Agency	Department/Division	Project Title	Project Number	Abstract	Topic Category(-ies)	Application Environment	Frequency Range	TRL/Maturity	Size	Status	Point of Contact	Sponsor	Additional Comments
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Distributed and Embedded SOTM Standard Terminal Architecture (DESSTA)	no-value	Research and develop cost effective technologies and methods for development of distributed and embedded SATCOM tactical terminals. Products include: (1) Vehicle Trade Study, (2) Open Standard Interface & Architecture(OSA) for the Distributed Terminals, (3) Prototype Distributed Terminal that targets WIN-T and Bradley M2A3 requirements, (4) Test and Evaluation Criteria for OSA.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Advanced RF Research & Compatibility (ARRC)	no-value	Investigate novel filtering techniques to reduce RF cosite interference, and develop hardware to prevent degradation in communications system operations in the presence of other co-site emitters	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC I2WD	Ground Moving Target Indicator Foilage Penetration (GMTI/F)	no-value	As part of the Ground Moving Target Indicator Foilage Penetration (GMTI/F) program, provide waveform diversity for spectrum-compliance and an open, flexible architecture for alternative mode development.	Technologies and applications for efficient spectrum use or legacy transformation	aeronautical	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Directional Networking Technologies	no-value	Develop a low-cost integrated directional networking (DN) capability including DN algorithms, DN antennas and enhancements to enable operation in contested/congested environments. Use of DN will enable greater frequency reuse and increase spectrum efficiency.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Future Advanced SATCOM Technologies (FAST)	no-value	Develop, mature, and demonstrate wideband digitization of Satellite Communications (SATCOM) signals at a common intermediate frequency to significantly improve terminal performance and bandwidth utilization, significantly reduce terminal Size, Weight and Power (SWAP), and greatly improve satellite resource management capabilities.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Integrated EW/Comms	no-value	Spectrum sharing between Communications (Comms) and Electronic Warfare (EW) systems through a coordinated real-time scheduling approach.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC I2WD	Next Generation Fires - Fires Open Systems Technology (FROST)	no-value	The purpose of the project is to develop the architectures, processing and components necessary to deliver next generation capability, flexibility and supportability to the FIRES family of radar systems.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Next Generation Waveform Interference Cancellation	no-value	Develop generic interference cancellation (IC) techniques for mitigating the effects of interference at the radio receiver.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Real-time Spectrum Situational Awareness	no-value	Develop algorithms, techniques, and standardized data models/interfaces to fuse disparate, incomplete, and conflicting spectrum data to populate spectrum databases and present spectrum situational awareness (SA) to the Commander based on: Real-time sensed spectrum data; Real-time position location and radio state data; Mission Command data (DDS, etc.)	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC I2WD	RF Converged Architecture (RCAD)	no-value	Integrate and demonstrate Communications, Electronic Warfare, and sensing capabilities into a multi-function architecture. Focus will be given to both demonstrating capabilities using existing hardware as well as maturing and refining the Modular Open RF Architecture (MORA) specification to include additional mission areas. The converged RF architecture will serve as an enabler to various approaches to share spectrum among disparate mission areas.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	Universal Adaptive PHY	no-value	Develop spectrally efficient modular adaptable Physical Layer (PHY) with the following characteristics: (1) Homogenous with DoD channelization, (2) Support wideband and narrowband operation, (3) Flexible resource allocation and noncontiguous channels, (4) Offer variable data rate depending on the available spectrum and mission requirements.	Technologies and applications for efficient spectrum use or legacy transformation	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	Army/RDECOM CERDEC S&TCD	MANET Real Time Frequency Management (MRFM)	no-value	Provides more efficient means of spectrum assignment to alleviate spectrum congestion. Uses node position information to deconflict and reassign frequencies to mobile networks in real time. Matures MRFM control technology and integrates it into relevant network management tools.	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure	terrestrial	no-value	no-value	no-value	ongoing	usarmy.apg.cerdec.mail.cerdec@mail.mil	no-value	no-value
Department of Defense (DoD)	AF/AFRL/RIT	Next-generation Software Defined RF (SDRF++)	no-value	Project Objective: Create and develop affordable, dynamic, next generation, multi-mission software defined RF capabilities tailored with resilient spectrum manuverability over broad, discontiguous RF bands to enable cyber-secure, on-demand quality of service, and dynamically adjusted for threat conditions. Project Synopsis: - Component-based rapid waveform development and visualization- Research and develop innovative software, waveforms and modular components, developer guides, reference designs and automated tools to rapidly model and visualize waveforms, create executable specifications from a waveform description language (WDL), and autogenerate code for target hardware. -Affordable secure SDRF systems with multi-mission RF capability that create an affordable government-owned hardware design approach with a continuum of hardware instantiations from low-end COTS Universal Software Radio Periphera(USRP), to mid-range FPGA-based hardware, to high-end mission-ready SDRF products with embedded crypto. --5x reduction in development cost/schedule for new waveform capability --5x reduction in platform integration cost by enabling flexible adaptation to existing apertures. Potential broader impacts: - Resilient spectrum maneuverability to adapt to changing frequency policies and mission constraints -Assured communications for elastic networking in contested environments -Low cost eco-system for gov-industry-academia Keywords: Software Defined Radio, waveform description language (WDL), FPGA, USRP, waveform development and visualization.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management; Integration of DSA networks and the Internet or other infrastructure; Modeling and Simulation; Education and outreach	general	various	TRL-3; TRL-4; TRL-5; TRL-6	Large	ongoing	Michael Gudaitis / michael.gudaitis@us.af.mil / 315-330-4478	AF/AFRL/RIT	Demonstrated interoperability between operational DoD Common Data Link (CDL) systems and COTS software defined radios (e.g. BladeRF and USRPs).
Department of Defense (DoD)	AF/AFRL/RIT	Aerial Layer Networking (ALN)	no-value	Project Objective: Improve AF networks by focusing on Network Centric Elements that help create a more Agile, Adaptable, Programmable, and Secure, Aerial Layer Network in support of the AF Combat Cloud concepts and enabling Network & Spectrum C2. Project Synopsis: - New Orderwire Capability: Fill existing "holes" in network messaging with low-BW protocol for spectrum & network situational awareness & management across heterogeneous networks (IP/Non IP/Other Tactical) - Provide "Technical Advisor" (adjunct to decision-maker) to a Multi-TDL Arch planning, monitoring, and link diagnostics tool to compare network performance and plan to mission data and increase agility in decision-making - Enable sharing of black core network among user elements belonging to different security classification levels. - Develop SW tools in support of mission operations that are 1) unable to achieve continuous network connectivity for voice and data exchange due to sub-optimal airborne coverage and 2) incapable of prioritizing the most useful class of service (e.g., text/chat) needed to most effectively execute their mission. - Distributed Software Defined Networking affectivity study and demonstration on wireless airborne Network Configuration. Potential broader impacts: - Technology developments aligned with overarching JALN concept - Partnered with DARPA; AFLCMC/EBS,EBM,EBJ; AFLCMC/HNA,HNC; and JALN Council - Proof of Concept (V&V) for future Joint Aerial Layer Network - Tactical network resilience & agility targeting transition to ACC Tactical Edge Network Command & Control (TEN C2) initiative Keywords: Software Defined Networking, low BW control, heterogeneous networks, network & spectrum C2	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	general	various	TRL-4; TRL-5; TRL-6	Large	ongoing	Robert Husnay / robert.husnay@us.af.mil / 315-330-4821	no-value	PA #88ABW-2016-3542
Department of Defense (DoD)	AF/AFRL/RIT	Assured Access Communications (AAC)	no-value	Project Objective: Insufficient comms in RF contested domains --Fixed, static allocation of communication resources -- Resource allocation decoupled from mission requirements --Inadequate Low Probability of Intercept (LPI) & Anti-Jam (AJ) Project Synopsis: Program develops advanced agile communications waveforms, mission-responsive routing techniques for joint spectrum-sharing, compact beamforming antennas for networking in A2AD environments. --Advanced comms waveform/technology - spectrum-efficient bandwidth augmentation and coop comms -- Modular, affordable, compact digital beamforming antenna with directional data link and net capabilities -- Mission-responsive dynamic resource allocation, optimal routing/channelization in time/freq/space/code -- Development of COTS-based comms signal modeling and dev for Electronic Warfare (EW) T&E facilities--Tool support to automate design process transforming written waveform specs into platform-specific SDRs Potential broader impacts: -- Robust Communications: Adaptive filtering, beamforming and directional antennas, and dynamic/covert single-user and multi-user/multiple-access interference-tolerant waveform design -- Mission-Responsive Agile Communications: Dynamic spectrum access/awareness, cooperative comms, mission-driven error protection/resource allocation, and directional wireless mesh networks --Deliverable: Small-scale network comms demo at Stockbridge Test Facility under various jamming and mobile node over-the-air scenarios.Keywords: anti-jamming, routing, beamforming, spectrum-sharing.	Technologies and applications for efficient spectrum use or legacy transformation	general	various	TRL-5; TRL-6	Large	ongoing	Dr. Michael Medley / michael.medley@us.af.mil / 315-330-4830	no-value	PA #88ABW-2016-3542
Department of Defense (DoD)	AF/AFRL/RIT	Wideband Comm. Links for Contested Environments (WBCLCE)	no-value	Project Objective: Provide wideband airborne secure communication connectivity for the relay of ISR sensors data in contested and highly contested environments. - Current communication links lack reliable operation in contested and highly contested environments. - There is a need to build secure high speed data links with multi-band resiliency for future combat operations. Project Synopsis: Supports multiple sensor types such as RF, Laser, and IR to overcome contested environment challenges for both LOS and BLOS connectivity. - QKD: Develop Quantum Key Distribution in concert with a multi-access laser comm. system - Flexible Data Link: Develop Flexible link for contested environments that reconfigures waveform characteristics on-the-fly based on engagement environment & spectrum conditions - MIMO: Use large MIMO (64x64) techniques to demonstrate high fidelity and high spectral efficiency system - V/W-band Comm: Develop and test attenuation prediction models; Reduce the uncertainty and extend the dynamic range of radiometer-based measurements of VW band attenuation statistics -- Measure elevation angle dependence of attenuation statistics -- Measure Site Diversity gain for VW band Potential broader impacts: - Continuous connectivity: Provides continuous connectivity in contested environments using waveforms that adapt to combat environments - High data rates: Provides high speed back haul connectivity to support high volume ISR data - Deliverables: -- Secure multi-Gbps RF modem, High speed hybrid RF-optical controller, V/W-band space comms, Large Aperture MIMO air to ground links, Quantum Key Encryption for airborne platforms -- Will provide 50% greater availability of RF-optical links, definable end to end V/W SATCOM architecture, 20X MIMO spectral efficiency, alternate BLOS paths for relay, secure encrypted communications using QKD Keywords: wideband comm, MIMO, multi-band RF-optical systems.	Technologies and applications for efficient spectrum use or legacy transformation	general	various; V-bands; W-bands; 71000 MHz - 76000 MHz; 81000 MHz - 86000 MHz	TRL-3; TRL-4; TRL-5	Extra-Large	ongoing	Mr. John Malowicki / john.malowicki@us.af.mil / 315-330-3634	no-value	PA #88ABW-2016-3542
Department of Defense (DoD)	AF/AFRL/RIT	Stockbridge Spectrum Experimentation, Verification & Validation	no-value	Project Objective: Understand complex RF interactions in congested environments, and develop near-term techniques to co-exist and enable future spectrum-sharing strategies Project Synopsis: -Build upon existing facilities, design and implement an enhanced RF environment to assess the impact of commercial & DoD systems - Measure & model the complex RF interactions of commercial & DoD systems (refined channel estimation/interference models; e.g. LTE) - Assess operational/mission impact on DoD systems; e.g., small UAS datalinks, Rifleman Radios (SRW), TTNT - Design, implement, and test efficacy of near-term interference mitigation techniques (e.g. commercial co-existence and multi-mission sharing) Potential broader impacts: - Cost effective flexible experimental facility -- 300 acre flexible test site, varying in relative distance, topology and foliage density -- Flexible frequency authorizations - Deliverable: Baseline for spectrum SA with up-to-date, valid characterization in relevant over-the-air RF signaling environments Keywords: measurement, modeling, spectrum access, sensing, RF experimentation, spectrum-sharing, spectrum situational awareness.	Methods, processes and toolsets for technology development and management; Test and Measurement; Modeling and Simulation; Education and outreach	general	various	various	Large	ongoing	John Heinig / john.heinig.1@us.af.mil / 315-330-7227	no-value	PA #88ABW-2016-3542

Department of Defense (DoD)	AF/AFRL/RIT	Heterogeneous Operationally Responsive Networks (HORNets)	no-value	Project Objective: - Develop cross-domain operationally-responsive network technologies to enable mission-specific, adaptive optimization of information exchange capabilities. - Provide advanced air/space/ground, mission responsive networked communications capability. Project Synopsis: Program develops cross-domain operationally-responsive network technologies to enable mission-specific, adaptive optimization of information exchange capabilities, and provide advanced air/space/ground, mission responsive networked communications capability. Enables a robust, dynamic and adaptive tactical edge network offering seamless warfighter information exchange capabilities, mission responsive/autonomous/self reconfiguring cognitive network capability, a 10-fold throughput improvement over current mobile ad-hoc networking approaches. Mbps total throughput vs Kbps, reduced support/manpower requirements, and improved availability and resilience in contested environments. - Cognitive networking capabilities based on distributed routing and spectrum allocation schemes - Dynamic, distributed, protocols providing mission responsive tactical networking - Jam resistant cognitive networking through adaptive response and reconfiguration.Potential broader impacts: - Provides a robust, dynamic and adaptive tactical edge network, offering seamless warfighter information exchange capabilities. - Mission responsive, autonomous, self reconfiguring cognitive network capability - 10-fold throughput improvement over current mobile ad hoc networking approaches - Mbps total throughput vs Kbps -- Reduced support/manpower requirements -- Improved availability and resilience in contested environs - Deliverable: -- FY16 (TRL 5) capability to dynamically route using multiple spectrum/waveforms.	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure	general	various	TRL-4; TRL-5	Large	ongoing	Stephen Reichhart / stephen.reichhart@us.af.mil / 315-330- 3918	no-value	PA #88ABW-2016-3542
Department of Defense (DoD)	DARPA/MTO	Adaptive RF Technologies (ART) - Cognitive Low Energy Signal Analysis ICs (CLASIC)	no-value	Program aims to implement extremely low energy signal classification techniques for SIGINT applications. Of particular interest are signals for which no a priori information is available, i.e. blind classification. Maximum energy per signal classified is targeted at 0.25 J for a 500 MHz input bandwidth containing as many as 20 distinct signals.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	complete d	Dr. Roy Olson / roy.olsson@darpa.mil / 703-526-2702	no-value	Performers will deliver hardware implementing low energy classification algorithms in addition to various channelization methods designed to lower power consumption and ease the computational burden. This hardware will be tested by an Demonstrations relevant to this data call include an electronic-photonic RF signal source at 20GHz output frequency with integrated jitter of 10fsec. Other demonstrations (ultra-low linewidth laser and LADAR system) are not relevant to this data call.
Department of Defense (DoD)	DARPA/MTO	Diverse Accessible Heterogeneous Integration (DAHI) - Electronic-Photonic Heterogeneous Integration (E-PHI)	no-value	E-PHI is developing novel heterogeneous integration technology to enable revolutionary electronic-photonic integrated circuits in which high-performance optoelectronic devices using III-V materials are integrated at the device-level with Si CMOS on a Si substrate. E-PHI is developing the processing techniques, design concepts, and design methodologies to enable the design of novel electronic-photonic integrated circuits.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	ongoing	Dr. Dan Green / sanjay.raman@darpa.mil / 571-218-4339	no-value	Demonstrations include a 13-bit DAC with SFDR averaging 74.5dBc over a frequency range of 0.75 - 1.25 GHz (achieved 3QFY11), an ultra-wideband DAC 26Gsps with 30dB SNDR and 6GHz bandwidth, and an ultra-wideband ADC with 43db SINAD across 8GHz bandwidth centered at 19.2GHz.
Department of Defense (DoD)	DARPA/MTO	Diverse Accessible Heterogeneous Integration (DAHI) - Compound Semiconductor Materials on Silicon (COSMOS)	no-value	COSMOS is developing novel high-performance DACs and ADCs using novel heterogeneous integration processes to combine InP HBTs with Si CMOS on a Si substrate. COSMOS is developing the novel heterogeneous integration processes as well as the circuit design concepts and techniques which take advantage of the high performance of InP HBTs (higher speed and breakdown voltage) and the integration complexity of Si CMOS (enables digitally assisted calibration techniques for correcting static and dynamic errors in situ).	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	complete d	Dr. Dan Green / daniel.green@darpa.mil / 703-526-2787	no-value	Performers will deliver MEMS filter hardware capable of spectrum channelization at high frequencies and demonstrate extremely fast (5600 GHz/s) spectrum sensing and parsing for potential dynamic
Department of Defense (DoD)	DARPA/MTO	Adaptive RF Technologies (ART) - Chip-Scale Spectrum Analyzers (CSSA)	no-value	Program aims to advance the state of the art in acoustic MEMS filters for the purposes of low-loss narrow-band channelization of the RF spectrum. Bandwidth tunable banks of CMOS-compatible filters covering up to 6 GHz are currently under investigation.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	complete d	Dr. Roy Olson / roy.olsson@darpa.mil / 703-526-2702	no-value	Several self-healing designs exhibiting high performance yield will be delivered to the DoD as a result of this program. For example, BAE is developing a 0.5 - 18 GHz self-healing EW receiver with an
Department of Defense (DoD)	DARPA/MTO	Self-HEALing Mixed-Signal Integrated Circuits (HEALICs)	no-value	Program aims to recover mixed-signal circuit performance lost to long-term ageing effects and the variability inherent in any deep sub-micron semiconductor fabrication process by integrating in situ self-healing techniques capable of sensing and correcting deviation from expected performancein real time. Ultimate goal is the realization of 95% performance yield for state of the art ADCs, PAs, and transceivers with a power consumption overhead of no more than 5% over a non-healing baseline.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	complete d	Kerry Bernstein / Kerry.Bernstein@darpa.mil / 703-526-2117	no-value	integrated interleaved ADC exhibiting 66 dB of SFDR at 3 GS/s with an instantaneous bandwidth of 1 GHz.
Department of Defense (DoD)	DARPA/MTO	RF Photonic Technologies (RPT) - Transmit and Receive Optimized Photonics (TROPHY)	no-value	The program aims to produce a photonic mixer capable of converting frequencies in the range of 20 - 100 GHz down to 1 GHz. The program will develop discrete photonic components and an integrated solution for both transmit and receive side of the link.	Technologies and applications for efficient spectrum use or legacy transformation;	no-value	no-value	no-value	no-value	complete d	Dr. Josh Conway / Joshua.Conway@darpa.mil / 703-696-2374	no-value	The program will deliver hardware for up- and down-converting of RF signals to an intermediate frequency where electronics are well-suited to process the data. The program will deliver hardware for
Department of Defense (DoD)	DARPA/MTO	Adaptive RF Technologies (ART) - Analog Signal Processors (ASP) and follow-on studies	no-value	Program aims to develop widely tunable pre-selection filters with low SWaP for the purposes of developing a 5 channel receiver with a volume less than 100 cc. Successfully developed VHF, UHF, L-, S, and C-band tunable filters covering a contiguous frequency range of 20 MHz - 6 GHz with insertion loss less than 4 dB across all frequencies. A follow-on effort is exploring the concept of fully field reconfigurable filters with high power handling and tuning to ~30 GHz.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	complete d	Dr. Roy Olson / roy.olsson@darpa.mil / 703-526-2702	no-value	Rockwell Collins (RCI) demonstrated a working 5 channel receiver complete with a 5 GHz/sec spectrum sensor. Purdue has demonstrated several functional field-programmable filter arrays capable of arbitrary filter transfer function synthesis on the fly.
Department of Defense (DoD)	DARPA/MTO	Adaptive RF Technologies (ART) - Feedback Linearized Amplifiers for RF Electronics (FLARE)	no-value	Program aimed to combine the high ft/fmax capabilities of Teledyne Scientific's (TSC) InP BiFET process with traditionally low frequency design techniques such as current-feedback to realize high linearity operational amplifiers at S-band frequencies. Maximum achieved OIP3 was 55.7 dBm with a power consumption of 1.36W at 2 GHz.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	complete d	Dr. Roy Olson / roy.olsson@darpa.mil / 703-526-2702	no-value	Example configurations include bandpass-bandstop cascades or Program was to deliver connectorized versions of the high-linearity amplifier before the end of the program; however packaging issues
Department of Defense (DoD)	DARPA/MTO	RF Photonic Technologies (RPT) - Remoted Analog-to-Digital Converter with De-Serialization and Reconstruction (RADER)	no-value	The program aims to produce an analog-to-digital converter capable of 10 effective number of bits at a bandwidth of 10 GHz. Both discrete and integrated photonic subsystems are being pursued.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	complete d	Dr. Josh Conway / Joshua.Conway@darpa.mil / 703-696-2374	no-value	delayed delivery. A follow-on program is underway to implement true time-delay phase shifters with this technology. A new InP BiFET The program will deliver a photonic-electronic ADC capable of sampling with < 10 fs jitter. The system will enable 9 ENOB across
Department of Defense (DoD)	DARPA/MTO	Adaptive RF Technologies (ART) - RF-FPGA	no-value	Program aims to develop widely reconfigurable and tunable RF components and transceivers with the ultimate goal of eliminating the costly design cycles that often accompany the deployment of a new communications standards or anti-jamming techniques. Computer aided design techniques that can optimize the design trade-space are also under exploration.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	ongoing	Dr. Roy Olson / roy.olsson@darpa.mil / 703-526-2702	no-value	10 GHz of instantaneous bandwidth. Performers are implementing designs that are capable of reconfiguration for at least 5 RF waveforms (comms, radar, etc.) at
Department of Defense (DoD)	DARPA/MTO	A-to-I LookThrough	no-value	Simultaneous monitoring of 10-15 GHz RF frequency bands and mitigation of electronic fratricide.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	ongoing	Dr. Daniel Purdy / daniel.purdy@darpa.mil / 571-218-4646	no-value	the factory or on the fly in the field. Performers will be tested on their ability to configure for a unknown standard without the benefit Ultra-wideband digital radio frequency (RF) receivers based on Analog-to-Information Converter (AIC) technology and broadband/linear/efficient/high output power transmitters based
Department of Defense (DoD)	DARPA/STO	Wireless Network after Next (WNaN) Program	no-value	The WNaN program developed a ground tactical communications with advanced capability, functionality, network reliability, and affordability. WNaN: (1) Employs Dynamic Spectrum Access (DSA) capability; (2) Enhances mobile network connectivity by using Disruption Tolerant Networking (DTN) technology; (3) Implements many novel front-end filtering designs; and (4) Implements Mobile MIMO	Technologies and applications for efficient spectrum use or legacy transformation;	no-value	no-value	no-value	no-value	complete d	no-value	no-value	Scaleable soldier radio that can scale to 100+ nodes, operate over 800 MHz - 6 GHz, that is cost affordable consisting of 4 transceivers with throughput up to 8 Mbps
Department of Defense (DoD)	DARPA/STO	Mobile Ad hoc Information Network GATEway (MAINGATE) Program	no-value	MAINGATE is an integrated network radio system that combines a highly mobile, DSA enabled, high capacity Internet-like wireless network with a gateway that permits integration of dissimilar US, Coalition and First Responder radios to seamlessly communicate among each other.	Technologies and applications for efficient spectrum use or legacy transformation;	no-value	no-value	no-value	no-value	complete d	no-value	no-value	Combined radio and gateway communication system that interfaces to many legacy and civilian radio networks. The MAINGATE self-assembles a radio network backbone for mid-tier routing capability
Department of Defense (DoD)	DARPA/STO	Advanced Wireless Networks for the Soldier (AWNS) Program	no-value	This program integrates multiple activities associated with the WNaN radio resulting in a Soldier Information System (SIS). AWNS includes: 1) completion of the WNAN radio hardware, firmware, and networking software, 2) integration of the Soldier Radio Waveform (SRW) for backward interoperability to legacy communication systems; 3) hardware and software interfaces to commercial communication devices; 4) network communication and infrastructure support for the Transformative Applications program, including Wireless Distributed Computing, and Content Based Access, and 5) enhancements to the radio physical layer communications capabilities from the distributed the MNM and DIMA programs into the WNaN radio, as well as the integration of Smart Antenna capabilities.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	complete d	no-value	no-value	Demonstrations of integrated soldier radio technologies including range extensions and data capacity improvements, integrated applications, user interface, and improved antennas.
Department of Defense (DoD)	DARPA/STO	Free space Optical Experimental Network Experiment (FOENEX)	no-value	FOENEX developed the requisite technologies and demonstrated 10 Gigabit per second air-to-air & air-to-ground communications networking among 4 air / ground platform separated by ranges >= 200 kilometers and > 100 km, respectively, and under high turbulence atmospheric conditions	Technologies and applications for efficient spectrum use or legacy transformation;	no-value	no-value	no-value	no-value	complete d	no-value	no-value	Demonstrated 10 Gbps over 200 km air-to-air radio network of 3 nodes that is scaleable.
Department of Defense (DoD)	DARPA/MTO	Behavioral Learning for Adaptive Electronic Warfare (BLADE)	no-value	The BLADE program is developing a highly adaptive Electronic Attack system that can rapidly detect and characterize new radio threats, synthesize new countermeasures, and provide accurate EW battle damage assessment in near real time. The goal is to provide enhanced spectrum situational awareness and produce highly efficient and targeted jam waveforms that allow US forces to strategically control the use of the electromagnetic spectrum within an area of interest.	Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	ongoing	Paul Tilghman / paul.tilghman@darpa.mil / 703-526-4767	no-value	Software upgrades to existing EW systems which enable cognitive functionality
Department of Defense (DoD)	DARPA/STO	Advanced RF Mapping (RadioMap)	no-value	RadioMap seeks to provide real-time awareness of radio spectrum use across frequency, geography and time. The program plans to provide this information in part by using radios deployed for other purposes, like data and voice communications systems. The program aims to develop ways to use the capabilities of modern radios to sense the spectrum without harm to their primary mission. More broadly, RadioMap seeks to enable addition of a range of secondary capabilities to tactical radios or other RF devices, affordably providing the dense network of sensors and transmitters needed for new EW functions and for universal access to EW capabilities at lower DOD echelons.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement; Modeling and Simulation	general	no-value	no-value	no-value	ongoing	Dr. Joseph Evans / joseph.evans@darpa.mil /571-218-4446	no-value	Demonstrations scale up to RF mapping of a 9 square mile dense urban area in CY2014. Deliverables include a software module that can be ported onto RF devices to enable them to join the sensor network, and server software that fuses information from the RF devices and outputs the map to users or other systems.
Department of Defense (DoD)	DARPA/STO	Computational Leveraging Against Surveillance Systems (CLASS)	no-value	CLASS provides anti-exploitation technology for military communications applications. CLASS develops integrated circuit radio technology to provide advanced signal complexity, spatial diversity of distributed radios and interference exploitation to force adversary exploitation systems into cost prohibitive levels of computation.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	ongoing	Dr. Ted Woodward / theodore.woodward@darpa.mil / 571-218-4452	no-value	Integrated circuit technology to distribute communications over multiple platforms to provide unprecedented signal complexity
Department of Defense (DoD)	DARPA/STO	Mobile Hotspots	no-value	Mobile Hotspots is developing high capacity point-to-point links at millimeter-wave frequencies for use as a mobility backbone capable of delivering tactical communications capacity to the warfighter at the company level and below. The program will investigate innovative approaches to produce steerable millimeter-wave antennas, high efficiency millimeter-wave amplifiers, and mobile networking to create and demonstrate a reliable backbone with data rates at or beyond 1 Gb/s between aerial, mobile and fixed nodes.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement; Modeling and Simulation	general	no-value	no-value	no-value	ongoing	Dr. Joseph Evans / joseph.evans@darpa.mil / 571-218-4446	no-value	A 1 Gbps millimeter wave link that will serve as a tactical backbone. The system will consist of pointing, acquisition, and tracking for the antennas, efficient power amplifiers of > 10W, and a fully network transceiver system along with discovery radio. The entire system will fit inside a Shadow-compatible pod.
Department of Defense (DoD)	DARPA/STO	Shared Spectrum Access for Radar and Communications (SSPARC)	no-value	The Shared Spectrum Access for Radar and Communications (SSPARC) program seeks to improve radar and communications capabilities through spectrum sharing.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security; Test and Measurement; Modeling and Simulation	general	no-value	no-value	no-value	ongoing	Dr. Joseph Evans / joseph.evans@darpa.mil / 571-218-4446	no-value	The SSPARC program seeks to support two types of spectrum sharing. * Spectrum sharing between military radars and military communications systems ("military/military sharing") increases both
Department of Defense (DoD)	DARPA/MTO	Adaptive Radar Countermeasures (ARC)	no-value	The goal of the Adaptive Radar Countermeasures (ARC) program is to provide effective electronic countermeasure (ECM) techniques against new or unknown threat radars. Current airborne electronic warfare (EW) systems rely on the ability to uniquely identify a threat radar system to apply an appropriate preprogrammed countermeasure technique which can take many months to develop. Countering radar systems is increasingly challenging as digitally programmed radars exhibit novel behaviors and agile waveform characteristics. ARC will develop new processing techniques and algorithms that adapt in real-time to generate suitable countermeasures. Using techniques such as state modeling, machine learning, and system probing, ARC will learn the behavior of the threat system, then choose and implement an appropriate countermeasure strategy.	Methods, processes and toolsets for technology development and management	no-value	no-value	no-value	no-value	ongoing	Paul Tilghman / paul.tilghman@darpa.mil / 703-526-4767	no-value	Software upgrades to existing EW systems which enable cognitive functionality
Department of Defense (DoD)	DARPA/STO	100 Gbps RF Backbone (100G)	no-value	The goal of the 100 Gb/s RF Backbone (100G) program is to design, build and test an airborne-based communications link with fiber-optic-equivalent capacity and long reach that can propagate through clouds and provide high availability. 100G will combine high-order modulation and spatial multiplexing to achieve spectral efficiencies at or above 20 bits-per-second per Hz. The system aims to provide 100 Gb/s capacity at ranges of 200 km for air-to-air links and 100 km for air-to-ground links from a high-altitude (e.g. 60,000 ft.) aerial platform. Additionally, the system will provide an all-weather (cloud, rain, and fog) capability while maintaining tactically-relevant throughput and link ranges. Size, weight, and power (SWaP) will be limited by the host platforms, which will primarily be high-altitude, long-endurance aerial platforms.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	ongoing	Dr. Ted Woodward / theodore.woodward@darpa.mil / 571-218-4452	no-value	no-value

