Spectrum Sharing Research and Development

Spectrum is the fuel powering the mobile broadband revolution. As millions of American consumers are demanding more voice, video, and data from their mobile devices, efficient use of scarce spectrum resources is a subject of increasing interest to policymakers, the information and communications technology (ICT) industry, other industry sectors, and the scientific research community.

Increasingly, the focus of these efforts has turned towards spectrum sharing. This has been necessitated in part by the parallel increase in demand for spectrum uses beyond commercial communications — including for satellite or aeronautical applications, radiolocation, or other civilian or military capabilities. Against this backdrop, spectrum sharing may hold promise as a means to increase the efficient use of spectrum — whether by accommodating multiple user groups or types of uses — and to help alleviate challenges in spectrum scarcity. However, significant technical research and development, as well as progress on the associated regulatory issues, is needed to broaden the range of sharing technologies and solutions that can be moved towards practical applications — and ultimately into the networks that consumers, businesses, and governments rely upon every day.

Spectrum "sharing" already exists in many forms today, including in licensed approaches whereby wireless carriers provide access to millions of customers using relatively narrow bands, or in unlicensed approaches such as Wi-Fi®. Moreover, very different types of spectrum uses — from commercial wireless services, to military or medical applications, or scientific and deep space research — have been assigned by the FCC to share the same spectrum band. Many current discussions of spectrum sharing have involved the possibility of re-purposing spectrum used by the federal government for commercial wireless use, and the President recently issued a memorandum urging agencies to take further actions to facilitate this process.[1] Meanwhile, the President's simultaneous announcement to target $100 million of R&D funding towards spectrum sharing research is a welcome and long-awaited step,[2] and follows a July 2012 report finding that spectrum sharing is essential to exploiting the nation's spectrum resources over the long term.[3]

This white paper reviews current and proposed sources of R&D funding for spectrum research, and identifies some specific research and development areas that hold promising potential for rapidly advancing the state of spectrum sharing technology. The recommendations below are intended to assist in guiding actions by policymakers in Congress and the Administration and as a blueprint for R&D activities in academia, industry, and elsewhere.

SECTION I — FUNDING FOR SPECTRUM SHARING R&D

Federal funding for research and development in networking technology, including for wireless research, has not kept pace with the relative importance of this field to the U.S. economy. Indeed, the ICT industry contributes $1 trillion to U.S. GDP (roughly 7 percent) and supports 3.5 million

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1 Presidential Memorandum, *Expanding America's Leadership in Wireless Innovation*, rel. June 14, 2013, available at http://www.whitehouse.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leadership-wireless-innovatio

2 *See* White House, *Fact Sheet: Administration Provides Another Boost to Wireless Broadband and Technological Innovation*, rel. June 14, 2013, available at http://www.whitehouse.gov/sites/default/files/spectrum_fact_sheet_final.pdf

3 *See* President's Council of Advisors on Science and Technology (PCAST), *Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth*, July 20, 2012, available at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf

jobs.[4] Estimates show that for every $1 of new wireless broadband investment, U.S. GDP will increase by $7-10;[5] a mere 1 percent increase in broadband deployment could mean the creation of as many as 300,000 new jobs.[6] Overall, the shift from 2G to 3G resulted in 1.6 million new jobs between April 2007 and June 2011.[7]

NITRD. The Networking and Information Technology Research and Development (NITRD) program is a multi-agency effort that coordinates the activities of 20 member agencies that support advanced IT R&D.[8] But while NITRD's annual budget report appears to indicate total federal IT R&D expenditures of approximately $4 billion (FY 2014),[9] the reality is quite different. As the President's Council of Advisors on Science and Technology (PCAST) has found, a large majority of the NITRD-reported funding is actually used for IT infrastructure to support R&D in fields other than network and information technology.[10]

Meanwhile, the NITRD program office has developed or coordinated working groups to address emerging areas of need. This includes a June 28, 2010, Presidential Memorandum that established a Wireless Spectrum Research and Development Senior Steering Group (WSRD SSG) to coordinate inter-agency efforts in that area.[11] Since its establishment, the WSRD SSG has conducted a series of workshops beginning in 2011 to help facilitate research, development, experimentation, and testing to explore innovative spectrum-sharing technologies. These efforts have occurred even as attempts in Congress to update the statutory foundations of the NITRD program have stalled.[12]

