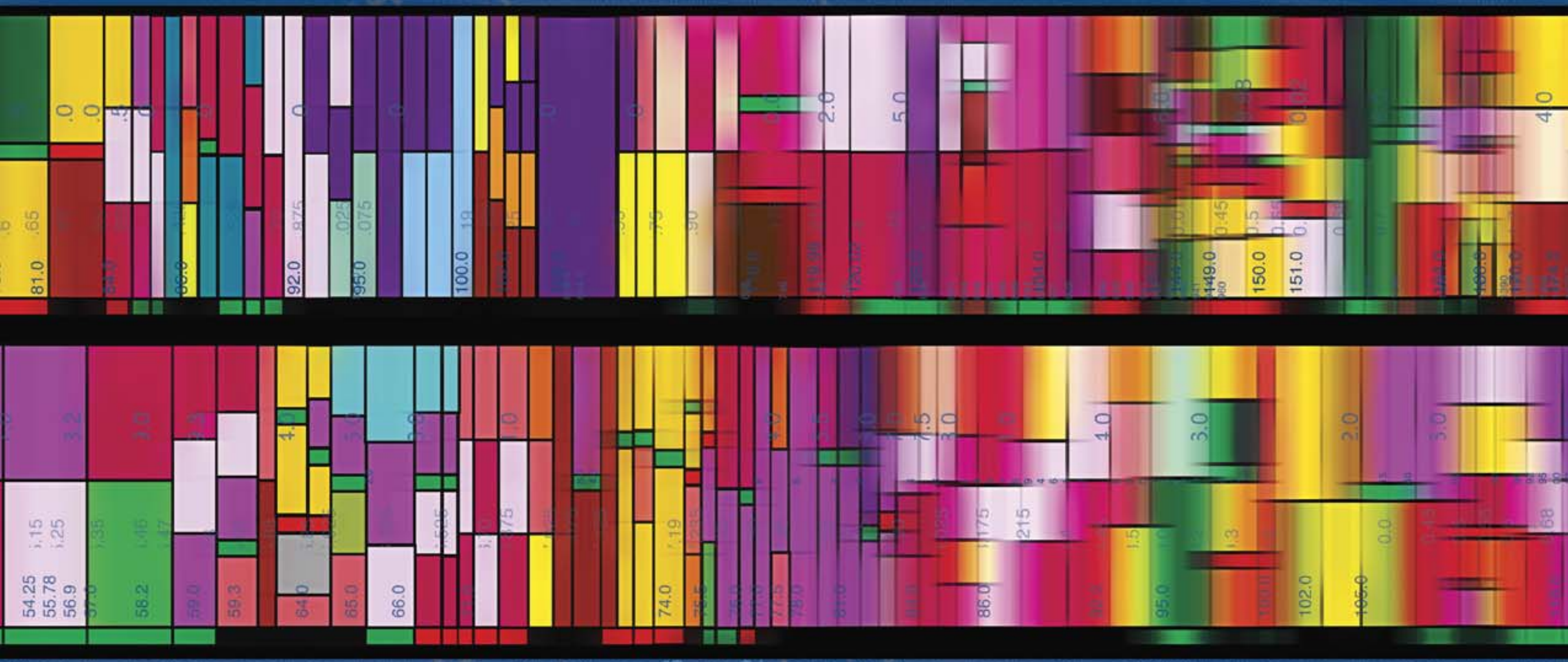
Workshop on ENHANCING ACCESS TO THE RADIO SPECTRUM



Arlington, Virginia, August 4-6, 2010

National Science Foundation

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NATIONAL SCIENCE FOUNDATION

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Funded under NSF collaborative awards 1035474 & 1035221

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Cover: Future technology developments may blur the lines between traditional definitions of radio services, spectrum allocations, and wireless applications, leading to new and more efficient ways to utilize available bandwidth.

Final Report of the National Science Foundation Workshop on

ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)

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1. Executive Summary

During the last two decades, the use of the radio spectrum has intensified and expanded enormously. Wireless systems have proven to be a major productivity tool for every sector of the national economy and have become integrated into the fabric of our society. As they have proliferated, and as new applications continue to emerge, precious spectrum resources are in ever-greater demand: Since the release of the latest generation of smart phones, for example, data traffic on some mobile networks has increased by over 6000%. We are undoubtedly just beginning to see the vastly increasing demand for higher data throughput as new applications, such as machine-to-machine communications, emerge that will drive even larger requirements.

To meet this growing challenge, new approaches, technologies, and policies will be required to enable more flexible and efficient access to the radio spectrum. The key to moving forward is the establishment of a comprehensive vision for future spectrum use, and a well-defined pathway to achieve that vision, which addresses the needs of all sectors of American society — public, private, industrial, scientific, and government.

The stakes are high in this technology development. The country that develops the key intellectual property to enable the efficient use of the spectrum and adopts new and effective spectrum regulations will have strong competitive advantages in the manufacturing of new communication systems and increased productivity in using this technology.

The importance of the spectrum as an economic growth engine was brought forth in two recent releases: The Presidential Memorandum on Unleashing the Wireless Broadband Revolution and the National Broadband Plan. Innovations in spectrum use will be necessary to achieve the goals of these important initiatives, which include making available a total of 500 MHz over the next ten years to support new applications and technologies. With wireless revenues presently reaching several hundred billion dollars annually, and with some estimates of the domestic economic impact of wireless technology approaching $1 trillion annually, these new technologies will provide a competitive economic advantage to American industry and bring exciting new services to all Americans.

With the Presidential Memorandum and the National Broadband Plan as backdrops, the National Science Foundation funded the Enhancing Access to the Radio Spectrum (EARS) workshop on August 4–6, 2010, in Arlington, Virginia. The workshop brought together a diverse set of stakeholders from across the nation, including representatives from public, commercial, scientific, and government sectors. Supported by the NSF directorates for Mathematical and Physical Sciences, Engineering, and Computer and Information Science and Engineering, the workshop was led by principal investigators Prof. Jennifer T. Bernhard (University of Illinois at Urbana-Champaign), Prof. Jeffrey H. Reed (Virginia Tech) and Prof. Jung-min "Jerry" Park (Virginia Tech).

Over the course of three days, a distinguished interdisciplinary group of researchers and spectrum stakeholders identified research topics that will help to develop technology and policies that can unlock the true potential of the radio spectrum while respecting the needs of established users. The participants included engineers, physical scientists, economists, regulators, members of private industry, representatives of government agencies, and others with expert knowledge of the radio spectrum.

The goals of the workshop were to identify and prioritize research opportunities that will contribute to the following objectives:

- To lead to future enhancements in the efficiency by which the radio spectrum is used
- To enhance the ability of all Americans to access broadband wireless services and realize other benefits derived from efficient spectrum use

The list of research opportunities is the main output of the workshop and could be used, for example, toward the creation of an NSF solicitation responsive to the objectives of EARS. The list appears in section 7 of this report. This research is expected to lead to substantial benefits, and among them are three areas that are presently of great national interest:

- Faster broadband access covering larger portions of the country, including traditionally underserved areas;
- Increased spectrum availability for public safety, homeland security, and national defense; and
- Recovery of spectrum capacity for federal government users impacted by reallocations.

Given the importance of the radio spectrum to the nation, the workshop participants agreed by consensus that a research initiative that addresses the identified challenges should be established as soon as possible.

2. Introduction & Workshop Structure

2.1 Introduction

Wireless systems have proven to be a major productivity tool for every sector of the national economy. Emerging applications, enabled by enhanced Internet connectivity and fueled by user demands and advanced technology, promise continuing productivity growth for society. However, these applications will also undoubtedly place greater demands on precious spectrum resources. This poses a considerable challenge for regulators who manage the spectrum. Regulators must try to anticipate these developments and designate appropriate spectrum allocations in ways that consider the needs and balances of all stakeholders, including public, commercial, scientific, and governmental interests. This task is complicated further because the impact of new applications in many regions of the spectrum may have unknown technical issues and uncertain economic impact. Fundamentally, the goal of flexible and efficient spectrum access is the maximization of utility across the dimensions of public access and safety, economic growth, scientific discovery, and national security. The financial stakes in managing spectrum are high, as evidenced by more than $70 billion received by the public treasury in auctions for spectrum rights. This figure is, however, greatly dwarfed by the broader economic, scientific, and societal impact that access to the spectrum engenders.