Department of Defense (DoD)	DARPA/TTO	Collaborative Operations in Denied Environment (CODE)	no-value	CODE seeks to develop and demonstrate the algorithms to expand the mission capabilities of legacy assets through autonomy and collaborative behaviors. This dependence on autonomy will greatly reduce the dependence on network bandwidth. Two of the Key Performance Objectives of the program directly address EMS efficiency. 1) For all assets performing a single mission, there must be less than 1 mission commander 2) Communications required must use less than 50 kb/s to and from the command station	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	ongoing	Jean-Charles "JC" Lede / jc.lede@darpa.mil /703-526-2844	no-value	The end of Phase 1 will culminate in PDR. The end of Phase 2 will demonstrate algorithmic functionality in flight-test with 1 or 2 air vehicles. The end of Phase 3 will culminate in a full-up demonstration of the single-vehicle and collaborative autonomy necessary to conduct a single mission in a live, virtual, constructive
Department of Defense (DoD)	DARPA/TTO	Collaborative Operations in Denied Environment (CODE)	AIR-01	CODE seeks to develop and demonstrate the algorithms necessary to expand the mission capabilities of legacy assets through autonomy and collaborative behaviors. This dependence on autonomy will greatly reduce the dependence on network bandwidth by design. Two of the key performance objectives of the program directly address EMS efficiency. 1) For all assets performing a single mission, there must be less than 1 mission commander. In other words, 1 person must be able to monitor and control multiple CODE assets among his/her other duties. 2) Communications required must use less than 50 kb/s to and from the command station as well as between air vehicles. Another potentially broader impact is that of the communication protocol. The CODE program does not require any particular protocol to be used; in fact, a new, more efficient protocol may be developed in order to efficiently use the available 50 kb/s. In doing so the value of information must be examined and properly prioritized. This protocol itself has the potential to greatly reduce bandwidth usage if only the right amount of data is passed to create a common operating picture.	Technologies and applications for efficient spectrum use or legacy transformation	aeronautical	no-value	TRL-4	Extra-Large	ongoing	Jean-Charles "JC" Lede / jc.lede@darpa.mil /703-526-2844	no-value	The projected TRL by the end of the program in FY18 is TRL-6
Department of Defense (DoD)	DARPA/DSO	Program in Ultrafast Laser Science and Engineering (PULSE)	DSO PE: 060110E / Project MS - 01	Objective: PULSE is a broad program in applications scope; however, there is a primary emphasis on fieldable, optical frequency comb sources, which will generally have a significant impact across that broad application space including communications, radar, and electronic warfare. In addition to developing fieldable optical frequency combs, which represent the state-of-art in stability and control of the electromagnetic spectrum, PULSE is also developing the techniques and hardware to up- or down-convert that stability from the optical domain across the electromagnetic spectrum from x-rays to RF. Project Synopsis: Specific needs (and deliverables) addressed directly in PULSE include: ultralow phase noise, tunable RF sources (ultralow phase noise - matching or exceeding lab-based SOA - tunable RF oscillators in rack mount-scale and chip-scale form factors; prototypes and potential fielded demonstrations by program end - current TRL: 3); frequency agile and adaptable RF photonic filtering with fast update rates (chip-scale frequency agile and adaptable RF photonic filters; prototypes by program end - current TRL: 3); and femtosecond-level precision free-space time and frequency transfer technology and protocols enabling the synchronization of remote oscillators at a precision better than the best demonstrated laboratory clocks (field deployable free-space time and frequency transfer at >10 km with mobile platforms by program end - current TRL: 2-3). Each of these key deliverables requires the development of robust, deployable optical frequency comb sources, which themselves may be used as effective spectrum analyzers. (TRL ranges represent specific efforts and targeted applications.) Broader Impact: Many areas of EMS R&D focus beyond those directly pursued in PULSE will benefit from optical frequency comb sources and applications such as low phase noise oscillators including EMS sharing, efficiency, flexibility, adaptability, agility, and operations. Potential applications relevant to the EMS data call represent a subset of the much broader application space being pursued in the PULSE program. Keywords: optical frequency comb; RF/microwave oscillator; RF filtering; time transfer and synchronization.	Technologies and applications for efficient spectrum use or legacy transformation	general	100 MHz - 100000 MHz; 1000 MHz - 25000 MHz;	TRL-2; TRL-3	Extra-Large	ongoing	Prem Kumar / prem.kumar@darpa.mil / 703-526-2709	no-value	Expected Frequency Range: The optical frequency combs will be in the optical/near-infrared spectral domain; specific applications enabled by optical frequency combs: ultralow phase noise RF oscillators: 100 MHz - 100000 MHz (100 MHz - 100 GHz) RF photonic filtering: 1000 MHz - 25000MHz (1-25 GHz; potentially scalable) time and frequency transfer: oscillator synchronization at the femtosecond (1E-15 s) level. Size: Individual efforts: L $1M-$10M; Overall program: XL > $10M Transition Strategy: PULSE is a basic research program designed with input from the user community. There are no targeted aquisition programs; however,technology transfer is central to the program development. Accordingly, PULSE is coordinating closely with the services research agencies to keep them aware of developments and to guide potential future demonstrations of technology. Additionally, several supporting SBIR/STTR efforts are ongoing to transition specific components into the commerical sector. Specific demonstrations and timelines are established for each individual effort and SBIR/STTR effort, with final PULSE deliverables anticipated in FY18. Ongoing long distance free-space time transfer demos (FY15/16) are anticipated to motivate additional investments/technology transfer efforts.
Department of Defense (DoD)	DARPA/STO	Mobile Network MIMO (MNM) Program	no-value	MNM investigated MIMO techniques that used multi-path to create independent (parallel) communications channels in the same frequency band, rather than just mitigating the effects of multi-path interference (e.g., rake filtering). This program extended previous commercial work to a mobile, dynamic environment.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	complete d		no-value	no-value
Department of Defense (DoD)	DARPA/STO	DARPA Inteference Multiple Access (DIMA) Program	no-value	DIMA program uses Multi-User Detection (MUD) techniques to enable multiple users to simultaneously occupy the same channel, while requiring no power or timing control, for highly efficient communications. This program determined whether multiple user equipment (UE) transmissions could be simultaneously made on the same channel; DIMA demonstrated this by program completions, showing 3-6 times capacity increasee over WCDMA networking.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	complete d		no-value	Radio system the demonstrated improvement in interference cancellation and thus spectrum efficiency (bits/second/hertz) of over 10x.
Department of Defense (DoD)	DARPA/STO	NETEX Program	no-value	NETEX investigated military ultra wideband sensors and communications systems. In the area of communications, the program investigated the use of large instanteous bandwidths (> 500 MHz), very little energy per Hz and signal processing to create increased capacity (e.g., more users and more data rate per user) and minimize cosite interference with existing and future RF systems.	Technologies and applications for efficient spectrum use or legacy transformation		no-value	no-value	no-value	complete d		no-value	no-value
Department of Defense (DoD)	DARPA/STO	DARPA Next Generation (XG) program	no-value	XG was the first government program to investigate the issues and feasibility of Dynamic Spectrum Access. In th absence of spectrum survey, XG provides a capability for automatic, dynamic and opportunistic access to unused spectrum based upon local RF environments and operational needs; sensing and adapting are not enough - radios must act according to rules.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	complete d		no-value	Development of a radio prototype that demonstrated greater than 10x improvement of spectrum access without impacting legacy radio operating in the same frequency range
Department of Defense (DoD)	DARPA/STO	Enhanced Position Location Reporting System - eXtended Frequency (EPLRS-XF) Program	no-value	Upgrade of Enhanced Position Location Reporting System (EPLRS) with MAINGATE MANET protocol / algorithms and XG Dynamic Spectrum Access.	Technologies and applications for efficient spectrum use or legacy transformation	no-value	no-value	no-value	no-value	complete d		no-value	Integration of dynamic spectrum access into EPLRS-XF radio and demonstration of interference avoidance.
Department of Defense (DoD)	DARPA/STO	Dyanmic Optical Tag Systems (DOTS)	no-value	The DOTs program developed modulating optical tags that are small, thin, and retro-reflecting. The tags will operate for long periods of time (greater than two months) in real-world environmental conditions (-40° to+70°C) and allow for a wide interrogation angle (±60°). The tags will be passive (in the sleep mode) for most of the time and they will only activate when interrogated by a laser of the correct code. Once correctly interrogated, the tags will begin to modulate and retro-reflect the incoming beam.	Technologies and applications for efficient spectrum use or legacy development and management	no-value	no-value	no-value	no-value	complete d		no-value	A technology demonstration of remote optical link of multiple kilometers using passive retrodirective optical modulation.
Department of Defense (DoD)	DARPA/MTO	Spectrum Challenge 2 (SC2)	no-value	The primary goal of SC2 is to imbue radios with advanced machine-learning capabilities so they can collectively develop strategies that optimize use of the wireless spectrum in ways not possible with today's intrinsically inefficient approach of pre-allocating exclusive access to designated frequencies. The challenge is expected to both take advantage of recent significant progress in the fields of artificial intelligence and machine learning and also spur new developments in those research domains, with potential applications in other fields where collaborative decision-making is critical.	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure; Test and Measurement; Education and outreach		no-value	no-value	no-value	ongoing	Paul Tilghman / paul.tilghman@darpa.mil / 703-526-4767	no-value	no-value
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	CyberSecure Communications OutReach	no-value	Transition to Practice of developed cybersecure RF communciations for utility and industrial applications and settings	Technologies and applications for efficient spectrum use or legacy transformation		ISM	TRL-7; TRL-8; TRL-9		ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	DOE	Transition to Industry underway
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Sensing and Instrumentation for Industrial Applications	no-value	Evaluation of "visible future" sensing and communications for circa 2020 industrial use. Emphasis on passive wireless sensors tags	Next gen wireless sensors		ISM	TRL-4	Small	ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	Yokogawa Corporation of America	Submission of study findings to industrial standards group
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Advanced Sensing for Manufacturing Environments	no-value	Examineusing a passive wireless sensor technology - no batteries, no active electronic components incorporated into the sensor itself.	no-value		ISM	TRL-5	Small	ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	Koch Industries	Probable adoption by sponsor
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Advanced Instrumentation for Security and Related Applications	no-value	Wireless sensor development tailored for dense deployments	no-value		ISM	TRL-4	Small	ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	Tyco Corporation	Probable adoption by sponsor
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Location Tracking and AGV Guidance System for a Manufacturing Setting	no-value	Multiparameter wireless sensor and communications tracking system development	no-value		OPTICAL; ISM; CELLULAR	TRL-4	Small	ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	Denso Corporation	Probable adoption by sponsor
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Undersea Communications for Advanced BlowOut Preventers	no-value	Replacement of existing undersea blowout preventer communications systems with advcned technologies	no-value		OPTICAL; ACOUSTIC; ELF	TRL-7	Medium	complete d	Dr. Peter Fuhr / fuhrpl@ornl.gov	Transocean Corporation	Technologies being implemented by sponsor
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Hybrid Spread Spectrum Development	no-value	Development of an FHSS DSSS communication module suitable for utility instrumentation integration	no-value		ISM	TRL-7	Large	complete d	Dr. Peter Fuhr / fuhrpl@ornl.gov	DOE	Transition to Industry underway, submission to industrial standards group
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Integrated Microgrid Security Architecture	no-value	Design of secure communications architecture for microgrid instrumentation and control	no-value		ALL	TRL-5	Medium	ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	ORNL (internal funding)	(probable) Transition to Industry, Inclusion on Recommended Architectures guides
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Secure Communications for Unmanned Aerial Systems (drones) in a Secure Grid World	no-value	Secure comms & control of unmanned aerial systems (UAS) Implications for remote inspections of grid components Secure communications and controls of unmanned aerial systems (drones); impliicaitons for remote inspection of grid components	no-value		ISM	TRL-5	Medium	ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	ORNL (internal funding)	Guidance to utilities, industry, UAS operators and designers
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Cybersecure Building Instrumentation Communications	no-value	Multimedia communications for building sensors and control systems	no-value		ISM	TRL-5		ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	DOE	Eventual transition to practice
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Vehicle Cyber Security	no-value	Vehicle-to-Grid (and G-to-V) Communications	no-value		ISM; INDUCTIVE CHARGING	TRL-4		ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	DOE, ORNL	Eventual transition to practice
Department of Energy (DOE)	OAK RIDGE NATIONAL LABORATORY	Practrical Quantum Security for Grid Automation	no-value	Quantum cryptographic applications for grid communications security	no-value		OPTICAL; RF	TRL-7	Medium	ongoing	Dr. Peter Fuhr / fuhrpl@ornl.gov	DOE	Demonstration phase
Department of Energy (DOE)	IDAHO NATIONAL LABORATORY	Secure Wireless Encryption Key Creation and Distribution	no-value	High security, creation and coordination of encryption keys without key distribution	Wireless Security	aeronautical; terrestrial; general;	100 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dr. Carl Kutsche / carl.kutsche@inl.gov	DOE	no-value
Department of Energy (DOE)	IDAHO NATIONAL LABORATORY	Public Safety Communications Operational Training	no-value	Operational experience in Band 14 use under controlled conditions	Methods, processes and toolsets for technology development and management; Integration of DSA networks and the Internet or other infrastructure; Spectrum access policy and regulation; Wireless Security; Test and Measurement; Education and outreach;	aeronautical; terrestrial; general;	700 MHz Bandclass 14; band 13; UAV	TRL-7	no-value	ongoing	Dr. Daniel Devasirvatham / daniel.devasirvatham@inl.gov	DOE	no-value
Department of Energy (DOE)	IDAHO NATIONAL LABORATORY	Dynamic Interference and Mulitpath Generation for Spectrum Sharing/ Dynamic Spectrum Test and Evaluation	no-value	Create a relevant but controlled test and evaluation environment for Spectrum Sharing and DSA testing	Methods, processes and toolsets for technology development and management; Integration of DSA networks and the Internet or other infrastructure; Spectrum access policy and regulation; Wireless Security; Test and Measurement; Education and outreach;	general	ALL	TRL-2	Large	ongoing	Dr. Daniel Devasirvatham / daniel.devasirvatham@inl.gov	DOE	no-value
Department of Energy (DOE)	IDAHO NATIONAL LABORATORY	Software Defined Radio Wireless Communications Security	no-value	Sense and avoid dynamic and persistent interference and threat to communications systems	Wireless Security	general	ALL	TRL-2	Large	ongoing	Dr. Carl Kutsche / carl.kutsche@inl.gov	DOE	no-value
Department of Energy (DOE)	IDAHO NATIONAL LABORATORY	Adaptive Filter Bank Technology	no-value	Adaptive Radio Physical Layer Technology to monitor and operate in Dynamic Spectrum RF Environments	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure; Wireless Security;	general	1 MHz - 6000 MHz	TRL-3; TRL-4	Large	ongoing	Dr. Carl Kutsche / carl.kutsche@inl.gov	DOE	no-value
Department of Energy (DOE)	IDAHO NATIONAL LABORATORY	Next Generation Wireless Test Bed	no-value	Test and Evaluation of DSA and cellular based technologies at full scale	Methods, processes and toolsets for technology development and management; Integration of DSA networks and the Internet or other infrastructure; Spectrum access policy and regulation; Wireless Security; Test and Measurement; Education and outreach;	general	600 MHz - 5000 MHz	TRL-8	Large	ongoing	Dr. Carl Kutsche / carl.kutsche@inl.gov	DOE	no-value