> **Recommendation: Congress should enact legislation to update the statutory basis of the NITRD program to encompass and prioritize areas such as spectrum sharing research.**

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4 Robert J. Shapiro and Aparna Mathur, *The Contributions of Information and Communication Technologies to American Growth, Productivity, Jobs, and Prosperity*, Sept. 2011, available at http://www.tiaonline.org/gov_affairs/fcc_filings/documents/Report_on_ICT_and_Innovation_Shapiro_Mathur_September_8_2011.pdf

5 *See* Alan Pearce and Michael S. Pagano, "Accelerated Wireless Broadband Infrastructure Deployment: The Impact on GDP and Employment," New York Law School, ***Media Law and Policy Law Journal***, vol. 18 at 11-12 (Spring 2009) ($17.4 billion will increase U.S. GDP by between $126.3 billion and $184.1 billion) available at http://www.nyls.edu/user_files/1/3/4/30/84/187/245/Pearce%20&%20Pagano,%20SPRING%202009%20&%20Pagano,%2018%20MEDIA%20L.%20&%20POL%E2%80%99Y.pdf

6 *See* Brookings Institute, *The Effects of Broadband Deployment on Output and Employment: A Cross-sectional Analysis of U.S. Data* at 2, 12 (July 2007), available at http://www.brookings.edu/views/papers/crandall/200706litan.pdf

7 Robert J. Shapiro and Kevin A. Hassett, *The Employment Effects of Advances in Internet and Wireless Technology: Evaluating the Transitions from 2G to 3G and from 3G to 4G*, Jan. 2012, available at http://ndn.org/sites/default/files/blog_files/The%20Employment%20Effects%20of%20Advances%20In%20Internet%20and%20Wireless%20Technology_1.pdf

8 *See* http://www.nitrd.gov/

9 *See* NITRD, *Supplement to the President's FY 2014 Budget Request*, available at http://www.nitrd.gov/pubs/2014supplement/FY2014NITRDSupplement.pdf

10 *See* PCAST, *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*, Dec. 2010, available at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf

11 *See* Presidential Memorandum, *Unleashing the Wireless Broadband Revolution*, June 28, 2010, § 3 ("The Secretary of Commerce, working through NTIA, in consultation with the National Institute of Standards and Technology, National Science Foundation (NSF), the Department of Defense, the Department of Justice, NASA, and other agencies as appropriate, shall 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."), available at http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution

12 *See* H.R. 967 (113th Congress), *Advancing America's Networking and Information Technology Research and Development Act of 2013*; *see also* H.R. 3834 (112th Congress) (same) and H.R. 2020 (111th Congress) (similar). In each case, the House has passed the bills by voice vote of overwhelming majorities. In recent years, however, the bill(s) have been caught up in House-Senate disagreements regarding comprehensive cybersecurity legislation.

Recommendation: Congress should enact legislation to update NITRD's reporting requirements to ensure a more accurate picture of federal funding for network and information technology research, including in priority areas such as spectrum sharing research.

NTIA. NTIA's Institute for Telecommunication Sciences (ITS), based in Boulder, Col., is the research and engineering laboratory of NTIA. The ITS conducts some basic research in radio sciences, including many different program areas such as digital land mobile radio, audio and video quality research, propagation measurements and models, and technology transfer.[13] While spectrum research is a component of ITS work, the total NTIA research budget (including all programs) is just $13 million,[14] insufficient to support the rapid pace of development needed to obtain transformation results in spectrum sharing technologies.

DARPA. Through the Defense Advanced Research Projects Agency (DARPA), the Department of Defense has solicited and awarded research proposals related to spectrum sharing. These include a 2012 solicitation to begin investigating Advanced Radio Frequency Mapping, or "RadioMap,"[15] and a February 2013 solicitation on Shared Spectrum Access for Radar and Communications (SSPARC) that focuses on mechanisms to improve performance or reduce interference when sharing spectrum.[16] SSPARC represents a significant departure from traditional, unilateral spectrum sharing approaches, because the envisioned radar and communications radio networks are contemplated to share both their current and next-state information in near-real-time. This will enable radar systems and radios to achieve unprecedented levels of spectrum sharing at short standoff ranges.