With such a valuable resource at stake, it is imperative that the spectrum be used in an efficient and effective manner. Spectrum management must be flexible to accommodate changing usage models and opportunities created by advances in technology. This management must mitigate the risks and interference associated with the interactions between established hardware installations that use traditional fixed spectrum and emerging systems that can use dynamically assigned wireless channels from across the spectrum. In the future, the effective management of this complex system requires a comprehensive plan that includes technological advances and consideration of societal, scientific, environmental, and economic factors. For example, these technological advances require research in cognitive and software-defined radio, reconfigurable/tunable antennas, range/coverage prediction tools, large-scale spectrum measurement, compression techniques, distributed networking, spectrum security mechanisms and protocols, and non-interfering spectrum access architectures and algorithms.. Societal, scientific, environmental, and economic factors include social network formation, preservation of existing scientific capabilities, expansion of geographic information systems and public wireless access, and prospective business and usage models. Ultimately the goal of the aforementioned plan is to set the stage for “future-proofing” the spectrum, accommodating unforeseen technology changes in an agile, efficient, and fair manner.

By bringing together a representative set of stakeholders from across the country, the NSF EARS workshop fostered new interactions and discussions among radio spectrum users that, by virtue of their current block spectrum allocations, may have had little reason to interact before. The connections and networking opportunities presented by this experience broadened the perspectives of all attendees in ways that will support a growing community of spectrum users and regulators who think about spectrum access in a fundamentally different way—a way that respects the rights of individual users while striving to raise the level of spectrum access for all. We anticipate that numerous follow-on activities, including presentations in scientific, industrial, and government professional meetings, will help to inform and engage the broader stakeholder communities, welcoming them to contribute their energies and ideas so that the vision of flexible and efficient radio spectrum access can be realized. Ultimately, improving spectrum access directly supports the National Broadband Plan and the Presidential Memorandum on Unleashing the Wireless Broadband Revolution, which both have the goal of making broadband Internet access available to all Americans.

The PIs for this workshop, Prof. Jennifer T. Bernhard (University of Illinois), Prof. Jeffrey H. Reed (Virginia Tech), and Prof. Jung-min "Jerry" Park (Virginia Tech), in consultation with the NSF program officers, selected seven individuals to serve as the workshop steering committee. These individuals are listed in Section 5. The steering committee members possess broad and diverse backgrounds representative of spectrum stakeholder communities. In both the composition of the steering committee and the workshop participants, efforts were made to involve a diverse group of individuals. The workshop steering committee provided extensive recommendations on the invitation list, including alternates to ensure that stakeholder communities were adequately represented. In total, there were 43 invited participants. Observers were also invited from about a dozen government and international agencies that have active interest in these issues.

2.2 Workshop Description and Breakout Structure

The future use of the electromagnetic spectrum is complicated and depends on multiple factors. To develop a research agenda for NSF that accurately addresses this complexity, this workshop brought together individuals from across the nation with a variety of specializations, experiences, and perspectives on the issue of spectrum access and use.

To provide background information and inspiration, the workshop featured several prominent speakers during the first two days of the workshop, including Dr. Cora B. Marrett, Acting Director of the National Science Foundation; The Honorable Gary Locke, Secretary of Commerce; and The Honorable Meredith Attwell-Baker, Commissioner, FCC. Additional presentations were made during the first plenary session by Julius Knapp (FCC), Byron Barker (NTIA), Ronald Hahn (DoD/JIOWC), Peter Cramton (U. Maryland), and Rajendra Singh (World Bank). The distinguished speakers shared their perspectives on the state of spectrum usage and related issues that could be addressed in the future.

The main activity of the workshop consisted of three breakout sessions designed to encourage innovative thought about both broad and specific research issues surrounding future spectrum access and use. For each breakout session, the participants were each assigned to one of four small discussion groups, each consisting of eight to nine participants. Workshop observers also attended any discussion group of their choice throughout the workshop duration. Assignments to the smaller groups changed for each breakout session in order to provide ample opportunities for individuals to interact more personally with as many other participants as possible. In addition, discussion group assignments were made such that each discussion group was composed of at least one economist, two or three policy experts and industry organization representatives, and four or five technology experts. For each discussion group, an assigned leader was tasked with facilitating the group discussion and ensuring that all individuals in the group contributed. Another member of each group acted as a scribe for the deliberations. Additionally, graduate student observers also took notes in each breakout session in order to capture the discussions as completely as possible. At the end of each breakout session, the entire group met in plenary session and each of the group leaders reported the results of their discussions. These reports formed the basis of the research agenda included in Section 7.

Breakout Session 1: Future Requirements and Impact of Spectrum Access and Use

The first breakout session was intended to be both educational and thought-provoking for each participant while supporting brainstorming across disciplines. Assigned breakout groups were selected to provide a diversity of perspectives. Participants briefly introduced themselves and their fields, providing their own perspectives on the issues of spectrum access and use. They then discussed as a group what, in their view, the key attributes and impact of future spectrum access and use would be, incorporating factors across multiple disciplines.

Breakout Session 2: Emerging and Alternative Spectrum Access and Usage Models and Their Challenges

With the foundation provided by the results of the first breakout discussions, workshop participants collaborated in the second breakout session to identify specific challenges that stand in the way of new approaches to future spectrum access and use. These challenges will be the drivers for the determination of NSF's research agenda in this area.

Possible topics of discussion included but were not limited to the following, in no particular order:

- Potential technological and scientific requirements and impact
- Policies and operation guidelines for legacy systems (technical, economic, etc.)
- Spectrum economics, including auctions, secondary markets, etc.
- Societal and economic impact of spectrum access and use and varying levels of spectrum access
- Regulatory structure and policy modeling and operation, including spectrum usage rights, responsibilities, monitoring, and enforcement
- Effects on domestic industries serving international markets
- Integrating national policy initiatives in the international framework
- Roles and approaches for currently unlicensed devices and fixed allocated spectrum
- Broad impact of wide-scale technology transitions, including costs
- Wireless standards and wireless standard evolution
- Coexistence/priority access for emergency, public safety, and military communications

Breakout Session #3: Necessary Interdisciplinary and Disciplinary Research to Address the Identified Challenges

With the list of challenges identified in breakout session #2, workshop participants used the final breakout session to define areas of research, both interdisciplinary and disciplinary, to address these challenges. Workshop participants were encouraged to think broadly about the impact of potential research topics that address multiple dimensions of this complex issue. Section 7 contains a listing of priority future research directions that can be supported by NSF in technology, public policy, economics, and other areas to serve as critical foundations that will enable flexible and efficient spectrum access.

3. Charge to the Workshop

Considering

- that access to the radio spectrum is vital to carry out national goals and priorities;
- the current state of wireless technology;
- the economic benefits, both direct and indirect, of access to the radio spectrum;
- the unique requirements of access to the radio spectrum by safety-of-life and science services;
- realistic regulatory scenarios; and
- the scope of research funded by the National Science Foundation,

the workshop should identify and prioritize research opportunities that will

- lead to future enhancements in the efficiency by which the radio spectrum is used; and
- enhance the ability of all Americans to access broadband wireless services and realize other benefits derived from efficient spectrum use.

