WSRD Workshop III Report: Research Topics and Proposals to Further the Adoption of Spectrum Sharing

Federal Government and Private Sector Collaboration on Research Development, Experimentation, and Testing of Innovative Spectrum Sharing Technologies

Organized by the Wireless Spectrum Research and Development Senior Steering Group
Under the NITRD Program

July 24, 2012

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Executive Summary

The third workshop sponsored by NITRD's Wireless Spectrum R&D (WSRD) Senior Steering Group was held in July 2012 in Boulder Colorado. The purpose of the workshop was to engage representatives of the academic sector on potential research topic areas that could move the nation towards the development of innovative new spectrum sharing technologies. The academic researchers were asked to come prepared with specific project ideas that, within the context of several recent major national spectrum initiatives, hold particular promise for helping to meet the nation's spectrum sharing goals. The ideas were discussed among the workshop participants, which included representatives of the government, public safety, and industrial sectors. An analysis of each of the proposed research projects, based on the SWOT (Strengths, Weaknesses, Opportunities, and Threats) methodology, was conducted. While no binding decisions were taken by the workshop with respect to specific projects, the highest-ranking projects could be broadly categorized by the following general topic areas:

- Mechanisms for sharing spectrum
- Methods for protecting privacy, security, and integrity
- Means of enforcement
- Metrics for dynamic spectrum monitoring, measurements, and analyses

Two of the projects presented at the workshop were concurrently submitted to the NSF EARS program and were successful in being awarded funding. The solicitation for the second year of the EARS program specifically included the four major topic areas identified at this workshop, and funding for additional research projects presented at this third workshop is anticipated during this second call for proposals.

This third WSRD workshop was successful at moving beyond discussions about spectrum sharing toward specific actions to facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies.

Foreword

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)[2] program created the Wireless Spectrum Research and Development Senior Steering Group (WSRD SSG), to bring together representatives of all of the Federal agencies that conduct or support spectrum-related research and development. Upon its formation in November, 2010, and at the urging of the U.S. Chief Technology Officer, the WSRD SSG quickly recognized the importance of reaching out to private industry and academia as an avenue for supporting national-level wireless R&D investments

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

[2] http://www.nitrd.gov

Workshop Description

WSRD Workshop III was held on July 24, 2012, in Boulder, Colorado, in conjunction with the International Symposium on Advanced Radio Technologies[3] (ISART). This meeting provided a venue to help build on the outcomes of Workshop I[4] and II[5] by reviewing and prioritizing research proposals designed to further the adoption of spectrum sharing by both the private and government sectors.

The goal was to synthesize the results of previous workshops with the various mandates, plans, and reports that have been released from various government entities, and propose research projects that would address the barriers to spectrum sharing adoption and use. Workshop participants were asked to submit abstracts for research proposals that would:

1. Help address specific technical objectives and requirements outlined in the following documents:
    a. Title VI of the Middle Class Tax Relief and Job Creation Act of 2012[6]
    b. National Broadband Plan Section 5[7]
    c. NTIA's 1755-1850 MHz Band Report[8]
    d. NTIA's Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband[9]
    e. WSRD Workshop II Report[10]
    f. PCAST Report on Spectrum, *Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth*[11]
2. Help facilitate the 500 MHz transition outlined in the Presidential Memorandum.
3. Reach a meaningful milestone in a 3 year timeframe.
4. Be consistent with the Federal Government's role in sponsoring "high-risk high-reward" research innovation and experimentation.
5. Include a description of how the technology would be realistically deployed in a spectrum sharing environment.

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[3] http://www.its.bldrdoc.gov/isart/isart-home.aspx

[4] In July, 2011, the WSRD SSG held Workshop I to engage key representatives from the industrial and academic communities. The workshop was hosted at the U.S. Department of Commerce's facility in Boulder, Colorado, and was held in conjunction with the National Telecommunications and Information Administration's (NTIA's) International Symposium on Advanced Radio Technologies. During the workshop, one of the many takeaways from wireless industry participants was the critical need for a national wireless testing capability for validating spectrum sharing technologies under realistic and controlled conditions. They emphasized the value proposition that such a facility would have on a diversity of users - such as testing spectrum sharing technologies among disparate systems - and cited this concept as being a key enabler to future wireless innovation. The full report is available upon request to wigen@nitrd.gov.

