos Gutierrez, to serve as a member of the Commerce Spectrum Advisory Committee, in Dec 2006. Education: B.S. in Engineering and Applied Science from the California Institute of Technology; M.S. in Electrical Engineering from the University of Colorado; Ph.D. in Electrical Engineering from Stanford University.

Jon Peha:

Jon Peha is a Full Professor at Carnegie Mellon University. He has been on leave in 2008-11 to serve in government, first as Chief Technologist of the Federal Communications Commission, and then Assistant Director of the White House Office of Science & Technology Policy where he focused on Communications and Research (including creation of the Wireless Spectrum Research & Development Committee). At Carnegie Mellon, he was a Professor in the Dept. of Engineering & Public Policy and the Dept. of Electrical & Computer Engineering, and Associate Director of the Center for Wireless & Broadband Networking. He has been Chief Technical Officer of three high-tech start-ups, and a member of technical staff at SRI International, AT&T Bell Laboratories, and Microsoft. He has addressed telecom and e-commerce on legislative staff in the House Energy & Commerce Committee and the Senate, and helped launch and led a US Government interagency program to assist developing countries with information infrastructure. Dr. Peha consults for industry and government agencies around the world. His research spans technical and policy issues of information networks, including spectrum management, broadband, wireless, video and voice over IP, communications for emergency responders, universal service, dissemination of copyrighted material, e-commerce, and network security.

Jerry Pi:

Jerry Pi is a Director at the Samsung R&D Center in Dallas, Texas, where he leads 4G standardization and development efforts. Before joining Samsung, he worked at Nokia Research Center in Dallas and San

Diego, California, on 3G standardization and modem development. He has published more than 15 research papers and more than 80 patents and patent applications. He received his B.E. degree in automation from Tsinghua University (with honors), his M.S. degree in electrical engineering from Ohio State University, and his M.B.A. degree from Cornell University (with distinction).

Ravi Prakash:

Dr. Ravi Prakash received the B.Tech. degree in Computer Science and Engineering from the Indian Institute of Technology, Delhi in 1990, and the M.S. and Ph.D. degrees in Computer and Information Science from The Ohio State University in 1991 and 1996, respectively. He joined the Computer Science program at U.T.Dallas in July 1997 where he is currently an associate professor. He is a recipient of the prestigious NSF CAREER award for his work in the area of mobile computing. He has served as an associate editor of the IEEE Transactions on Mobile Computing and as the technical program committee chair or vice-chair for several international conferences and symposia. Dr. Prakash's areas of research are mobile computing, wireless networking and sensor networking. He is leading an NSF MRI funded project, WiNeTestEr, to build a reliable wireless networking testbed and emulator. He has also worked extensively in network and MAC layer protocols for mobile ad hoc networks and cellular networks.

Tod Sizer:

Dr. Theodore (Tod) Sizer is leader of the Wireless Access Domain in Bell Laboratories. In this role he leads teams in six worldwide locations innovating in all aspects of wireless access systems and technology. In December 2008 he relocated on International Assignment to Bell Labs Stuttgart to assume the director position for Wireless Physical Layer Research. Prior to his relocation, he was director of the Converged Access Systems Research Department of Bell Laboratories in Murray Hill, NJ. His department performed research in High Speed Wireless Systems, next generation PON and DSL systems, and design of next generation Cellular Base Stations. During his tenure at Bell Labs he has performed research in Wired and Wireless Home Networking, Fixed Wireless Loop systems, Video Watermarking technologies, Optical Computing and Switching Systems, and High Power Laser Design. He was a member of the technical team in Lucent's role as a promoter in the Bluetooth Special Interest Group (SIG). His responsibilities in the SIG included being Chair of the Coexistence Working Group. Tod graduated from Amherst College, *Magna Cum Laude* and received his Masters and Doctorate from the Institute of Optics at the University of Rochester. In 2007 Tod was named a Bell Labs Fellow "*For sustained creative contributions to wireless systems, particularly in the convergence of packet and wireless technologies".* He is the author of 43 patents, 16 patents pending and over 50 refereed publications and is a member of the IEEE and OSA.