4. AGENDA

Wednesday, August 4, 2010

- 8:00–8:30 AM (Room 555)
  - ◊ Registration and light breakfast
- 8:30–9:45 AM (Room 555)
  - ◊ Welcome and opening remarks
    - ♦ Dr. Cora Marrett, Acting Director, National Science Foundation
    - ♦ Dr. Ed Seidel, NSF Assistant Director, Mathematical and Physical Sciences
    - ♦ Dr. Tom Peterson, NSF Assistant Director, Engineering
    - ♦ Dr. Deborah Crawford, NSF Deputy Assistant Director, Computer and Information Science & Engineering
  - ◊ NSF/EARS context and background
    - ♦ Dr. Andrew Clegg, EARS program director
  - ◊ Introductions, workshop overview, and charge (workshop PIs)
    - ♦ Prof. Jennifer Bernhard, University of Illinois
    - ♦ Prof. Jeff Reed, Virginia Tech
    - ♦ Prof. Jerry Park, Virginia Tech
- 9:45–10:00 AM (Room 555)
  - ◊ Coffee break
- 10:00 AM–12:15 PM (Room 555)
  - ◊ Opening plenary
    - ♦ Presentations
      - Julius Knapp, FCC
      - Byron Barker, NTIA
      - Ronald Hahn, DoD/JIOWC
      - Prof. Peter Cramton, University of Maryland
      - Rajendra Singh, World Bank
    - ♦ Outline of workshop activities:

        - Definition of what future spectrum use could look like and the complexity of the issues
        - Identification of challenges that stand in the way of this future
        - Conception of interdisciplinary and disciplinary research paths that NSF can support that address these challenges
    - ♦ Definition of breakout sessions and expected work products, flow of expectations for participation, explanation of the purpose of breakout sessions, assignment of participants, leaders, and scribes
    - ♦ Identification of rooms with breakout sessions

- 12:15–12:30 PM (Room 555)
    - ◊ Lunch collection and move to assigned breakout rooms
- 12:30–2:45 PM (Rooms 525, 535, 545, 555, and 575)
    - ◊ Breakout Session #1: Future Requirements and Impact of Spectrum Access and Use
- 2:45–3:00 PM (Room 555)
    - ◊ Coffee break
- 3:00–3:30 PM (Room 555)
    - ◊ The Honorable Meredith Attwell Baker, Commissioner, Federal Communications Commission
- 3:30–4:15 PM (Rooms 525, 535, 545, 555, and 575)
    - ◊ Breakout Session #1 (continued); preparation for reporting
- 4:15–5:30 PM (Room 555)
    - ◊ Plenary: reporting on results from Breakout Session #1
- 6:00—~7:30 PM (Quincy Plaza building)
    - ◊ Informal wine and cheese gathering (partially sponsored by IEEE Broadcast Technology Society)
- >~7:30 PM
    - ◊ Dinner (on your own)

Thursday, August 5, 2010

- 8:30–9:00 AM
  - ◊ Light breakfast; preparation for Breakout Session #2 (Room 555)
- 9:00–9:45 AM (Room 555)
  - ◊ The Honorable Gary Locke, Secretary of Commerce
- 9:45–10:00 AM (Room 555)
  - ◊ Coffee break
- 10:00–11:00 AM (Room 555)
  - ◊ The President's Spectrum Initiative (panel and discussion forum)
    - ♦ Philip J. Weiser, White House, National Economic Council
    - ♦ Scott M. Deutchman, White House, Office of Science and Technology Policy
- 11:00 AM–12:15 PM (Rooms 525, 535, 545, 555, and 575)
  - ◊ Breakout Session #2: Emerging and Alternative Spectrum Usage Models and Their Challenges
- 12:15–12:30 PM (Room 555)
  - ◊ Lunch collection and return to breakout sessions
- 12:30–1:45 PM (Rooms 525, 535, 545, 555, and 575)
  - ◊ Breakout Session #2 (continued); preparation for reporting
- 1:45–3:00 PM (Room 555)
  - ◊ Plenary: reporting from Breakout Session #2
  - ◊ Preparation for Breakout Session #3
- 3:00–3:15 PM (Room 555)
  - ◊ Coffee break
- 3:15–5:30 PM (Rooms 525, 535, 545, 555, and 575)
  - ◊ Breakout Session #3: Necessary Interdisciplinary and Disciplinary Research to Address Identified Challenges
- > 5:30 PM Dinner (on your own)

Friday, August 6, 2010

- 8:30 AM–12:00 Noon (Room 555)
  - ◊ Closing plenary and light breakfast
    - ♦ Breakout Session #3 Reporting (8:30–10:00)
    - ♦ Communication of next steps: report writing schedule and logistics (10:00–11:30)
  - ◊ Workshop closing

Background Documents

National Broadband Plan

Presidential Memorandum: Unleashing the Wireless Broadband Revolution

White House Fact Sheet: Doubling the Amount of Commercial Spectrum to Unleash the Innovative Potential of Wireless Broadband

"Technological Opportunities, Job Creation, and Economic Growth," Remarks at the New America Foundation on the President's Spectrum Initiative, Lawrence H. Summers

5. STEERING COMMITTEE & LIST OF PARTICIPANTS

Principal Investigators

Jennifer Bernhard	*University of Illinois* Professor, Department of Electrical & Computer Engineering
Jeffrey Reed	*Virginia Tech* Willis G. Worcester Professor, Bradley Department of Electrical & Computer Engineering
Jung-Min (Jerry) Park	*Virginia Tech* Associate Professor, Department of Electrical & Computer Engineering

Steering Committee

Charles Clancy	*Virginia Tech* Associate Director, Hume Center for National Security & Technology; Research Fellow, National Capital Region Research Development Team
Michelle Connolly	*Duke University* Associate Professor, Department of Economics; Chief Economist, Federal Communications Commission (2008–2009)
Rhonda Franklin	*University of Minnesota* Associate Professor, Department of Electrical & Computer Engineering
Albin Gasiewski	*University of Colorado* Professor, Department of Electrical & Computer Engineering; Director, NOAA-CU Center for Environmental Technology
Bill Hayes	*Iowa Public Television*; President, IEEE Broadcast Technology Society

Ali Niknejad	*University of California Berkeley* Associate Professor, Department of Electrical Engineering & Computer Sciences; Co-director, Berkeley Wireless Research Center
Jonathan Peha	*Carnegie Mellon University* Professor, Departments of Engineering & Public Policy and Electrical & Computer Engineering Chief Technologist, Federal Communications Commission

Participants

Byron Barker	*National Telecommunications and Information Administration* Chief, Strategic Planning Division
Robert Calderbank	*Princeton University* Professor, Department of Electrical Engineering; Director, Program in Applied & Computational Mathematics
Peter Cramton	*University of Maryland* Professor, Department of Economics; Chairman, Market Design, Inc.
Scott Deutchman	*White House Office of Science and Technology Policy* Deputy Chief Technology Officer for Telecommunications
Christine Di Lapi	*MITRE Corporation* IEEE Broadcast Technology Society
Richard DuBroff	*Missouri University of Science and Technology* Professor, Department of Electrical & Computer Engineering; Director, I/UCRC Center for Electromagnetic Compatibility; Director, EMC Laboratory
Rick Fisher	*National Radio Astronomy Observatory* Technical R&D Leader
Ronald Hahn	*U.S. Strategic Command,* *Joint Information Operations Warfare Center* Deputy Director, Electronic Warfare Directorate

Charles Holt	*University of Virginia* A. Willis Robertson Professor of Political Economy and Chair, Department of Economics
Michael Jensen	*Brigham Young University* Professor and Chair, Department of Electrical & Computer Engineering
John Kagel	*Ohio State University* University Chaired Professor, Department of Economics
Michael Katz	*University of California Berkeley* Sarin Chair in Strategy & Leadership and Director, Institute for Business Innovation, Haas School of Business
Julius Knapp	*Federal Communications Commission* Chief, Office of Engineering & Technology
Paul Kolodzy	*Kolodzy Consulting*
Robin Kravets	*University of Illinois* Associate Professor, Department of Computer Science; Head, Mobius Group
Evan Kwerel	*Federal Communications Commission* Senior Economic Advisor, Office of Strategic Planning & Policy Analysis; Acting Chief Economist, Wireless Telecommunications Bureau
William Lehr	*Massachusetts Institute of Technology* Research Associate, Computer Science & Artificial Intelligence Laboratory
Stephen Lockwood	*Hatfield & Dawson Consulting Engineers* Partner
Shiwen Mao	*Auburn University* Assistant Professor, Department of Electrical & Computer Engineering
Michael Marcus	*Marcus Spectrum Solutions*