[5] In January, 2012, the WSRD SSG held Workshop II to engage key representatives from the industrial and academic communities. The workshop was hosted at the Berkeley Wireless Research Center in Berkeley, California, and focused on the concept of creating a national-level testing environment for spectrum research, development, experimentation, and demonstration that would be available to researchers from all sectors. The workshop identified opportunities that would warrant a national effort in this area. The full report is available at: https://connect.nitrd.gov/nitrdgroups/images/2/20/WSRD_Workshop_II_Report.pdf

[6] http://www.gpo.gov/fdsys/pkg/BILLS-112hr3630enr/pdf/BILLS-112hr3630enr.pdf

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

[8] http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf

[9] http://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf

[10] https://connect.nitrd.gov/nitrdgroups/images/2/20/WSRD_Workshop_II_Report.pdf

[11] http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf

The workshop brought together top industry and academic experts to review the proposals, voice their opinions, and help inform the WSRD SSG recommendations contained in this report. Emphasis was placed on generating a set of research projects that could help remove barriers to adoption and could potentially be acted on by funding agencies.

The Workshop Planning Committee adopted a multi-step process to accomplish this goal. They identified the relevant researchers, invited them to submit short abstracts, reviewed the abstracts, offered suggestions for modifications, chose a final set of 20 abstracts, and distributed them to all of the workshop participants for their review. The workshop was open to the public and the information was published in the Federal Register on July 10. Once the workshop began, those who had abstracts accepted were allowed to give a short presentation and take questions. At the conclusion of the presentations, participants were asked to establish a prioritized list of the abstracts according to which concepts warranted further discussion. The resulting prioritized list was analyzed in terms of Strengths, Weaknesses, Opportunities, and Threats (SWOT). After the workshop was completed, the WSRD SSG met to discuss the results and established the following major areas of spectrum sharing research that they would recommend for Federal investment:

- Mechanisms for sharing spectrum
- Methods for protecting privacy, security, and integrity
- Means of enforcement
- Metrics for dynamic spectrum monitoring, measurements, and analyses

Analysis

The overriding theme of this workshop and its request for proposal abstracts is the question of interference. How do we share spectrum without interfering with an incumbent or other simultaneous user? How much interference is tolerable and who determines and enforces the interfering activity? How can spectrum sharing become easy, credible, and profitable enough to overcome the fear of interference? While this is not an exhaustive list of the necessary components, these categories represent the best first steps towards answering the question of interference and improving the use of spectrum sharing and dynamic spectrum access.

1. **Mechanisms for sharing spectrum:** A variety of possible mechanisms were identified. These include beaconing, which is an active wireless or wired method of broadcasting the existence of spectrum users on a time, frequency, and location basis; network sharing, which is the sharing of spectrum resources enabled through integrated sharing concepts at higher network layers; spectrum databases, which include details of spectrum use that are shared among some or all users to help mitigate potentially incompatible spectrum use; and the use of heterogeneous networks, which distributes spectrum users' access across cells of a wide range of size or access methods to allow dynamic offloading of bandwidth requirements to the most suitable radio access architecture. Each mechanism has its own benefits and drawbacks. Further research is needed to determine which methods are the most promising under specific spectrum sharing scenarios.

2. **Methods for protecting privacy, security, and integrity:** For spectrum sharing to be successful and to address lingering concerns of incumbent users who may be required to share spectrum in a future dynamic spectrum access environment, any new spectrum sharing technology must be able to co-exist without compromising the integrity and security of other users' signals and data. A number of privacy issues must also be addressed. For example, information about specific government spectrum assignments, which are not publicly released, must be protected from discovery even though federal government spectrum is heavily targeted for spectrum sharing opportunities. Methods to obfuscate federal spectrum use must be derived, while still enabling sharing opportunities.

3. **Means of enforcement:** Related to topic 2, mechanisms must be developed to discourage or prohibit improper behavior in a spectrum sharing environment. For example, user equipment that is malicious, unauthorized, or malfunctioning (by virtue of hardware and/or software) must be quickly identified and muted before significant disruption to authorized spectrum users occurs.

4. **Metrics for dynamic spectrum monitoring, measurements, and analyses:** In many spectrum sharing scenarios, identifying and quantifying unused or underutilized spectrum will be key. Also, monitoring, measurement, and analysis will be an important component for successful enforcement. Measuring spectrum use is a complex concept involving many variables, including time, frequency, geography, direction, polarization, natural and man-made noise, equipment limitations, and others. Time scales for monitoring, measurements, and analyses may be as short as fractions of a second to enable quick bursts of packetized data, or as long as days,

weeks, or months, to identify perennially underutilized spectrum that may be suitable for repurposing or reallocation.

Conclusion

The goal of this workshop was to provide recommendations, based on tangible research proposal abstracts, and the comments of experts in the field, to help guide federal spectrum sharing research decisions. The WSRD SSG members deem this workshop a success in moving beyond rhetoric and toward a specific plan for spectrum-sharing technology R&D that is innovative, secure, and resilient. In fact, impact has already occurred at the agency level. For example, two of the projects discussed in the workshop have now been fully funded through the National Science Foundation's Enhancing Access to the Radio Spectrum (EARS) program. (The two projects deal with enforcement and with dynamic spectrum sharing between active and passive services). The most promising research areas are also being incorporated as priorities in the FY13 EARS solicitation, which is expected to be issued in December 2012. In addition, another participating Agency has already begun new research activity into security metrics and techniques for protection of information about specific government spectrum assignments under a spectrum sharing regime based on discussions at this workshop.