June 2013 White House Initiative. On June 14, 2013, the White House announced that $100 million would be invested in research on spectrum sharing and advanced communications. This includes $23 million in NSF spectrum sharing research and development grants by September 2013, DARPA spectrum sharing contracts worth $60 million to be issued over five years (an average of $12 million/year) beginning in FY 2014, and $17.5 million at NIST for spectrum and advanced communications research, along with accelerating public-private collaboration at Federal laboratories.[17] These executive actions represent an important step forward and will help build on the current efforts underway at these various agencies.

Recommendation: The White House and funding agencies should continue to seek opportunities to administratively target research funding towards spectrum sharing R&D.

Proposals for Additional Funding. The Administration has previously proposed a $3 billion Wireless Innovation Fund (WIN) to help drive innovation. The WIN fund was intended to support

13 NTIA Institute for Telecommunications Sciences, *ITS Mission and History*, http://www.its.bldrdoc.gov/about-its/its-mission-history.aspx

14 *See* NTIA, *FY 2013 budget request*, available at http://www.osec.doc.gov/bmi/budget/13CJ/NTIA_2013%20Budget_to_Congress.pdf

15 DARPA-BAA-12-26, available at https://www.fbo.gov/index?s=opportunity&mode=form&id=701c80210c46b7e497bc90cb0b5c120c&tab=core&_cview=1

16 DARPA-BAA-13-24, available at https://www.fbo.gov/index?s=opportunity&mode=form&id=8e85f738e53747b502b4b9c3732c2e54&tab=core&_cview=1

17 *See* White House, *Fact Sheet: Administration Provides Another Boost to Wireless Broadband and Technological Innovation*, rel. June 14, 2013, available at http://www.whitehouse.gov/sites/default/files/spectrum_fact_sheet_final.pdf

basic research, experimentation and testbeds, and applied development in a number of areas, with spectrum R&D being a key component of any such work.[18] Unfortunately, these funding proposals were progressively reduced or eliminated during the legislative process. Although a leading Senate proposal called for spending $1 billion over five years to fund advanced information and technology research through NSF and DARPA (plus $500 million for public safety research),[19] the spectrum auction legislation that eventually passed in 2012 included only $100 million for public safety research, and no funding specifically dedicated to spectrum sharing or other advanced communications R&D.[20]

> **Recommendation: To achieve transformational advances in spectrum sharing R&D that will yield economic benefits several times over, Congress should provide significant additional funding for spectrum sharing research.**

SECTION II — RESEARCH AREAS

As the White House, Congress, and various funding agencies seek to support spectrum sharing R&D activities, several different research areas should be considered. A survey of some important topics for further research is presented here.

Authorized Shared Access/Licensed Shared Access. Much of the current research work in spectrum sharing has been focused on unlicensed sharing regimes (television white spaces, Wi-Fi, etc.). Meanwhile, more efforts are needed to facilitate the deployment of Authorized Shared Access (ASA)/Licensed Shared Access (LSA) approaches. ASA is a "third way" spectrum management system that combines elements of traditional "command and control" spectrum management with geolocation technology, e.g., by providing users with a "token" to use spectrum at certain times/places. It leverages existing 4G technologies and harmonized spectrum and has significant support from the wireless industry including Ericsson, Intel, Nokia Siemens Networks, and Qualcomm.[21]

The ASA/LSA approach is being considered for shared access to the 2.3 GHz band in the European Union, where government-funded trials have begun,[22] while in the United States, the FCC is

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18 *See* White House, *Fact Sheet: President Obama's Plan to Win the Future through the Wireless Innovation and Infrastructure Initiative*, FY 2012, available at http://www.whitehouse.gov/sites/default/files/microsites/ostp/Wi3-fs.pdf. More specifically, the proposal would have provided $1 billion to NSF; $500 million each to DARPA, the Spectrum Relocation Fund, and NIST for a Public Safety Innovation Fund; and $100 million each to the Economic Development Administration, DOT/Intelligent Transportation, ARPA-Energy, the Centers for Medicare & Medicaid Services, and ARPA-Education. *See* OMB, *FY 2012 Budget Appendix* at p. 1231, available at http://www.gpo.gov/fdsys/pkg/BUDGET-2012-APP/pdf/BUDGET-2012-APP-1-31.pdf

19 *See* SPECTRUM Act, S. 911 (as reported in Senate), 112th Congress, at §§ 223, 224, 401.