Kathleen Melde	*University of Arizona* Professor, Department of Electrical & Computer Engineering
Paul Nikolich	*Chair, IEEE 802 Committee*
Dimitrios Peroulis	*Purdue University* Associate Professor, School of Electrical & Computer Engineering
Lee Pucker	*Wireless Innovation Forum* Chief Executive Officer
Lili Qiu	*University of Texas* Assistant Professor, Department of Computer Science
Anant Sahai	*University of California Berkeley* Associate Professor, Department of Electrical Engineering & Computer Sciences
Christian Sandvig	*University of Illinois* Associate Professor, Department of Communication and *Harvard University* Fellow, Berkman Center for Internet & Society
Wayne Shiroma	*University of Hawaii* Professor, Department of Electrical Engineering
David Shively	*CTIA*
Rajendra Singh	*World Bank* Senior Regulatory Specialist, Global ICT Department
David Staelin	*Massachusetts Institute of Technology* Professor, Department of Electrical & Computer Engineering
Philip Weiser	*White House, National Economic Council* Senior Advisor to the National Economic Council Director for Technology, Innovation, & Competition Policy
Jianzhong (Charlie) Zhang	*3GPP RAN 1 Vice Chair/Samsung*

Qing Zhao *University of California Davis*
Associate Professor,
Department of Electrical & Computer Engineering

NSF Program Officers

Andrew Clegg	Directorate for Mathematical & Physical Sciences
Andreas Weisshaar	Directorate for Engineering
Alhussein Abouzeid	Directorate for Computer & Information Science & Engineering

6. Remarks to the Workshop

Dr. Cora B. Marrett
Acting Director, National Science Foundation

Good morning, everyone. On behalf of the National Science Foundation, I am delighted to welcome you to Washington in these splendid days of early August.

I am grateful to Ed Seidel, Tom Peterson, Deborah Crawford, and Andy Clegg for inviting my participation in this workshop on Enhancing Access to the Radio Spectrum.

And to the EARS workshop Principal Investigators—Professors Jennifer Bernhard, Jeff Reed, and Jerry Park—please know that you have our gratitude.

Above all, I especially want to thank you, the participants, for your time and your commitment to a topic that is so key to the vitality of our nation, the vibrancy of our culture, and the strength of our economy.

The challenge to communicate instantaneously over great distance has fueled the ingenuity of leading—and competing—scientists and innovators for nearly two centuries. Morse and Wheatstone wrought the telegraph, Bell rang up the telephone, Marconi and Tesla developed the wireless, Fessenden gave voice to radio.

Today our world runs on our ability to send and receive signals, ciphers, and conversations, all at the speed of light.

These inventions and others have grown into global networks that support communications, sensing, networking, and commerce. Managing this technology calls for collaboration in the organizational infrastructure commensurate with our physical networks.

As you well know, the demand for access to the radio spectrum is at a peak, and still growing rapidly. Some mobile networks are experiencing growth in information flow exceeding 250% per year. Most of this demand is driven by smart phones, wireless broadband, and the desire to expand public safety capabilities.

Because wireless services are embedded in and critical to our economy, spectrum demand and potential shortages have drawn attention at the highest levels of our government, including Congress and the President.

NSF is in a pivotal position for ensuring that the nation avoids wireless gridlock. While investigators funded by NSF use the radio spectrum for a variety of scientific research, the Foundation also has a history of funding ground-breaking research into breathtaking wireless technologies and applications. This research speeds the technology behind wireless devices and services used by all industrialized societies.

The issue of technological advances and spectrum access spans every research area funded by NSF. This week's workshop is likely to be only the first of several on the topic of the radio spectrum, in light of the panoply of research opportunities emerging in the field.

Our merit-review process strives to favor the best ideas and the brightest talent. Our funding spans the range of opportunities to innovate: from basic research with long-term and potentially transformational impact, to more immediate payoffs through awards that help translate academic research to the commercial world.

While today's economic drivers are smart phones and mobile broadband, our principal investigators are renowned for inventing or enabling tomorrow's killer technologies and applications—innovations that may not even be dreamed about today.

Research into spectrum efficiency and access is an area ripe for investment. NSF is the right place to lead this investment, and the EARS concept is responsive to developing assets in this arena. But before any such initiative can be launched, we must identify the key challenges, pitfalls, and research opportunities. That is the purpose of this workshop.

We invite you to help envision the future of the radio spectrum and then prioritize the potential research avenues that can help realize that engaging future vision. Your work here will have tremendous influence within and beyond the NSF. I look forward personally to the lessons for NSF and the U.S. emerging [from] this inaugural EARS conference. Again, thank you.

The Honorable Gary Locke

Secretary of Commerce

I want to thank the National Science Foundation for inviting me to speak with you and for hosting this critical workshop.

I know that yesterday, you had a full day of highly technical discussions on how to enhance America's use of one its most valuable assets—our radio spectrum.

As we work through these complicated issues, I think it's important to take a step back and look at the big picture. . . .

. . . to think about why the work you are doing isn't just important to the relatively small number of people in the radio spectrum and telecommunications community . . . but to this entire country.

On June 28, when President Obama issued his memorandum directing federal agencies to begin freeing up 500 megahertz of federal and nonfederal radio spectrum over the next 10 years, he explained the implications for America very clearly. He stated that:

"Expanded wireless broadband access will trigger the creation of innovative new businesses, provide cost-effective connections in rural areas, increase productivity, improve public safety, and allow for the development of mobile telemedicine, tele-work, distance learning, and other new applications that will transform Americans' lives."

Above all, improving the lives of the American people and keeping our economy strong for decades to come—that's what this workshop is really about.

America, more than any other country, celebrates the idea of entrepreneurial innovators and companies bringing new technologies and new ways of doing business to market.

We venerate those willing to shake up the status quo.

And the Obama Administration seeks to empower them.

In these difficult economic times, nothing is more important to American prosperity than jumpstarting our engine of technological innovation. Unfortunately, that engine broke down over the last decade.

For years, the American economy was on a path of illusory growth – one driven by speculation and debt-fueled consumption.

The United States simply must get back to cultivating businesses and lines of scientific discovery that provide long-term benefits to society and spur sustainable innovation.

That's the type of work that all of you are engaged in every day.

I do not need to tell this audience that in the United States and around the world, we are seeing a virtual explosion of uses for wireless technologies.

Mobile broadband use, in particular, has experienced growth in the United States that was unimaginable only a few short years ago.

Consider the fact that: the number of active mobile Internet users has doubled in the past two years to over 40 million users; and the growth rate for the adoption of mobile broadband is greater than the growth rate for DSL and cable modem services combined.

This is barely the tip of the iceberg. Smart phones, smart grids, and countless other technologies will be placing unprecedented demands on our spectrum capacity.

By 2014, Cisco projects wireless networks in North America will carry some 740 petabytes per month, a greater than 40-fold increase over last year.

Right now, radio and broadband technology is an area where the United States unquestionably has a competitive advantage in the world economy.

If we want to maintain and expand that advantage, we've got to be very creative about making more radio spectrum available and finding ways to use spectrum more efficiently.

Traditionally, calls for more spectrum have led to Federal agencies' and incumbents in the private sector being required to relocate operations to free up spectrum for commercial users.

Of course, we must continue to do that, but things are about to get much more complicated.

As we look over the horizon, we know that relying solely on relocation of existing Federal and commercial users will not meet the burgeoning demand for spectrum for broadband. Sharing arrangements and new technical solutions are needed so that we can continually intensify the use of our spectrum resources.