Based on the analysis of the workshop, the WSRD SSG identified specific project descriptions[12] that correspond with the recommendations. The proposal descriptions are organized alphabetically by primary author and presented under the relevant topic area as follows:

- Mechanisms for sharing spectrum under specific scenarios. (See Attachment A.)
- Methods for protecting the privacy, security, and integrity of users' signals and data. (See Attachment B.)
- Means of enforcement to discourage or prohibit improper behavior in a spectrum sharing environment. (See Attachment C.)
- Metrics for dynamic spectrum monitoring, measurements, and analyses. (See Attachment D.)

Next Steps

With this report the WSRD SSG has completed a series of three workshops that focused primarily on the technical research agenda:

- Sharing related research that is currently underway,
- Describing the type of testing environments that need to be made available, and
- Gathering input from the research community on establishing priorities.

The WSRD SSG will focus next on the economic and policy research necessary to improve the management and use of spectrum resources. The WSRD SSG members agree that further research is

[12] Please note: Due to the innovative and potentially competitive nature of the work that was discussed, not all researchers agreed to have their project descriptions included in this public report.

needed in these two critical areas to compliment the technological advances and to improve the rate of technology transfer.

Therefore, a fourth workshop has been planned for April 2013 with the goal to identify economic and policy research that will facilitate the commercialization of wireless system technologies through innovative business models and policy frameworks.

Attachment A: Mechanisms for spectrum sharing under specific scenarios.

Brown, Tim – University of Colorado
Spectrum Sharing for Aviation Communication
Objectives: 1. To develop spectrum sharing mechanisms specific to aviation to increase spectrum for aviation applications. 2. To narrow spectrum sharing research onto a specific application area to promote real progress in resolving the implementation challenges. **Background:** Radar bands and bands with potential for sharing are used by aviation. Many aviation applications require additional spectrum for video payloads, sensors, and, in the case of unmanned aircraft, for command and control. Aviation spectrum sharing presents both challenges and opportunities. Aircraft have a large and dynamic radio footprint. But, because the communication is mainly line-of-site and aircraft often follow pre-defined flight plans it is more predictable. Aviation communication must support flight safety while accommodating many and varied needs. A modest number of radios can have a big impact, e.g. enabling more unmanned aircraft missions for the few dozen border patrol aircraft. Thus, aviation provides a rich environment for solving real-world spectrum sharing challenges. **Approach:** One approach is policy-based radios. Machine readable policies enable automated processing of spectrum opportunities in the dynamic aircraft environment. Policies are supported by the accurate time and location maintained by the aircraft. Flight safety is improved by assessing communication in advance along planned flight paths. Policy ontologies are needed to capture the application specifics. Methods to reliably and securely author and distribute policies are required. **How the technology would be realistically deployed in a spectrum sharing environment:** Test flights can use the policy-based radios to manage non-flight-safety critical communication in order to gain field experience.

Buddhikot, Milind – Alcatel-Lucent
WhiteCell: A Novel Framework for Exploiting Variable Grade Federal Whitespace Spectrum in Cellular Networks
Objective: Design, architect and demonstrate approaches that can successfully exploit "sharable federal and commercial whitespace spectrum in various bands" in heterogeneous cellular networks to address the multi-fold increase in wireless capacity required to meet escalating data traffic. **Background:** The cellular traffic is expected to increase 25-30x fold in next 5 years. Use of metro and small cells that reduce the cell size to increase area spectral efficiency (bps/Hz/m^2) represent the first step to increasing wireless capacity. However, in absence of any new spectrum, operators are forced to use the same licensed spectrum that they use in macro-cells in metro and femto cells layers. In dense deployments, this can lead to severe interference interactions that can provide limited gains for the complexity incurred. Therefore it is necessary to operate metro and femto cells on alternate spectrum bands orthogonal to macro-cells layer. Unfortunately, additional spectrum is hard to find and this makes sharable (federal and commercial) whitespace spectrum bands as ideal candidates. **Approach:** We have designed and demonstrated via a prototype how spectrum database server based approach that serves dual roles: (a) collaborative spectrum sensor and radio environment mapper (REM) and (b) spectrum manager can be combined with multi-band small cells to dramatically improve capacity and performance. Specifically, we have built WhiteCell — a dual technology small cell architecture in which each small cell is equipped with the ability to communicate over two classes spectrum blocks — the cellular operator's own spectrum using the same technology as before, and the variable grade whitespace spectrum (such as DTV whitespaces, Federal Govt band whitespaces). The two classes of spectrum blocks and their corresponding technologies complement each other very well. While