Rangam Subramanian:

Dr. Subramanian is a Principal, Wireless Technology and Business Strategy, in the National and Homeland Security Directorate at the Idaho National Laboratory, Idaho Falls, ID. His primary responsibilities include: Developing and executing on wireless R&D strategy, setting the direction and roadmap for the wireless research center; Developing the INL wireless business and brand equity; and Providing wireless technology thought and execution leadership for research and testing programs of national importance, working across the government stakeholders, academia, industry and entrepreneurs. Dr. Subramanian has more than 20 years of international experience in wireline, wireless, satellite and converged multimedia Telecommunication technologies. He has contributed in several areas including, research, technology development and deployment, mergers & acquisitions, technology strategy and innovation, business development, global partnerships and organizational leadership. He is currently serving the White House/ National Information Technology R&D (NITRD) National Task Force on wireless spectrum sharing research innovation and experimentation. Dr. Subramanian holds a BS in Electronics Engineering from the Regional Engineering College, Calicut, India; a MS in Telecommunications from the Asian Institute of Technology, Bangkok, Thailand; a PhD in Computer & Systems Engineering from the School of Computer Science, Oakland University, Rochester, Michigan, USA; and a MBA from the Kellogg School of Management, Northwestern University, Evanston, IL, USA.

Stephen A. Wilkus:

Stephen A. Wilkus (IEEE M'83, SM'07) received a B.S. degree in physics and an M.S.E.E. degree from the University of Illinois, Urbana, in 1981. After working at the startup, RF Monolithics, he joined Bell Laboratories (then part of AT&T), Lucent Technologies, in 1986 as a Researcher and Developer of Surface Acoustic Wave devices used in undersea cable and wireless products. His interest in wireless communications lead to work on standards and regulatory work in the AT&T Chief Architect's Office, including the early meetings of the IEEE 802.11 Wi-Fi standards efforts. In 1991, he spearheaded the development of a wireless electronic shelf label system sold through NCR (also once part of AT&T). He later led a team (Holmdel, NJ) that first demonstrated HSDPA in 2003 and was the solutions architect for a DVB-SH deployment using a hybrid Satellite-terrestrial Single Frequency Network. Steve has been named to the Alcatel-Lucent Technical Academy and is a Distinguished Member of Technical Staff. In 2007 he was inducted as a Senior Member of the institute of Electrical and Electronics Engineers (IEEE).

Appendix 3 - Invitation

Dear…….

On behalf of the Wireless Spectrum Research and Development Senior Steering Group (WSRD) of the Federal Government's Networking and Information Technology Research and Development Program (NITRD), we invite you to participate in a technical workshop, *Toward Innovative Spectrum-Sharing Technologies: A Technical Workshop on Coordinating Federal Government/Private Sector R&D Investments.* It will be held in Boulder, Colorado, on July 26, at the Department of Commerce Boulder Labs.

The Presidential Memorandum on Unleashing the Wireless Broadband Revolution, released on June 28, 2010, directed the federal agencies to work together and with the non-federal community, including the academic, commercial, and public safety sectors, to create and implement a plan that "facilitates research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies." In accordance with the Presidential directive, we invite you to share your expertise with this gathering of esteemed researchers and technology experts and assist in this important process.

The workshop is being held in conjunction with the International Symposium on Advanced Radio Technologies (ISART), on July 27-29. Additional information on both the workshop and the ISART conference is available on our joint website.

Your RSVP is sincerely appreciated. If you have further questions do not hesitate to contact Wendy Wigen at wigen@NITRD.gov or at 703.292.7921.

Best regards,

Byron Barker, NTIA, Co-Chair WSRD

Andrew Clegg, NSF, Co-Chair WSRD

Appendix 4 – Federal Register Notice

Federal Register Notice: June 7, 2011

NATIONAL SCIENCE FOUNDATION
Toward Innovative Spectrum-Sharing Technologies: A Technical Workshop on Coordinating Federal Government/ Private Sector R&D Investments

AGENCY: The National Coordination Office (NCO) for Networking and Information Technology Research and Development (NITRD).

ACTION: Notice.

FOR FURTHER INFORMATION CONTACT: Wendy Wigen at 703–292–4873 or *wigen@nitrd.gov.* Individuals who use a telecommunications device for the deaf (TDD) may call the Federal Information Relay Service (FIRS) at 1–800–877–8339 between 8 a.m. and 8 p.m., Eastern time, Monday through Friday.

DATES: July 26, 2011.

SUMMARY: Representatives from Federal research agencies, private industry, and academia will discuss the future research needs for developing innovative spectrum-sharing technologies.