As most of you know, some spectrum is not used continuously all the time or across all geographic locations, so finding technical and regulatory mechanisms to utilize the "open spaces" in these bands is one very promising area of innovation.

But this promising approach has its own set of challenges.

To cite just one example, law enforcement utilizes certain radio spectrum bands for the most sensitive covert surveillance operations.

If we only looked at the amount of use of those particular frequencies, you might find that law enforcement is only using the spectrum for a few hours during the day, meaning that it could be available for commercial use for the remainder.

But if the FBI is running a surveillance operation, they need to have this spectrum available when and where it is needed and when it is being used. They may only use it for a few hours a day, but they can't tell you exactly when they are going to need it.

The FBI has to know that there will not be any interference from other users that might imperil the operation or the lives of the agents involved.

And when we do get involved in evaluating specific bands for reallocation, it is an increasingly complex process.

Many Federal systems such as radar or satellite systems have unique capabilities that cannot be met by commercial services, easily replaced with off-the-shelf equipment, or moved to other bands.

This means it may not be possible to relocate these uses or would require many years and large expenditures to do so.

Overcoming these challenges will require new, more sophisticated rules that create fixed geographic or frequency separations, as well as dynamic sharing solutions.

President Obama's executive memorandum recognizes this and specifically calls for a "plan to facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies, including those that are secure and resilient."

And the Commerce Department is at the forefront of this effort.

Our National Telecommunications and Information Agency (or NTIA) and our National Institute of Standards and Technology (or NIST) are working with the National Science Foundation and other agencies, to create and implement a plan to explore innovative spectrum-sharing technologies.

Today's event is an important early step on that path.

NTIA is also working closely with OMB as they work to incorporate new tools and new incentives for federal agencies to ensure the timely and effective reallocation of spectrum.

And of course, NTIA and the FCC are collaborating to deliver by October 1st, a timetable and milestones to the president on how we plan to open up the additional 500 megahertz over the coming decade.

NTIA is not only playing a key role coordinating the work of agencies throughout the federal government—they are also facilitating and conducting critical research and development.

In fact, as many of you know, they have launched a Spectrum Sharing Innovation Test Bed, which is evaluating the ability of geo-location and sensing devices to permit sharing of land mobile radio spectrum.

We are trying to determine what dynamic spectrum access technology can and cannot do, both in the lab and in the real world.

And this test bed is proving to be an important opportunity for Federal agencies to work co-operatively with industry, researchers, and academia to evaluate new technologies for both sensing and geolocation.

More broadly, I think the approach my Department, NIST, and especially NTIA are taking on radio spectrum reflects the Obama administration's collaborative approach to spurring innovation in America.

Despite the claims of critics that government has never or will never play a constructive role in the American economy, groundbreaking innovation has frequently involved public–private sector cooperation, be it the development of the Internet or solar panels or even memory foam mattresses.

The federal government can help set the stage for innovation with investments in basic research and with sensible rules, regulations, and incentives, which enable the actual innovating, creating, and commercializing in the private sector.

That's the message the administration has been sending throughout the country.

In the past few weeks, I've attended a series of events that explored different facets of innovation in America, from technology commercialization and cyber security to clean energy and, here today, radio spectrum. These are all completely different issues.

And yet the common denominator of all of them is that the Obama administration is trying to learn how we can serve as a catalyst for innovation for the people on the frontlines of these challenges . . . how we can empower universities, entrepreneurs, and businesses to develop the breakthrough technologies we need to get this economy roaring and creating new jobs again.

This administration knows full well that we don't have all the answers . . .

. . . that when you're talking about an issue as complex as radio spectrum, you've got to have all the stakeholders at the table to ensure we're moving forward with policies that will grow our economy and protect our security.

I know we are moving the right direction, and I just want to thank you all for the immeasurable help that you're providing in getting these policies right.

Thank you.

The Honorable Meredith Attwell-Baker

Commissioner, Federal Communications Commission

Thank you, Dr. Marrett. It is a great pleasure to be here. I am happy to see some familiar faces and look forward to meeting new friends here today. But, I must admit, it is a little daunting. At the FCC we talk about wireless innovation. But you are the men and women who actually do it. I want to thank you for your hard work and dedication. And I want to help you do more.

A little more than a month ago, the President focused our collective attention on spectrum issues. In announcing his plan to make 500 megahertz of spectrum available for wireless broadband, the President gave each of us a unique and important challenge: rethinking the way we conceive of spectrum access to take the wireless revolution to the next level. Looking at it from the perspective of both my former job at NTIA and now at the FCC, I think finding the 500 megahertz the President has requested will require action on several fronts. To get there, we will need spectrum reallocations, which can be costly, controversial, and time-consuming. We will need more traditional spectrum trading, which can be relatively straight forward. And, where neither of these is possible, we will need to develop comprehensive new approaches to dynamic spectrum access that are technologically advanced; rules-based; informed by an up-to-date, intelligent, and interactive database; and powered by cognitive radios. We all have a lot of work to do together, in research and development, on the implementation of innovative policies, and, frankly, on plain old confidence building.

Your meetings this week are an important step in the process. The National Science Foundation has long played an important role in helping to develop our communications infrastructure, particularly the Internet in the 1970s. NSF has been present ever since. Much of the work has involved radio spectrum, and the list of NSF accomplishments in this area is long. NSF-funded innovations in circuit design and miniaturization have contributed to state-of-the art mobile wireless systems incorporating advanced energy-efficient technologies that can use radio spectrum more efficiently than anyone could have hoped just a few years ago. NSF-funded research has contributed to compression algorithms and hardware that allow us to watch spectacular images on mobile devices in challenging reception conditions. NSF-funded researchers have worked on developing the advanced transmission technologies like OFDM. These are the technologies that enable today's already fast wireless connectivity for countless devices where we work, live, and study. They will be at the heart of the 4G revolution that is just around the corner.

Recognizing this great history of promoting innovation, the National Broadband Plan calls upon the National Science Foundation to answer the call yet again and help promote broadband deployment and related issues in several areas, including cybersecurity, accessibility, technology transfers, and in an area that is of great personal interest to me: wireless research and development.

Specifically, the National Broadband Plan recommends that the NSF, in consultation with the Commission and NTIA, fund wireless research and development that will advance the science of spectrum access. Now, when I was growing up, my parents always used to tell me that it was impolite to tell other people what to do with their money, and I always try to respect that advice. However, I feel so strongly that more and better research in the area of spectrum access and use is critical to address this country's spectrum requirements that I am going to ignore it on just this one occasion. I think additional NSF participation in the area of spectrum access is a great idea and would like to lend my support and help in any way to make it possible.

During the fifteen or so years that I have been involved with wireless issues, we have seen a dramatic decline in our country's ability to conduct the research that will be necessary to meet the challenges of more intense spectrum use. The two U.S. companies most commonly associated with the development of the cell phone are now shadows of their former selves. Bell Labs, at the time a part of AT&T, is no longer the intellectual powerhouse it once was. Motorola, once an undisputed leader in all things wireless, struggles to find a new role in a world now defined by companies that no one had heard of twenty years ago—if they even existed. It is not clear that we have any U.S. companies that can continue their legacy in basic research. While there are certainly impressive innovators in the wireless space, it is not apparent that even the most vibrant players today are devoting the systematic attention to basic research in wireless technologies that will be necessary to revolutionize spectrum use. Yet the need for smarter, better approaches for radio access has never been more acute. And it is clear that it is only going to get more intense for the foreseeable future.

Against this discouraging backdrop, the EARS initiative could not be more welcome. As a vehicle to fund interdisciplinary research in all science and technology issues relevant to improving the use of radio spectrum, EARS can help catalyze the critical work we need to advance our wireless economy.