whitespace spectrum allows us to add significant capacity to the otherwise constrained cellular spectrum, the cellular frequencies allows the system to support some minimal expectation of performance guarantee that whitespace spectrum alone cannot, due to license exclusivity. While this symbiotic extension is conceptually simple, it provides dramatic performance gains for both the cellular operator and the end users who are putting increasing demands on the limited cellular spectrum. This talk describes the overall WhiteCell architecture, a system implementation, and various challenges addressed in efficiently utilizing whitespace spectrum including a collaborative spectrum database approach in spectrum sensing and whitespace spectrum management, as well as in efficiently transitioning traffic across this dual spectrum classes. In addition, our work demonstrates the significant performance advantages of the architecture through detailed evaluation of our WhiteCell prototype. **How the technology would be realistically deployed in a spectrum sharing environment:** The "light-weight network based (i.e. spectrum server) controlled sharing approach" in WhiteCell framework guarantees that security and protection concerns of primary devices are satisfied effectively at the same time making large quantities of spectrum available to cellular networks in a timely and cost-effective fashion to sustain mobile broadband growth. If regulatory policies can be enacted, we believe this approach can be brought to market in full force in 3 years.

Chandramouli, Rajarathnam – Stevens Institute of Technology
Cloud Sourcing Spectrum
Objective: A major bottleneck in current wireless technologies is the inability to dynamically access and share heterogeneous radio spectrum across space and time. Let us consider the following example: a smartphone equipped with multiple radio interfaces (e.g., WiFi and LTE) connects to only wireless network at a time thereby not exploiting all the available spectrum. Our research addresses this issue by investigating cognitive radio networking protocols and their software stack implementation. **Background:** Majority of cognition based dynamic spectrum access (DSA) networking R&D considers one radio network only. Extension of DSA to multi-radio networking scenarios is not straightforward. We consider multi-radio cognitive wireless communication where spectrum is dynamically accessed within one as well as across multiple wireless networks. This is shown to significantly improve the data rate as well as reliability. **Approach:** Our approach includes sensing at PHY as well as network layers and cross-layer optimization. Client and server software running at the mobile device and the Internet cloud respectively co-ordinate the end-to-end optimization of dynamic spectrum access and management across multiple wireless networks, based on real-time multi-layer sensing information. **How the technology would be realistically deployed in a spectrum sharing environment:** Consider a public safety communications scenario where a typical first responder has access to multiple communication radios. Our client and server software layer will allow the first responder to seamless inter-operate, aggregate data rate from multiple wireless networks and also automatically switch to an ad hoc networking mode if the wireless base stations or access points are down during an emergency.

Eltawil, Ahmed – University of California, Irvine
Engineering and Economics of Spectrum Sharing via Reconfigurable Devices and Cooperative Networks
Objective: Improving access to spectrum requires a combination of cognitive device capabilities AND a component of the resource allocation control that operates at the global level via large scale, unified wireless networks that can cooperate and collectively guide agile or reconfigurable devices to improve the efficiency with which spectrum is used. **Background:** Currently mobile nodes are typically simultaneously covered by multiple access technologies. Our recent published results show that if the network takes an active role in guiding terminals to the most efficient access mode, the end user

benefits in all performance metrics. **Approach:** In this effort, we focus on advancing resource allocation methods and techniques for heterogeneous networks that take into account the capabilities and costs of utilizing highly agile and reconfigurable mobile devices. We address how to build large scale, wireless networks that can cooperate and guide terminal devices to select the most efficient access technology available among a number of possible options. **How the technology would be realistically deployed in a spectrum sharing environment:** In addition to addressing engineering challenges, we investigate the viability of different economic and usage models, since a successful deployment has to encompass both dimensions. The project will involve two investigators from the University of California Irvine, namely Ahmed Eltawil (Associate Professor, School of Engineering) and Shivendu Shivendu (Assistant Professor, School of Business) cooperating with Jim Martin (Associate Professor, School of Computing) at Clemson University.