SUPPLEMENTARY INFORMATION:

Overview: This notice is issued by the National Coordination Office for the Networking and Information Technology Research and Development (NITRD) Program. Agencies of the NITRD Program are holding a technical workshop to bring together experts from private industry and academia to help ‘‘create and implement a plan to facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies, including those that are secure and resilient.’’ The workshop will take place on July 26, 2011 from 8:30 a.m. to 5 p.m. MT in Boulder, Colorado at the U.S. Department of Commerce (DOC) Boulder Labs, 325 Broadway, Building 1 Lobby, Boulder, Colorado 80305. This event will be Webcast. For the event agenda and information about the Webcast, go to: *http:// www.its.bldrdoc.gov/isart/WSRD/.*

Background: The dramatic rise of radio frequency-based applications has sparked a new sense of urgency among federal users, commercial service providers, equipment developers, and spectrum management professionals on how best to manage and use the radio spectrum. While near-term solutions such as spectrum re-allocations are critical to meeting national needs, so is the development of the next generation of technologies that can enable more efficient use of the radio spectrum.

NITRD established the Wireless Spectrum Research and Development Senior Steering Group (WSRD–SSG) in late 2010. The committee was asked to identify current spectrum-related research projects funded by the Federal Government, and to work with the nonfederal community, including the academic, commercial, and public safety sectors, to implement a plan that ‘‘facilitates research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies,’’ in accordance with the Presidential Memorandum on Unleashing the Wireless Broadband Revolution. WSRD–SSG operates under the auspices of the Networking and Information Technology Research and Development (NITRD) program of the National Coordination Office (NCO), and has recently put together a preliminary inventory of federal R&D in the spectrum arena.

This workshop will present an opportunity for relevant interested parties, including technical experts from private industry and public safety, together with academic researchers, to explore ongoing spectrum-related Federal Government R&D activities as listed in the WSRD–SSG inventory, and offer their expertise on developing recommendations for a wireless technology innovation initiative. We will ask private industry participants to suggest research avenues that they believe are presently underrepresented in federal R&D and that are not being pursued in private industry research laboratories. The focus will be on identifying R&D that may have large potential payoffs for wireless technologies and the nation’s economy at large, which are consistent with the Federal Government’s role in sponsoring important basic and applied research and development. The workshop will also address possible frameworks for supporting long-term research that may result in yet-to-beconceived improvements in spectrum utilization.

Submitted by the National Science Foundation for the National Coordination Office (NCO) for Networking and Information Technology Research and Development (NITRD) on June 2, 2011.

Suzanne H. Plimpton, *Management Analyst, National Science Foundation.*

Appendix 5 – Keynote Address

Thoughts on Spectrum Sharing

Keynote Address
by

Dale N. Hatfield
Senior Fellow, Silicon Flatirons Center
University of Colorado at Boulder

Before the

Wireless Spectrum R&D (WSRD)
Senior Steering Group (SSG)
Working Group Meeting

Boulder, Colorado
July 26, 2011

Thank you, Andy, for the very kind introduction. Since the Boulder area is my home, I would like to start by welcoming all of our out-of-town visitors to our city. I believe Boulder is an exceptional place and I hope you will have time to share it and the surrounding mountains with us.

I would also like to say that this building is rather special to me personally because I started my professional career in radio communications in this building when it housed the Central Radio Propagation Laboratory – CRPL – which is a predecessor organization to our hosts today, the Institute for Telecommunications Science of the National Telecommunications and Information Administration. I started work in this building at CRPL in September of 1963 – going on 50 years ago.

My interest in – nay my utter fascination with – radio communications began when I received my first amateur radio license – my "ham ticket" in the mid-1950s. That fascination led me to selecting electrical engineering as my vocation and, when I got here to Boulder in 1963, I quite frankly thought I had "died and gone to heaven" as the expression goes. I was involved in the technical aspects of radio communications all day and got paid for it. Can you imagine? Radio was both my vocation and avocation – and I thought it could never get better than that.

I promise that I will not reminisce much longer but I do want to mention one point that is related to the topic of today's workshop. When I arrived here in the early 1960s, the increasing importance of radio spectrum to the Nation was beginning to be more fully appreciated.