With EARS, the NSF has a chance to play a real leadership role that will be of lasting value. Interdisciplinary EARS-related research can be directly responsive to many of the most important challenges that we face as we seek to use existing spectrum more efficiently and share it more effectively for both scientific and other national purposes, as well as for commercial use. Hopefully separated from the competitive forces that can at times narrow the scope of work and collaboration on wireless issues in the private sector, EARS can promote and encourage basic and applied research across a wide range of topics. The list is as long and varied as the spectrum challenge itself. The outcome promises to be significant. EARS can leverage existing activities in the areas of wireless communications and networking technologies, including not just cognitive radios but millimeter wave and terahertz technologies, nanotechnologies, energy efficiency and battery development, smart antennas and smarter receivers, interference mitigation, and so much more.

While I know this is hard, I also know it can work. I am pleased to have been a part of an early initiative to promote collaboration on spectrum issues: the NTIA–FCC Spectrum Sharing Test Bed, which was implemented pursuant to an earlier Presidential recommendation to establish a pilot program to explore increased spectrum sharing between Federal and non-Federal users. The Test Bed program is not perfect. But, it does offer a unique opportunity for the Federal agencies to work with industry, researchers, and academia to examine new technologies that can improve management of the nation's airwaves. And I believe it has provided valuable insights to inform development of spectrum policy. However, the Test Bed is only a first step. We need more of them. They need to be more accessible and function more efficiently to be timely enablers of innovation. Even improved, the Test Bed program cannot be the only vehicle we use to meet the challenges of more efficient spectrum use. That's why EARS is so important.

For my part, I will continue to encourage FCC leadership in adopting innovative spectrum policies that address the needs of all spectrum users. The Chairman has announced an ambitious agenda for spectrum policy, and we have a full plate. Of particular relevance to your work, we are slated to act on a list of additional Broadband Plan recommendations that includes opportunistic spectrum access, innovative uses of broadcast spectrum, contiguous unlicensed use, and experimental licensing. I hope we get through the whole list.

I will confess that I have two key priorities of my own. First, just as basic research is critical to the development of new technologies, I believe a spectrum inventory is a critical tool to provide the Commission, NTIA, industry—and all of you—with essential information about how, where, and when spectrum is used today. The inventory is not, however, a stand-alone policy objective. Rather, it enables stakeholders like each of you here today to make informed decisions on where to focus your efforts. And, I hope it can provide men and women like you with the basic information you need to develop a dynamic, user-friendly spectrum database, which can help facilitate and promote more efficient sharing and use of spectrum resources.

I also think we need a long-term spectrum plan. We undertook a similar exercise with regard to federal spectrum when I was at NTIA—and thank you to those here who helped make that possible—and we need to do it now on the commercial side. Without it, all of our efforts are handicapped.

Going forward, I will continue to encourage a global perspective on spectrum issues to avoid the creation of additional spectrum islands that limit the scale and reach of technologies. I will promote the allocation of significant spectrum blocks wherever possible so we can take full advantage of the new technologies you are helping to develop. And I will promote more flexible and collaborative use of spectrum. In so doing, I hope we can be informed by your hard work and leverage your achievements to enhance consumer welfare and ensure greater spectrum utilization.

I welcome your input and collaboration in our deliberative process. Under Chairman Genachowski we are finding new and better ways to interact with our colleagues in other agencies and with the public at large. We are overhauling our web portal to make it even more useful and could easily imagine creating links to the important work you are doing here.

Close collaboration between all the interests represented at this conference will be critical. It is very encouraging to me that there are representatives here from a broad range of disciplines and branches of government. But we are going to have to learn to do more than sit in rooms together. We are going to have to make a concerted effort to take down the silos in which we operate and to take the quick and concerted actions necessary to make the rapid progress we need.

As we go forward, we are building on the broad consensus that the wireless industry is a major driver of economic growth. Nearly 270,000 men and women are directly employed in the sector, and another 2.4 million jobs are directly or indirectly connected with the wireless industry. In less than a generation, we have become a country recognized for leadership in the development not only of wireless technologies, but also of devices and a whole new wireless ecosystem dominated by applications. But as you all know way better than I do, there is no such thing as a perpetual motion machine, and wireless cannot continue on this dramatic growth curve without our action. Let us make the promise of next-generation mobile broadband our catalyst.

I look forward to working closely with you all in the coming months as we find solutions to our nation's spectrum challenges and set the stage for the next generation of American competitiveness.

7. Research Challenges & Opportunities

The primary goal of the EARS workshop was to discuss the existing technical, economic, and policy challenges to improving the efficiency and flexibility with which the radio spectrum is used, and to identify research opportunities within and across NSF-sponsored disciplines that can help address those challenges. What follows is a list of key topics responsive to the workshop's primary goal. The list is not intended to cover every possible avenue for addressing the growing spectrum crisis—indeed, lines of research not specifically identified here could contribute to transformational improvements in spectrum use. For this reason, the list will evolve with time as new technology, modulated by realistic economic and regulatory policies, is developed.

The list is subdivided into broad categories. "Research," "Development & Technology Transfer," and "Experimentation & Testing" imply a logical progression from fundamental discoveries to mature solutions. However, simultaneous investments across all of these categories will be necessary to achieve the desired goals for the nation.

A consistent theme that emerged during the workshop was the need to address virtually all of the challenges across multiple disciplines. In addition to interdisciplinary issues addressed in each broad category, a category entitled "Education/Work Force Development" identifies opportunities to improve cross-disciplinary awareness of the complex factors that enter into achieving improved utilization of limited spectrum resources.

Reflecting the interdisciplinary nature of the proposed research priorities, some concepts appear under multiple headings. The order of topics within each category does not imply relative priority. To the extent possible, topic areas have been written so as to be understandable by the non-specialist.

Metrics to Quantify Spectrum Parameters Relevant to Efficiency and Access

An important component of achieving improvements in spectrum efficiency and access is an ability to measure those improvements. A variety of metrics can be used, but further research is needed to develop and advance our ability to quantify our use of the spectrum. Some fundamental metrics, such as spectrum efficiency, harmful interference, and spectrum value, have no universal definitions, despite being used in technology and regulatory discussions for decades. If future spectrum use increasingly relies upon flexible allocations, dynamic access, and agile markets for limited bandwidth, the foundation for policy decisions will be based upon proper metrics.

- Defining and measuring spectrum efficiency
- Quantitative definition of harmful interference, and its application
  - ◊ Objective standards for planning interference-tolerant systems
  - ◊ Preserving access to the spectrum for specialized services (for example, passive and science services)
- Quantifying receiver performance, especially in the context of real-world spectrum environments with multiple signals with unpredictable characteristics
- Spectrum measurement/survey/visualization techniques and standards
  - ◊ Standardized methods for measuring spectrum occupancy, accounting for temporal, spectral, and spatial complexities of ambient signals as well as the characteristics of the measurement system
  - ◊ Practicality of using highly distributed sensors (e.g., mobile devices) to provide robust statistics of spectrum occupancy
  - ◊ Detection methods for channel occupancy, including protections for “hidden nodes”
  - ◊ Development of techniques to support and maintain a national spectrum census to better gauge the overall efficiency with which spectrum is used
- Quantifying the value of spectrum
  - ◊ Economic and other value models for spectrum uses
  - ◊ Measuring the cost of using the spectrum, considering externalities, overhead, and modeling of operational expense and capital expenditures

- ◊ Quantifying the value of spectrum in dynamic and/or prioritized access environments
  - ♦ Real-time auctions and trading
  - ♦ Intermediate and longer-term trading
- Quantifying fair access to the spectrum
  - ◊ Increasing innovation by improving freedom and openness

Interdisciplinary Technology Innovation to Enable Spectrum Efficiency

New technology solutions that support enhanced access to the electromagnetic spectrum call for truly interdisciplinary and transformational research approaches. New advances in the areas of radio hardware, signal processing, modulations, protocols and access theory, interference mitigation, and propagation all need to be developed such that they will work in concert, flexibly and over time, to maximize spectrum utility for a range of users with diverse needs.