Farhang, Behrouz – University of Utah
Filter Band Methods: An Integrated Solution to Spectrum Sensing, Control Channel Design, and Spectrum Sharing, WSComm
Objective: To develop a complete physical (PHY) layer for implementation of dynamic spectrum access systems. **Background**: Dynamic spectrum access requires mechanisms for spectrum sensing, a control channel to exchanged sensed spectra, and data channelization through the available white spaces. **Approach:** We plan to use filter bank methods as a universal solution to serve the above tasks. In collaboration with Idaho National Laboratory, we have already developed and prototyped a control channel based on the proposed approach. Preliminary study on the spectrum sensing has also been carried out by the presenter. We propose to complete the rest of the components of the PHY layer as well as to develop a MAC layer to support it. **How the technology would be realistically deployed in a spectrum sharing environment:** We believe our proposal is practical and can be successfully implemented in practice as we have already prototyped and demonstrated satisfactory operation of the most difficult part of the design; the control channel. Our design has been evaluated by the referees/editors of the R&D magazine for the R&D 100 awards and has been recognized as one of the top 100 inventions of 2012. Please see: http://www.rdmag.com/Awards/RD-100-Awards/R-D-100-Awards/

Moorut, Prakash – Nokia Siemens Networks (Presented at the workshop by Scott Marin)
Authorized/Licensed Sharing Access (ASA/LSA)
Objective: Discuss a new model to make underutilized licensed spectrum available to a limited number of users while maintaining quality of service. **Background:** While efficient usage of exclusive spectrum allocations will continue to be an integral part and a high priority for future networks, spectrum sharing could be used as a complementary solution to support more capacity for mobile broadband deployments, especially when the clearing of a band can be costly and lengthy like in the 1755-1850 MHz Band. **Approach:** A primary license holder (incumbent) would grant spectrum access rights to another user which can use the band under secondary service conditions. The details of the spectrum usage would be subject to an individual agreement between the incumbent and ASA/LSA licensee and to permission by the regulator. Interference issues could be resolved and avoided either statically or dynamically through the use of database access and more cognitive technologies. Moreover, availability of the secondary spectrum is not guaranteed, i.e., evacuation from the spectrum is needed if the primary service needs the spectrum e.g. in a specific area. **How the technology would be realistically deployed in a spectrum sharing environment:** An interesting sharing scenario is the case when a 4G LTE network would be allowed to use spectrum resources which are primarily used by some other services (e.g. fixed satellite systems, Federal government systems). Spectrum sharing is done via interfacing to external controller/databases, dynamic usage of the resources and evacuation mechanisms.

Sujit Dey, Laurence B. Milstein, Pamela Cosman – University of California, San Diego (Presented at the workshop by Laurence B. Milstein)

Efficient Video Delivery Utilizing Shared Spectrum

Objective: We propose to develop video delivery solutions that enable efficient use of shared spectrum to maximize video capacity and user experience, while ensuring priority of primary users, and coping with uncertainties associated with shared spectrum. **Background:** While network operators have begun to urgently investigate ways to address the video tsunami underway, including offloading, the use of shared spectrum presents a significant new opportunity. **Approach:** Our proposed multi-spectrum resource allocation and scheduling techniques will dynamically allocate video flows, or their partitions, to different dedicated and shared channels, aware of the types and demands of different video flows. While an entire encrypted video must be allocated to a dedicated or shared channel, non-encrypted videos can be partitioned dynamically across both, increasing robustness against temporal uncertainties of the shared spectrum. We will investigate video partitioning approaches across dedicated and shared spectrum, including the use of slices, frames, temporal and quality scalable layers, etc. Scheduling algorithms will use realistic models of the physical channel including the effects of mobility. We will introduce just-in-time buffering aware of multi-spectrum allocation of video layers, enabling trade-off between bandwidth savings and robustness. **How the technology would be realistically deployed in a spectrum sharing environment:** We will collaboratively develop a prototype based on the white space testbed at Bell Labs, and the WSComm platform at INL. We will test and demonstrate at the indoor and outdoor wireless testbed facilities at INL. Verizon Wireless expressed interest in participating in the trial.

Mody, Apurva – BAE Systems

Radar, Commercial Comms Co-existence in 3550-3650 Bands in the US Using IEEE 802.22.1 Advanced Beaconing

Objective: Universal availability of 3550-3650 MHz spectrum in the United States by enabling Radar and Commercial Communications Co-existence using IEEE 802.22.1 Advanced Beaconing. **Background:** As per the Presidential Memorandum, one of the portions of the spectrum identified to achieve the goal of freeing up 500MHz of spectrum, is the 3550-3650 MHz where maritime radars have been deployed. The current plan is to use exclusion zones to protect U.S. Navy coastal operations and other Department of Defense test and training areas. This means that major part of the US population will not be able to use these bands. However, there may be some other approaches which will make 100 MHz of spectrum available nation-wide, and especially in the coastal areas where significant US population resides. **Approach:** The designed beacon will contain Peace Time temporal patterns of the radars which when combined with some universal time clock such as GPS can help commercial communications systems to use the empty time slots for their operation. During War Time or Emergency Scenarios, the beacon will send Urgent Co-existence request, to ask all the commercial systems to shut down immediately. If the beacon cannot be heard or decoded, commercial comms will cease operation by default. Security features for such beacons are very important. IEEE Std, 802.22.1-2010 has incorporated many such security mechanisms that may be applied to the 3550-3650 band relatively readily. In this talk, we explore this possibility and identify the pros and cons of this approach. **How the technology would be realistically deployed in a spectrum sharing environment:** In general, three techniques have been widely accepted to enable spectrum sharing (1) Spectrum sensing based detection and avoidance, (2) Database driven approaches (e. g. in the Television Band WhiteSpaces) and (3) Beaconing approaches (e. g. the IEEE Standard 802.22.1-2010). Neither spectrum sensing nor database driven approaches are suitable for radar, comms co-existence. However, advanced beaconing approaches, such as the one developed in the IEEE Standard 802.22.1-2011 for co-existence between the primary signals and incumbent signals may be used for the 3550-3650 band. Such a beacon transmitter will be deployed on all the Radar sites to ensure successful operation.