20 *See* Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, at § 6413(b)(4) (providing $100 million to NIST for public safety research).

21 *See* Qualcomm, *1000x – More Spectrum, Especially for Small Cells, Including ASA – A New License Model to Access Underutilized, High Quality Spectrum*, http://www.qualcomm.com/media/documents/files/wireless-networks-1000x-more-spectrum-especially-for-small-cells.pdf; Nokia Siemens Networks, 2020: Beyond 4G Radio Evolution for the Gigabit Experience, http://www.nokiasiemensnetworks.com/sites/default/files/document/nokia_siemens_networks_beyond_4g_white_paper_online_20082011_0.pdf ; *see also* Red Technologies, *Licensed Shared Access (LSA)*, http://www.redtechnologies.fr/en/lsa.html

22 The ASA/LSA concept was demonstrated with a live LTE network operating in the 2.3 GHz band in Finland on April 25, 2013. The trial was carried out by the Finnish CORE+ consortium coordinated by the VTT Technical Research Center of Finland. The project was funded by Tekes – the Finnish Funding Agency for Technology and Innovation – and involved participation from three research organizations, seven industry companies, and two governmental agencies. See VTT, *Up to 18% more bandwidth for mobile broadband users with spectrum sharing*, Apr. 25, 2013, available at http://www.vtt.fi/news/2013/25042013_ASA.jsp?lang=en

currently considering such approaches as part of its 3.5 GHz proceeding.[23] Tiered spectrum sharing in the 3.5 GHz band may offer an excellent opportunity to manage multiple spectrum users through database-driven prioritized access. Researching such methods might identify solutions that could allow Federal/DoD users to successfully coexist with commercial users to unlock valuable spectrum resources. ASA/LSA approaches may also be useful in the 1.7 GHz band in cases where federal users cannot be moved. Database-driven spectrum sharing approaches could offer the ability to dynamically allocate spectrum to the highest and best uses on a near real-time basis.

> **Recommendation: Government R&D funding should be used to support further ASA/LSA trials, potentially leading to a viable near-term option for spectrum sharing in the United States.**

ASA/LSA approaches show great promise as a means to enable sharing among disparate uses. They provide a means to ensure ongoing viability of incumbent uses by creating a policy environment that enables compatible operations with new uses. Meanwhile, these approaches also provide secondary users a means to gain access to spectrum that is already licensed to one or more primary users, but may be under-utilized or capable of supporting multiple uses. As such, they can enable new business models through differentiated service offerings (driving affordable mobile broadband) and low-cost access strategies.

However, to achieve these benefits, spectrum released on a shared basis should be globally harmonized to ensure the economies of scale that will facilitate the large-scale deployments necessary to fully utilize the promise of these technologies. Harmonization will thus facilitate further private-sector development of standards that incorporate spectrum sharing into the toolbox of techniques used for network management and operational support.

> **Recommendation: Policymakers should facilitate the development of globally harmonized spectrum sharing access technologies.**

Geolocation Database Effectiveness. Effective geolocation is essential to both unlicensed spectrum sharing (such as TV white spaces) and for ASA/LSA models requiring heightened coordination. Geolocation capabilities in networks may be assisted by databases that map location, time, and usage characteristics to rules and policies for spectrum under management. Some database systems are now operational, perhaps most notably for implementing the FCC's rules for utilizing television white spaces.[24] The effectiveness of such systems depends on various factors, including accurate propagation models and systems to manage geolocation and frequency

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23 *See* Notice of Proposed Rulemaking and Order, *Enabling Innovative Small Cell Use in 3.5 GHz Band*, FCC 12-148, Dec. 12, 2012, available at http://www.fcc.gov/document/enabling-innovative-small-cell-use-35-ghz-band-nprm-order. The FCC has proposed general authorized access for Tier 3 (effectively unlicensed or licensed by rule as in white space) and priority access for Tier 2 (for safety of life). Ericsson, Nokia Siemens Networks, and Qualcomm have asked the FCC to modify their proposed rules for the 3.5 GHz band in the United States to use LSA.