Department of Energy (DOE)	IDAHO NATIONAL LABORATORY	DoD National Wireless Range	no-value	Multiple Range Collaboration to optimize international coalition Dynamic Spectrum Test and Evaluation	Methods, processes and toolsets for technology development and management; Integration of DSA networks and the Internet or other infrastructure; Spectrum access policy and regulation; Wireless Security; Test and Measurement; Education and outreach;	terrestrial	100 MHz - 10000 MHz	TRL-8	Large	ongoing	Dr. Carl Kutsche / carl.kutsche@inl.gov	DOE	no-value
Department of Justice (DOJ)	Drug Enforcement Administration (DEA) Office of Investigative Technology	Wireless Spectrum Communications (WSComm)	no-value	the Idaho National Laboratory (INL) to further the research and development for deploying next generation spectrum agile wireless technologies, specifically Wireless Spectrum Communications (WSComm), to enable efficient use of the spectrum, determine its effectiveness in simulated operational scenarios, and analyze results to identify realistic next steps. This technology allows for efficient use of spectrum without pre-coordination and has low probability of detection and intercept. It employs spectral-awareness properties and does not rely on a database for spectrum assignments. This effort will enhance development of hardware and software and better position DOJ and the law enforcement community to adopt spectrally efficient RF technologies by investing in the development of next generation video and audio surveillance solutions in a variety form factors to meet mission needs. The state of this project exceeds TRL 3, as it has moved beyond the proof-of concept phase and is undergoing laboratory testing. Project Synopsis The Drug Enforcement Administration`s (DEA) Office of Investigative Technology has been engaged with the INL`s Wireless Research and Development team in efforts to develop a spectrum-agile, secure wireless communication platform to support video audio surveillance and other mission activities. This new technology is based on Filter Bank Multi-Carrier Spread Spectrum (FB-MC-SS) and would provide a true spectrum sharing capability. Using algorithms, WSComm as a spectrum-agile technology enables a robust wireless underlay channel, which can coexist with an existing network. This low to medium data-rate channel is foundational to building an adaptive/intelligent radio network that maximizes the use of the available white spaces in the RF spectrum, where high data-rate overlay channels can be dynamically assigned. WSComm`s control channel can use the identified available spaces in harsh RF environments to operate and still maintain a low probability of detection. It is resistant to high-energy narrow-band and wide-band interference and can perform robustly in high-speed mobility environment without putting an undue burden on the operating spectrum. In the underlay mode, this technology enables operation in any spectral band(s) at or near the noise floor by spreading the signal over a set of spectrally isolated subcarriers. The operating frequency bands can be positioned anywhere within the radio spectrum. This underlay feature enables instantaneous deployment of: Point-to-point communications, Mobile Adhoc Networks (MANETs), large-scale networks that might need low-speed or secure control communication channel and/or mission-critical alternate emergency communications channel in a natural disaster emergency, friendly or hostile environment. WSComm also can be modified for use in an overlay mode (a primary communications channel) where a high rate transmission is established by sending different information on multiple subcarriers. Also, in the overlay mode, this technology allows deployment of white space spectrum in licensed and unlicensed bands, and in mission-critical situations. This technology solution would be capable of operating and sharing in newly assigned bands and integrating features that will give the users maximum flexibility	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure; Spectrum access policy and regulation; Wireless Security;	terrestrial; general	ALL	TRL-3	Extra-Large	ongoing	Stanley E. Causey / Office 703-495-6525; Cell 202-904-9564	Drug Enforcement Administration	WSComm has been presented and well received at the following forums: OSTP, NTIA, FCC, and DoD.
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	Data Compression Standards	no-value	Technologies and standards to efficiently compress image data including data from hyper-spectral instruments (i.e., reduce spectrum needs)	Technologies and applications for efficient spectrum use or legacy transformation	general	Any	TRL-6; TRL-8	Medium	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	no-value
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	Deep Space Optical Communications (DSOC)	no-value	Development of laser communication components & systems, including ground terminal, for the deep space environment	Technologies and applications for efficient spectrum use or legacy transformation	space	Optical; Near-Infrared	TRL-4; TRL-6	Extra-Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Utilization of higher frequencies
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	Integrated RF/Optical Communications (iROC) System	no-value	Development of integrted RF and laser communication components & systems for the deep space environment	Technologies and applications for efficient spectrum use or legacy transformation	space	RF; Optical; Near-Infrared	TRL-4	Extra-Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Utilization of higher frequencies
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	Atmospheric Calibration/RF Propagation Studies	no-value	Long-term measurement and characerization project for understanding and modeling atmospheric propagation effects around 26 GHz	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management; Test and Measurement	space	20000 - 90000 MHz	not applicable - see comments	Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Characterizing the space-Earth propagation path that can be used to support technology development and operations planning using this band. Such an understanding of the propagation can assist in defining technology and operations needed to improve efficiency
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	SCaN Testbed & Experiments	no-value	The SCaN Testbed, hosted on the International Space Station (ISS), consists of 3 re-programmable software defined radios (SDRs) available for waveform experimentation	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management; Test and Measurement	space	2025 - 2110 MHz; 2200 - 2290 MHz; 25500 - 27000 MHz	TRL-7	Extra-Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Techniques and waveforms are applicable across all frequency bands; Collaboration with other agencies, universities, and commercial entities welcomed
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	NASA Near Earth Network Upgrades	no-value	Deploy higher frequency (26 GHz) Earth station systems for supporting space communications (space-to-Earth)	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure	space	25500-27000 MHz	TRL-7	Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Utilization of higher frequencies
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	Cognitive Radio Development	no-value	Development, demonstration, and test of cognitive radio technologies	Technologies and applications for efficient spectrum use or legacy transformation	space; terrestrial	Any	TRL-3; TRL-4	Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Applicable to many bands
National Aeronautics and Space Administration (NASA)	Human Exploration and Operations Mission Directorate (HEO)	Disruption Tolerant Networking (DTN)	no-value	Developing network and transport layer technologies and standards to enable higher performance networking where disrupted and long-delay links are encountered	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure	space; terrestrial	Any	TRL-6; TRL-7	Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Applicable to many bands
National Aeronautics and Space Administration (NASA)	Science Mission Directorate (SMD)	Soil Moisture Active Passive(SMAP) Instrument RFI Mitigation	no-value	Developed and applied signal processing techniques for passive (radiometers) and active (radar) sensors to remove or mitigate affects from radio frequency interference sources	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement	general; space	1215 - 1300 MHz; 1400 - 1427 MHz	TRL-7; TRL-8	Extra-Large	complete d	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Science Sensor RFI Mitigation and Sharing - Techniques applied to mitigate the RFI observed by SMAP (launched 31 Jan 2015)
National Aeronautics and Space Administration (NASA)	Science Mission Directorate (SMD)	Wideband Radio Frequency Interference (RFI) Mitigation Subsystem for Microwave Radiometers	no-value	Develop a wideband (>200 MHz) digital detector subsystem to demonstrate innovative RFI detection and removal techniques for microwave radiometers	Technologies and applications for efficient spectrum use or legacy transformation	space	Any radio frequency band; Will target various passive bands such as 1400-1427 MHz, 10.6 GHz, 18.6 GHz)	TRL-2; TRL-4	Medium	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Science Sensor RFI Mitigation and Sharing
National Aeronautics and Space Administration (NASA)	Science Mission Directorate (SMD)	UWBRAD: Ultra Wideband Software Defined Microwave Radiometer for Ice Sheet Subsurface Temperature Sensing Project	no-value	Design, develop, test, and validate an ultra-wide band, 0.5-2.0 GHz software defined microwave radiometer for sensing ice sheet internal temperature - Includes capability for radio frequency interference (RFI) detection and mitigation - Assess real time RFI mitigation capability enabling operation in different bands enabling sharing	Technologies and applications for efficient spectrum use or legacy transformation	space	500 - 2000 MHz	TRL-3; TRL-4	Medium	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Science Sensor RFI Mitigation and Sharing
National Aeronautics and Space Administration (NASA)	Science Mission Directorate (SMD)	Signals of Opportunity Airborne Demonstrator Project (SoOp-AD)	no-value	Develop new microwave remote sensing instrument to directly measure soil moisture; develop spaceborne Signals of Opportunity (SoOp) measurement technique, a form of sharing, that would lead to a substantially smaller antenna and power than current radiometers and radars	Technologies and applications for efficient spectrum use or legacy transformation	space	30 - 3000 MHz	TRL-3; TRL-4	Medium	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Science Sensor RFI Mitigation and Sharing
National Aeronautics and Space Administration (NASA)	Science Mission Directorate (SMD)	CubeRRT: CubeSat Radiometer Radio Frequency Interference Technology Validation	no-value	Demonstrate wideband RFI mitigating technologies vital for future space-borne microwave radiometers. Recent passive microwave measurements below 40 GHz have shown an increase in the amount of man-made interference, corrupting measurements important for science. Due to shared spectrum allocations, microwave radiometers must co-exist with terrestrial RFI sources, an increasingly difficult RFI environment. Co-existence in some cases should be possible that will not only enable microwave radiometry in any RFI intensive environment, but will also enable operations over a larger bandwidth resulting in lower measurement noise	Technologies and applications for efficient spectrum use or legacy transformation	no-value	1000 - 40000 MHz; Will target passive bands such as 1400 MHz, 10.6 GHz, 18.6 GHz	TRL-3; TRL-4	Medium	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Science Sensor RFI Mitigation and Sharing
National Aeronautics and Space Administration (NASA)	Space Technology Mission Directorate (STMD)	Laser Communication Relay Demonstration (LCRD)	no-value	Flight demonstration of a laser communications relay communications system as a hosted payload on a geostationary spacecraft	Technologies and applications for efficient spectrum use or legacy transformation	space	Optical; Near-Infrared	TRL-7	Extra-Large	ongoing	William Horne / william.horne@nasa.gov / (202) 358-5167	no-value	Utilization of higher frequencies; Flight demo to launch 2019
National Institute of Standards and Technology (NIST)	COMMUNICATIONS TECHNOLOGY LABORATORY (CTL)	Spectrum Coordination Technologies	no-value	This project develops protocols, algorithms, and architectures for spectrum coordination in support of spectrum sharing standards and metrology. It investigates algorithms, protocols, and software systems for coordinating spectrum usage among disparate systems in a tiered-access arrangement, realized in both distributed and centralized architectures. Applications of centralized approaches include the 3.5 GHz Citizens Broadband Radio Service. In addition, this project studies techniques for protecting the operational security of incumbent systems in shared bands.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management; Spectrum access policy and regulation; Wireless Security; Modeling and Simulation;	general	3550 MHz - 3700 MHz;	TRL-3; TRL-4; TRL-5	Medium	ongoing	Dr. Michael Souryal / michael.souryal@nist.gov / (301) 975-4342	no-value	no-value
National Institute of Standards and Technology (NIST)	COMMUNICATIONS TECHNOLOGY LABORATORY (CTL)	Specturm Sensing and Monitoring	no-value	This project, which regroups a number of tasks, pursues spectrum sensing techniques and spectrum monitoring capabilities that advance the state-of-the-art in measurement and analysis of radio frequency (RF) spectrum occupancy. Sensing techniques aim to improve the sensitivity of a spectrum sensor and widen the bandwidth it can observe through innovations in signal processing. This project also includes the specification and pilot implementation of a spectrum monitoring infrastructure composed of sensors, a spectrum occupancy database, and a server for delivery of real-time occupancy measurements, the latter being useful for spectrum coordination.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management; Test and Measurement; Modeling and Simulation;	general	< 6000 MHz	TRL-3; TRL-4; TRL-5; TRL-6	Large	ongoing	Dr. Michael Souryal / michael.souryal@nist.gov / (301)-975-4342	no-value	See M. Cotton, M. Souryal, et al., "An Overview of the NTIA/NIST Spectrum Monitoring Pilot Program," in Proc. IEEE Wireless Network Communications Conference Workshops (WCNCW), pp. 217-222, Mar. 2015, http://dx.doi.org/10.1109/WCNCW.2015.7122557.
National Institute of Standards and Technology (NIST)	COMMUNICATIONS TECHNOLOGY LABORATORY (CTL)	Test and Evaluation of Shared Spectrum Systems	no-value	This project aims to advance the metrology of shared spectrum systems with metrics and measurement methods for test and evaluation. They include test methods for evaluating wireless technologies sharing spectrum in either an uncoordinated fashion (coexistence), or in a coordinated manner where protection of higher priority users is imperative. In both cases, appropriate metrics need to be identified and methods developed to measure them. An important aspect of this work is the characterization of uncertainty in the identified metrics and its reduction through calibration and proper test procedures.	Test and Measurement	general	< 6000 MHz	TRL-6	Large	ongoing	Dr. Bill Young / william.young@nist.gov / (303)-497-3471	no-value	M. Souryal et al., "Real-Time Centralized Spectrum Monitoring: Feasibility, Architecture, and Latency," to appear in Proc. IEEE DySPAN, Sept. 2015.
National Institute of Standards and Technology (NIST)	COMMUNICATIONS TECHNOLOGY LABORATORY (CTL)	Antenna metrology	no-value	This project develops and provides near-field measurements of antenna radiation with sufficient accuracy to extrapolate to far-field characteristics. Near field measurements are made using a dynamic laser-based antenna-probe tracking system with probe-position correction algorithms, to obtain near-field scanning ranges at much higher frequencies than previously attainable. We are initiating work to apply this to massive-MIMO antenna characterization.	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management; Test and Measurement;	general	< 110000 MHz	TRL-3; TRL-4; TRL-5; TRL-6	Large	no-value	Dr. Mike Kelley / michael.kelley@nist.gov/ (303)-497-4736	no-value	See D.R. Novotney, et al, "Evaluation of a Robotically Controlled Millimeter-Wave Near-Field Pattern Range at NIST Determining mechanical suitability for antenna measurements," http://www.nist.gov/manuscript-publication-search.cfm?pub_id=913071
National Institute of Standards and Technology (NIST)	COMMUNICATIONS TECHNOLOGY LABORATORY (CTL)	Broadband Interoperability Test Facility	no-value	This project is developing a test bed for characterizing coexistence of disimilar signals, using both conductive and radiated testing. The facility includes and LTE eNodeB, evolved packert core and load tester to create LTE signaling sets, and both a reverberation chamber and an anechoic chamber for mixing LTE signals with interfering signals and/or victim receivers. The facility is designed to allow various LTE radio heads so that new frequencies can be characterized. A variety of test equipment (and supporting NIST metrology) is available for measurement, as well as modeling tools for analysis	Technologies and applications for efficient spectrum use or legacy transformation; Methods, processes and toolsets for technology development and management; Test and Measurement;	general	< 6000 MHz	TRL-3; TRL-4; TRL-5	Large	no-value	Dr. Mike Janezic / michael.janezic@nist.gov / (303) 497-3656	no-value	no-value
National Institute of Standards and Technology (NIST)	COMMUNICATIONS TECHNOLOGY LABORATORY (CTL)	High speed measurements	no-value	This project develops and provides highly accurate measurement of high speed waveforms to 110 GHz (and beyond), both connected and on-wafer. Amplitude, frequency, and phase are obtained with point-by-point uncertainty analysis. These methods can be used to calibrate all manner of RF and microwave equipment, including oscilloscopes, vector network analyzers, large signal analyzers, etc.	Methods, processes and toolsets for technology development and management; Test and Measurement;	general	< 110000 MHz	TRL-3; TRL-4; TRL-5; TRL-6	Large	no-value	Dr. Paul Hale / paul.hale@nist.gov / (303) 497-5367	no-value	Remley, et. Al., "Baseband Corrections for Precision Millimeter Wave Signal Measurements," http://www.nist.gov/customcf/get_pdf.cfm?pub_id=914309

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	A Comprehensive Approach to Interference Cancellation and Spurious Reduction in Broadband Wireless Transceivers	1408575	Proposal Title:A Comprehensive Approach to Interference Cancellation and Spurious Reduction in Broadband Wireless Transceivers.Institution: University of Texas at Austin.This proposed effort will make significant contributions to wireless communication systems and will enhance access to the radio spectrum which has been identified as a national priority. If successful it will be transformative and will have major societal, commercial and economic benefits.The architectures and techniques researched here will find wide use in current and future radio technologies that enable broadband wireless access. Additionally, this research will impact multiple applications beyond communications, including safety, sensing, and medical devices. The investigators will collaborate closely amongst themselves, and with current industrial partners. Results of the research will be broadly disseminated through publications. Graduate students will be provided a cross-disciplinary learning experience that spans communication systems, architecture definition, integrated circuit design and measurement techniques. A strong educational program is a key aspect to ensuring the long-term dissemination of the proposed research results. As such, the principal investigators intend to integrate much of the aforementioned research into their regular course work. A diverse group of graduate and undergraduate students will be engaged in this and related effort in the research teams.Broadband wireless systems offer a viable approach for enabling ubiquitous high-speed communications. This effort will focus on key hardware challenges in the design of transceivers for such systems. Multiple questions will be addressed including: (a) the ability of the transmitter and the receiver to span a desired frequency range, with minimal hardware overhead and complexity, (b) the ability of the receiver to tolerate and operate satisfactorily in the presence of interference and (c) the ability of the transmitter to minimize its out-of-band spectral emissions, so as to minimize co-existence issues. This proposal seeks to address these considerations by developing a comprehensive approach for interference mitigation in broadband, rapidly tunable, integrated, wireless transceivers. The designs will be engineered to meet future high data-rate needs by enabling devices that allow for flexible, and reconfigurable use of spectrum.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ranjit Gharpurey / ranjitg@mail.utexas.edu	University of Texas at Austin	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	A High-Performance Wideband Receiver for Cognitive Radio	1310279	Intellectual Merit:Cognitive radio enables efficient use of the scarce radio spectrum by sensing available bands and communicating in an opportunistic manner. Although significant work has been reported in the literature that enables dynamic use of these under-utilized spectrum resources, the underlying assumption in cognitive radio is the availability of a flexible and efficient wideband receiver. Designing such a receiver, however, is challenging. The specific problems are the inter-modulation and harmonic distortion caused by the wide passband of the receiver, the need for a wide tuning range frequency synthesizer to span the frequency band of interest, and the use of power-hungry high-speed ADCs to reduce sensing time. In the proposed research, the harmonic mixing process in wideband receivers is viewed as a multi-user access system in communications. This perspective allows leveraging on existing work on multi-user detection theory to develop techniques to overcome many of the implementation challenges. To fully realize the benefits of the proposed approach, several research tasks will be pursued, including developing a scalable receiver architecture, exploring analog combining methods of multi-phase/multi-frequency clocks to maximize performance after digital equalization, and devising a robust and high-performance digital equalizer that exploits the structure of the mixing process. Furthermore, this research will demonstrate the feasibility and the advantages of the proposed approach to wideband receiver design by realizing it on silicon. A complete design framework will be developed based on a clear understanding of various design options and the corresponding tradeoffs in performance and implementation complexity.Broader Impact:The proposed research should help realize a high-performance cognitive radio, which has emerged as a promising approach to efficiently exploit the scarce radio electromagnetic spectrum. In addition, the concepts developed in this research are broadly applicable to many existing and emerging wideband systems such as in multi-standard/multi-band radios and software defined radios. The principles can also be applied to non-communication applications in radar systems and sensor networks. The above research plan is coupled with an education plan that describes how the proposed research will help train both graduate and undergraduate students. The multi-disciplinary nature of the proposed research will broaden the students technical understanding, which the PI believes is essential for next generation of engineers. The proposal also includes plans to improve the participation of undergraduate students and members of under-represented groups.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Won Namgoong / namgoong@utdallas.edu	University of Texas at Dallas	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	A New Design Paradigm for Switch-Mode Power Amplifiers Supporting Concurrent Multi-Band Wireless Communication	1509001	telephones is reaching 1.8 billion units, as of 2013. With mobile technology becoming almost ubiquitous and with the types of enriched features and services that are available to the end user, mobile devices are being required to support higher data rates. Unfortunately, this need for higher data rates is resulting in systems that are now required to support communication in many different, non-contiguous frequency bands spread between 0.4 and 6000 MHz. The current solution consists of using multiple, parallel, single-band power amplifiers resulting in modern cellular telephones having upwards of ten separate power amplifiers. Ultimately, this problem will result in mobile devices becoming bulkier, more expensive, and unable to support key new multi-band technologies. The root problem is that, conventionally, a single power amplifier can support only a single band. Researchers have tried to address this problem through the design of concurrent multi-band power amplifiers, but, these systems suffered significant drops in performance that were largely unexplainable using conventional design theories. This research will provide a detailed understanding of the design trade-offs in concurrent multi-band power amplifiers and a new set of design techniques. The proposed research will give radio frequency (RF) designers a new set of tools enabling them to address the challenges posed by next generation wireless system design. In addition, this project will provide methods for increasing overall power efficiency and thereby increasing battery life in multi-band systems. Moreover, this project will strengthen the U.S. transceiver industry through research, through bolstering the number of women and minorities in undergraduate and graduate STEM programs, and through supporting local industry with presentations and collaborations.Modern power amplifier design is besieged on two fronts: concurrent multi-band communication is becoming a reality and wireless devices must support a variety of different communication standards. This is leading to transmitters that must support communication over many different frequency bands spread between 0.4 and 6000 MHz. The current approach of using multiple, single-band power amplifiers in parallel is becoming unsustainable and new technology is going to be required for next generation wireless devices. One promising technique is the use of concurrent multi-band power amplifiers wherein a single power cell/matching network is capable of supporting multiple, simultaneous signals. Unfortunately, there is currently no existing theoretical framework to describe the maximum efficiency, output power, stability, or linearity of concurrent multi-band power. The continued lack of such basic knowledge will fundamentally limit the potential of this new technology to address the needs of future wireless devices. This proposal will develop both a theoretical framework and a set of practical guidelines for the analysis and physical implementation of such power amplifiers. Together, these results will give RF designers a new set of tools with which they can reduce the current number of power amplifiers in modern devices, and facilitate new techniques for improving data rates and efficiency in already-designated communication bands. This, in turn, will	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Nathan Neihart / neihart@iastate.edu	Iowa State University	no-value
National Science Foundation (NSF)	BROAD PARTIC IN ENG (BRIGE)	BRIGE: Investigation of Improved Antenna Reconfiguration Mechanisms	1342367	Intellectual Merit: This BRIGE proposal describes a plan to develop mechanisms for slot antennas that will enable numerous unique reconfigurable antenna designs for the next generation of wireless technology. The project represents the first step of a long-term goal to build a diverse team of researchers at the University of Oklahoma (OU) investigating novel antenna architectures that address a national need to solve the spectrum crisis. The first step in designing practical and efficient, reconfigurable slot antennas is development of the loading mechanism that electrically alters a property of the antenna. Slot antennas have many desirable properties such as omnidirectional radiation and relative placement insensitivity. However, reconfigurable antennas are challenging with slotline due to the presence of only one ground plane, which makes the required bias networks problematic and detrimental to the antenna's performance. The proposed work will develop easily-biased and efficient loading mechanisms for slot antennas that will enable many reconfigurable antenna designs and lead to more practical designs to be implemented in systems.Broader Impacts: The proposed work will advance many types of reconfigurable antennas, which have the potential to operate at a range of frequencies, change the main beam to receive/transmit from a different direction, and/or adapt to changes in operating conditions. This will enable truly cognitive radio/radar that can find and operate in unused spectrum - eliminating the requirement for strictly assigned spectrum use. Transmission line models will be developed for all investigated structures allowing the structures to be broadly applicable and transferable for use as loading mechanisms for many different reconfigurable antenna designs. Accurate models for these structures will have far-reaching effects beyond the proposed work since with these models the fundamental structure behavior can be more easily understood. In addition to the broad impact upon future wireless systems, the proposed work will enhance the retention and recruitment of women in Electrical and Computer Engineering (ECE). The PI is the founder and faculty advisor of Women in ECE (WECE) at OU. The proposed work will expand previously initiated events and implement a laboratory workshop with WECE. Students who complete the workshop will be recruited to participate in undergraduate research with the PI. Additionally, the PI will begin tracking all students in ECE through a detailed data set for each cohort of students for the next five years to determine critical points for intervention methods to improve retention.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jessica Ruyle / ruyle@ou.edu	University of Oklahoma Norman Campus	no-value

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	CAREER: Design and Implementation of an Evolving Intelligent Wideband Digital Receiver System on a Tribrid Computing Platform Capable of Cognitive Learning	1150507	CAREER: Design and Implementation of an Evolving Intelligent Wideband Digital Receiver System on a Tribrid Computing Platform Capable of Cognitive LearningIntellectual Merit: The fundamental function of a modern radar receiver is to intercept radio frequency signals to identify and locate its source. Lack of a priori knowledge of the waveform of interest, multitude of signals and the noise energy that occupies the same frequency spectrum as the signal, makes the design of a modern wideband receiver a daunting task. The objective of this effort is to design and implement an intelligent wideband digital receiver capable of achieving a near-zero false alarm rate (Broader Impacts: Outcomes of the proposed research can be applied to a broad range of areas such as wireless communication systems, biomedical signal processing, and other applications that utilize fast Fourier transform based spectral estimation. The proposed learning system design will be realized in two distinct hardware form factors which will serve as a starting point for researchers to incorporate the proposed cognitive learning model into their specific applications. Likewise, the proposed customized silicon photonic interface card design can be utilized by engineers to improve the data transfer rate between data acquisition card and processors in real-time systems. The proposed research will generate both educational and research opportunities at California State University, Fullerton (CSUF), Wright State University and Cypress College (CC) through graduate research program, undergraduate apprentice program, lunch speaker series, and undergraduate summer research program. Planned educational activities include the integration of research findings into engineering courses and the introduction of a specialty track. Concrete outreach efforts to expose the underrepresented and minority students at CSUF, CC and local high schools are planned. Outcomes will be widely disseminated to academic and industrial communities through international conferences, journals, CSUF website, and at on-campus events.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kiran George / kgeorge@fullerton.edu	California State University-Fullerton Foundation	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	CAREER: Exploiting Interference in Wireless Networks	1150177	The goal of this proposal is a fundamental redesign of wireless networks to systematically exploit interference to increase network capacity. Traditionally interference is considered harmful, hence current designs strive to avoid interference by scheduling concurrent transmissions in separate frequencies/time slots. Hence the only way to add more capacity is to add more spectrum. However spectrum that can be used for building wireless networks has mostly been allocated and is in use, thus imposing hard limit on the scalability of the current network design. This proposal makes a fundamental shift: instead of avoiding interference, it designs techniques that systematically encourage and exploit interference to increase network capacity. The key insight is that interference is not random noise, but has structure since it is a synthetic signal created by another transmitter. If transmitters and receivers are aware of the interference structure, they can exploit it to actively shape/code interference and better decode their own transmissions to cancel interference, and thus greatly increase capacity. The proposed research will produce techniques that can each have substantial impact of the design of wireless networks. This project will design single channel full duplex radios, a technical feat that has hitherto been considered impossible. Second, this research will produce rateless codes that can decode constituent packets from collisions, obviating the need for complex scheduling primitives and thus simplify PHY/MAC design. Finally, it will produce smart radios that can adaptively operate in dense radio neighborhoods and maximize throughput, and thus coexist in environments with a variety of interfering radios.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Sachin Katti / sachin.katti@gmail.com	Stanford University	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	CAREER: Low-Power Transceiver Design Methods for Wireless Medical Monitoring	1451213	Wireless communication chips with lower power consumption are needed to enable more widespread wireless connectivity for numerous battery-powered portable and implantable biosignal measurement devices. However, reduced power consumptions lead to degraded performance and reliability, which inhibits the adoption of low-power circuit design approaches. Innovative integrated circuit design techniques are required to alleviate this tradeoff in medical applications, wireless sensor networks and chips with energy harvesting features. The primary research objective of this project is to create design methodologies for performance and reliability enhancements of tunable low-power analog circuits through the incorporation of efficient digital circuits. A key educational goal is to pioneer a unified approach through which students collaboratively learn to combine low-power analog integrated circuit design and digitally assisted performance tuning methods with a primary focus on cutting-edge medical applications. New course materials will establish a long-lasting research and education program aimed at creating reliable wireless capabilities for various miniaturized devices. Undergraduates and high school interns will be directly involved in research tasks. The project team will collaborate with Northeastern University`s Center for STEM Education to organize on-campus activities with K-12 students and teachers as well as outreach visits to connect with underrepresented groups in local schools. State-of-the-art low-power receivers are prone to interference due to their limited dynamic ranges, which is particularly severe when multiple wireless medical monitoring devices coexist in close proximity to each other. To overcome this challenge, an adaptive design methodology will be devised to enhance interference suppression through extra filtering in the receiver path. This research effort will address the performance deficiencies of low-power integrated circuits such that a broader range of devices can be equipped with short-range wireless connectivity. It will provide new knowledge to design transceivers with better immunity to interference through the introduction of adaptive filtering in RF front-ends, digitally assisted linearity improvements for low-power analog circuits, and digital spectrum analysis for self-calibrations. Novel circuit-level linearization methods will be demonstrated to enable the design of analog circuits that include transistors operating in the subthreshold region with substantially improved dynamic ranges. These methods will be leveraged to achieve leading-edge performance with less than one-sixth of the power compared to current transceivers. The research will produce techniques to evaluate gain and linearity characteristics of analog circuits using an efficient fast Fourier transform engine that calculates the frequency spectrum of signals with significantly less chip area than existing methods. This will be a foundation for new built-in test and calibration strategies that counteract rising process variations of advanced chip manufacturing technologies.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Marvin Onabajo / monabajo@ece.neu.edu	Northeastern University	no-value
National Science Foundation (NSF)	ELECT, PHOTONICS, & MAG DEVICE	CAREER: MEMS Reconfigurable Filters for Multi-Band Low-Power Radios	1055308	[illegible] standard radios through fusion of acoustoelectrically amplified nano-mechanicalfilters and 3D tunable components. Reconfigurable filters can greatly enhance the performance andreduce the size of RF front-ends, and as such have received great attention for effective and low-powerprocessing of the frequency spectrum. Despite their great promise, lack of integration and narrowfrequency coverage of current reconfigurable filters continue to hinder their use in practical applications.In addition, current technologies have failed to reduce the size of filters without deteriorating criticalperformance metrics such as loss, power handling and termination impedance. To-date, a versatile andreconfigurable filter array platform does not exist in monolithic form, an important problem that hasremained unsolved despite major advancement in MEMS. This proposal tackles the fundamental issuesrelated to reconfigurable filter arrays and proposes a novel technique that offers frequency, bandwidth andamplitude tunability through integration of narrow-band acoustic filters with tunable lumped filters.These are believed to be the most prominent steps toward the realization of a single-chip multi-band lowpowerradio.Intellectual merits: The proposed work explores a new approach to developing integrated reconfigurablefilters with wide tuning range and reduced loss. This new approach relies on the acoustoelectric effect, aphenomenon caused by interactions between electrons and phonons. Using this effect, which is mosteffective in nano-scale, a new class of nano-mechanical acoustic filters with potentially negative loss (i.e.positive gain) will be developed. This will yield new opportunities for acoustic devices andinstrumentation. In addition, using advanced 3D micromachining techniques microscale tunable lumpedcomponents with unparalleled Qs exceeding 150 and wide tuning range will be developed. The high-Qtunable passives will be utilized to reduce parasitics of acoustic filters and assist in tuning their frequencyresponse. The PI will leverage her prior work on high-Q passives and micro-fabrication techniquestowards this proposed research. Along with the experimental work, the proposed research aims toadvance the scientific community's understanding of the physical phenomena that govern theperformance of the proposed MEMS arrays and new technologies that overcome these physical limits.Broader Impact: The proposed research enables on-chip reconfigurable high-Q filtering, eliminatingmany of the redundant components in RF transceivers, which results in drastically smaller form factor andreduced power consumption. In a cellular phone, elimination of only one off-chip fixed-frequency filteras well as the associated matching network using the proposed technique reduces the transmit printedcircuit board area by more than 75%, while lowering the bill-of-materials. As such, the proposed researchwill have transformative impact on telecommunication. The reconfigurable MEMS filters developed inthis CAREER program could have far-reaching applications beyond wireless communication rangingfrom medical ultrasonic imaging to non-contact sensing. In addition to the outlined research effort, anintegrated educational program will be established which aims to educate	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Mina Rais-Zadeh / minar@umich.edu	University of Michigan Ann Arbor	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	CAREER: Routing in Cognitive Radio Networks Considering Activities of Primary Users	1252292	Two types of users, Primary Users (PUs) and Secondary Users (SUs), share common spectrum bands in Cognitive Radio Networks (CRNs). SUs communicate through un-assigned spectrum bands without disrupting PUs. It is widely assumed that the activities of PUs follow some probabilistic models regardless of time, geography and social relationships. However, the time-and-geography-dependent social activity patterns of PUs can definitely be taken advantage of by SUs to obtain more spectrum opportunities and help with featuring the fundamental characteristics of CRNs in a more meaningful way. Unfortunately, this fact has been overlooked. This project conducts a comprehensive study on designing routing protocols/algorithms integrating technologies from social networks and traditional CRNs. New statistic learning models and community detection methods considering PUs` activity patterns are proposed. The fundamental properties of secondary networks under certain activity patterns and community patterns of PUs are investigated. Corresponding guidance for designing upper layer protocols for CRNs is provided. This project has a strong impact on both theoretical and practical aspects of CRNs as well as social networks. Considering the characteristics of PUs, new research challenges and significance of the corresponding problems are elaborated. The project integrates research and education with the intent of attracting undergraduate and graduate students to the area of CRNs. It also outreaches high school students. The outcomes will provide valuable resources for the CRN society and will be published in conferences, journals, and on the Internet.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Zhipeng Cai / zcai@gsu.edu	Georgia State University Research Foundation, Inc.	no-value