Peha, Jon – Carnegie Mellon University
Rotating Radar Sharing Spectrum with Broadband
Objective: Allow wireless devices to operate in spectrum that is actively being used by rotating radar without causing harmful interference. **Background:** Although early efforts to share spectrum with radar should focus on allowing secondary devices to operate only when those devices are sufficiently far away that harmful interference to radar is not a concern, much greater spectral efficiency can be achieved through more dynamic forms of sharing. In the case of rotating radar, our early work showed that secondary devices can operate quite close to a single rotating radar, and can transmit much of the time with relatively high mean data rates. **Approach:** A secondary device can avoid harmful interference by dynamically adjusting transmit power as the main beam of the radar's antenna rotates. In further work, we will seek the most effective sharing mechanisms in more complex scenarios involving multiple radars operating in the same region and frequency band. We will also look at how a secondary spectrum user might use this spectrum most effectively, despite sporadic interruptions and fluctuations in achievable data rate caused by sharing. **How the technology would be realistically deployed in a spectrum sharing environment:** Secondary devices would be designed to be interruptible. Their power control mechanisms would be preconfigured with some information about the radar systems nearby, and equipped with sensors to observe the radar. These devices would have mechanisms that shut transmitters off when there is any indication that there is risk of harmful interference to radar. Designing these mechanisms is part of the research.

Sahai, Anant – University of California, Berkeley
Model Menagerie
Objective: How shall we identify which classes of uses can "play well with others" and which really need to be kept separate? **Background**: The nation's wireless broadband plan needs to find 500 MHz of spectrum and it is clear that this will require spectral coexistence of new broadband uses with other non-broadband uses. But if we ask the incumbents, they will claim that they really must be kept separate (they'd rather that sharing was somebody else's problem) and even the wireless providers claim that they want to have exclusive reassignment and not sharing. Meanwhile defense contractors and others are happy to sell coexistence as (expensive) pixie-dust as long as someone else is footing the bill. How can we evaluate the *real* opportunities for consolidation and sharing? The only simple models that exist are for cellular-style systems, WiFi-like systems, and TV Broadcast-like systems. **Approach:** Build a "menagerie" of simple back-of-the-envelope-friendly models that encompasses the diversity of uses out there, including radars, military systems, etc. **How the technology would be realistically deployed in a spectrum sharing environment**: A realistic field test of multiple operational systems showing peaceful coexistence is the gold standard. But before testing, there is a need for simple coarse models that can be explored in simulations and analyzed analytically. Having a model menagerie will also lower the barrier to entry for studying coexistence. This will enable simple spectrum management tools to estimate the "compatibility" of different systems placed into the same band.

Stine, John - MITRE
Conveying Spectrum Usage Rights in Models (Possible combination with #3 above)
Objective: Demonstrate that modeling spectrum use with Spectrum Consumption Models (SCMs) enables better analysis of sharing opportunities, enables conveying sharing opportunities without revealing details of incumbent use, and enables development of dynamic spectrum management systems. Develop models of radar spectrum use that articulate sharing opportunities with other types

of RF systems. Determine improvements to modeling that address regulator and government user needs. **Background:** Model-Based Spectrum Management (MBSM) is spectrum management based on the creation and exchange of spectrum consumption models (SCMs). SCMs define the boundaries of spectrum use so that the compatibility of uses can be arbitrated objectively. They enhance spectrum management and reuse in several ways: In regulation, SCM can define a user's spectrum usage rights (SURs); In commerce, SCMs capture the quanta of spectrum that are traded; In technology, SCMs convey machine readable spectrum assignments and spectrum policy to RF systems; In operations, SCMs enable very dynamic and flexible management. Currently, the IEEE DySPAN SC intends to support standardization of SCM methods. **Approach:** This research will replicate the analysis of the 3550 – 3650 MHz band that was done as part of the NTIA Fast Track Evaluation report, October 2010, but with using SCM. We will compare results. **How the technology would be realistically deployed in a spectrum sharing environment:** Spectrum consumption modeling captures the information at the intersection of stakeholder interests. An effective modeling capability would serve as a catalyst for the development of a DSA enterprise.