- Radio frequency interference (RFI) mitigation
  - ◊ Unilateral and cooperative RFI mitigation techniques for passive sensing and protection of spectrum incumbents
- Spectrum management/access theory and modeling
  - ◊ Mathematical models for spectrum sharing
  - ◊ Mathematical models of interference
  - ◊ Technical and economic models for flexible spectrum access
  - ◊ Simulation and modeling tool development that captures component through system-level functionality
  - ◊ Models for radio system performance with tradeoff assessment capabilities
- Reconfigurable radio hardware and components, including antennas, filters, tuners, amplifiers, etc.
  - ◊ Defining needs and capabilities of radio hardware and components, including the need for efficient spectrum-sensing techniques, direction-finding capabilities, interference nulling, frequency tunability, etc.
  - ◊ Interfaces and control schemes with links to protocols, access models, modulation schemes, propagation models, and channel/environment sensing
  - ◊ Fundamental limits of reconfigurable hardware and related system-level metrics

- Propagation and channel models
  - ◊ Integration of real-time propagation modeling and prediction in network operations to enable sharing in space, time, and/or frequency
- New access paradigms and protocols for efficient spectrum use
  - ◊ Frequency, space-, and time-cognizant protocols that dynamically leverage multifunctional radio hardware and software
  - ◊ New techniques for coexistence, avoidance, collaboration, and spectrum sharing, addressing applications such as scientific/sensing systems (e.g., radio astronomy and remote sensing), radar systems, and communications systems
  - ◊ Abilities to accommodate/incorporate future technology transitions and developments
  - ◊ Methodologies that support pre-emptive spectrum access (e.g., for emergency services, national security)
  - ◊ Determination of fundamental limits and attainable metrics for spectrum efficiency and accessibility based on system-level analyses, including technical and economic viability
  - ◊ Deliverable protocol/algorithm stability, scalability, and quality of service in various operating environments
    - ♦ Effects on existing applications and impact on user experience
    - ♦ New application development and support, including broadcast services, radionavigation, etc.
- Modulation
  - ◊ Modulation schemes that adapt in concert with other system components to enable coexistence and interference mitigation/avoidance
- New radio system design techniques
  - ◊ Design for compatibility and evolution with new regulatory, privacy, and security requirements, operating policies, economic viability and competition, technologic advances, etc.
  - ◊ Techniques for aesthetic design and deployments (i.e., reduction of tower installations)
- Policy database development
  - ◊ Encoding of domestic regulations into detailed time/space/frequency requirements

  - ◊ Investigation of scalability requirements for flexible spectrum operating models
  - ◊ Regulations that are amenable to being encoded in policy languages
- Technical/economical feasibility of channel aggregation/bonding
- Models to evaluate spectrum property rights and/or access as a function of technical capability
- Identification of proper roles for users, providers, vendors, standards bodies, and regulators
- Spectrum property rights and harmful interference
  - ◊ Spectrum usage rights and enforcement
  - ◊ Service level agreements for negotiated sharing

Spectrum Security and Enforcement

New innovative spectrum access technologies, such as the cognitive radio, promise to alleviate the spectrum shortage problem and bring about remarkable improvements in the efficiency of spectrum utilization. However, the successful deployment of such technologies and the realization of their benefits will partly depend on the placement of essential security mechanisms in sufficiently robust form to resist misuse of the technologies. The emergence of new spectrum access technologies and related spectrum access paradigms—e.g., opportunistic spectrum sharing paradigm—raise new security implications that have not been studied previously. The following list prescribes a number of key research challenges that will directly impact the trustworthiness of those technologies and their applications.

- Investigate tradeoffs in security, privacy, and implementation complexity in spectrum sharing protocols and mechanisms
- Hardware and software technologies for enforcing spectrum rules/etiquettes
- Investigate social, resource, and policy tradeoffs in spectrum security
- Vulnerability studies of flexible spectrum access systems and development of countermeasures
- Techniques for identifying, deterring, and punishing noncompliant radio devices
- Analysis and management of trustworthiness, reliability, and quality of service

Spectrum Allocation/Assignment: Market and Nonmarket Mechanisms

New levels of use of the electromagnetic spectrum require that this valuable and often scarce resource be allocated efficiently and fairly. Therefore, interdisciplinary research in the areas of market- and non-market-based mechanisms for spectrum access and usage needs to be pursued. This research will tie economic models to functional hardware and software so that future wireless systems can fulfill the promise of enhanced and flexible access for all spectrum users.

- Market/institutional design and stakeholder analysis
- Defining property rights, and mechanisms to enforce those rights
- Models and techniques for assignment and reassignment of spectrum
    - ◊ Secondary markets/subleasing
    - ◊ Flexible contracting and cooperative sharing (multilateral contracting, club goods)
    - ◊ New kinds of unlicensed use
- Real-time auctions
    - ◊ Support for real-time auctions within protocol stacks for spectrum-using devices
    - ◊ Mathematical models/simulations of the use of real-time auctions for spectrum use
- Auction incentives and strategies, and alternative auction design (royalty, interference)
- Auction alternatives including voting, spectrum fees, lotteries, barter, etc.
- Spectrum valuation
    - ◊ Value in dynamic settings
    - ◊ Intermediate to longer-term trading
- Relocation incentives
    - ◊ Interruptible spectrum
    - ◊ Spectrum recovery and enforcement
- Micropayments
- Bundled/complementary goods markets (e.g., equipment-based spectrum sharing)
- Sharing between commercial and noncommercial users/uses (nonprofit motivated)
    - ◊ Pre-emptible spectrum sharing models

Green Technology

Given the major changes that the innovative spectrum access technologies will require of communication system design, it is important to understand how these new design paths will eventually impact the environment. For instance, growth of wireless system deployment is greatest in the developing world, yet for many of these countries, particularly those with under-developed power grids, polluting diesel power is used to power the infrastructure. The incorporation of renewable sources of energy and provisioning within the design of these new communications systems means that lower-power and less consistent sources of energy should have a major impact on the design of these systems. Likewise, reducing the dependency on rechargeable batteries containing substances that are difficult to dispose of should also drive future designs.

- Environmental impact of new radio technologies, both from an operational and manufacturing perspectives
    - ◊ Energy reduction and reliance on less consistent forms of energy
    - ◊ Waste produced by the manufacturing process, operation, and disposal
    - ◊ Sustainability through the use of renewal and lower-output energy devices such as energy harvesters
- Protection of human and animal health/well-being by understanding the possible health ramifications of radiation from the new spectral access techniques

New Frontiers and Research That May Lead to Transformational Improvements in the Use of the Radio Spectrum

- Inferential propagation models (e.g., models that allow the prediction of signal loss at one frequency from measurements at another)
- Using millimeter-wave signals (frequencies above 30 GHz) for mobile communications
- Communications at frequencies above 275 GHz, where spectrum allocations presently do not exist
- Improved radiolocation (geolocation using radio techniques) in challenging environments, especially indoors
    - ◊ Extending availability and accuracy of radionavigation satellite coverage (e.g., GPS) to indoor environments

- ◊ Improvements in availability and accuracy of radionavigation satellite coverage (e.g., GPS) in very challenging outdoor environments, such as urban canyons and dense foliage

7.2 Development and Technology Transfer

In the past few decades, the United States Government has advanced a number of important initiatives—such as the Federal Technology Transfer Act of 1986—to encourage technology transfer and stimulate the commercialization of technologies. To ensure that knowledge, technologies, and methods of manufacturing resulting from research in next-generation spectrum access technologies are shared and accessible to a broad range of spectrum stakeholders (e.g., government agencies, industry, and academia), additional measures, above and beyond existing initiatives, need to be taken. The following list prescribes a number of key challenges that need to be addressed in order to support the development and technology transfer of spectrum access technologies that are vital to achieving improvements in spectrum efficiency and access.