24 *See* Second Memorandum Opinion and Order, *Unlicensed Operations in the TV Broadcast Bands*, FCC 10-174, Sep. 23, 2010 ("FCC White Spaces Order"), available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-174A1.pdf

information from TV white space devices and other users such as wireless microphones. Three FCC-certified TV white space databases are now operational in the United States.[25]

> **Recommendation: Geolocation databases should be further enhanced or adapted to address scalability and applicability to different domains and use cases, such as in bands shared with non-commercial systems and/or using ASA/LSA or some other shared spectrum access system.**

Cognitive Radio and Intelligent Network Selection. Cognitive Radio refers to a class of radios capable of dynamically reconfiguring their operational characteristics in accordance with their usage or environment. At the extreme, cognitive radios are synonymous with software-defined radios and can have the ability to change a wide range of characteristics such as frequency of operation, protocol stacks, waveforms, and bandwidth. However, cognitive behavior can span a wide variety of techniques.

One recognized class of cognitive radios is designed to be aware of dynamically changing conditions of spectrum quality and thereby automatically choose the best wireless channels in the vicinity of operation. This can, for example, be accomplished by means of spectrum sensing, and research has been ongoing towards developing better algorithms for spectrum sensing, both in narrowband and in wideband.[26] However, while sensing is one tool enabling cognitive behavior, its effectiveness is limited in some scenarios that involve widely dispersed operation, lack of coverage, non-reciprocal use cases, etc. Moreover, some obstacles to practical operation of autonomous cognitive radios must eventually be addressed on the policy level, such as modifying existing regulations regarding the frequencies used by such radios.

Cognitive radio technologies can also be enabled through intelligent network management, where individual radios are made aware of spectrum opportunities through network assistance. Database-directed spectrum allocation schemes, as well as database-assisted policy control are thus another set of enablers for cognitive radio. Cooperation between network sensors and database directed approaches can offer synergistic advantages when used together.

> **Recommendation: Cognitive radio research should be funded and should focus on both intelligent network management and advanced sensing techniques.**

Wideband Sensing. Traditional narrowband sensing algorithms include matched filtering, energy detection, and cyclostationary feature detection.[27] However, efficient spectrum use will eventually require wideband sensing; i.e., device sensors that can operate across a bandwidth ranging from hundreds of megahertz to several gigahertz. For example, future wideband devices may eventually make use of the entire UHF band from 300 MHz to 3 GHz.

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25 Spectrum Bridge, iconectiv, and Google have been certified. *See* FCC, *White Space Database Administrators' Guide*, http://www.fcc.gov/encyclopedia/white-space-database-administrators-guide

26 *See* Hongjian Sun and Arumugam Nallanathan, et al, "Wideband Spectrum Sensing for Cognitive Radio Networks: A Survey," March 6, 2013, accepted for publication in *IEEE Wireless Communications*, 2013, ("Survey of Wideband Sensing Techniques"), available at http://arxiv.org/pdf/1302.1777v2.pdf or at http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6507397

27 *See Survey of Wideband Sensing Techniques*, supra n. 26 at 3.

Some wideband sensing and sampling techniques are theoretically more effective, but in practice are difficult to implement.[28] Therefore, recent interest in wideband sensing techniques has focused on less computationally intensive sub-Nyquist wideband sensing, i.e., acquiring wideband signals using sampling rates lower than the Nyquist rate and detecting spectral opportunities through partial measurements. However, these approaches will require further work on problems, including sparse basis selection, adaptive wideband sensing, and cooperative wideband sensing.[29]

Distributed Sensing. Distributed sensing allows smart devices (and networks) to exploit information about the spectrum environment obtained by many different sensors operating simultaneously. Some research efforts are underway — in early 2012, DARPA issued a solicitation to begin investigating Advanced Radio Frequency Mapping, or "RadioMap."[30] Such research efforts should be expanded and should include work towards exploiting millions of sensors in existing sensor networks for multiple purposes such as assessments of the spectrum environment.