Attachment B: Methods for protecting the privacy, security, and integrity of users' signals and data.

Sahai, Anant, University of California, Berkeley

The security/privacy/overhead tradeoff

Objective: Signal-level interference isn't the only performance degradation that matters. There are also security/privacy concerns. **Background**: Consider the 3600-3700 band. Spectrum used exclusively by aircraft carriers certainly seems like low-hanging fruit. Carriers move. But excluding a coastal swath hundreds of kilometers wide would exclude the majority of the population, thus making technology development economically unattractive. But there are few carriers and they move slowly. Would the Navy feel comfortable reporting the exact position of each of its carriers to a database? The visceral response is clearly no! What if we mandated decentralized network sensing so devices could collectively tell where aircraft carriers are and then avoid using spectrum in their vicinity? That seems even worse! We'd have promoted COTS technology that can localize our carriers! **Approach:** We need to understand the tension between security/privacy and spectrum sharing overhead to overcome visceral objections. There are many options: e.g. the database can randomly dither positions by many tens of kilometers. Then, even tactical nukes couldn't be accurately targeted using the database, but the overhead of unnecessary exclusions would be relatively small. By further adding "ghost carriers," it seems that even geopolitically strategic information could be masked. **How the technology would be realistically deployed in a spectrum sharing environment**: Having a clear framework for security/privacy tradeoffs will enable us to reduce the resistance to sharing from military and public safety users, because this will enable us to protect what really needs to be protected.

Attachment C: Means of enforcement to discourage or prohibit improper behavior in a spectrum sharing environment.

Zheng, Heather – University of California, Santa Barbara
Enforcing Dynamic Spectrum Access with Spectrum Permits
Objective: Enforce allocated spectrum, protect allocated users from spectrum misuse. **Background:** Dynamic spectrum allocation is a maturing technology to make highly efficient use of radio spectrum. Spectrum can be allocated on an on-demand basis for a given geographic area, time duration and frequency range. However, a major obstacle for adopting this new model is the lack of effective solution to address spectrum misuse, where users transmit without properly licensing spectrum, and in doing so, interfere and disrupt legitimate transmissions to whom the spectrum is assigned. Given the flexibility of cognitive radio devices, an application can easily misuse spectrum, either accidentally due to misconfiguration, or intentionally to avoid spectrum licensing costs. **Approach:** Like how we enforce parking in real life, we propose a spectrum permit system to detect spectrum misuse. Authorized spectrum users, by embedding secure and universally decodable spectrum permits into data transmissions, prove their usage right. Patrolling trusted devices then detect devices transmitting without proper authorization. This approach is of low cost, and is scalable to large networks. **How the technology would be realistically deployed in a spectrum sharing environment:** Our proposed solution displays permits using OFDM transmissions. The proposed solution is of low cost and is transparent to data transmissions

Attachment D: Metrics for dynamic spectrum monitoring, measurements, and analyses.

Fulton, Calib – University of Oklahoma
Spectrum Sharing Technologies in Next-Generation Digital Phased Array Radar Systems
Objective: to develop a cross-cutting, multi-user testbed that will mature a number of game-changing circuit-and system-level technologies and techniques for use in next-generation military and civilian phased array radar systems; together, these will provide new levels of situational performance and flexibility in spectral exploitation, monitoring, and coexistence.   **Background:** Next-generation radar systems are faced with encroachment on their spectrum and must cope with demands to share their traditional bands. However, future systems with modular, open architectures and ubiquitous use of element-level digital transceivers will provide viable platforms for implementing emerging technologies to overcome these challenges. In particular, distributed transceiver arrays can concurrently monitor the spectrum during normal operation and utilize emerging techniques for adaptive and precise transmit and receive pattern control to mitigate interference; the efficacy of this approach would be significantly enhanced with a knowledge-aided co-processor with an evolving database of known emitter and receiver locations. Additionally, significant recent advancements in substrate-integrated tunable filtering technologies will provide flexible, frequency-domain interference mitigation on top of the aforementioned spatial and temporal mechanisms. **Approach:** bring together a diverse set of talent from industry, academia, and government to create a low-cost digital transceiver array testbed with modular RF frontends that mimics the hardware capabilities of these future systems; this will enable real-world testing that seeks to individually mature and ultimately combine the above techniques to enable new spectrum management modalities. **How the technology would be realistically deployed in a spectrum sharing environment:** The desired outcome of the effort is risk mitigation, encouraging future system specifications to demand the use of these techniques as part of any new acquisition.