For example, in 1964, the Joint Technical Advisory Committee (JTAC) of the International Electrical and Electronic Engineers (IEEE) and the Electronic Industries Association (EIA) published an important report entitled "Radio Spectrum Utilization." It called attention to radio spectrum as an underappreciated natural resource and identified problems that needed to be overcome if continued growth and utilization of the resource was to be ensured.

That publication was followed in 1966 by another important report entitled "Electromagnetic Utilization – The Silent Crisis." It was produced by Telecommunication Science Panel of the Commerce Technical Advisory Board. It focused on identifying and describing research and technical programs needed, and I quote, "to promote more efficient utilization of the electromagnetic frequency spectrum for telecommunications." A lot of the staff work for the latter report was done here in this building under the direction of C. Gordon Little and Richard C. Kirby. There is a lot of similarity between what they were trying to do then – identifying research needs relating to spectrum utilization – and what we are addressing in the workshop today. Thus, in some ways, it is especially fitting that we are meeting here in this building.

I have entitled my remarks this morning "Thoughts on Spectrum Sharing" and I would like to begin by putting those thoughts into perspective:

<u>First</u>, I agree passionately with President Obama's June 10, 2010 Memorandum in which he stated that "America's future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum."

<u>Second</u>, while I believe that improving the technical efficiency of spectrum utilization – squeezing out more "bits-per-second-per-Hertz of bandwidth" and getting closer to the Shannon Limit if you will – is important, I also believe that to meet the rapidly expanding needs for additional spectrum, even more dramatic improvements in utilization are needed.

I see those more dramatic improvements falling into two major categories:

(1) increasing frequency reuse through the deployment of smaller cell sizes (in systems where the cellular architecture is appropriate) and/or by employing higher performance (e.g., more directive and perhaps electronically steerable) antennas (where they are feasible) and

(2) increasing the amount of spectrum sharing so that critically needed spectrum does not unnecessarily lie fallow on either a long term or short term basis.

For less technical audiences, I often distinguish between technical efficiency – achieving more bits-per-second-per-Hertz-per-square-kilometer – and operational efficiency which is associated with increased spectrum sharing. I distinguish between the two notions – technical and operational efficiency – by using a transportation example. We can be more efficient in transporting people between Boulder and Denver by improving the fuel efficiency of the vehicles involved – getting more miles-per-gallon – or by encouraging more carpooling – sharing – so as to reduce the effective number of gallons of fuel used per passenger.

As I understand it, much of your focus here today is on the latter approach – the second of the two major categories; namely, increasing the amount of spectrum sharing. I think that is entirely appropriate given the needs for dramatic gains in utilization. I also agree with the suggestion in the some of the material that was passed out in advance of the meeting that:

(1) the opportunities for outright reallocation of spectrum for new services are diminishing significantly and

(2) more dynamic forms of sharing of existing allocations both spatially and temporally are, accordingly, necessary if this Nation is going to achieve greater utilization – more access – to this increasingly precious resource.

My own interest in more intensive spectrum sharing goes back decades to when we were considering how to improve spectrum efficiency in the land mobile radio services and trunking on both a private and commercial (e.g., Specialized Mobile Radio or SMR) basis was proposed as one possible solution.

That is, rather than assign individual channels to each licensee, the channels were pooled and meted out to users only when needed and only for the duration of the actual communications. As we all learned in our systems engineering or traffic engineering courses, trunking significantly increases the capacity – and hence the utilization efficiency – of a given block of spectrum.

(I might add parenthetically that the type of dynamic sharing of spectrum we are considering here today could be regarded as a sophisticated form of trunking – temporal sharing if you will – involving larger blocks of spectrum – e.g., an entire band of spectrum rather than just an individual channel.)

Before I turn to some more recent thinking of my own about spectrum sharing, I would like to add one more comment or point that relates to the charge your Senior Steering Group has of identifying opportunities and gaps in technology developments that would facilitate greater and more rapid sharing. As I indicated earlier, I think your work is particularly important because increased sharing is vital to achieving increased spectrum utilization and access going forward.

But I think it is especially important given the pressures on the Federal government budget. Clearly, given those budgetary pressures, it is more important than ever that overlaps be minimized and that government and private sector research resources be disbursed in a collaborative fashion that maximizes the opportunity for "the development of advanced, situation-aware spectrum-sharing technologies" as called for in the Presidential Memorandum.