> **Recommendation: Spectrum sensing research should be focused on both individual sensing and distributed sensing approaches.**

Spectrum Aggregation. The newest wireless technologies, such as LTE-Advanced (3GPP release 11) include standards by which wireless operators can aggregate multiple non-contiguous blocks of physical spectrum to create a single, high-rate aggregate logical data channel.[31] As these new technologies are deployed, the amount (and type) of use in particular blocks of physical spectrum should be tracked, since this information may help inform future research in this area.

Interference Mitigation. In an increasingly active spectral environment, more sophisticated interference mitigation techniques should be studied. This includes the need for further research and development regarding receiver performance — particularly before any mandatory performance objectives are imposed by the FCC. Policymakers have been actively exploring possible actions in this area, even as the need for underlying technical research remains.[32]

Meanwhile, in systems using database approaches to avoid interference — including the FCC's White Spaces database system — research is needed to determine and refine the appropriate size of various exclusion zones. In this respect, a significant gap exists in the modeling of propagation in cellular environments when compared with accepted models for long-range propagation observed with airborne systems, radar, and broadcast. Each of these environments has a justified basis for using particular propagation models, but the models do not behave consistently when analyzing co-existence between different use cases.

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[28] For example, wideband sampling at the Nyquist rate (twice maximum frequency) over the range from zero to 10 GHz would require sampling at up to 20 GHz. Given today's hardware technologies, high-rate analog-to-digital conversion would be difficult to implement, or at best very expensive in the context of contemporary wireless networks. *See Survey of Wideband Sensing Techniques*, supra n. 26 at 5.

[29] *See Survey of Wideband Sensing Techniques*, supra n. 26 at 8-10.

[30] DARPA-BAA-12-26, available at https://www.fbo.gov/index?s=opportunity&mode=form&id=701c80210c46b7e497bc90cb0b5c120c&tab=core&_cview=1

[31] *See, e.g.*, Elko Seidel, *LTE-A Carrier Aggregation Enhancements in Release 11*, August 2012, available at http://www.nomor.de/uploads/44/31/4431565c44fed73a799493f63b07aeaf/NewsletterNomor_CA_Enhancements_2012-08.pdf

[32] *See* FCC Public Notice, *Office of Engineering and Technology Invites Comments on Technological Advisory Council (TAC) White Paper and Recommendations for Improving Receiver Performance*, DA 13-801, Apr. 22, 2013, available at http://transition.fcc.gov/Daily_Releases/Daily_Business/2013/db0423/DA-13-801A1.pdf. *See also* House Energy and Commerce Committee, Subcommittee on Communications and Technology, *The Role of Receivers in a Spectrum Scarce World*, hearing held Nov. 29, 2012, available at http://energycommerce.house.gov/hearing/role-receivers-spectrum-scarce-world

Recommendation: More research into cross-application and environment propagation modeling is needed to allow more accurate prediction of interference across various use cases.

In addition, directional signal transmission approaches, such as transmit beamforming and the use of "smart antennas," can improve transmit-receive performance while potentially reducing overall levels of interference. Such approaches are present to some extent in current versions of LTE but could be further developed.

The recent (February 2013) DARPA solicitation for the SSPARC program (see above) includes research on several separation mechanisms to improve performance or reduce interference when sharing spectrum, including:

- Radar beam avoidance by communications systems.
- Communication nodes adjust transmit power based on measured path loss to the radar receivers.
- Identify the specific devices causing interference followed by modifying their transmission parameters to mitigate it.
- Hardware components, subsystems, waveforms, and signal processing methods that improve separation.

The solicitation also seeks additional separation mechanisms, noting that mechanisms that leverage the information sharing subsystem and mechanisms that operate in isolation are both of interest.[33] This work should be continued and expanded upon.