National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; ADVANCED NET INFRA & RSCH; TRUSTWORTHY COMPUTING; EXP PROG TO STIM COMP RES	CAREER:THAWS--Towards Highly Available Wireless Services	845671	With the continuing proliferation of wireless technology, a wide spectrum of emerging applications using this technology will be tightly interwoven into the fabric of our everyday lives: wireless sensor networks can monitor personal health or critical infrastructures. The viability and success of many of these applications critically hinges on the availability of the underlying wireless communication. As wireless networks become increasingly pervasive, the problem of radio interference and jamming will be inevitable, raising a serious threat to the availability of wireless services. To enable the continuous and highly-available data delivery services over the entire lifetime of wireless networks in support of wireless applications, it is crucial that the wireless networks have built-in strong defense mechanisms against interference and jamming.This project aims to develop a suite of holistic solutions that monitor the radio environment and provide quick recovery to interrupted services in case of jamming or radio interference. In contrast to traditional techniques, such as spread spectrum which requires costly new hardware, the proposed techniques involve networks to manage their resources collaboratively across all layers to assure the availability of network services, leveraging existing commodity wireless platforms. Through the interaction with industry partners, the project results are expected to provide guidance for coping with jamming in future network architecture. The educational component of this project seeks to prepare students to face the challenges of rapidly evolving technologies in wireless networks. The experimental and design components of this project will enhance both the undergraduate and graduate students' education in related areas.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Wenyuan Xu / wyxu@cse.sc.edu	University South Carolina Research Foundation	no-value
National Science Foundation (NSF)	SIGNAL PROCESSING	CCF: Small: Online Learning and Exploitation of the Radio Frequency Spectrum with Sub-Nyquist Sampling	1534957	This project will close technical gaps to enable cognitive radio receivers to explore the radio frequency spectrum online, using the most advanced form of Analog to Digital conversion, referred to as Finite Rate of Innovation (FRI) sampling coupled with the most advanced learning techniques. We plan to use the well-established framework of the multi-armed bandit (MAB) problem, which models the situation of a cognitive radio agent that simultaneously attempts to acquire new knowledge and to optimize its decisions based on what it has previously learned. Our main contribution lies in combining this framework with this novel Analog to Digital receiver front-end, sampling rate below the so called Nyquist limit, adaptively tuning parameters in the sampling structure to sense spectrum opportunities over a much wider range of frequencies than was previously considered possible, and specifically further below what is attainable myopically, without adaptation.The outcome of our study is a cohesive system model for a cognitive sensors, endowed with a decision engine that can optimize not only what to sample but also how to sample analog signals, leveraging on its expected success in finding spectrum holes. The project will explore the complexity of the overall architecture and, ultimately, evaluate the potential benefits of a cognitive MAB-FRI receiver. By moving learning algorithms a step closer to manage directly the data-acquisition interface to the physical world, the research as broad implications in a variety of related sensing problems. The project will also include activities to engage students in classrooms presenting the basic mathematical tools used in this research and minorities in research projects that contribute to advance the broad field of adaptive systems.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Anna Scaglione / Anna.Scaglione@asu.edu	Arizona State University	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS; COMM & INFORMATION THEORY	CIF: Medium: Interference Alignment and the Rate-Reliability Tradeoff of Wireless Networks	963925	Modern society is increasingly relying on wireless networks. Spectrum is the most valuable resource in a wireless network. How to share this limited resource among different users is one of the main challenges. When different users share the same spectrum, their signals cause interference to each other. Therefore, the most distinctive feature of wireless networks is the phenomenon of interference. In this research, we place special emphasis on practical considerations to ultimately find new 'realistic' methods to deal with interference.A recent development is the idea of interference alignment which has shown that the capacity of wireless networks may be significantly higher than previously believed. Since higher rates invariably come at the cost of lower reliability, the emerging capacity results present only half the picture. This research is motivated by the need to complete this picture by evaluating the benefits of interference alignment schemes on the performance of wireless networks when both rate and reliability are of concern. The research follows three main thrusts. First, we examine the rate-reliability tradeoff of interference alignment schemes from the traditional coding perspective which places emphasis on low decoding complexity, usually at the cost of a restricted notion of optimality. Second, we examine the rate-reliability tradeoff of interference alignment schemes in the Shannon framework which allows strong definitions of optimality, usually at the cost of unbounded delay and complexity. These two thrusts are the stepping stones to the final thrust to reconcile the findings from the two distinct perspectives and use the collective insights to develop new physical layer schemes that can operate at the frontier of the rate-reliability tradeoff.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hamid Jafarkhani / hamidj@uci.edu	University of California-Irvine	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS	CIF: Small: Collaborative Research: Synergistic Exploitation of Network Dynamics and Knowledge Heterogeneity in Wireless Networks	1422090	The ubiquity and accelerated growth of wireless networks and services is critically dependent on the availability and efficient use of wireless spectrum. Increasing demand for spectrum is already pushing the current commercial wireless networks to their limits and accentuates the need for transformative approaches for wireless system design. In order to meet this demand, wireless networks are rapidly evolving towards a highly dense, user-deployed, heterogeneous infrastructure characterized by aggressive spectral reuse. Such evolutionary architectures can realize high data rates although they must operate in the presence of severe interference. In traditional system design, interference is viewed as a negative externality with the end goal being its suppression or mitigation. This project develops new approaches for embracing interference through synergistic exploitation of feedback, network dynamics and network knowledge heterogeneity. The key angle leveraged in this work is to exploit interference as side information. The project will characterize the gain provided by feedback, and analyze the scalability and dependence of such gains on network topology. In addition, the researchers investigate the impact of dynamical variations in network topology and devise algorithms that harness such variations to enhance the overall network performance. The researchers also investigate the optimal utilization of heterogeneous channel knowledge for multi-flow multi-antenna wireless systems, by considering scenarios in which network channel knowledge exhibits variability in spatial and temporal domains and developing algorithms to exploit such variability.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ravi Tandon / tandonr@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS	CIF: Small: Collaborative Research: Synergistic Exploitation of Network Dynamics and Knowledge Heterogeneity in Wireless Networks	1422129	The ubiquity and accelerated growth of wireless networks and services is critically dependent on the availability and efficient use of wireless spectrum. Increasing demand for spectrum is already pushing the current commercial wireless networks to their limits and accentuates the need for transformative approaches for wireless system design. In order to meet this demand, wireless networks are rapidly evolving towards a highly dense, user-deployed, heterogeneous infrastructure characterized by aggressive spectral reuse. Such evolutionary architectures can realize high data rates although they must operate in the presence of severe interference. In traditional system design, interference is viewed as a negative externality with the end goal being its suppression or mitigation. This project develops new approaches for embracing interference through synergistic exploitation of feedback, network dynamics and network knowledge heterogeneity. The key angle leveraged in this work is to exploit interference as side information. The project will characterize the gain provided by feedback, and analyze the scalability and dependence of such gains on network topology. In addition, the researchers investigate the impact of dynamical variations in network topology and devise algorithms that harness such variations to enhance the overall network performance. The researchers also investigate the optimal utilization of heterogeneous channel knowledge for multi-flow multi-antenna wireless systems, by considering scenarios in which network channel knowledge exhibits variability in spatial and temporal domains and developing algorithms to exploit such variability.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Sennur Ulukus / ulukus@umd.edu	University of Maryland College Park	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS	CIF: Small: Network Beamforming: A Distributed Source Coding Perspective	1218771	Wireless networks have influenced our life tremendously through the promise of portability, mobility, and accessibility. Spectrum is the most valuable resource in a wireless network. As the number of users in a wireless network is increased, different users compete for the same portion of the available spectrum. The result of such a competition may be a lower quality of service, dropping of some users, higher prices and so on. One promising idea to resolve some of these challenges is to let the users cooperate in addition to compete with each other. The study of such a multi-user cooperative communications system is the main goal of this proposal. Most of the emphasis in cooperative communications has been on improving the performance of a single-user (point-to-point) communication. The insights from the single-user setting are not sufficient to address the challenges of multi-user communication networks. When shifting the paradigm from single-user to multi-user, the natural question that arises is the following - what are the benefits of cooperation in a multi-user network setting suffering from interference and how to achieve them. We start by defining new performance measures called generalized diversity orders. Then, we study different aspects of the above question including the maximum possible diversity orders in different multi-user cooperative communications network scenarios. We also propose to design practical systems that achieve these maximum diversity orders.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hamid Jafarkhani / hamidj@uci.edu	University of California-Irvine	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS	CIF: Small:Interference Engineering in Wireless Systems	1216407	Demands for wireless access to the Internet and voice communicationskeep growing exponentially, while the available spectrum remains scarce.As a result, cellular, WiFi, mesh, and cognitive networks areincreasingly interference-limited.Despite significant efforts over the last decade, key aspects of theinterference are still not well understood. In particular, the spatialand temporal correlation of the interference has been largely ignored,despite its profound impact on the performance. With the propermathematical and numerical tools from stochastic geometry and spatialstatistics, the impact of protocol decisions on the interference as arandom field in space and time can be assessed, and, even moreimportantly, the question of how to engineer the interference foroptimum performance can be addressed.This project aims at taking a major step in this direction. It focuseson developing a fundamental understanding of the structure of theinterference using a rigorous analytical approach. While the outcomes ofthe project will be applicable to and relevant for most modern wirelesssystems, they are particularly pertinent for cognitive systems, whereinterference between primary and secondary users is not just a technicalproblem leading to a performance reduction, but also a regulatory andlegal issue.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Martin Haenggi / haenggi.1@nd.edu	University of Notre Dame	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Applying Behavioral-Ecological Network Models to Enhance Distributed Spectrum Access in Cognitive Radio	1443985	The scientists identify fair resource sharing methods as a critical concern in the design of smart radio networks. The researchers note that fair sharing of resources is of fundamental importance in human communities, and propose to apply social network methods to the design of dynamic spectrum access systems. By applying the experience from a mature field, they plan to solve some of the more complex issues related to spectrum sharing in a constantly changing technical environment.In drawing the connection from the problem of resource-sharing in Cognitive Radio (CR), to models of solutions found within human/animal societies, the proposed research evaluates the extent to which our models of patterns of co-use in biological systems can be profitably leveraged within the context of distributed uncoordinated CR societies to enable individuals and groups to maximize their utility. Of particular relevance to this endeavor is recent ethnographic research on foraging networks of indigenous peoples and human foragers, which has found social relations to be a critical context in which natural selection acts on resource use and co-use behaviors. These findings concerning human behavior lie at the forefront of anthropology, revealing the tensions between sharing networks and optimal strategies and altering our understanding of past human social evolution, and by extension, our vision of the future evolution of artificial CR societies.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Bilal Khan / bkhan@jjay.cuny.edu	CUNY John Jay College of Criminal Justice	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: CCSS: D2D Wireless Networks: An Interference Nightmare or Resource Allocation Auspice	1405121	communications are expected to become a key feature supported by next generation cellular networks with advantages of: 1) extended coverage; 2) offloading in cellular networks; 3) improved energy efficiency; 4) enhanced throughput and spectrum efficiency; and 5) creation of new services. Interference management is of key importance for deployment of D2D networks. Although D2D communications bring improvement in spectral efficiency and system capacity, it also causes interference to the cellular network as a result of spectrum sharing. Thus, efficient resource allocation and interference coordination must be addressed to guarantee a target performance level of the cellular communications. This project constructs a distributed and cross-layer framework to turn the interference challenges into dynamic resource allocation auspice. The fundamental results to be obtained from this project will enable transformative techniques that can lead to improved performance of the next generation wireless networks. The results will be publicly available through publications and open source software release. The research results will be integrated into the existing combined education and research effort. Furthermore, the education component will equip both undergraduate and graduate students with the skills needed to contribute to the field of wireless networking. Outreach activities will be directed to high school students and increase the participation of women and minority in science and engineering. As such, the broader impact resulting from the proposed activities is also reflected through the integration of research and education for the training of future wireless workforce.The proposed activities are primarily targeted at constructing the new D2D networks, and then uncovering the design challenges, tradeoffs, and requirements for cross layer resource allocation approaches. Major intellectual merits in our proposed research thrusts are: 1) Resource Allocation with Underlay D2D Communication in Cellular Networks: Innovative resource allocation schemes are proposed to maximize the overall network throughput while ensuring quality-of-service. The proposed schemes consist of techniques, such as admission control, power control, and matching potential D2D partners, and then conduct joint cross-layer optimization for both D2D users and cellular users. 2) Game Theoretical Distributed Scheme: A variety of game theory approaches, such as reverse iterative combinatorial auction and Stackelberg game, are adopted for dynamic opportunistic resource allocation. Furthermore, the equilibrium of the game is investigated, and the approaches are designed for the game equilibria to be close-optimal compared to the optimal solutions. 3) Joint Consideration with Femtocell: Since femtocell/smallcell networking and D2D networking are two major research directions pushed by cellular service providers, open access is designed for femtocell together with D2D LTE-Advanced networks in order to optimize network connectivity, coverage, system performance, and balance. 4) Context Aware Network: a context aware framework is optimized for resource management in D2D networks, which is aligned with LTE-direct. Ultimately, the proposed interdisciplinary and cross layer framework will provide a blueprint towards	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Zhu Han / zhan2@uh.edu	University of Houston	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: CCSS: D2D Wireless Networks: An Interference Nightmare or Resource Allocation Auspice	1405116	communications are expected to become a key feature supported by next generation cellular networks with advantages of: 1) extended coverage; 2) offloading in cellular networks; 3) improved energy efficiency; 4) enhanced throughput and spectrum efficiency; and 5) creation of new services. Interference management is of key importance for deployment of D2D networks. Although D2D communications bring improvement in spectral efficiency and system capacity, it also causes interference to the cellular network as a result of spectrum sharing. Thus, efficient resource allocation and interference coordination must be addressed to guarantee a target performance level of the cellular communications. This project constructs a distributed and cross-layer framework to turn the interference challenges into dynamic resource allocation auspice. The fundamental results to be obtained from this project will enable transformative techniques that can lead to improved performance of the next generation wireless networks. The results will be publicly available through publications and open source software release. The research results will be integrated into the existing combined education and research effort. Furthermore, the education component will equip both undergraduate and graduate students with the skills needed to contribute to the field of wireless networking. Outreach activities will be directed to high school students and increase the participation of women and minority in science and engineering. As such, the broader impact resulting from the proposed activities is also reflected through the integration of research and education for the training of future wireless workforce.The proposed activities are primarily targeted at constructing the new D2D networks, and then uncovering the design challenges, tradeoffs, and requirements for cross layer resource allocation approaches. Major intellectual merits in our proposed research thrusts are: 1) Resource Allocation with Underlay D2D Communication in Cellular Networks: Innovative resource allocation schemes are proposed to maximize the overall network throughput while ensuring quality-of-service. The proposed schemes consist of techniques, such as admission control, power control, and matching potential D2D partners, and then conduct joint cross-layer optimization for both D2D users and cellular users. 2) Game Theoretical Distributed Scheme: A variety of game theory approaches, such as reverse iterative combinatorial auction and Stackelberg game, are adopted for dynamic opportunistic resource allocation. Furthermore, the equilibrium of the game is investigated, and the approaches are designed for the game equilibria to be close-optimal compared to the optimal solutions. 3) Joint Consideration with Femtocell: Since femtocell/smallcell networking and D2D networking are two major research directions pushed by cellular service providers, open access is designed for femtocell together with D2D LTE-Advanced networks in order to optimize network connectivity, coverage, system performance, and balance. 4) Context Aware Network: a context aware framework is optimized for resource management in D2D networks, which is aligned with LTE-direct. Ultimately, the proposed interdisciplinary and cross layer framework will provide a blueprint towards	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Geoffrey Ye Li / liye@ece.gatech.edu	Georgia Tech Research Corporation	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: C-HetNet -Towards Spectrum and Energy Efficient Next Generation Wireless Access Networks	1308006	The objective of this research is to exploit and establish the theoretical foundations to support the design of next generation cooperative, clean and centralized heterogeneous wireless access networks, or, C-HetNet. The approaches include designing novel algorithms for spectrum efficiency, energy efficiency and quality of service based mobile association, multi-layer interference management and power control, network wide cooperation and dynamic resource allocation in the C-HetNet; and seeking the design principles of balancing and optimizing spectrum efficiency, energy efficiency and quality of service in the C-HetNet.Intellectual merit: The project is expected to significantly advance the understanding in the heterogeneous wireless networks, which are expected to play a key role in meeting the future data capacity explosion and energy consumption escalation. The project will address the unique technical challenges in the C-HetNet and explore new solutions to spectrum and energy efficiency in mobile association, multi-layer interference management and power control, and dynamic cooperative resource allocation. Broader Impacts: The C-HetNet research activities have significant potentials to revolutionize wireless access networking technologies and wireless cross-layer design approaches. The research will provide a new wireless network paradigm to meet the ever-increasing wireless traffic demand and to address the needs on network cost reduction and global environmental protection; and will improve many application scenarios such as coverage extension, hotspots, and emergency network deployment for public safety, disaster rescues and medical applications. The research outcomes will be disseminated through publications and seminars and will be incorporated into undergraduate and graduate courses taught by the PIs.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Rose Qingyang Hu / rose.hu@usu.edu	Utah State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Investigation of Spectrum Sharing Between Radar and Wireless Communications Systems	1443909	This project will enable more efficient use of a scarce resource, the radio spectrum. This project will have broad impact on the public by enabling increased efficiency in communications between citizens, while simultaneously shared use of the same frequency range for radar applications. The techniques developed will potentially reduce the impact by both accidental and intentional (jamming) interference. Students, who will carry out part of the research, will be better trained to join the US work force. Furthermore, their use of the research in the classroom presentations will lead to a keener appreciation of the use and issues faced by permitting widespread use of cognitive radio devices, devices that can change its wireless channel at will.This proposal explores the potential for Synthetic Aperture Radars to operate with other users of the spectrum. In particular it aims to explore the capacity for a Radar system to operate efficiently by recognizing and discarding false positive signals; in effect by using a variety schemes to identify and ignore interference. Their approach is unique in that it attempts to integrate the spectrum sharing into the fundamental operation of the radar.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hai Deng / Hai.Deng@FIU.EDU	Florida International University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Investigation of Spectrum Sharing Between Radar and Wireless Communications Systems	1443857	This project will enable more efficient use of a scarce resource, the radio spectrum. This project will have broad impact on the public by enabling increased efficiency in communications between citizens, while simultaneously shared use of the same frequency range for radar applications. The techniques developed will potentially reduce the impact by both accidental and intentional (jamming) interference. Students, who will carry out part of the research, will be better trained to join the US work force. Furthermore, their use of the research in the classroom presentations will lead to a keener appreciation of the use and issues faced by permitting widespread use of cognitive radio devices, devices that can change its wireless channel at will.This proposal explores the potential for Synthetic Aperture Radars to operate with other users of the spectrum. In particular it aims to explore the capacity for a Radar system to operate efficiently by recognizing and discarding false positive signals; in effect by using a variety schemes to identify and ignore interference. Their approach is unique in that it attempts to integrate the spectrum sharing into the fundamental operation of the radar.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hao Ling / ling@ece.utexas.edu	University of Texas at Austin	no-value