Skipping over some important details, from a jurisdiction standpoint under the U.S. system of spectrum management anyway, there are four possible sharing arrangements:

1. Between two commercial or other private entities using spectrum administered by the FCC
2. Between commercial entities or other private entities and Federal government agencies using spectrum administered by NTIA and IRAC
3. Between two Federal government entities using spectrum administered by the NTIA and IRAC
4. Between Federal government agencies and entities using spectrum administered by the FCC.

In the interest of time here this morning and because I have concentrated most of thinking on the first two possibilities – sharing between commercial/private entities and sharing between commercial/private entities and Federal government agencies – I will focus my attention on them.

When I returned to the FCC in 1997 as Chief Technologist and then Chief of the Office on Engineering and Technology, I became fascinated by two developments – the emergence of Software Defined Radios/Cognitive Radios on the technology side on the one hand and, on the other hand, by the increased interest among policy-makers in the potential of secondary markets in spectrum to reduce some of the inherent rigidities in the traditional "command and control" method of allocating and assigning the resource. In short, I saw SDR/CR systems as a <u>means</u> of providing more opportunities for dynamic sharing and secondary markets as an <u>incentive</u> to use that technology to achieve more sharing. Reiterating for emphasis, the two critical components for increased sharing are (1) having the means to accomplish spectrum sharing (within acceptable limits of interference) and (2) having sufficient incentives on both sides to strike the sharing bargain.

In principle, this sharing between or among commercial/private entities (licensees) should work along the following lines: Entity A, the existing licensee, has spectrum that is not fully utilized at all times and/or locations and Entity B has an unmet demand for use of the resource. Entity B would go to Entity A and say, in effect, that I have a technology available (in the form of an SDR/CR system) that will enable me use your spectrum with acceptable levels of interference when and/or where you are not using it. Moreover, I am willing to pay so much for the privilege under the rules that apply to the secondary market. Entity A would then decide whether the amount offered would lead to a sufficiently profitable transaction to adequately compensate them for the costs and risks involved.

Normal commercial negotiations would then take place and if a voluntary agreement was reached everyone would be better off. Entity A would increase its profitability by putting an idle asset to work and Entity B would gain access to badly needed spectrum. Finally, the public would benefit through the new or expanded service created and more generally from seeing otherwise underutilized spectrum put to productive use. In short, combining SDR/CR technology with liberalized rules regarding spectrum leasing produces both the means and the incentive necessary to produce a voluntary market in the resource to the benefit of all.

Over the past few years, the FCC has – to its credit in my opinion – liberalized the secondary market rules. While that liberalization has led to valuable voluntary spectrum transactions, from what I can observe the voluntary transactions have not involved the sort of opportunistic sharing based upon SDR/CR techniques that I originally envisioned and that are an important component of your deliberations here today. Assuming my observation is correct – and I believe it is – why is that the case? I think that trying to answer that question even in the abstract can provide guidance in terms of where to invest our Nation's limited R&D dollars. So let's look at the situation from both sides of the market – i.e., from the standpoint of both the lessor and lessee of underutilized spectrum – and then focus on those issues or risks that are unique to transactions involving licensed spectrum.

As we all learned in Micro-economics 101 or in our engineering economics classes, a typical way for the spectrum holder – the lessor – to decide whether or not to accept the offer to lease his or her underutilized spectrum would be to compute the Internal Rate of Return – the IRR – associated with the potential transaction. Basically, it involves computing a rate of return that considers both positive and negative cash flows (e.g., revenues and expenses) over the life of a project while taking into account the time-value of money. For the project to make sense from the potential lessor's standpoint – i.e., in deciding to go ahead and lease the spectrum -- the computed IRR must be sufficient to compensate the spectrum holder for the risks involved.

As I indicated a moment ago, some of the risks in spectrum transactions are not very different from other commercial lease transactions. For example, will the lessee actually be able to make the agreed upon lease payments over the life of the contract. In an ordinary commercial transaction, the lessor will try to minimize this risk by doing a thorough credit check or by asking for some type of guarantee of payment. But let's look at some of the other risks or disincentives that are more uniquely associated with sharing spectrum through a voluntary lease arrangement and how those risks and potential disincentives may inform your deliberations.

One risk that jumps immediately to mind is associated with whether or not the sharing technology proposed by the lessee will actually work as promised. That risk can be reduced not only by the development of more advanced technologies but also through the use of test beds and demonstration projects that validate the chosen technical approach.