Grunwald, Dirk – University of Colorado
A Spectrum Sharing Testbed for Passive Earth Observation (EESS) Bands
Objective: A Spectrum Sharing Testbed for Passive Earth Observation (EESS) Bands. **Background:** Passive uses of the radio spectrum rely on very sensitive radio measurements to capture the naturally occur thermal emissions from physical processes such as the atmosphere, soil, ocean surface, or snow and ice. Certain materials emit or absorb in specific radio bands, allowing the quantification of key environmental variables to be made. The 1400-1427 MHz frequency range is allocated to EESS and is used for satellite measurements of soil moisture and ocean salinity. Other measurements are taken at a combination of unreserved frequencies to retrieve properties such as atmospheric humidity, snow water equivalent, and vegetation water content. For example, the EESS uses measurements at 22.235 GHz and 37 GHz to distinguish between cloud water and water vapor in the atmosphere. **Approach:** Much of the interference appears to be from telecommunication networks, often for wireless backhaul. It is useful to either correct for or mitigate the interference. Correction requires knowing where and when these Gaussian signals occur. Methods to mitigate involve moving such telecom traffic during the short period where a “sweep” occurs. **Path to a Test Bed:** Establishing a nationwide inventory of possible interfering transmitters (using e.g. FCC database) is a useful first step. Testing using a wireless backhaul testbed at 6, 10, 20 & 30GHz would allow direct experimentation on mitigation.

Laneman, Nick – University of Notre Dame
Breaking Down Some Barriers to Spectrum Sharing

Objective: To further develop models and tune spectrum sensing and dynamic spectrum access protocols using measurements from real-world settings. **Background:** The Wireless Institute at Notre Dame couples wireless chipset and RF development expertise in industry (Beceem, acquired by Broadcom), cognitive radio and dynamic spectrum access research (funded by NIJ and NSF), wideband software radios and test equipment for generation and processing of OFDM waveforms such as WiFi and LTE (Lead User Partnership with National Instruments), and a large mobile data collection effort with a pool of 200+ student testers on campus (supported by NSF, Sprint, and Alcatel-Lucent). Ongoing collaborations with nearby public safety agencies around South Bend and in Chicago can be leveraged, or tests could be conducted in coordination with on-going projects in other regions, e.g., Brookline and Boston. **Approach:** Despite considerable investments in basic research on spectrum sharing, we need to conduct more applied research and experimental validation of spectrum sharing technologies in targeted bands and real-world environments. Specific barriers that must be broken down include: measurements and models for interference effects as a function of modulations, center frequencies, bandwidths, ranges, and propagation environments; modulation and access protocols that enable coexistence and / or cooperation, including prioritization; and data collection and user studies from instrumented devices and networks to characterize when interference becomes harmful and how effectively spectrum is utilized. **How the technology would be realistically deployed in a spectrum sharing environment:** We believe the 4.9 GHz public safety band is an ideal initial candidate for such development and experimentation, and similar programs should eventually be conducted in the 700 MHz LTE band, the 1755-1780 MHz band, and the 5.9 GHz ITS band.

McHenry, Mark – Shared Spectrum Company
Sensing-Based Spectrum Sharing Rule Parameter Development and Validation
Objective: The objective of this project to validate the rules used to determine various algorithm parameters of a sensing-based DSA transceiver system. Sensing is expected to be needed to detect Air Combat Training communications in the 1755-1850 MHz band because DoD reports exclusion zones are unrealistic given the mobility and altitudes of operation. **Background:** Rules are used to determine the DSA transceiver's co-channel detection threshold, the adjacent channel detection threshold, the detection rate, the non-occupancy period, and other DSA sensing rules. These rules are a function of the propagation losses, TX power levels, the signal bandwidths, the incumbent TX duty cycle, the incumbent receiver noise figure, the specified incumbent interference to noise ratio (INR), and other parameters. The rules have been validated in simulations, and field testing is now required because of the impact of the difficult to model propagation losses have on the results. **Approach:** Conduct field tests with entrant DSA radios that are operated with incumbent radios. The incumbent radios are instrumented to provide continuous measurement of the INR caused by the DSA radios. The DSA radios have variable sensing and other parameters to enable parametric investigation of the sensing rules. The DSA and incumbent radios have log files to record their positions and the received signals levels to enable measured and predicted performance comparisons. The project is completed in 18 months. **How the Technology Would be Realistically Deployed in a Spectrum Sharing Environment:** The rules are used for regulatory development and for DSA system requirements.

Appendix E: Acknowledgements

NITRD and its WSRD SSG thank the workshop participants for their time and effort in providing valuable insight on such a worthy cause. This was the third in a planned series of workshops organized to engage federal and non-federal communities in furthering the goal of a nationwide environment of shared spectrum access. We look forward to your continued support on future workshops as we collectively endeavor to develop an environment that serves as a national venue to test and demonstrate innovative spectrum sharing technologies.

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