National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: Collaborative Research: Joint Adaptation of Multiple Cognitive Systems without Explicit Coordination	1265280	Cognitive wireless systems are a collection of wireless network entities that are able to adapt intelligently to the environment through observation, exploration and learning. This project designs methods for cognitive radio systems to compete for inhomogeneous spectrum resources and to establish, without explicit coordination, a spectrum etiquette. Each system's resource utilization strategy must be decided with only imperfect information of other systems' actions, and the resulting adaptations must discourage any one system from manipulating the agreed spectrum etiquette. The framework of dynamic games with imperfect private monitoring is adopted to design coexistence mechanisms for cognitive radio systems sharing inhomogeneous resources and to analyze the stability, robustness, complexity, and convergence of these mechanisms. This work directly impacts the development and standardization of frequency agile wireless systems that can more efficiently use the available spectrum to support increasing demand for ubiquitous wireless connectivity at high data rates. The project is a collaborative effort between researchers in the US (at Virginia Tech and the University of Houston) and Finland (at the University of Oulu). This work will extend the state of the art in cognitive system adaptations by incorporating the ability to: efficiently adapt under imperfect information; fairly share inhomogeneous resources; and discourage manipulation of resource use by selfish adversaries. Results will be disseminated in high impact journals and conferences; the designed coexistence mechanisms will also be presented to industry and regulators in the US and Europe.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Luiz DaSilva / ldasilva@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS	EAGER: Ultra-FFAST Alias Codes for Sparse Spectrum Estimation: Next Generation Compressed Sensing	1439725	This proposal targets the theoretical foundations and algorithmic design of ultra-large-scale sparse signal recovery and spectral estimation problems, with applications to fast MRI acquisition, low-power spectrum-sensing for cognitive radio, and low-power spectroscopy for deep-space exploration. While compressed sensing has recently emerged as a powerful framework for understanding the fundamental limits of sparse signal processing, current algorithms based on convex optimization, are difficult to scale efficiently. This proposal is motivated therefore to address the challenge of scale in the theory and design of sparse signal recovery problems, with the goal of enabling real-time processing capability.This proposal develops the mathematical foundations as well as practical sub-linear-time algorithms for ultra-large-scale sparse signal recovery and spectral estimation problems. The theory and algorithms are derived through an interdisciplinary mix of intellectual tools from coding theory, graph theory, number theory, and statistical signal processing. This leads to the proposal of new computational primitives dubbed as sparse-graph alias codes that are analogous to Low-Density-Parity-Check (LDPC) codes that have revolutionized modern communication systems. The proposed framework is envisioned to provide a similar impact on next-generation sparse signal processing systems with respect to (i) acquisition overhead; (ii) computational and energy efficiency; and (iii) performance guarantees and stability.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kannan Ramchandran / kannanr@eecs.berkeley.edu	University of California-Berkeley	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Cognitive Mesh: Making Cellular Networks More Flexible	1343356	Innovative use of wireless devices such as smartphones in various mobile applications has exacerbated the congestion over cellular spectrum. On the other hand, many licensed spectrum blocks are left unused. Although cognitive radios (CR) technology has emerged as an enabler for unlicensed users to opportunistically access the unused licensed spectrum, most previous works commonly assume that each user is equipped with a CR which can operate across a wide range of spectrum. This may be possible in theory, but may not be practical for light-weight devices such as cell phones. How to effectively utilize the CR technology to build more flexible networks so that even non-CR capable devices can benefit from the opportunistic access to the unused spectrum is therefore in dire need.In this project, the PIs propose a novel cognitive mesh assisted cellular network (CMCN) and investigate: 1) the architectural design of CMCN so that unoccupied licensed spectrum can be efficiently utilized and non-cognitive cellular devices can benefit from the CR technology, 2) spectrum and energy efficient CR mesh router placement under uncertain spectrum availability, 3) how to construct a fine-grained spectrum map to facilitate efficient spectrum allocation and intelligent traffic delivery, and 4) experimental validation and implementation for the proposed design. The research outcome provides a viable solution to the spectrum congestion in cellular systems. Moreover, with this flexible architecture, telecommunication industries can be rejuvenated with new innovations, leading to further development of cellular networks with high capacity and better support of new applications such as mobile healthcare, which has significant impact on individuals' lives and further provides greater opportunities for job creation and economic growth. The results of the project will be disseminated through publications and presentations. Finally, this project will actively recruit and train minority students for the future workforce and mentor junior faculty.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yuguang Fang / fang@ece.ufl.edu	University of Florida	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Let`s share CommRad -- spectrum sharing between communications and radar systems	1443967	The 2012 report to the President entitled "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth" recommends releasing portions of the large governmental radar bands to be shared with commercial wireless services. This proposal identifies viable sharing mechanisms between radar and communication systems, which traditionally are operated on non-overlapping bands and are engineered to attain very different goals, so that they may co-exist in a way that is minimally harmful, or ideally beneficial, to both. This research first examines the impact unaltered radar and communication systems would have on one another and thereafter proposes a series of solutions for co-existence that range from realistic solutions with respect to legacy systems (where one of the radar or communication systems remains unaltered) to novel transformative joint designs. The availability of proven robust and optimal sharing mechanisms will pave the way to the development of new wireless services while preserving the critical roles radar systems play in the globally networked society.A multidisciplinary team with expertise in radar and statistical signal processing, cognitive radio and spectrum sharing, communication and information theory, and electromagnetics and propagation, has been assembled to address the following thrusts: 1) understand and model the impact of overlapping frequency bands on current, unaltered radar and communication systems; 2) a radar centric approach, where adaptive radar processing is the key to reduce interference from communication systems; 3) a communication network centric approach, where coding is used to improve resilience to radar interference; 4) the joint design of communication and radar systems, where the information-theoretic understanding of the tradeoffs between communication data rates and estimation rates is at the base of this cooperative design; 5) validation of the models and proposed algorithms by using real experimental data. The results of this research will be timely presented at major national and international professional venues; the general public will be reached by means of modern social media, such as videos of undergraduate-run experiments that demonstrate the developed technology and its practical impact. The developed fundamental framework will form a solid foundation for spectrum sharing between radar and communication systems; the developed technology is expected to be of immediate and far-reaching use for both radar and communication private and public sectors alike. Students involved in this research will receive a cutting edge education and training in radar and communication sciences, acquiring fundamental skills to be successful in the current competitive, diverse, and global workforce market.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Daniela Tuninetti / danielat@uic.edu	University of Illinois at Chicago	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Let`s share CommRad -- spectrum sharing between communications and radar systems	1443971	The 2012 report to the President entitled "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth" recommends releasing portions of the large governmental radar bands to be shared with commercial wireless services. This proposal identifies viable sharing mechanisms between radar and communication systems, which traditionally are operated on non-overlapping bands and are engineered to attain very different goals, so that they may co-exist in a way that is minimally harmful, or ideally beneficial, to both. This research first examines the impact unaltered radar and communication systems would have on one another and thereafter proposes a series of solutions for co-existence that range from realistic solutions with respect to legacy systems (where one of the radar or communication systems remains unaltered) to novel transformative joint designs. The availability of proven robust and optimal sharing mechanisms will pave the way to the development of new wireless services while preserving the critical roles radar systems play in the globally networked society.A multidisciplinary team with expertise in radar and statistical signal processing, cognitive radio and spectrum sharing, communication and information theory, and electromagnetics and propagation, has been assembled to address the following thrusts: 1) understand and model the impact of overlapping frequency bands on current, unaltered radar and communication systems; 2) a radar centric approach, where adaptive radar processing is the key to reduce interference from communication systems; 3) a communication network centric approach, where coding is used to improve resilience to radar interference; 4) the joint design of communication and radar systems, where the information-theoretic understanding of the tradeoffs between communication data rates and estimation rates is at the base of this cooperative design; 5) validation of the models and proposed algorithms by using real experimental data. The results of this research will be timely presented at major national and international professional venues; the general public will be reached by means of modern social media, such as videos of undergraduate-run experiments that demonstrate the developed technology and its practical impact. The developed fundamental framework will form a solid foundation for spectrum sharing between radar and communication systems; the developed technology is expected to be of immediate and far-reaching use for both radar and communication private and public sectors alike. Students involved in this research will receive a cutting edge education and training in radar and communication sciences, acquiring fundamental skills to be successful in the current competitive, diverse, and global workforce market.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Mark Bell / mrb@ecn.purdue.edu	Purdue University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Efficient Management and Opportunistic Usage of Radio Spectrum based Graph Theory	1247545	The tremendous increasing demand to support various data applications requires a wireless network to be more agile and spectral-efficient. Cognitive Radio technology allows secondary users to access the underutilized licensed bands and is a promising solution. However, the coexistence of secondary users with the authorized primary users requires careful and dynamic resource management to deal with interference, which is a very challenging issue. The major objective of this project is to deal with the issue by utilizing graph theory/algorithms to develop efficient resource management schemes for general coexistence scenarios.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Geoffrey Ye Li / liye@ece.gatech.edu	Georgia Tech Research Corporation	no-value

National Science Foundation (NSF)	COMPUTING RES INFRASTRUCTURE	II-NEW: A Reconfigurable Multi-Cell Research Platform for Massive Multiple Input Multiple Output (MIMO) Networks	1405937	Mobile data usage is skyrocketing thanks to the popularity of smartphones and tablets. Wireless network carriers are scrambling to increase their capacity by acquiring spectrum and deploying more base stations. Multiple input, multiple output (MIMO) technologies have been widely recognized for their potential to significantly improve the spectral efficiency of wireless communication. In theory, the capacity of MIMO grows with the number of antennas. Because mobile devices are form factor-constrained, the majority of research has focused on placing many antennas on base stations, with aggressive proposals calling for hundreds of them. Such effort has created three pressing needs in wireless research platforms. First, there is a need for base stations with many antennas so that there is flexibility in how antennas are used, both for communication and experimental measurement. Second, there is a need for a network research platform in which emerging ideas that deal with inter-cell interference can be experimentally studied. Finally, there is a need for a network research platform with adequate and distributed computing resources to address the computational requirement and systems challenges of implementing advanced MIMO technologies. This project will develop ArgosNet, a reconfigurable multi-cell research platform that will meet the above three needs. ArgosNet will not only allow cutting-edge ideas for using MIMO to be experimentally tested under realistic settings, but also enable the teaching of them with a real-world experimental deployment. ArgosNet has three completely programmable key components: (i) a configurable number of base stations each of which can have up to several hundreds of antennas, (ii) battery-powered mobile terminals, (iii) a server cluster that are connected with the base stations with high-throughout, precisely synchronized backhaul. Real-time, wideband communication between base station and terminal will be supported for UHF and 2.4/5 GHz. Base stations will be precisely synchronized via the backhaul and will cooperate to fully support network functions such as handoff and localization. ArgosNet will be digitally and mechanically reconfigurable with a default configuration of three outdoor base stations each with 108 antennas. It can be easily reconfigured to have fewer base stations each with more antennas or more base stations each with fewer antennas. The research platform will be a new infrastructure deployed on the campus of Rice University. The project will develop an open-access repository with the complete hardware and software design for ArgosNet's many-antenna base station, as well as examples and a toolkit for rapid prototyping with ArgosNet so that other researchers can build similar research platforms at their own organizations.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-3	Medium	ongoing	Lin Zhong / LZhong@rice.edu	William Marsh Rice University	no-value
National Science Foundation (NSF)	ADVANCED TECHNOLOGIES & INSTRM	Innovative Multiband Filters	1006993	Filters for astronomical imaging have typically admitted more or less uniformly all of the light between two wavelength extremes. However, there are instances where more complex transmission functions are highly desirable. One such case is in the near-infrared, where terrestrial atmospheric emission arising from the molecule OH occurs in narrow bands. Here, the background for imaging with a broadband filter could be reduced by a factor of two if the molecular lines could be selectively blocked. Until recently, custom "tuning" of filters was not possible. However, it is now not only practical but also a compelling technique for improving the speed of near-IR surveys. Compared to other methods of enhancing efficiency, there is every reason to believe that such innovative imaging filters should also be inexpensive.Dr. James Rhoads of the Arizona State University proposes to carry out the development of custom infrared imaging filters, working with commercial vendors in their design and characterization for a variety of applications in astronomy. Among the research areas that will see a qualitative benefit are a) finding the earliest galaxies and quasars, b) discovering high-redshift supernovae and characterizing dark energy, and c) identifying the lowest-mass brown dwarfs through the development of a special filter tuned to its unique near-IR spectrum. The PI will oversee the design, construction, and evaluation of these filters, and in addition provide functioning optics for use by the public on instruments operated at the National Optical Astronomy Observatories. Furthermore, the filter prescriptions will be publicized for duplication by the entire observational astronomy community. Funding for this work is being provided by NSF's Division of Astronomical Sciences through its Advanced Technologies and Instrumentation program.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	James Rhoads / James.Rhoads@asu.edu	Arizona State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Manifold-Based System for Passive-Active Spectrum Sharing	1248010	Terrestrial-based wireless transmitters can often cause interference to space-based remote sensing instrumentation, such as satellites that are designed to probe the Earth's land, ocean, and atmosphere. Remote sensing observations of the Earth are often acquired using low-Earth orbit satellites that scan a narrow swath of the Earth at any one time, and orbit the Earth once each 90 minutes or so. The satellite detectors are often exposed to specific interference sources for only a few tens of milliseconds as the satellite passes overhead and the detector beam passes over the Earth's surface at very high speed, but that exposure is sufficient to produce substantial interference to the very sensitive observations being acquired by the satellite. One method of mitigating the interference is to synchronize very brief blanking of terrestrial interference sources as a remote sensing satellite using the same band passes overhead, leveraging the fact that satellite orbits are very well known and the specific point of time at which a sensor pixel will be passing over a particular point on the Earth can be determined with high accuracy. This method is one example of a broader application of coordinated interference mitigation techniques that will be explored as part of this research. The broader applications may extend beyond satellites to cases of interference between and among a large variety of land-, air-, and space-based users.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Albin Gasiewski / al.gasiewski@colorado.edu	University of Colorado at Boulder	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Microfluidically-Tunable Metamaterial Lenses for Wideband, High-Power, Phased-Array Applications	1101146	The objective of this research is to fundamentally advance the development of affordable, high-power phased-array antenna technology. The approach is to use the recent advances in the areas of microwave metamaterials and microfluidics to develop a new class of high-power-capable, tunable, true-time-delay microwave lenses.Intellectual Merit: The fundamental tradeoffs that exist between cost, power handling capability, thermal management, and efficiency have hindered the development of high-power, affordable phased-array antenna technology. This project seeks to address these fundamental shortcomings using a previously unexplored interdisciplinary approach. A new class of metamaterials will be used to develop true-time-delay microwave lenses capable of handling very high power levels. A microfluidic mechanism will be used to rapidly reconfigure the lens response and achieve dynamic beam steering in lens-based phased arrays.Broader Impacts: This project is expected to positively impact the society and the economy by proliferating the use of phased-array technology in future wireless systems that aim at addressing grand societal and economic challenges, including efficient access to the radio spectrum and economically viable solar power transmission. Educational goals of this work are intimately linked to the research objectives and include involvement of underrepresented undergraduate and graduate students in research activities, integration of research into the teaching of engineering at the undergraduate and graduate levels, and development and broad dissemination of research-based educational materials. The research findings of this work will be integrated with existing University of Wisconsin-Madison courses to enhance the undergraduate and graduate engineering curricula.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Nader Behdad / behdad@engr.wisc.edu	University of Wisconsin-Madison	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Modeling, Monitoring, and Optimization of Cognitive Networks	1202135	The objective of this proposal is to establish transformative novel solutions to fundamental problems in cognitive network modeling, monitoring and optimization with significant impact to both theory, algorithms, and implementation. The intellectual merit comprises the novel concept of network cartography as the tool for distilling and summarizing the "network state" for the purpose of network management. The resultant holistic approach to network monitoring offers modular and scalable statistical representations driven by past (and driving future) measurements and system design specifications. Further, it enables inference of global network behavior and adaptation of protocol designs to enhance network robustness and quality-of-service. Dramatic improvements in CR network performance will be attained by augmenting the vivid description of the network global state with models that account for the intrinsic non-tangible connectivity of cognitive wireless links, and the interference challenges arising from spectrum sharing hierarchies. The broader impacts include advances of the IEEE 802.22 compliant cognitive radio technologies, and smart grid, surveillance, geo-monitoring, and institutional networks. Furthermore, tangible advances in the fundamental tools exploited will permeate benefits to bio-informatics, speech and image compression, machine learning and data mining for social networks, and the emerging smart grid communication network protocols. Through Honors Theses and Senior Design Projects, the proposed research will also impact student training with hands-on experience in state-of-the-art wireless cognitive systems and network optimization subjects that are not fully provided by coursework.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Georgios Giannakis / georgios@umn.edu	University of Minnesota-Twin Cities	no-value

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Multiplexing Techniques for Scalable Wireless Interconnects at sub-THz Frequencies: Circuits-EM-Communication Codesign Approach	1408490	frequencies as scalable, energy-efficient solution towards one terabit per second (1 Tb/s). As we enter the era of terra-scale computing, massive amounts of data crunching by these processors will require inordinately large amount of bandwidth, not currently served by either electrical or optical interconnect solutions. Current methods of scaling of electrical interconnects to higher data rates are either limited by the available bandwidth density (Gb/s/mm2), energy cost, the circuit complexities in driving high-speed data through the long and lossy physical traces, or by the maximum number of parallel physical traces possible to accommodate in a constrained form factor. Wireless interconnects near THz frequencies are promising , but wireless data rates of 10Gb/s and the high energy/bit requirement, falls way short of meeting the bandwidth requirements for future off-chip interconnects. In this proposal, we aim to investigate techniques where the capacity of the channel can be increased many-fold using communication theoretic spatial-domain multiplexing techniques. Under the same total power constraint, such architectures have orders of magnitude more channel capacity, thereby providing a scalable solution towards wireless Tb/s interconnects. A key component in this proposal is to combine seamlessly, high-frequency circuits and systems and antennas with communication-theoretic techniques to increase capacity and data-rates by orders of magnitude, not otherwise possible in a single directional partitioned approach. Metal-based interconnect traces on printed circuit boards(PCB) serve as the most common method of chip-chip interconnects. However, increasing need of computational power to crunch more and more data in specialized server systems, high-performance computing or even portable devices, requires that communication data-rate from the processor to the peripherals be scaled proportionately. In most cases, the number of input-output pins is limited by the form factor, which puts a bottleneck on communication capacity among all the processors. In this proposal, we investigate techniques to use very high-frequency electromagnetic waves located in the Terahertz portion of the spectrum (between microwaves and infra-red) to establish seamless wireless communication links among the chipsets. Moving to such high frequencies enables us to exploit orders of magnitude higher bandwidth needed for sustaining such high data rates. Additionally, we investigate techniques to increase the communication links capacity by another order through spatial multiplexing techniques in a short-range communication setting. The success of this project is envisioned to bring new forms of smart interconnect solutions for a host of various applications from high-performance computing to internet data centers. The results of this research effort are also expected to have major impact in advancing the field of THz electronics benefitting diverse applications such as imaging and sensing. In a broader vision, this will have major impacts in radically new technologies in communication and computation, which not only makes us a more connected society, but also fuel research in other areas of applied science. This research is also expected to train both graduate and undergraduate students in multi-disciplinary fields,	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kaushik Sengupta / kaushiks@princeton.edu	Princeton University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Broadcast in Cognitive Radio Ad Hoc Networks	1218751	Broadcast is an important operation in ad hoc networks, especially in distributed multi-hop multichannel networks. Although the broadcasting issue has been extensively investigated in traditional single channel and multi-channel ad hoc networks, there are unique challenges that are un-explored in the broadcast design in cognitive radio ad hoc networks. Existing schemes can have serious performance degradation due to the neglect of the dynamics in the spectrum availability in cognitive radio networks. The research objective of this project is to design, analyze, and evaluate new broadcast protocols for multi-hop cognitive radio ad hoc networks without a common control channel. The broadcast design is aimed at maximizing the broadcast success rate and minimizing the average broadcast delay simultaneously. The approach is focused on exploiting the spectrum correlations of neighboring nodes and the spectrum diversity of different nodes in designing new channel rendezvous, scheduling, and collision avoidance algorithms to achieve the broadcast performance goals in practical scenarios. This project will provide fundamental and complementary solutions to existing cognitive radio networking research on other network operations. It will also help generate innovative techniques to numerous applications of the cognitive radio and dynamic spectrum access technology. This project provides an excellent opportunity for graduate and undergraduate research students to gain valuable educational training and research experiences. The research results will be presented at IEEE/ACM journals and international conferences.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jiang (Linda) Xie / Linda.Xie@uncc.edu	University of North Carolina at Charlotte	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Coexistence and Cooperation in Future Spectrum Sharing Heterogeneous Networks	1422153	The world has witnessed an exponential growth in the number and demand of wireless devices, and an increase in the array of wireless broadband network applications that has permeated virtually all aspects of our daily lives. However, this progress cannot be sustained with the current wireless communication network technologies, and this fact has spurred research innovations towards the next generation of wireless systems, typically termed 5G technologies. Two key paradigm shifts that will help meet these demands in 5G networks are the deployment of heterogeneous small cell networks combined with device to device and multi-hop wireless communication, and the adoption of more innovative ways of sharing the spectrum through cognitive radio and dynamic spectrum access.This project provides tools for quantifying the design trade-offs in future spectrum-agile heterogeneous networks, as well as the theoretical performance limits. Several networks are expected to exist in the same geographical area, each with varying access rules and access protocols. The project studies co-existence and possible cooperation between such networks. Two modes of cooperation are considered: relay cooperation and content cooperation. Two approaches are considered for the analysis of each of these modes, which compose the two thrusts of the proposal: Thrust I: queuing network approaches, which characterize finite as well as asymptotic performance, and focus on random-access based schemes; and Thrust II: scheduling and optimization approaches, which characterize the theoretical best possible performance. The broader impacts of the work include the development of course projects and modules for two graduate level courses that integrate results from the two thrusts of this research, K-12 outreach, enhancement of student diversity and increase of number of women and under-represented groups in engineering, and international collaboration that offers international exposure for students.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Alhussein Abouzeid / abouzeid@ecse.rpi.edu	Rensselaer Polytechnic Institute	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Exploring the 60 GHz Spectral Frontier for Multi-Gigabit Wireless Networks	1320472	The exponential growth of wireless data traffic causes spectrum depletion and significantly stresses the capacity of existing and future wireless networks. The massive unlicensed bandwidth in the 60 GHz band provides great potential to meet the surging wireless data demand. The goal of this project is to gain a deep understanding of the 60 GHz propagation and channel characteristics, and to develop effective 60 GHz network protocols. This project falls into four interacted thrusts: (i) 60 GHz 3-D channel propagation measurement and modeling; (ii) MAC scheduling in 60 GHz networks; (iii) 60 GHz mesh network protocols; and (iv) enabling rich multimedia communications in 60 GHz networks. Various methods including field testing and measurements, mathematical modeling, network protocol design, distributed control, and cross-layer optimization are adopted to address the research challenges. This project is part of a broad and ambitious global effort to develop novel techniques to exploit the huge license-free spectrum in the 60 GHz band in face of the exponential wireless data growth. It has the potential to accelerate the deployment of more powerful, bandwidth intensive, ubiquitous and cheaper wireless applications and services, and the support of more versatile, robust and rich-multimedia wireless networks. Complementary to the research agenda, the project also carries out a broad range of education and outreach activities, including integration of research findings into wireless engineering courses, textbook development, promoting underrepresented and undergraduate populations, collaboration with an HBCU, and participating in existing programs at the PIs` institutions for outreach to K-12 students and teachers.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Theodore Rappaport / tsr@nyu.edu	New York University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Exploring the 60 GHz Spectral Frontier for Multi-Gigabit Wireless Networks	1320664	The exponential growth of wireless data traffic causes spectrum depletion and significantly stresses the capacity of existing and future wireless networks. The massive unlicensed bandwidth in the 60 GHz band provides great potential to meet the surging wireless data demand. The goal of this project is to gain a deep understanding of the 60 GHz propagation and channel characteristics, and to develop effective 60 GHz network protocols. This project falls into four interacted thrusts: (i) 60 GHz 3-D channel propagation measurement and modeling; (ii) MAC scheduling in 60 GHz networks; (iii) 60 GHz mesh network protocols; and (iv) enabling rich multimedia communications in 60 GHz networks. Various methods including field testing and measurements, mathematical modeling, network protocol design, distributed control, and cross-layer optimization are adopted to address the research challenges. This project is part of a broad and ambitious global effort to develop novel techniques to exploit the huge license-free spectrum in the 60 GHz band in face of the exponential wireless data growth. It has the potential to accelerate the deployment of more powerful, bandwidth intensive, ubiquitous and cheaper wireless applications and services, and the support of more versatile, robust and rich-multimedia wireless networks. Complementary to the research agenda, the project also carries out a broad range of education and outreach activities, including integration of research findings into wireless engineering courses, textbook development, promoting underrepresented and undergraduate populations, collaboration with an HBCU, and participating in existing programs at the PIs` institutions for outreach to K-12 students and teachers.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Shiwen Mao / smao@auburn.edu	Auburn University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: LAWN: Scaling Up Cellular Data Networks using a Large Number of Antennas	1218457	The exponential growth of mobile data is a major challenge to the operators of cellular networks. Looking beyond conventional capacity-improving approaches such as adding more cells and acquiring more spectrum, this project seeks to fundamentally improve the spectral efficiency of cellular data networks. The project investigates LAWN (Large number of Antenna based Wireless Networking), a radically new cellular network architecture, in which a large number of antennas simultaneously serve a relatively much smaller number of wireless terminals using multiuser beamforming. The project has two inter-related thrusts. The first investigates a novel LAWN base station design and prototype that can cost-effectively scale to hundreds of antennas and exploit physical-layer tradeoffs between computational complexity and network capacity. The second thrust studies the resulting new network architecture that efficiently schedules terminals, intelligently allocates transmission power, and coordinates pilot signal transmissions to mitigate inter-cell interference.The project targets improving the spectral and power efficiency of cellular networks by many fold, leading to not only fast wireless data networks but also longer battery lifetime of mobile terminals. Results from the project are likely to provide fresh insights for new theoretical development, bringing large-scale multi-user beamforming one significant leap closer to practical deployment in cellular data networks. In addition to academic publications, the project will produce an open platform, including hardware, software, and documentation available on-line, for teaching and researching base station design. It will actively involve undergraduate students as well as students from under-represented populations.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yang Yang / yry@cs.yale.edu	Yale University	no-value