Next-Generation Developments in Smart Radios, Including Software-Defined Radios and Cognitive Radio Systems

- Improvements in smart radio architectures
- Development of robust smart radio hardware components, such as reconfigurable and/or wideband transmitters/receivers/antennas
- Integration of smart radio hardware components
- Methods for ensuring smart radio compliance with spectrum policy
- Development of a standardized, modular, low-cost radio platform for flexible/dynamic spectrum access that will be adaptable to research developments in hardware, software, and policy
- Development of programs to promote collaboration among spectrum stakeholders (e.g., industry, academia, government agencies)
    - ◊ Expanded use of Grant Opportunities for Academic Liaison with Industry (GOALI) awards
    - ◊ Funding for academic/industry advisory boards
    - ◊ Travel grants to accommodate academic liaisons to standards committees and coordination bodies

◊ Encouragement of Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) awards

◊ Investigate avenues that encourage transfer of academic intellectual property to domestic industries

◊ Education of the spectrum management workforce on new paradigms for spectrum access

7.3 Experimentation and Testing

Testing of new technology through large-scale experimentation is going to be absolutely essential before these technologies are allowed by regulators and adopted by companies. Regulators will want to make sure that the new technologies will not cause harm to legacy systems, are robust and secure, and are efficient users of the spectrum before they act, especially given the large paradigm change these technologies offer. Incumbent users of the spectrum will need to see these technologies working without harm to their systems, and results must be demonstrated to a broad number of users in all regions of the country to have buy-in. Close collaboration with the FCC, NTIA, and perhaps international regulatory agencies along with industry will need to play a significant role in the research program.

Creation of Wireless Test Beds and Demonstration of New Concepts

- Clearly defined goals and metrics, allowing for quantifiable advances in spectrum efficiency, hardware, software, and policy
- Development of advanced test beds with programmable/adaptable capabilities using advances in hardware, software, and policy
- Large-scale test beds (for example, in expansive and relatively remote locations), capable of facilitating tests with full system loads under realistic conditions
- Large-scale demonstrations with FCC/NTIA collaboration to demonstrate compatibility of new techniques with legacy systems
- Standardization and collaboration of current and future test beds (logically or physically) to allow for remote access for many researchers and facilitate an easily used experimental infrastructure

- Proofs-of-concept demonstrations covering a variety of bands, applications, and geographical areas
  - ◊ Research and prototype new systems that demonstrate coexistence with legacy systems
  - ◊ Experimental mechanisms for scalability proof to understand issues that may arise in large-scale adoption of the new technologies
  - ◊ Greater efficiency compared to old systems, in areas such as energy, spectrum usage, and monetary costs
  - ◊ Creation of open-source hardware/firmware/software to drive further innovation and facilitate rapid transition of research to products
- Creation of a robust information infrastructure (e.g., real-time spectrum sensing database, information repository) to distribute and share operational information and results of the test bed experiments
- Virtual test beds, including the use of computer simulations to model large-scale spectrum sharing among new and legacy technologies
- Transitioning of test bed results to real-world testing and commercial-scale demonstrations, through, for example, NSF programs such as the Grants for Academic Liaisons with Industry (GOALI) and Industry & University Cooperative Research Programs (I/UCRCs)

Development of Methods to Create and Maintain a Comprehensive Spectrum Survey and Inventory

- Incorporation of feedback from cognitive networks
- Availability of near-real-time surveys/inventories
- Development and storage of statistical data on spectrum use

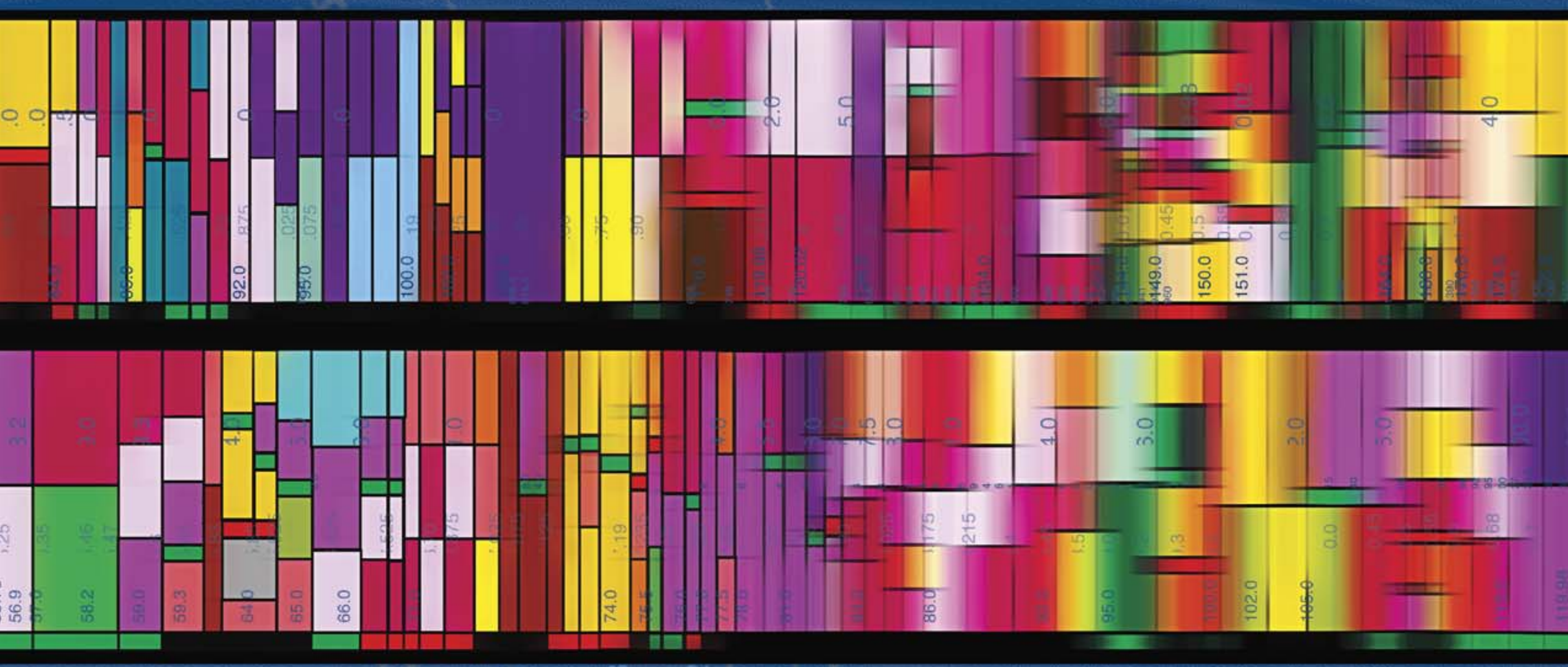
Development of Simulation Tools Relevant to Spectrum Efficiency and Access

- Simulation tools and software at all technology levels
- Simulation tools for evaluating the economic and technical tradeoffs in spectrum sharing
- Large-scale network simulations for dynamic spectrum access with adaptability as new capabilities in hardware, software, and policy emerge

7.4 Education/Work Force Development

Shaping the workforce to master technology and promote innovation is perhaps the most important mission that NSF plays. Certainly with the paradigm changes that these technologies offer in spectrum efficiency, enabling new applications and challenging the old ways of regulating the spectrum will require changes in education in a variety of fields. Furthermore, new links are needed between fields that have historically been distinct. The breadth of the changes in education is significant, but the depth of these changes is also significant. Educational initiatives at the university level as well as in professional education for the existing workforce are necessary to adapt to the new technology changes. These new spectrum technologies are also a great example of how technology will impact economics, social relationships, and business models, and this is an excellent lesson for high school and middle school students to study.

- Education of future interdisciplinary leaders and workforce (including undergraduate and graduate students) who can advance the state of the art in spectrum management and resource utilization
- Development of spectrum policy and regulatory teaching materials suitable for incorporation in engineering/computer science curricula
- Development of teaching material covering technical issues relevant to spectrum use suitable for incorporation in economics, social sciences, and legal curricula
- Support for interdisciplinary courses and workshops for professionals that work in relevant areas
- International exchange programs that enable new perspectives in spectrum management



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