Wireless Ad Hoc Networks. Wireless ad hoc networks are decentralized networks established between devices without reliance on pre-existing infrastructure, such as access points. Spectrum sharing poses a unique challenge for such networks, and these issues require further study.

Network Resiliency. Spectrum sharing presents new challenges regarding network resiliency. For example, geolocation database-based approaches need studies to address redundancy in the event of database failure. Meanwhile, the type of frequency agility needed in devices to support spectrum sharing techniques may actually promote hardening of systems against certain forms of attack, but further research is needed to determine the practical extent of such benefits.

Security. Spectrum sharing in certain well-defined cases, such as between the U.S. Department of Defense and commercial systems, may pose unique challenges regarding system security. To promote assurance and confidence among federal stakeholders, research should be conducted regarding potential spectrum-based security considerations. For instance, given the need to protect both location and/or frequency identification data of some sensitive and advanced federal capabilities, additional research into how to facilitate sharing through spectrum access databases or other means should be undertaken. Meanwhile, waveform interference susceptibility research may help determine which portions of spectral waveforms for particular networks/protocols are most vulnerable, and such research may have useful applications both in security contexts and toward interference mitigation.

[33] *See* DARPA-BAA-13-24, supra n. 16.

Network protocol and architecture evaluation. Systemic research is needed to determine how various network protocols and architectures respond in environments with link-layer interference caused by spectrum sharing.

> **General Recommendation: Spectrum sharing research and development should proceed in the following areas — authorized shared access, geolocation database effectiveness, cognitive radio and intelligent network selection, wideband sensing, distributed sensing, spectrum aggregation, interference mitigation, wireless ad-hoc networks, network resiliency, security, and network protocol and architecture evaluation.**

SECTION III – NEAR-TERM POLICY OPTIONS

Many current discussions of spectrum sharing have involved the possibility of re-purposing federal spectrum for commercial use, often from the Department of Defense. In the near-term, policymakers should support the clearing of re-purposed federal spectrum bands to the maximum extent feasible, while ensuring that the Department of Defense and other agencies' capabilities to execute their missions are not compromised. Cleared, exclusively licensed spectrum bands currently allow the most efficient and dependable use of spectrum suitable for mobile broadband deployment and maximize network investment, marketability, availability and consumer use.

In spectrum bands that cannot be cleared for exclusive licensed use, the most promising forms of sharing by mobile broadband networks, including those based on LTE technology, are licensed sharing with geographic, frequency or time-based coordination, as well as exclusion zones. Spectrum sharing, whether based on sensing technology or the FCC's Part 15 unlicensed rules, still presents technical challenges when required of certain technologies, including LTE.

Meanwhile, on June 14, 2013, the President issued a memorandum on federal spectrum management in conjunction with the research funding discussed above.[34] This memorandum will encourage further progress in federal-commercial spectrum sharing by improving public-private collaboration, requiring agencies to report on their spectrum use, placing constraints on agency requests for additional spectrum, and requiring spectrum efficiency to be considered in procurements, among other steps. Congress has also done its part by holding numerous hearings that continue to draw attention to the important issue of federal spectrum management.

CONCLUSION

Spectrum is not just powering the wireless revolution, but helping to transform the entire U.S. economy. Wireless broadband growth is one of the nation's largest economic drivers, and the need for spectrum will only increase in the coming years. Investment in innovative spectrum technologies is therefore essential to maintaining U.S. economic leadership in an increasingly competitive global marketplace. Moreover, spectrum will also play an ever more important role in supporting the mission of government agencies (civilian or military).

Even as policymakers are focused on near-term issues, it is essential to continue investing in long-term solutions that will enable more efficient use of scarce spectrum resources. Spectrum sharing technologies hold great promise, but a significant and sustained research and development effort

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34 Presidential Memorandum, *Expanding America's Leadership in Wireless Innovation*, rel. June 14, 2013, available at http://www.whitehouse.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leadership-wireless-innovatio

is required to help move many of these technologies into the mainstream. By modernizing the foundations of the research ecosystem and focusing R&D efforts in priority areas, Congress and the Administration can work in partnership with industry to ensure that the future for spectrum remains a bright one.

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