National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Maximizing Network Capacity in Multihop Wireless MIMO Networks	1219109	Multiple-input multiple-output (MIMO) technology provides a means of boosting network capacity without requiring additional spectrum by exploiting spatially multiplexing, interference suppression, and spatial diversity. It has received widespread attention over the past decade from both industry and academic researchers, now forming a key component of nearly all emerging wireless standards. Despite the huge promise and considerable attention, a rigorous algorithm-theoretic framework for maximizing network capacity in multihop wireless MIMO networks is missing in the state of the art. This project establishes both the computational hardness and approximation hardness of maximizing network capacity in multihop wireless MIMO networks, and develops practical approximation algorithms with provably good performance. A polyhedral approach is taken by the project to construct various polynomial approximate capacity subregions of multihop wireless MIMO networks. These approximate capacity subregions not only are the algorithmic foundation of maximizing network capacity in multihop wireless MIMO networks, but also serve as a basis for interesting future projects on cross-layer design and optimizations in multihop wireless MIMO networks. They are also of independent interest to the theoretical computer science community and communications community at large. This project provides scholarships to graduate students and offers research topics for strong dissertation works on multihop wireless networks. The outcome of this project will not only be disseminated to the professional researchers through journals and conference proceedings, but also be integrated into the lecture notes targeted for senior undergraduate students and graduate students.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Peng-Jun Wan / wan@cs.iit.edu	Illinois Institute of Technology	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Maximizing Network Capacity in Multihop Wireless MIMO Networks	1217309	Multiple-input multiple-output (MIMO) technology provides a means of boosting network capacity without requiring additional spectrum by exploiting spatially multiplexing, interference suppression, and spatial diversity. It has received widespread attention over the past decade from both industry and academic researchers, now forming a key component of nearly all emerging wireless standards. Despite the huge promise and considerable attention, a rigorous algorithm-theoretic framework for maximizing network capacity in multihop wireless MIMO networks is missing in the state of the art. This project establishes both the computational hardness and approximation hardness of maximizing network capacity in multihop wireless MIMO networks, and develops practical approximation algorithms with provably good performance. A polyhedral approach is taken by the project to construct various polynomial approximate capacity subregions of multihop wireless MIMO networks. These approximate capacity subregions not only are the algorithmic foundation of maximizing network capacity in multihop wireless MIMO networks, but also serve as a basis for interesting future projects on cross-layer design and optimizations in multihop wireless MIMO networks. They are also of independent interest to the theoretical computer science community and communications community at large. This project provides scholarships to graduate students and offers research topics for strong dissertation works on multihop wireless networks. The outcome of this project will not only be disseminated to the professional researchers through journals and conference proceedings, but also be integrated into the lecture notes targeted for senior undergraduate students and graduate students.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ophir Frieder / of22@georgetown.edu	Georgetown University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: FreeNet: Cognitive Wireless Networking Powered by Green Energy	1320468	The project aims to liberate wireless access networks currently constrained by spectral and energy scarcity via a new framework, referred to as FreeNet, by exploiting cognitive networking and green energy. FreeNet will be designed and optimized using a series of novel techniques such as dynamic network architecture optimization, network resource aware traffic scheduling, and spectrum sharing. The network architecture optimization framework will apply advanced probability theory to investigate inherent relationships between the optimal network architecture and the availability of spare spectrum and green energy, and adopt control theory to adapt the network architecture according to the dynamics of the spare spectrum and green energy. The network resource aware traffic scheduling and spectrum sharing algorithms will be designed based on optimization theory. Finally, theoretical analysis will be reduced to practice and translated into communications protocols in enabling and prototyping FreeNet. The theoretical analysis will elicit a series of theorems to direct the utilization of green energy in communication networks. The communication protocols design and FreeNet prototyping will provide guidelines for designing resource aware communication systems. The research activities will advance the understanding of inherent relationships among the network architecture, traffic scheduling, spectrum utilization, and energy consumption. FreeNet will be deployed for offloading mobile traffic in urban areas, delivering content in rural areas, and enhancing emergency communication capacity during natural disasters. FreeNet will improve the availability and capacity of wireless networks, broaden the benefits of wireless networking, and enhance the living environment, the earth, by reducing the release of carbon footprints. Research outcomes from this project will be disseminated via publications and a website with frequent updates. Other broader impacts include integration of research and education through participation of both undergraduate and graduate students in the project, incorporation of research outcomes into course work, interactions and exchanges with invited speakers, and seeking involvement of REU students and under-represented groups.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Nirwan Ansari / ansari@njit.edu	New Jersey Institute of Technology	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Mobile mmWaves: Addressing the Cellular Capacity Crisis with 60 GHz Picocells	1317153	Smart phones and tablets enable consumers to enjoy rich audio and video content on the go, but the proliferation of such increasingly sophisticated mobile devices has created a capacity crisis for mobile operators. It is estimated that supporting rich media content for a rapidly increasing fraction of mobile users requires a 1000-fold increase in cellular network capacity, which current cellular bands simply cannot support. The research pursued under this grant explores an alternative, and potentially transformational, approach to cellular data, using unlicensed spectrum in the 60 GHz band, where the available bandwidth is orders of magnitude higher than those used in existing systems, at the level of multiple Gigabits per second throughput on the downlink to the mobile devices. Base stations for the envisioned network will be deployed opportunistically (e.g., on lampposts and rooftops). Due to the small carrier wavelength, many antenna arrays with a very large number (e.g., 1000) of elements can be built into base stations which are no larger than a typical WiFi access point. Such antenna arrays can be used to direct pencil beams at mobile users, with peak data rates of multiples of Gigabits per second (order of magnitude higher than the highest WiFi data rates available today). However, the small carrier wavelength also implies that the radio waves are easily blocked by obstacles such as buildings, walls, and humans, including the body of the person carrying the mobile device. In order to handle such rapid changes in the propagation environment, novel techniques are developed for multiple base stations to coordinate, such that they can adapt their beams to maintain connectivity with a given mobile device, and can ensure that the data destined for the mobile follows it around. A novel asymmetric network architecture is employed, with low-bandwidth 60 GHz beaconing and multi-Gbps data on the downlink, and LTE feedback and lower-speed data on the uplink. The base stations employ compressive signal processing for rapid channel estimation and beam adaptation, based on the feedback from the mobiles. Distributed base station coordination mechanisms are developed for seamlessly switching base stations or paths. The architecture minimizes complexity and power consumption in the mobile device: the device`s 60 GHz radio only needs to receive, and the device is oblivious of handoffs.The mobile broadband capacity crisis is the greatest challenge facing cellular providers today, hence the success of this project can impact a multi-billion dollar industry. In order to maximize the potential for impact, the results and models will be widely disseminated to both industry and academia. The investigators plan significant efforts for recruitment and mentoring of female undergraduate and graduate students, organized around the concept of a caring community.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Upamanyu Madhow / madhow@ece.ucsb.edu	University of California-Santa Barbara	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Resilient and Efficient Data Access in Cognitive Radio Networks	1320278	In cognitive radio networks, to avoid interference with licensed users, unlicensed users must vacate the spectrum accessed by the primary users. Since it takes some time for the unlicensed users to detect and switch to other available spectrum, the ongoing data transmission may have to be interrupted, leading to poor data access performance. Although there is a lot of research on cognitive radio networks, not much work has been done on data access. This project focuses on three intertwined issues to support resilient and efficient data access: (i) Various topology control protocols which carefully assign communication channels considering network robustness and channel interference to achieve better data accessibility, are designed and evaluated; (ii) Delay-constrained caching techniques are introduced to deal with primary user appearance, where data is cached/replicated at appropriate nodes to statistically limit the data access delay; (iii) Spectrum-aware data replication schemes are designed to improve data access performance in intermittently connected cognitive radio networks, by considering both node mobility pattern and primary user appearance. This project will make significant theoretical and technological advances in understanding and supporting resilient and efficient data access in cognitive radio networks. The success of this project is likely to have a broader impact on making cognitive radio networks more affordable and amenable to commercial, civilian, and military applications. The results of the project will be disseminated widely through high quality publications and presentations. The proposed research will also be integrated with the education curricula at the Pennsylvania State University.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Guohong Cao / gcao@cse.psu.edu	Pennsylvania State Univ University Park	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Enabling Algorithms, Signal Processing, and Circuits for Agile Cognitive Radio in CMOS Technology	1543894	Cognitive radio techniques will be developed that enable rapid, wideband spectrum sensing in the presence of strong interference. Cognitive radios must detect available spectrum quickly in real time with high-probability of success, which requires extremely high dynamic range in the presence of powerful interference signals. Furthermore, future cognitive radio will operate over multiple frequency bands spread out over a wide frequency range. This compounds the challenges to the receiver design since all filtering must be capable of tuning over wide frequency ranges. Finally, the radio must agilely hop among frequency bands. The time required to detect the power in any channel is an overhead that limits the network throughput.Most prior cognitive radio research applies digital baseband algorithms to conventional RF and analog radio circuitry, which is not designed to address the spectrum sensing application. This limits the achievable spectrum sensing bandwidth and agility and results in high power consumption for the RF, analog, and digital signal processing blocks. This work is fundamentally different in that it will customize the entire receive chain from the RF circuitry through the digital signal processing (DSP) to incorporate new techniques specifically targeted to address spectrum sensing. The techniques involve the injection of pseudonoise-modulated RF signals into the receiver to identify the blockers via correlation algorithms in the DSP as well as to calibrate and cancel the nonlinear characteristics of the receiver. We will develop and refine the proposed algorithms and demonstrate their utility in a 28-nm CMOS receiver integrated circuit.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Large	ongoing	James Buckwalter / buckwalter@ece.ucsb.edu	University of California-Santa Barbara	no-value

National Science Foundation (NSF)	ACCELERATING INNOVATION RESEARCH	PFI:AIR - TT: Technology for Sustainable Growth of Wireless Communication Capacity	1414250	This PFI: AIR Technology Translation project focuses on translating a novel communication signal design algorithm, named "dual link algorithm", to fill the need of sustainable growth of wireless communication capacity. The project will result in prototypes on a software defined radio platform and an FPGA platform of the dual link algorithm. The dual link algorithm has the following unique features: near optimal interference management, it is suitable for distributed implementation, it is scalable with the size of the networks, and it has fast and provable convergence. These features provide the following advantages: allows users to share frequency spectrum with asymptotic data rates that do not diminish with the increased number of users, useful for large and small networks, and able to accommodate faster channel time variation, as compared to the leading competing technology in this market space: weighted sum-rate maximization algorithms. This project addresses the following technology gap as it translates from research discovery toward commercial application. The dual link algorithm was designed under the assumption of centralized optimization and full channel knowledge of the network, while in practice, distributed implementation is desired and each node has only local channel knowledge through imperfect estimation. To bridge the gap, the project will 1) implement the dual link algorithm in distributed fashion with distributed channel and covariance matrix estimation; 2) optimize performance under constraints of hardware resource and power limits; 3) build a prototype on software defined radio platform; 4) further develop a real-time hardware IP for FPGA-based platform.The project engages Prof. Xinming Huang`s research group at Worcester Polytechnic Institute to perform hardware design and to prototype the algorithm on FPGA platform in this technology translation effort from research discovery toward commercial reality.As the number of smart phone users increases, the current method of capacity growth is not sustainable, which will ultimately result in a decrease in the speed of data transfer for users. The successful prototype demonstration of the dual link algorithm will offer a solution to accommodate the exponentially growing data demand caused by the popularity of smart phones. The wireless communication industry is facing a capacity crunch caused by interference from more users and higher data rates and is in urgent need of such technologies translated in this project. In addition, the potential economic impact is expected to be significant for the upcoming 5G wireless networks in the next five years, which will contribute to the U.S. competitiveness in the sector of wireless communication technology and service.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Youjian Liu / youjian.liu@colorado.edu	University of Colorado at Boulder	no-value
National Science Foundation (NSF)	SMALL BUSINESS PHASE I	SBIR Phase I: Ultra-Wideband Wireless Optical Transceiver	1520405	The broader impact/commercial potential of this Small-Business Innovation Research (SBIR) Phase I project is to lead the develop of next generation wireless communication technology and provide ultra-high-speed, broadband connectivity to consumers. The enormous consumer demand for mobile multimedia content on smart phones and tablets is accelerating growth of data traffic on wireless networks. This trend will continue in the next decade as billions more devices will be connected to the Internet-Of-Things including automobiles and home appliances. To support such growth, wireless smart phones and tablets need to have faster connectivity speeds to the network. The networks must also adapt to handle the exponential growth in data traffic with smaller cells and higher backhaul capacity. With the congestion of existing commercial spectrum, new innovations in wireless technology are required to meet this challenge. This project offers a new technology and solution to multiply the bandwidth of of wireless devices and networks and help expand ultra-fast broadband access to consumers. The Small Business Innovation Research (SBIR) Phase I project is focused on the proof-of-concept demonstration of a wireless optical transceiver module that can increase the connectivity speeds of next generation wireless devices by several folds. Novel device and material designs will be investigated to achieve the target performance of this project. Today, the fastest WiFi technology is capable of nearly one Gigabit per second (Gbps) speed while the next-generation WiFi solution can deliver 5Gbps. The speed limitation of wireless modems are due to limited availability of commercial spectrum. The speed required to transfer ultra-definition video content without compression is 20Gbps. As 4G-LTE wireless technology is rapidly gaining adoption, wireless operators are wrestling with data capacity bottlenecks in their networks. Concurrently, wireless industry is beginning to debate requirements for fifth-generation (5G) wireless devices and networks and increased connectivity speed is high on their agenda. The technology pursued under this project can offer a viable solution for the 5G generation of mobile devices. In addition to smart phones and tablets, the proposed technology can expand wireless backhaul capacity and provide novel communication solution for connected cars, unmanned aerial vehicles and other devices connected to the Internet.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-3	Medium	ongoing	Mohammad Khatibzadeh / ali.khatibzadeh@lumeova.com	Lumeova, LLC	no-value
National Science Foundation (NSF)	SMALL BUSINESS PHASE II	SBIR Phase II: Low-complexity, High-throughput Wireless Networking	1353630	This Small Business Innovation Research (SBIR) Phase II project uses enhanced MIMO (multiple-input, multiple-output) technology to boost capacity, coverage, and enhance link robustness in wireless communications without using additional spectrum. This is accomplished by transmitting independent data streams all at the same frequency but on different antennas. MIMO technologies have been widely adopted and have been incorporated into the 802.11n and 802.11ac WiFi, WiMax, and the LTE-A cellular standards. However, for MIMO systems, the computational complexity required to detect data symbols increases dramatically as the system size (number of antennas) and data constellation size increases. Thus, MIMO symbol detection has become a critical step for wireless communication systems. Lattice-reduction (LR)-aided MIMO equalization has shown great potential to reduce complexity and improve the performance. This research develops and transitions advanced LR-aided equalization technology to real-time, hardware implementations that meet the stringent requirements of next generation wireless communication systems. These advanced LR-aided equalization techniques can reach near-optimal performance (an additional 5-20 dB of signal-to-noise-ratio gain relative to common equalizers currently used in industry). This project will result in the creation of a commercial-grade hardware implementation capable of realizing these gains in existing systems at only a slight increase in cost. The broader impact/commercial potential of this project extends to nearly all high-speed wireless data communications including WiFi, cellular, and backhaul/infrastructure. The advanced LR technology can be implemented in MIMO receivers to improve range, power, and spectral efficiency without requiring changes to existing standards or infrastructure. Furthermore, the advanced LR technology also enables the development of future systems with higher-order MIMO for higher data rates and better reliability. This project will develop and commercialize integrated circuit designs that directly address the problem of spectrum crunch being experienced by wireless network providers seeking to supply ever increasing data rates to meet customers' demands. This project will also establish a conduit for commercialization of further advances in communications and enhance the research partnership between the investigators and the researchers in the wireless communication industry facilitating application of scientific discoveries to the application domains.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-5	Medium	ongoing	Sung Eun LEE / sungeun@gatech.edu	Ratrix Technologies, LLC	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Self-Sustaining Tunable Multi-Frequency Oscillators Using Atomically-Thin Semiconducting Multimode Resonators	1509721	[illegible] communication and sensing technologies. While miniaturization of devices in recent decades has created many resonant micro- and nanoelectromechanical systems (MEMS and NEMS) as new frequency references for making oscillators and clocks, major challenges remain in engineering ultralow-power, low-noise crystal oscillators by utilizing emerging resonators in new nanostructures. This project aims to discover new science and engineering principles in multi-frequency self-sustained oscillators enabled by multimode resonators based on atomic layer two-dimensional (2D) semiconductors, with a focus on previously unexplored effects and potentially unprecedented functions and performance. 2D NEMS are based on mechanically active atomically-thin semiconducting crystals derived from "beyond-graphene" layered materials that offer a spectrum of attractive electromechanical attributes. Multimode 2D NEMS resonators are a new class of vibrating NEMS with intriguing and tunable properties rich in their multiple resonance modes. With frequency reference and selectivity functions harnessed from multimode 2D NEMS resonators vibrating in radio-frequency (RF) and microwave bands, the self-sustaining feedback oscillators are distinct from passive resonators in that they possess their own stable limit cycles, and can sustain periodic oscillations without an external periodic drive. The goal of the integrated STEM educational plan is to educate and motivate youth by (i) a new outreach program for K-12 students to understand oscillations and learn the fascinating history of clocks and timing devices, (ii) summer research at Case Western Reserve University (CWRU) for high-school students, and (iii) actively broadening participations from underrepresented and economically disadvantaged groups, especially by extending outreach programs to public schools in Cleveland area. The objectives of this project are to demonstrate that 2D semiconductors can enable highly tunable self-sustaining oscillators, to develop the principles of 2D NEMS oscillator engineering and on-chip integration, and to explore pathways toward ultimate limits of crystal oscillators in the 2D platform. This project will establish the fundamental principles of signal transduction and feedback mechanisms in 2D crystal oscillators, lay the foundation for ultralow-power and tuning circuit design suitable for 2D systems, and address critical challenges in small-signal detection, parasitic effect suppression, nonlinearity, tuning and power handling. It will also explore phase noise in self-sustaining oscillations in 2D crystals at RF and microwave frequencies. The research will be enabled by innovative feedback circuit designs that will go significantly beyond the simple sustaining amplifiers that are sufficient for single-resonator, single-mode feedback oscillators. This project features a circuit-device co-design perspective, with the goal of eventually enabling entirely new, monolithic, multimode oscillators with phase noise engineering. This project will create and establish a new branch, 2D crystal oscillators, in the rapidly emerging and growing field of 2D devices and systems. The research will generate a plethora of new knowledge in both device physics and engineering principles that govern the 2D crystal oscillators, thus broadening the horizon of current	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Philip Feng / philip.feng@case.edu	Case Western Reserve University	no-value

National Science Foundation (NSF)	STTR PHASE II	STTR Phase II: Reconfigurable Wireless Platforms for Spectrally Agile Coexistence	1353600	This Small Business Technology Transfer (STTR) Phase II project will involve research on and development of a reconfigurable wireless platform enabling broadband communications in rural areas via secondary access of television white spaces (TVWS) spectrum. The recently ratified IEEE standard, 802.22, is the most promising technique proposed for TVWS operation. Unfortunately, current 802.22 implementations create unacceptable levels of out-of-band (OOB) emissions, greatly degrading the performance of both primary and secondary TVWS users. Current designs also fail to sense the presence of other TVWS users as necessary for coexistence. Such limitations have prevented the rollout of 802.22 solutions. The proposed work overcomes these limitations, leading to a low-cost, high throughput, and robust implementation for the 802.22 wireless regional area network (WRAN). Phase II laboratory and field testing will validate the viability of Phase II developed 802.22 WRAN prototype devices for rural broadband deployment. The activities described in this proposal will significantly advance the community's understanding of methods to make cognitive radio networks such as 802.22 practical and effective in offering broadband services in rural areas.The broader impact/commercial potential of this project centers on offering a low-cost broadband solution to the 14.5 million Americans who live in rural areas currently beyond the reach of broadband access, while appealing to those in rural areas that have broadband access but are unable to afford the high equipment and service costs of current solutions. Rural communities with broadband access have lower unemployment, higher per capita earnings, and greater educational opportunity. Broadband improves rural area healthcare effectiveness while lowering cost. Public safety, emergency service, and first responder communities also call for high data-rate communications to better predict and respond to natural disasters.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-5	Medium	ongoing	Samuel MacMullan / sam.macmullan@orbanalytics.com	ORB Analytics	no-value
National Science Foundation (NSF)	TRUSTWORTHY COMPUTING; SECURE & TRUSTWORTHY CYBERSPACE	TC: Small: Defending against Insider Jammers in DSSS- and FH-Based Wireless Communication Systems	1016260	Jamming resistance is crucial for applications where reliable wireless communication is required, such as rescue missions and military operations. Spread spectrum technologies such as Frequency Hopping (FH) and Direct Sequence Spread Spectrum (DSSS) have been used as countermeasures against jamming attacks. However, these anti-jamming techniques require that senders and receivers share a secret key in order to communicate with each other. In situations where the adversary can compromise a legitimate communication device and learn the secret key, she can effectively defeat FH or DSSS wireless communication and thus disrupt normal network operations. In general, traditional anti-jamming techniques such as FH and DSSS are vulnerable to insider attacks where the adversary has access to the secret key used for anti-jamming wireless communication. This project develops novel and efficient insider-jamming-resistant techniques for both DSSS and FH-based wireless communication systems. This research consists of two thrusts: The first thrust develops novel spreading/despreading techniques to enhance DSSS-based wireless communication to defend against insider jamming threats, while the second thrust develops a new approach to enable FH-based wireless communication to be resistant against insider jammers. A key property of these new approaches is that they do not depend on any secret shared by the sender and receivers. This project will significantly enhance the resilience of future wireless communication systems, especially those for mission-critical applications that may face potential adversaries (e.g., rescue missions and military operations). The results obtained in this project will be disseminated through publications, graduate-level courses, and public release of software packages.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Peng Ning / pning@ncsu.edu	North Carolina State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Transparent Coexistence for Multi-Hop Secondary Cognitive Radio Networks: Theoretical Foundation, Algorithms, and Implementation	1247830	Recently, the idea of simultaneous activation (or transparent coexistence) of secondary and primary nodes is being explored. Under this new paradigm, secondary nodes are solely responsible for canceling their interference with the primary nodes so that the primary nodes do not feel the presence of the secondary nodes. Although this new paradigm has the potential of offering much greater spectrum efficiency and network capacity than those under the existing interference avoidance paradigm, it is still in its infancy and current results are only limited to very simple network settings. The goal of this project is to make a fundamental advance in the transparent coexistence paradigm for multi-hop secondary networks. Specifically, this project aims to study the following important problems in the context of multi-hop networks: (1) developing new analytical models for the transparent coexistence paradigm; (2) exploring performance bounds and theoretical limits for multi-hop secondary networks; and (3) developing distributed algorithms for multi-hop secondary networks that can offer performance approaching that of a global optimal solution.The findings from this project are expected to make a timely contribution to the research community by removing some fundamental barriers associated with the transparent coexistence paradigm. An important educational activity of this project is to develop new cross-disciplinary course materials for wireless networking, particularly efficient sharing of the radio spectrum. This project also has plans to involve undergraduates and under-represented students in wireless networking research.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Thomas Hou / thou@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Wideband cognitive sensing from a few bits	1231504	Objective: Spectrum sensing is the most important element of cognitive radio, as it forms the ba-sis for adaptive spectrum sharing. Wideband spectrum sensing without frequency sweeping orNyquist-rate sampling is a challenging problem, especially for network sensing from low-end sen-sors with limited communication capabilities. Assume that each sensor can only down-convert,filter, and send out a binary signal when it measures energy above threshold at its filters output.Is it possible to form a satisfactory estimate of the ambient power spectrum using just a few such bits. This is the question at the core of this project, and exciting preliminary results suggest thatthe answer is on the affirmative. A well-rounded research program has been designed to buildupon these preliminary findings. The research will evolve along four thrusts: i) core system designand performance analysis; ii) distributed implementation; iii) relevant extensions, such as adaptivesensing; and iv) software radio experiments.Intellectual merit: Power spectrum estimation from few wideband energy detection bits has neverbeen considered - yet is a fundamental extension of spectral analysis. Exciting new applicationsof convex optimization theory and methods will be found in the area of network-based spectrumestimation.Broader impacts: Wideband spectrum sensing using cheap sensors and few bits is a transformativeidea that has the potential to permeate the benefits of cognitive radio down to commodity hardware- something currently far from reality. The topic is highly conducive for involving students andtraining the next generation of wireless engineers.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Nikolaos Sidiropoulos / nikos@ece.umn.edu	University of Minnesota-Twin Cities	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Collaborative Research: Data-Guided Resource Management for Dense Heterogeneous Networks	1457060	The emerging paradigm of dense heterogeneous wireless networks (HetNet), while essential to meeting the explosive growth of wireless traffic, poses unseen challenges to classical cellular network design principles. In traditional cellular systems, spectrum and resource management are often based on the assumption of static and regular topology/traffic patterns. Further, each cell operates with an orthogonal set of resources and requires little inter-cell coordination. However, such traditional approaches are out-dated and inefficient in dense HetNets:the proliferation of small-size cells makes the network topology and traffic characteristics highly irregular and varying; and tighter coordination across cells becomes a necessity when users traverse many small-cells frequently. Thus, there is an acute need to re-examine fundamental ways to design HetNets that can (i) quickly adapt to irregular topology and changing load patterns, and (ii) manage cell coordination at scale with minimal overhead to achieve robust and dependable application-level performance. To address this open challenge, this WiFiUS project develops new framework, architecture and algorithms for adaptive, efficient, and dependable spectrum management and resource allocation in dense heterogeneous cellular networks. First, the project team develops a new hypercell architecture that views a macro-cell and the overlapping small-cells as a single logical entity. This new architecture allows hypercells to acquire a global view of the load/channel/mobility/application patterns across multiple base-cells, thereby enabling more effective and dynamic multi-cell coordination at scale. Furthermore, the team develops a data-guided operational framework that exploits both provider-collected and user-contributed data to address the inherent complexity of dynamic multi-cell coordination. Based on historical data, this approach migrates higher-complexity computations to offline, and thus achieves high spectrum efficiency and user QoE with low-overhead. The US/Finland team brings together a wide range of wireless expertise from physical layer design to network resource management. Having a successful collaboration record, the team carries out joint research activities in the following three aspects: 1) data collection and traffic pattern identification; 2) data-guided spectrum management and base-station cooperation; and 3) hypercell link adaptation, measurement, and resource management. The success of the project has a broad impact on the wireless communications industry by addressing multiple timely and critical challenges that arise from the exponential growth of cellular traffic. The project outcomes will also provide important insights into big-data mining and learning for cellular resource management. The results from this work will be widely disseminated through journal/conference publications, and be incorporated into undergraduate and graduate education endeavors.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xin Liu / liu@cs.ucdavis.edu	University of California-Davis	no-value