Another, somewhat more subtle risk to the lessor is that the service delivered by the lessee over the lessor's heretofore underutilized spectrum will compete with one of its existing or future services. This decreases the incentives to engage in sharing, especially if the potential lessee has few other options. Rather than being a technological risk, this is an economic or, perhaps more precisely, a market structure risk that induces strategic behavior that may deter voluntary spectrum sharing among commercial entities.

Even more subtly, if a new perhaps unique service is successfully offered by the lessee and becomes very popular with its customers, it is possible that the spectrum manager – in this case the FCC – would take the spectrum away from the existing licensee and reallocate or reassign it from the lessor to the lessee. Because of the broad powers that the FCC has under its "public interest" standard and because, as my colleague Pierre de Vries often reminds me, the current FCC cannot bind future Commissions, this concern – this risk – cannot be easily dismissed. Stated another way, unlike rights in real property, spectrum usage rights are not particularly strong. Note that this is more of a policy, legal or regulatory risk rather than a technological risk or, in some respects at least, an economic risk.

Somewhat similar risks also face the potential lessee of underutilized spectrum but, in the interests of time, I will not dig into them here. I would like to emphasize however the even greater challenges that face a potential new entrant in trying to gain access to Federal government held spectrum. Under existing approaches at least, positive incentives for commercial sharing of spectrum with Federal government agencies on a more dynamic basis are not only missing but, in my opinion, there are strong disincentives as well. For example, Mark McHenry of Shared Spectrum Company recently observed and I quote:

> "The military believe that once they've given away even a fraction of access to civilian uses, even on a contingent basis … they'll never get it back; if they don't trust the politics of the process why should we expect them to embrace increased commercial sharing of federal government spectrum?"

Note that this is not a technological issue nor an economic or industry structure issue nor a policy, legal or regulatory issue. Rather it is a political issue; it falls largely into the realm of political science.

Well I have about run out of time so let me wrap-up by offering a few conclusions based upon my remarks here this morning:

- First, what you are doing is extremely important to America's future competitiveness and global technological leadership as described in the Presidential Memorandum

- Second, while I believe that incremental improvements in technical efficiency are important, I also agree that more dynamic forms of spectrum sharing are necessary if this Nation is going to achieve significant increases in access to – and utilization of – this ever more precious resource

- Third, your work in identifying gaps in government and private sector sponsored research in the area and your focus on trying to ensure that research resources are distributed in a more coordinated, cooperative fashion is especially important given the current and likely persistent pressures on the Federal government budget

- Fourth, while continuing to reduce the technological risks associated with more dynamic forms of spectrum sharing are necessary, they are not sufficient to guarantee the ultimate success of the technology in "wringing abundance from scarcity;" rather, more emphasis will have to be placed on an interdisciplinary approach that focuses on economic, policy/legal, and political science aspects of the problem – not just the technological.

Again, I greatly appreciate the opportunity to speak to you today and I hope my remarks have been useful to you as you continue your important work.

Appendix 6 – Reading and Resource List

WSRD Project Inventory:

- http://www.nitrd.gov/nitrdgroups/images/f/f0/WSRD_Project_Inventory_15.pdf

WSRD First Interim Report:

- http://www.nitrd.gov/nitrdgroups/images/6/6d/WSRD_Interim_Report_1_v_5.0.pdf
- NTIA Fact Sheet on Spectrum Plan and Timetable, Fast Track Evaluation:
- http://www.ntia.doc.gov/reports/2010/SpectrumFactSheet_11152010.pdf
- NTIA Report: Plan and Timetable to Make Available 500 MHz of Spectrum for Wireless Broadband
- http://www.ntia.doc.gov/reports/2010/TenYearPlan_11152010.pdf
- NTIA Report: An Assessment of the Near-Term Viability of QAccommodating Wireless Broadband Systems in the …… Bands
- http://www.ntia.doc.gov/reports/2010/FastTrackEvaluation_11152010.pdf
- EARS Report:
- http://www.nsf.gov/mps/ast/nsf_ears_workshop_2010_final_report.pdf

FCC National Broadband Plan: Chapter 5: Spectrum:

- http://download.broadband.gov/plan/national-broadband-plan-chapter-5-spectrum.pdf

NRC (National Research Council) Report: Spectrum Management for Science in the 21st Century:

- http://www.nap.edu/catalog.php?record_id=12800