National Science Foundation (NSF)	SPECIAL PROJECTS - CCF; SPECIAL PROJECTS - CISE	WiFiUS: Message and CSI Sharing for Cellular Interference Management with Backhaul Constraints	1457168	The past decade has witnessed significant growth in the use of cellular networks, reflecting increased data demands. This has been the driver of recent research for new ways of managing interference in wireless networks. The focus of this project is to explore the potential benefits of exploiting anticipated infrastructure enhancements, particularly in terms of a more flexible use of the backhaul network connecting the base-stations, through the lens of information-theoretic models of single hop wireless networks. The goal is to show how centralized channel-aware decisions for assigning backhaul resources, by sharing messages and channel state information, can lead to rate gains and simplification of interference management schemes in network models that prove relevant to practial deployments.The project connects three research thrusts. The first is to study the fundamental limits of the rate of communication in large interference networks with a rate-limited backhaul that allows for sharing messages between base stations in both downlink and uplink scenarios. This study uses high level channel state information to identify the topology of the network and carry out a degrees of freedom based analysis and design of message sharing schemes. The second thrust builds on the first thrust to design distributed multi-antenna interference control and resource management schemes using more detailed channel state information and exchange. The third thrust addresses interference management in dynamic networks, accounting for dynamics in topology due to fading as well as due to users entering and leaving the cellular network. An important component of this thrust is the joint optimization of the rate-limited backhaul for message sharing and channel state information exchange.Research on interference management, coordination and related resource allocation will advance our understanding of how to significantly improve the energy and spectral efficiency of evolving wireless networks. While this project will advance the science and engineering of wireless networking, it should also impact the national and international wireless industry by developing new design principles and methodologies for the design and implementation of future wireless networks. By enabling more efficient use of wireless spectrum, such networks have the potential to improve broadband access across the world and provide the communication infrastructure for numerous new wireless services. Furthermore, these advances are necessary to enable the evolving internet of connected objects or the Internet of Things (IoT). Education initiatives include the involvement of undergraduate students in the research project; integration of the research results developed under this project into graduate and undergraduate curricula; presentation of tutorials on topics related to the project at international conferences, seasonal schools and WiFiUS meetings; and facilitating student exchanges between the two collaborating institutions.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Venugopal Veeravalli / vvv@illinois.edu	University of Illinois at Urbana-Champaign	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Ubiquitous Video over Dynamic Spectrum	1456847	Mobile phones and tablets are the most widely-used wireless communication devices nowadays. Video already represents the majority of mobile traffic and is expected to grow significantly in the coming years. Network operators are already facing shortage of bandwidth to support such a huge amount of traffic, despite the availability of newer cellular communication technologies. A solution to increase the availability and the efficiency of wireless communication technologies is given by cognitive radio networks (CRNs). Enabled by adaptive communication protocols, CRNs have the capability to sense a wide range of the spectrum and the agility to make use of the available resources dynamically. Accordingly, they can reclaim unused spectrum (i.e., whitespace) for wireless communications while avoiding interferences with between licensed and unlicensed users. However, video delivery over CRNs presents several challenges related to the highly-varying nature of the channel, the presence of misbehaving users, and the dynamic availability of heterogeneous resources.This project addresses such challenges and makes CRNs suitable as a platform to provide ubiquitous wireless video. The research takes a flexible approach that is applicable to diverse regulations across national boundaries and specifically targets mobile devices. It helps create a cognitive phone, i.e., a smartphone with cognitive radio capabilities, to bridge the gap between the technologies behind CRNs and real applications. The project builds on two major research thrusts. First, it adopts spectrum crowd-sensing as a means to model the availability of whitespace at multiple scales and support long-lived communications. Such an approach enables novel solutions to accurately characterize the channel and enforce the policies established by the communication authorities. Second, it leverages adaptive mechanisms as foundations to efficiently deliver video streams to end users. These mechanisms are implemented through streaming protocols and components in the network infrastructure that provide video content with a target quality of experience. The project also integrates synergistic activities between the United States and Finland in education, industry collaboration, and entrepreneurship.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Mung Chiang / chiangm@princeton.edu	Princeton University	no-value
National Science Foundation (NSF)	SMALL BUSINESS PHASE I	SBIR Phase I: Cognitive Radio Small Cell for Pervasive Coverage and Sustained	1520453	The broader impact/commercial potential of this project includes three market segments and domestic/international collaboration in technology development and engineering training. The first market segment will be to provide first responders with a way to improve reliability in the communication for incident management through the deployment of on-the-scene smart self-configurable communication systems. This is expected to improve first responder reliance on communications equipment at times of disasters and crisis. The second segment is to target the proposed small cells to domestic carriers for use by enterprise customers and consumers to increase capacity and coverage locally. Finally, the third segment is to provide key spectrum management capability to the deployment of a 4G/5G system in emerging markets through partnerships. The program will also enable training programs for graduate students and complex research & development partnerships with domestic and international partners. This Small Business Innovation Research (SBIR) Phase I project seeks to develop a cognitive carrier-neutral small cell for mobile communications. The ability to effectively use wireless spectrum is becoming more prevalent, and even more of a requirement, as time goes on due to regulatory issues and spectrum scarcity. However, current communication systems are not sufficiently spectrum-efficient, which is why there is a land-grab for spectrum. A critical improvement needed in communication technology to address spectrum scarcity is smart spectrum reuse. This proposal seeks to develop a cognitive small cell capable of providing smart reliable coverage, and sustained data rates to users in the vicinity. The main advantages of this communication system will be to: 1) Operate as a plug-and-play access point; 2) Provide carrier neutral 4th generation/5th generation (4G/5G) wireless coverage; 3) Provide seamless coverage and sustained data rates to mobile users when multiple cells are deployed in contiguous areas; 4) Operate in multiple bands simultaneously through bandwidth aggregation; and 5) Offload traffic from the carrier network through an Internet Protocol version 6 (IPv6) backhaul.	Technologies and applications for efficient spectrum use or legacy transformation; Integration of DSA networks and the Internet or other infrastructure; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-5	Medium	ongoing	Kamil Agi / kagi@ka-wireless.com	K&A Wireless, LLC	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	CAREER: Survivability and Selfcoexistence in the Battle of Cognitive Radio Network Societies	1346600	Dynamic spectrum access (DSA) based on cognitive radio (CR) allows unused licensed bands to be used by unlicensed (secondary) networks in an opportunistic/dynamic manner under the provision that they would vacate upon the return of the licensed users. DSA allows unlicensed users to share frequencies, but the paradigm does not provide good protection from interference. This raises serious challenge of self-coexistence among the secondary networks as well as risks of disruption from malicious CR devices/networks through various non-traditional spectrum attacks. This project studies the self-coexistence challenges of CR networks under adversarial conditions and investigates inter-disciplinary methodologies based on game theory, behavioral adaptation, stochastic learning and network forensics that aid survivability of these networks. To assess effectiveness, the mechanisms are implemented on CR prototype testbed. The intellectual merit of this project lies in: 1) constructing behavioral frameworks studying the evolutionary dynamics of spectrum conflict, 2) systematically understanding the unique shadow-disruptive nature of the malicious CRs exploiting the finest granularity of spectrum agility, and 3) developing a suite of survival mechanisms against cognitive disruptions and exploring their effectiveness. The project has broader impact on wireless technologies/policies and is expected to help in the efficient and secure design of future cognitive radios. This project is committed to tightly integrate research and educational plans which revolve around student mentoring, graduate/undergraduate curriculum enhancement and hands-on project based learning taking feedback from research findings and K-12 outreach. Research results will be disseminated through publications, seminars, and tutorials.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Shamik Sengupta / ssengupta@unr.edu	Board of Regents, NSHE, obo University of Nevada, Reno	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	CAREER: Toward Cooperative Interference Mitigation for Heterogeneous Multi-Hop MIMO Wireless Networks	1350655	The ever-growing number of wireless systems and the scarcity for available spectrum necessitates highly efficient spectrum sharing among disparate wireless networks. Many of them are heterogeneous in hardware capabilities, wireless technologies, or protocol standards. The resulting cross-technology interference (CTI) can be detrimental to the performance of co-locating networks if not properly mitigated. Current interference management approaches mostly follow the interference-avoidance paradigm, where transmissions are separated in frequency, time, or space to enable spectrum sharing, rather than to reduce or eliminate interference. This project explores cooperative interference mitigation (CIM), a new coexistence paradigm among heterogeneous multi-hop wireless networks. By exploiting recent advances in multi-input multi-output (MIMO) interference cancellation (IC) techniques, the proposed approach allows disparate networks to cooperatively cancel/mitigate their CTI to enhance everyone's performance. This research focuses on the following objectives: 1) Develop tractable models/frameworks to analyze the theoretical limits and performance bounds of CIM for heterogeneous multi-hop networks, considering various forms of network heterogeneity; 2) Study the incentives of CIM through a novel game theoretic framework, that characterizes the conditions of mutual cooperation and thwarts selfish or malicious behavior; 3) Design distributed performance-approaching algorithms to achieve CIM and integrate them into practical network/MAC layer protocols, by exploiting machine learning tools and implicit inter-system communications. The expected outcomes also include the development of various simulation toolkits and system prototypes for experimental validation. The integrated education plan includes cross-discipline curriculum development, student mentoring and outreach. The proposed research will have broad impacts on unplanned heterogeneous multi-hop networks that share spectrum resources, such as current and future networks in unlicensed bands, and secondary networks in TV white spaces. Applications will benefit multiple domains including healthcare, energy, emergency services and military etc. Major results will be disseminated via conference and journal publications, software packages, talks and tutorials.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ming Li / lim@email.arizona.edu	Utah State University	no-value

National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	CAREER: Towards Reliable and Efficient Network Monitoring in White Space	1502584	Monitoring the detailed characteristics of an operational cognitive radio network in white space is critical to many system administrative tasks. It faces unique challenges due to dynamic spectrum access policy, low-power primary users, wide spectrum, and radio agility. Towards reliable and efficient monitoring of cognitive radio networks in white space, this project develops mechanisms for monitoring the activity of low power primary users (wireless microphones) and secondary networks. There are two main thrusts in this project. The first thrust focuses on a novel approach for reliable and fast detection of wireless microphone systems by integrating acoustic sensing and RF sensing under low SNR and multi-user scenarios. The second thrust is on customizable efficient monitoring of the traffic and spectrum usage pattern in secondary networks with limited number of monitors through online learning and dynamic monitoring channel switching.The research will open up a new avenue for reliable, fast, and low-complexity primary user (wireless microphone) monitoring in white space. It will promote the understanding of the data monitoring problem in dynamic spectrum access systems, and largely facilitate the operation and optimization of cognitive radio networks in white space. This project develops curricula and educates students. Materials of this project will be available online in the forms of tutorials, talks, publications, and software toolkits. Major results will be disseminated through presentations and publications in meetings, conferences and journals.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kai Zeng / kzeng2@gmu.edu	George Mason University	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	CCSS: Collaborative Research: Stochastic Modeling and Optimization for Cognitive Radio Networks	1129062	The objective of this research is to develop network protocols and optimizationtechniques to efficiently utilize the spectrum white spaces for cognitive radio networks.The proposed approach is based on a novel cognitive radio network (CRN) networkarchitecture under which effective design methodologies can be developed to take betteradvantage of cognitive radio technologies in harvesting and managing unutilizedspectrum for better service provisioning.The PIs will first study the proposed CRN architecture to enable collective spectrumsensing and let the secondary service provider manage the harvested spectrum for betterspectral efficiency while shifting the design complexity from the user side to the systemside. They will then investigate how to split traffic over harvested spectral bands tobalance the risk and reward, how to optimally utilize the spectral resource by jointlydesigning frequency allocation and routing while supporting traffic demands, and how tomaximize the throughput by joint link scheduling and routing. The proposed researchoutcome will lay the solid foundation for practical implementation of CRNs, which could potentially revolutionizes the way how cognitive radios should be more effectively used.The research outcome will significantly advance the state of the art in CRNs, opening anew avenue to designing smart living environments for public safety, disaster rescue,mobile healthcare and online social networks to improve peoples quality of life.Research findings will be disseminated through publications and talks, and in classroomteaching. This project will also actively recruit and train minority students for futureworkforce and mentor junior faculty.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yuguang Fang / fang@ece.ufl.edu	University of Florida	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: C-HetNet - Towards Spectrum and Energy Efficient Next Generation Wireless Access Networks	1307580	The objective of this research is to exploit and establish the theoretical foundations to support the design of next generation cooperative, clean and centralized heterogeneous wireless access networks, or, C-HetNet. The approaches include designing novel algorithms for spectrum efficiency, energy efficiency and quality of service based mobile association, multi-layer interference management and power control, network wide cooperation and dynamic resource allocation in the C-HetNet; and seeking the design principles of balancing and optimizing spectrum efficiency, energy efficiency and quality of service in the C-HetNet.Intellectual merit: The project is expected to significantly advance the understanding in the heterogeneous wireless networks, which are expected to play a key role in meeting the future data capacity explosion and energy consumption escalation. The project will address the unique technical challenges in the C-HetNet and explore new solutions to spectrum and energy efficiency in mobile association, multi-layer interference management and power control, and dynamic cooperative resource allocation. Broader Impacts: The C-HetNet research activities have significant potentials to revolutionize wireless access networking technologies and wireless cross-layer design approaches. The research will provide a new wireless network paradigm to meet the ever-increasing wireless traffic demand and to address the needs on network cost reduction and global environmental protection; and will improve many application scenarios such as coverage extension, hotspots, and emergency network deployment for public safety, disaster rescues and medical applications. The research outcomes will be disseminated through publications and seminars and will be incorporated into undergraduate and graduate courses taught by the PIs.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yi Qian / yqian2@unl.edu	University of Nebraska-Lincoln	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: Delay-Sensitive Hybrid Broadcast/Unicast Traffic over Heterogeneous Cellular Networks	1509514	In cellular networks, wireless traffic can be categorized into broadcast traffic and unicast traffic where broadcast is defined as the unidirectional delivery of common information such as mobile TV from the base station (BS) to many users; unicast refers to the delivery of private information such as voice telephony and wireless data access, which requires a bi-directional network. Because a significant portion of the mobile data traffic is delay-sensitive, future cellular networks will face the dual challenge of supporting large traffic volumes and providing reliable service for delay-sensitive applications. On the other hand, wireless community across the globe is facing severe spectrum shortage. The goal of this project is to maximize the spectrum utilization efficiency and guarantee quality of service for delay-sensitive hybrid broadcast/unicast traffic by studying new collaborative spectrum sharing and resource allocation technologies for heterogeneous cellular networks.Intellectual Merits: This project defines new performance metrics that can accurately measure the spectrum utilization efficiency as well as the quality of service requirements of delay-sensitive wireless traffic. In particular, the concept of hybrid rate region is defined to simultaneously characterize the broadcast outage capacity and unicast effective capacity. To maximize the hybrid rate region, a two-pronged approach is proposed to achieve a synthesis of pragmatism and fundamentally new principles to systems engineering. The proposed research activities are streamlined into two mutually supportive thrusts: (1) maximize the hybrid rate region for the single-cell cellular network using both orthogonal and non-orthogonal spectrum sharing technologies; (2) maximize the hybrid rate region for a multi-cell heterogeneous cellular network where macro base stations and low power relay nodes are overlaid in the coverage area. The project outcomes include enabling spectrum sharing and resource allocation technologies that are heavily dependent on the delay-sensitivity of the underlying traffic, and characterization of optimal network topology for heterogeneous cellular networks with hybrid broadcast/unicast traffic.Broader Impacts: The project addresses the worldwide spectrum shortage for broadband cellular network. It has potential impact on emerging wireless industrial standards and practices, such that the research outputs will likely influence and transform, rather than follow, scientific and technological trends. Meanwhile, the PIs will recruit students of underrepresented groups in Kentucky and Kansas, including Native American, female, low incoming and first generation students to participate in the project. By collaborating with the McNair program, the PIs will broaden the participation of underrepresented groups in electrical engineering.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Lingjia Liu / lingjialiu@ittc.ku.edu	University of Kansas Center for Research Inc	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: Delay-Sensitive Hybrid Broadcast/Unicast Traffic over Heterogeneous Cellular Networks	1509047	In cellular networks, wireless traffic can be categorized into broadcast traffic and unicast traffic where broadcast is defined as the unidirectional delivery of common information such as mobile TV from the base station (BS) to many users; unicast refers to the delivery of private information such as voice telephony and wireless data access, which requires a bi-directional network. Because a significant portion of the mobile data traffic is delay-sensitive, future cellular networks will face the dual challenge of supporting large traffic volumes and providing reliable service for delay-sensitive applications. On the other hand, wireless community across the globe is facing severe spectrum shortage. The goal of this project is to maximize the spectrum utilization efficiency and guarantee quality of service for delay-sensitive hybrid broadcast/unicast traffic by studying new collaborative spectrum sharing and resource allocation technologies for heterogeneous cellular networks.Intellectual Merits: This project defines new performance metrics that can accurately measure the spectrum utilization efficiency as well as the quality of service requirements of delay-sensitive wireless traffic. In particular, the concept of hybrid rate region is defined to simultaneously characterize the broadcast outage capacity and unicast effective capacity. To maximize the hybrid rate region, a two-pronged approach is proposed to achieve a synthesis of pragmatism and fundamentally new principles to systems engineering. The proposed research activities are streamlined into two mutually supportive thrusts: (1) maximize the hybrid rate region for the single-cell cellular network using both orthogonal and non-orthogonal spectrum sharing technologies; (2) maximize the hybrid rate region for a multi-cell heterogeneous cellular network where macro base stations and low power relay nodes are overlaid in the coverage area. The project outcomes include enabling spectrum sharing and resource allocation technologies that are heavily dependent on the delay-sensitivity of the underlying traffic, and characterization of optimal network topology for heterogeneous cellular networks with hybrid broadcast/unicast traffic.Broader Impacts: The project addresses the worldwide spectrum shortage for broadband cellular network. It has potential impact on emerging wireless industrial standards and practices, such that the research outputs will likely influence and transform, rather than follow, scientific and technological trends. Meanwhile, the PIs will recruit students of underrepresented groups in Kentucky and Kansas, including Native American, female, low incoming and first generation students to participate in the project. By collaborating with the McNair program, the PIs will broaden the participation of underrepresented groups in electrical engineering.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hongxiang Li / hongxiangli@gmail.com	University of Louisville Research Foundation Inc	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Creating an Ecosystem for Enhanced Spectrum Utilization Through Dynamic Market Mechanisms	1516075	The surge in demand for Internet access using smart hand held devices has resulted in the emergence of a multitude of apps and devices, which have diverse requirements and capabilities. However, underlying policies for scheduling cellular resources are optimized for average or worst case performance, and do not allow end-users to indicate the relative value of resources on the packet level. Simultaneously, it has become clear that while there are insufficient bandwidth resources for unlimited cellular data plans, the prevailing scheme of degrading access after a certain limit is exceeded is both unpopular and inefficient.The main goal of this project is to bridge the disconnects between user preferences and allocated resources by the use of dynamic market mechanisms that allow for packet-level value determination over time. The objective is to study both primary markets in which service providers sell network access to end-users, as well as secondary markets in which end-users share resources via hot spots and device-to-device networking. While doing so, the project identifies the impact of such packet-scale transactions on the incentives and efficiency of the market at a long time-scale, packet-aggregate level. The project takes an important step towards the systematic design of dynamic mechanisms for resource sharing in wireless communication networks, which would innately account for user preferences and valuations. The PIs will develop an analytical framework for designing dynamic market-based mechanisms that would implicitly allow the determination of the value of allocating and trading resources among various agents. The research is organized into three inter-dependent areas: 1) Value Identification and Resource Scheduling in Single-Sided Markets; 2) Utilizing End-User Resources through Two-sided Markets; 3) Policy and Provisioning Decisions. The dynamic market mechanisms that are developed will be tested via experiments conducted on a smart phone test bed in order to better understand real-world implications. All three PIs are heavily involved in the education and training of graduate and undergraduate students, and the proposed work will further strengthen the students' exposure to network control, game theory and optimization. The project will disseminate results to the public through seminars and summer camps focusing on electrical engineering concepts appropriate for high school level students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Vijay Subramanian / vgsubram@umich.edu	University of Michigan Ann Arbor	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Spectrum Sharing in the Shadow of Uncertainty: Risk, Incentives and Investment	1343381	Sharing of spectrum among government and/or commercial entities has the potential to unleash large amounts of spectrum to meet the dramatic increase in demand for mobile broadband services. Although there has been substantial work on developing technologies for such sharing, the adoption of extensive sharing by commercial service providers is by no means a forgone conclusion. This project is addressing three fundamental issues that need to be resolved in order for spectrum sharing to realize its potential.The first issue is concerned with developing models and techniques for mitigating the risks associated with secondary spectrum sharing. Such risks arise, for example, due to uncertainty in a primary user's activity. The impact of both different technologies (e.g., more flexible devices) and different contractual arrangements (e.g., the possibility of offering "spectrum insurance") on such risks are being studied.The second issue is addressing how different spectrum agreements and associated risk may affect competition and strategic behavior among service providers. That affects their decisions to invest in both infrastructure and develop new spectrum sharing technologies.The final issue is understanding how to balance the benefits of using spectrum to provide a public good, such as defense, against its use to provide commercial broadband access. Identifying associated incentive issues and transaction costs with each type of service can lead to better sharing mechanisms that produce efficient outcomes.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Large	ongoing	Randall Berry / rberry@ece.northwestern.edu	Northwestern University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Creating an Ecosystem for Enhanced Spectrum Utilization Through Dynamic Market Mechanisms	1443891	The surge in demand for Internet access using smart hand held devices has resulted in the emergence of a multitude of apps and devices, which have diverse requirements and capabilities. However, underlying policies for scheduling cellular resources are optimized for average or worst case performance, and do not allow end-users to indicate the relative value of resources on the packet level. Simultaneously, it has become clear that while there are insufficient bandwidth resources for unlimited cellular data plans, the prevailing scheme of degrading access after a certain limit is exceeded is both unpopular and inefficient.The main goal of this project is to bridge the disconnects between user preferences and allocated resources by the use of dynamic market mechanisms that allow for packet-level value determination over time. The objective is to study both primary markets in which service providers sell network access to end-users, as well as secondary markets in which end-users share resources via hot spots and device-to-device networking. While doing so, the project identifies the impact of such packet-scale transactions on the incentives and efficiency of the market at a long time-scale, packet-aggregate level. The project takes an important step towards the systematic design of dynamic mechanisms for resource sharing in wireless communication networks, which would innately account for user preferences and valuations. The PIs will develop an analytical framework for designing dynamic market-based mechanisms that would implicitly allow the determination of the value of allocating and trading resources among various agents. The research is organized into three inter-dependent areas: 1) Value Identification and Resource Scheduling in Single-Sided Markets; 2) Utilizing End-User Resources through Two-sided Markets; 3) Policy and Provisioning Decisions. The dynamic market mechanisms that are developed will be tested via experiments conducted on a smart phone test bed in order to better understand real-world implications. All three PIs are heavily involved in the education and training of graduate and undergraduate students, and the proposed work will further strengthen the students' exposure to network control, game theory and optimization. The project will disseminate results to the public through seminars and summer camps focusing on electrical engineering concepts appropriate for high school level students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Srinivas Shakkottai / sshakkot@tamu.edu	Texas A&M Engineering Experiment Station	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Fundamental Limits of Spectrum Sensing	1455228	Objective:Ubiquity of wireless connectivity and its constant growth in application and scale necessitate extremely efficient usage of spectrum as the main commodity in wireless industry. Highly regulated spectrum access policies and growing demands for spectrum access have promoted the notion of accommodating the needs of unlicensed services when the license-holding ones under-utilize the spectrum. The goal of this proposed project is to characterize the fundamental limits of spectrum sensing while recognizing the system-level and physical-level limitations imposed by costs of information acquisition, data traffic demands, and model uncertainties with sound guarantees on agility, responsiveness, and adaptability to the geo-temporal spectral occupancy variations. Intellectual merit:The proposed research lies at the crossroad of wireless communication, sequential statistics, and stochastic optimization. It aims to find the fundamental limits of spectrum sensing and delineates the interplay among the performance guarantees on the decisions about spectral activities, cost of sensing, communication delay tolerance, and the uncertainty level about model dynamics. This leads to novel spectrum sensing procedures in which an optimal balance among can be struck among different aspects based on the operational needs. Broader impact:The research has multiple technological and societal impacts. It furnishes a baseline for assessing the competency of different available spectrum sensing procedures within the same framework, and also provides novel sensing procedures that yield performance levels that match the theoretical fundamental limits. The theoretical models and concepts that are developed in this project have the potential to impact adjacent research domains, especially those involving experimental design and hypothesis testing for high-dimensional data.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ali Tajer / tajer@ecse.rpi.edu	Rensselaer Polytechnic Institute	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Large-Scale Statistical Learning based Spectrum Sensing and Cognitive Networking	1343189	As cognitive radio (CR) research advances to multihop and complex systems over large geographic regions, the spectrum utilization enhancement should be generalized to fully exploit the spectrum usage diversity in three dimensions (3D): time, frequency, and space, with new emphasis on the under-explored spatial dimension. Accordingly, this project focuses on the following three research objectives. The first one is to utilize the recent advancements in statistical learning over big data to develop efficient 3D spectrum sensing schemes, where a hierarchical approach is taken in developing novel finite-bit and single-bit learning techniques to efficiently explore the correlation structure across the three dimensions, with an advanced distributed approach also developed. The second one is to develop two key building blocks in large-scale CR networking based on the 3D spectrum sensing; 1) a novel multi-scale routing scheme to enhance the overall spectrum utilization, with a focus on exploiting the layered spectrum usage correlation structure in the spatial dimension; and 2) a reliable hierarchical common control channel identification scheme. The last research objective is to validate some key aspects in the proposed sensing and networking schemes via both intensive simulations and a concept-proving testbed. Throughout the project, an interdisciplinary approach is taken to combine the methods of statistical learning, signal processing, and wireless networking, with the core built upon the hierarchical treatment of both spectrum usage statistics and CR networking methodologies. The project provides both theories and algorithms for large-scale spectrum sensing and cognitive networking. Through a coherent education plan, the research findings will be incorporated into courses, and disseminated to the community via journal papers and conference presentations.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Liuqing Yang / lqyang@engr.colostate.edu	Colorado State University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Multi-Input Multi-Output (MIMO) Aware Cooperative Dynamic Spectrum Access	1443773	The objective of this project is to develop a multi-input multi-output (MIMO) aware cooperative dynamic spectrum access framework, termed McDysa, which enables multiple primary users and multiple secondary users to cooperate in dynamic spectrum sharing. By exploiting the underlying cognitive radio and MIMO techniques, McDysa is expected to achieve significant gains on spectrum efficiency while providing substantial enhancements to physical layer security as well. The technical merit and impact of this project are both fundamental and applied, including new problems, algorithms, and methodologies. The McDysa architecture considers multiple simultaneous primary- and secondary-user transmissions by exploiting MIMO techniques. A number of problems studied in the project may foster the development of novel techniques and methodologies toward MIMO-aware dynamic spectrum access. Examples include the novel problem of MIMO-enabled relay selection, insightful analysis of McDysa transmission capacity, and the consideration of secrecy capacity enhancement via friendly jamming. As many of the methodologies in McDysa leverage knowledge from other domains such as game theory, the research outcomes of this project may also motivate advancements of the corresponding domain-specific research. The broader impact of this project also extends to education. The project contains a detailed plan for disseminating the research results and for outreaching to students from underrepresented groups via various channels established in the past years. It also includes a plan for integrating undergraduate and graduate education with research through curriculum development and student involvement. Specifically, the testbed validation of McDysa can offer undergraduate and graduate students valuable hands-on experience, and is therefore an excellent educational vehicle to broaden the participation of students, especially those from underrepresented groups, in computer science research. Technically, this project defines novel problems and develops new performance-optimization techniques in the following three thrusts that are critical to MIMO-aware cooperative dynamic spectrum access: (i) Relay selection and resource sharing, which focuses on developing novel centralized and distributed relay selection and resource management algorithms based on game theory to enable multiple MIMO-empowered primary and secondary users to cooperate for joint optimization. (ii) Achievable transmission capacity analysis, which investigates the achievable transmission capacity of secondary networks and secrecy capacity of the primary network, and the usage of beamforming optimization to maximize such capacities. (iii) Secrecy capacity enhancement, which studies the usage of two friendly jamming mechanisms, cooperative jamming and artificial interference, in the design of novel beamforming techniques and interference signals for nulling the interference at the receivers, in order to enhance the secrecy capacity of the primary network. Besides the three thrusts, this project also includes the design and validation of a testbed that supports a number of experimental tasks for validating the effectiveness of approaches and methodologies developed in the project. This project also has strong societal impact as the rigorously proven solutions developed in the project can serve as guidelines and backbone for	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hang Liu / liuh@cua.edu	Catholic University of America	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Collaborative Research: Data-Guided Resource Management for Dense Heterogeneous Networks	1457137	The emerging paradigm of dense heterogeneous wireless networks (HetNet), while essential to meeting the explosive growth of wireless traffic, poses unseen challenges to classical cellular network design principles. In traditional cellular systems, spectrum and resource management are often based on the assumption of static and regular topology/traffic patterns. Further, each cell operates with an orthogonal set of resources and requires little inter-cell coordination. However, such traditional approaches are out-dated and inefficient in dense HetNets:the proliferation of small-size cells makes the network topology and traffic characteristics highly irregular and varying; and tighter coordination across cells becomes a necessity when users traverse many small-cells frequently. Thus, there is an acute need to re-examine fundamental ways to design HetNets that can (i) quickly adapt to irregular topology and changing load patterns, and (ii) manage cell coordination at scale with minimal overhead to achieve robust and dependable application-level performance. To address this open challenge, this WiFiUS project develops new framework, architecture and algorithms for adaptive, efficient, and dependable spectrum management and resource allocation in dense heterogeneous cellular networks. First, the project team develops a new hypercell architecture that views a macro-cell and the overlapping small-cells as a single logical entity. This new architecture allows hypercells to acquire a global view of the load/channel/mobility/application patterns across multiple base-cells, thereby enabling more effective and dynamic multi-cell coordination at scale. Furthermore, the team develops a data-guided operational framework that exploits both provider-collected and user-contributed data to address the inherent complexity of dynamic multi-cell coordination. Based on historical data, this approach migrates higher-complexity computations to offline, and thus achieves high spectrum efficiency and user QoE with low-overhead. The US/Finland team brings together a wide range of wireless expertise from physical layer design to network resource management. Having a successful collaboration record, the team carries out joint research activities in the following three aspects: 1) data collection and traffic pattern identification; 2) data-guided spectrum management and base-station cooperation; and 3) hypercell link adaptation, measurement, and resource management. The success of the project has a broad impact on the wireless communications industry by addressing multiple timely and critical challenges that arise from the exponential growth of cellular traffic. The project outcomes will also provide important insights into big-data mining and learning for cellular resource management. The results from this work will be widely disseminated through journal/conference publications, and be incorporated into undergraduate and graduate education endeavors.	Technologies and applications for efficient spectrum use or legacy transformation	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Xiaojun Lin / linx@purdue.edu	Purdue University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Pervasive Spectrum Sharing for Public Safety Communications	1506297	Next-generation public safety communication (PSC) systems must deliver high-capacity wireless services to public safety personnel and users in disaster-affected areas, with little reliance on infrastructure. Remarkably, modern-day PSC systems have yet to catch up with the past decade`s wireless revolution, as they still rely on technologies of yesteryears that fall short on delivering high-speed wireless access. Indeed, coping with the foreseen stringent service requirements in future PSC systems mandates major innovations that can increase spectral efficiency. This, in turn, requires tackling multidisciplinary challenges: 1) developing incentive mechanisms for government agencies, providers, and users to share their precious spectrum resources; 2) dynamically managing interdependent spectrum markets; and 3) efficiently modeling and operating sustainable communication protocols that can function with little infrastructure support. This project brings together researchers in wireless communications and networking, game theory, mathematics, and public safety administration to address these challenges and boost the efficiency of PSC by introducing a novel framework that provides the necessary analytical tools for modeling, designing, analyzing, and operating large-scale spectrum sharing in disaster and emergency situations. The overarching scientific merit of this research is to initiate the much-needed leap towards a more open, highly participatory, and pervasive sharing of the wireless spectrum for PSC. This project offers an array of spectrum sharing innovations: 1) new economic approaches and PSC mechanisms that provide incentives for government agencies, providers, and end-users, to effectively subsidize the scarce radio spectrum and facilitate novel public safety and spectrum allocation policies; 2) a foundational framework that tightly integrates tools from game theory and auction theory for enabling a dynamic operation of co-existing spectrum sharing markets with multi-hop capabilities; 3) novel realistic models for characterizing wireless channels, traffic, topology, user behavior, and mobility in PSC; and 4) effective and accelerated transition of theoretical results to practice via a new PSC testbed for extensive validation and close collaboration with several major industry partners and local public safety agencies. In a nutshell, the project provides a new generation of PSC systems and protocols that expedite the response to disasters, save lives, and reduce economic costs.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Walid Saad / walids@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Pervasive Spectrum Sharing for Public Safety Communications	1443999	Next-generation public safety communication (PSC) systems must deliver high-capacity wireless services to public safety personnel and users in disaster-affected areas, with little reliance on infrastructure. Remarkably, modern-day PSC systems have yet to catch up with the past decade`s wireless revolution, as they still rely on technologies of yesteryears that fall short on delivering high-speed wireless access. Indeed, coping with the foreseen stringent service requirements in future PSC systems mandates major innovations that can increase spectral efficiency. This, in turn, requires tackling multidisciplinary challenges: 1) developing incentive mechanisms for government agencies, providers, and users to share their precious spectrum resources; 2) dynamically managing interdependent spectrum markets; and 3) efficiently modeling and operating sustainable communication protocols that can function with little infrastructure support. This project brings together researchers in wireless communications and networking, game theory, mathematics, and public safety administration to address these challenges and boost the efficiency of PSC by introducing a novel framework that provides the necessary analytical tools for modeling, designing, analyzing, and operating large-scale spectrum sharing in disaster and emergency situations. The overarching scientific merit of this research is to initiate the much-needed leap towards a more open, highly participatory, and pervasive sharing of the wireless spectrum for PSC. This project offers an array of spectrum sharing innovations: 1) new economic approaches and PSC mechanisms that provide incentives for government agencies, providers, and end-users, to effectively subsidize the scarce radio spectrum and facilitate novel public safety and spectrum allocation policies; 2) a foundational framework that tightly integrates tools from game theory and auction theory for enabling a dynamic operation of co-existing spectrum sharing markets with multi-hop capabilities; 3) novel realistic models for characterizing wireless channels, traffic, topology, user behavior, and mobility in PSC; and 4) effective and accelerated transition of theoretical results to practice via a new PSC testbed for extensive validation and close collaboration with several major industry partners and local public safety agencies. In a nutshell, the projedt provides a new generation of PSC systems and protocols that expedite the response to disasters, save lives, and reduce economic costs.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ismail Guvenc / iguvenc@fiu.edu	Florida International University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Spectrum Efficient Waveform Design with Application to Wireless Networks	1247875	Spectrum efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized. In this project, innovative spectrum efficient waveform designs are studied towards narrower mainlobe and lower sidelobe in spectrum. It has been recognized that judicious use of properly designed waveforms, coupled with advanced receiver strategies, is fundamental to fully utilizing the capacity of the electromagnetic spectrum. This project seeks innovative approaches on nested and co-prime samplers for spectrum efficiency, and subsequently applies it to wireless networks. Different waveforms designs and diversities are studied based on nested and co-prime samplers. Co-prime samplers are used for Multi-Input Multi-Output communication system. In the application to spectrum efficient wireless networks, nodes exchange information over a common wireless channel. Under different traffic scenarios and different constraints, e.g., bandwidth and signal to noise and interference ratio, the amount of data exchanged among these nodes may vary. A key question then is how the throughput capacity of wireless network improves with the new waveform design schemes and different network setup and how it grows with the number of nodes in the network. This project seeks to help reach the nation`s broadband goals and the larger objective of alleviating growing pressure on limited spectrum resources. This project will attract minority and woman students to participate in the project.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jie Wang / wang@cs.uml.edu	University of Massachusetts Lowell	no-value

National Science Foundation (NSF)	INFORMATION TECHNOLOGY RESEARCH	Collaborative Research: Virtualized Wireless Networks and Their Impact on Capacity Markets	1443978	This project develops a new vision for wireless networks, predicated on the creation of service-driven virtual networks constructed from a pool for resources that belong to a variety of stakeholders. The resources include spectrum, physical infrastructure, and control and management support, and the stakeholders include traditional mobile operators, operators of WiFi access networks, businesses and households that support wireless connectivity through small cell deployment, traffic aggregators (such as Mobile Virtual Network Operators (MVNOs)), and regulators. The resulting architecture separates the consumer-facing service provision from the technologies used to construct the network, enabling the disintermediation of current wireless service provision systems. Moving the point at which network access transactions take place up the value chain (or the protocol stack) means that a greater range of service types can be provided to consumers without requiring large up-front capital investments on the part of the (consumer-facing) service providers. This will have profound impact on both industry and society, affecting the way that these networks are designed and built, spectrum and infrastructure resources are managed, and pricing structures for services provided over the network.This project first defines a new architecture that enables the virtualization of a wireless network over a combination of spectrum licensed under different regimes and infrastructure with different ownership. Relying on game theoretic and market models of virtual network construction, new resource management mechanisms are designed to select the appropriate set of resources to build a virtual wireless network with given coverage and capacity requirements. Combinatorial auctions for multiple objects are practical mechanisms for the dynamic allocation and aggregation of resources for such a virtualized wireless network. In analyzing the impact of the proposed architecture on spectrum markets, a key question is whether the incorporation of a virtualized spectrum commodity influences the viability of these markets (as measured by the liquidity outcome), and how this compares to previous scenarios in which the traded commodity was the physical spectrum resource or 'naked spectrum'. Finally, this project explores how markets in virtual wireless capacity would work when implemented in current wireless networks, in the context of LTE-Advanced and expected 5G developments.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Luiz DaSilva / ldasilva@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research:EARS: Creating an Ecosystem for Enhanced Spectrum Utilization Through Dynamic Market Mechanisms.	1443965	The surge in demand for Internet access using smart hand held devices has resulted in the emergence of a multitude of apps and devices, which have diverse requirements and capabilities. However, underlying policies for scheduling cellular resources are optimized for average or worst case performance, and do not allow end-users to indicate the relative value of resources on the packet level. Simultaneously, it has become clear that while there are insufficient bandwidth resources for unlimited cellular data plans, the prevailing scheme of degrading access after a certain limit is exceeded is both unpopular and inefficient.The main goal of this project is to bridge the disconnects between user preferences and allocated resources by the use of dynamic market mechanisms that allow for packet-level value determination over time. The objective is to study both primary markets in which service providers sell network access to end-users, as well as secondary markets in which end-users share resources via hot spots and device-to-device networking. While doing so, the project identifies the impact of such packet-scale transactions on the incentives and efficiency of the market at a long time-scale, packet-aggregate level. The project takes an important step towards the systematic design of dynamic mechanisms for resource sharing in wireless communication networks, which would innately account for user preferences and valuations. The PIs will develop an analytical framework for designing dynamic market-based mechanisms that would implicitly allow the determination of the value of allocating and trading resources among various agents. The research is organized into three inter-dependent areas: 1) Value Identification and Resource Scheduling in Single-Sided Markets; 2) Utilizing End-User Resources through Two-sided Markets; 3) Policy and Provisioning Decisions. The dynamic market mechanisms that are developed will be tested via experiments conducted on a smart phone test bed in order to better understand real-world implications. All three PIs are heavily involved in the education and training of graduate and undergraduate students, and the proposed work will further strengthen the students' exposure to network control, game theory and optimization. The project will disseminate results to the public through seminars and summer camps focusing on electrical engineering concepts appropriate for high school level students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Thanh Nguyen / nguye161@purdue.edu	Purdue University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Dynamic Behavior and Coexistence of Intelligent Radio Spectrum Access Systems	1247909	Dynamic spectrum access (DSA) allows new wireless systems to reuse the spectrum currently occupied exclusively by primary systems. A DSA system must be intelligent enough to detect primary system's activity and be flexible enough to allow new and advanced technology to be adopted to compete for spectrum access. The intelligence and flexibility make DSA system to have complex dynamic behaviors such as oscillation and fluctuation that are quite different from what was intended. They also make it difficult to guarantee the coexistence of heterogeneous DSA systems. This project develops a theoretical framework for modeling and analyzing the dynamic behavior and the coexistence of heterogeneous DSA systems. It employs many methodologies from theoretical ecology to study the cooperation, competition, altruism, selfishness, and other intelligent human-like behaviors. Two approaches are exploited to study such complex interactions among multiple spectrum access strategies: an evolutionary game theoretic approach based on an efficient Markov-model bank, and a population dynamic approach based on a spectrum-usage model. In addition, this project initiates pioneering research on DSA policy modeling and analysis by applying the two approaches. This project builds the underlying theoretical foundation to support the development of new DSA techniques, new heterogeneous DSA systems, and new DSA policies that enhance the efficiency and fairness of spectrum access. The theoretical methodologies are useful for the development of many other heterogeneous and intelligent systems in general. This project stimulates the integration of the two traditionally disparate areas: wireless communications and theoretical ecology, in both research and education.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiaohua Li / xli@binghamton.edu	SUNY at Binghamton	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: A Social and Context Aware Spectrum Management Framework for Heterogeneous Cognitive Radio Networks	1352726	Cognitive radio is a promising technology that can significantly alleviate spectrum scarcity and improve the spectral efficiency. This project conducts a comprehensive study on developing a social and context aware spectrum management framework that targets maximizing the spectral efficiency for cognitive radio networks with heterogeneous devices and applications. This research is motivated by the idea that the efficient management of spectrum requires the consideration of the entire network ecosystem where the users and their applications interact with each other. In the proposed framework, a novel fairness criterion is developed for the network scenarios under consideration. With the developed fairness criterion as a constraint, a social and context aware spectrum allocation scheme is developed, which contributes to the maximization of the spectral efficiency. In addition, a fair opportunistic spectrum sharing mechanism is proposed to further improve the spectral efficiency. Lastly, various aspects of social bonding in a group of users are exploited to reduce the delay occurred in the spectrum sharing process.The expected results of this project include novel algorithms, designs, and technologies to enable the future deployment of commercial cognitive radio networks and new emerging applications. The findings of this project will be disseminated through journal and conference publications. The developed hardware and software tools will be made available to the research community at large as well. The project integrates research and education with the intent of training undergraduate students. It also outreaches to high school students in the local area.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Liran Ma / l.ma@tcu.edu	Texas Christian University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Accelerating Spectrum Access in Cognitive Radio Networks via Social Analysis of Secondary Users	1343355	A fundamental operation for users in cognitive radio networks (CRNs) to access the spectrum is channel rendezvous. After rendezvous is established, channel information exchange and propagation among users are also essential for efficient spectrum access. Existing studies on channel rendezvous in CRNs have limitations and are unsuitable for efficient access scenarios. Additional information about users can help generate intelligent designs in CRNs that can shorten spectrum access delay. However, due to practical constraints, such information is extremely difficult to obtain before rendezvous is established. Mining the social patterns of CR users (or secondary users, SUs) and intelligently utilizing the captured social information is a promising approach. The objective of this project is to design, analyze, and evaluate fast and efficient spectrum access schemes for CRNs without a common control channel. One unique feature of this work is the consideration of SU social patterns and the incorporation of social analysis to enhance spectrum access efficiency. The approach involves analyzing the time, location, and spectrum-dependent social patterns of SUs; identifying and addressing new challenges in channel rendezvous, security, and recommendation designs with the assistance of SU social analysis; and proactively utilizing social patterns of SUs for fully distributed fast and secure spectrum access design. This project will have a significant impact on efficient spectrum access. Social analysis of users is a critical component to further enhance spectrum access efficiency and accelerate CRN deployment. This interdisciplinary research is potentially transformative as it will help generate innovative techniques to numerous CRN applications. It will also greatly enhance the understanding of social interactions of mobile users in wireless networks. This project provides an excellent opportunity for graduate and undergraduate research students to gain valuable educational training and research experiences. The research results will be presented at IEEE/ACM journals and international conferences.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jiang (Linda) Xie / Linda.Xie@uncc.edu	University of North Carolina at Charlotte	no-value

National Science Foundation (NSF)	INFORMATION TECHNOLOGY RESEARCH; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Achieving Spectrum Efficient Broadcast Under Cross-Technology Interference	1444021	Wireless technologies have percolated into people`s daily life for personal communication, mobile Internet surfing, global positioning, digital media broadcasting, and smart home automation. These technologies are deployed in environments ranging from well-controlled laboratories and residential houses to highly dynamic urban surroundings. This work aims at improving a range of wireless technologies so that information can be broadcast more reliably, quickly and cost-efficiently in highly crowded WiFi, Bluetooth and LTE environments. Research has shown that uncoordinated wireless coexistence in overlapping channels leads to severe inefficiency in spectrum utilization. Although a few coexistence designs have been done recently to deal with cross-technology interference (CTI), those studies focus primarily on improving spectrum utilization in unicast communication. Unlike in one-to-one unicast communication, network topological features in one-to-many broadcast communication significantly impact broadcast spectrum efficiency. With the increasing demand for broadcast support, the field is facing an urgent need to investigate broadcast spectrum efficiency in the context of wireless coexistence.This project conducts a systematic cross-layer study of broadcast under CTI, contributing novel designs across physical, data link, and network layers. The research topics include: 1) conducting extensive measurement studies to collect traces regarding cross-technology interference patterns in a wide range of environments; 2) building synthetic models to generalize instances of measure traces into a set of parameterized models that precisely characterize features of cross-technology interference; 3) empirically and theoretically modeling how uncontrolled CTI affects multiple wireless links simultaneously and proposing mitigation methods through network topology management; 4) delivering a spatial, temporal, and spectral CTI mapping device that exposures CTI information as a service to surrounding wireless ISM devices, so that these devices can seek white space opportunities in spatial, temporal and spectral domains for effective broadcast, and 5) supporting cross-technology broadcast by embedding side-channel information through cross-technology modulation. The broader impact of this work is amplified by (i) improving curriculum development with enhanced course projects; (ii) disseminating research results through high-profile tutorials and open-source sites; (iii) raising interest in technology among K-12 students and under-represented minority groups through open houses; and (iv) supporting talented female and minority PhD students to successfully accomplish their doctoral studies.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Tian He / tianhe@cs.umn.edu	University of Minnesota-Twin Cities	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Big Bandwidth: Finding Anomalous Needles in the Spectrum Haystack	1247864	Objective:The objective of the proposed project is to explore the problem of scanning large amounts of spectrum in order to detect anomalous usage of that spectrum. The project will examine spectrum scanning using a single spectrum sensor and using multiple spectrum sensors. The approach will involve using game theoretic formulations that allow for the determination of scanning strategies that give an optimal likelihood of detecting an adversarial or accidental misuse of spectrum in terms of the bandwidth that can be scanned in a single scan and the bandwidth that an anomalous activity might involve. The optimization of strategies are complemented by techniques that increase the amount of spectrum that can be scanned in a single scan, and spectrum mapping algorithms that estimate the received power levels at arbitrary spatial locations.Intellectual merit:The intellectual merit of the proposed effort stems from the pulling together of a mixture of technologies from different fields, including game theory, signal processing, security, wireless communications, and RF photonics to address the challenging problem of detecting and preventing anomalous spectrum activity across a wide swath of bandwidth. Broader impacts:The broader impacts of the proposed effort will include the cross-pollination between different disciplines, such as game theory, security, photonics and signal processing. Additionally, the project will guide the development of graduate and undergraduate students at both participating institutions, giving the students new tools with which to contribute to wireless and optical communications. Finally, new interdisciplinary curricula will be developed as part of the effort.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Wade Trappe / trappe@winlab.rutgers.edu	Rutgers University New Brunswick	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Directional Spectrum Sensing and Communications Utilizing Beam- and Frequency-Agile Parasitic Antenna Arrays	1443942	ArraysThis multidisciplinary research will address some of the major challenges in enabling the next generation of spectrum efficient and energy efficient wireless communication systems for a wide range of applications, including personal communications, emergency-response, and cyber-physical systems (e.g., intelligent transportation systems and the smart-grid), by developing collaboration between two fields of signal processing and communication theory and antenna design. The principal investigators (PIs) will develop a novel beam- and frequency-agile antenna and new signal processing and communication techniques that take full advantage of the antenna capabilities, in order to enable directional spectrum sensing and communications for portable lightweight terminals and provide significant spectral efficiency gains. This research has multifaceted benefits in advancing the field, and in education and diversity (i) It will make a significant impact on the theory and practice of the evolving cognitive radio networks and technologies, for a variety of applications that benefit society. (ii) It will provide a unique opportunity to bond the two research groups supervised by the PIs and enhance research and education through this partnership. The PIs will train graduate and undergraduate students and will actively engage in the stimulation and development of the field. The undergraduate students will gain experience with research in an interesting area. (iii) It will increase the participation of under-represented students in the PIs' research groups. The PIs will use the resources available through the UCF Summer mentoring fellowship program, which provides financial support for the minority students who are interested in conducting research with a faculty mentor. (iv) It will integrate research and education through incorporation of the research results into the Electrical and Computer Engineering graduate curriculum. The research thrusts are: (i) Design of a low-cost beam- and frequency-agile antenna, using an Electrically Steerable Parasitic Array Radiator (ESPAR) approach: These ESPAR antenna arrays require minimum number of phase shifters by parasitically coupling antenna elements. Continuous beam (main lobe and null) as well as frequency scanning can be realized simultaneously within the antenna structure. The ESPAR antenna arrays will be used for both directional spectrum sensing and communications. (ii) Model-based signal processing for directional spectrum sensing utilizing the ESPAR antennas: The PIs will develop a signal model for the ESPAR antennas. Based on this signal model, energy and eigenvalue-based detectors will be developed, which do not require any prior information about the signal of primary users (PUs) to be detected. The energy detector, although simple, requires knowledge of the receiver noise level. On the other hand, the eigenvalue-based detectors do not require this information and hence are insensitive to uncertainties in receiver noise level. Comparing detection performance of eigenvalue-based detectors against that of energy detectors for omnidirectional antennas unveils the improvement in spectrum sensing accuracy provided by the ESPAR antennas. (iii) Directional communications utilizing the ESPAR antennas: For a system where a pair of secondary users	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Azadeh Vosoughi / azadeh@ucf.edu	University of Central Florida	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Enhanced Spectrum Availability and MU-MIMO Coordination for High Spatial-Spectral Efficiency	1444056	Astounding spectral efficiencies exceeding 40 bits per second per Hertz have already been achieved in multi-user MIMO systems. Unfortunately, the coordination needed to facilitate transmissions in space, frequency, and time can severely limit efficiency. Moreover, many spectral bands are today deemed unavailable even if no active receiver is nearby and hence resources cannot be used at all.This project fuses three integrated thrusts towards achieving high spectral-spatial efficiency (bits per second per Hertz per square meter) with high spectrum availability (permission to transmit in a particular band at a particular location). First, this project enables a new mode of spectrum availability by exploiting smart primary receivers. The key idea is that a typical primary spectrum transmitter such as a TV broadcaster does not have active receivers in all locations. This thrust realizes an architecture and algorithms for smart primary receivers to inform a controller of their usage, creating vast new dynamically available spatial-spectral resources. Second, this project overcomes fundamental limits in the coordination that is today required for spectrum access. This thrust considers channel sounding and user-state coordination to be a foundational resource of system design that must itself be allocated. An integrated suite of new methods for coordination limited MU-MIMO protocols is developed. The final thrust provides an implementation and measurement study. This thrust yields the first demonstration of spectrum access enhanced by smart primary users and the first multi-user MIMO diverse spectrum system enhanced by coordination limited protocol mechanisms. The platform targets "at scale" experiments via use of maximally amplified signals and real-word scenarios spanning from tower-to-user to indoor WLAN.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Edward Knightly / knightly@ece.rice.edu	William Marsh Rice University	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Joint Circuit and Waveform Optimization for Cognitive, Spectrally Confined Radar Transmission	1343316	Joint Circuit and Waveform Optimization for Cognitive, Spectrally Confined Radar TransmissionIntellectual Merit: Due to the continued development and use of new wireless broadband devices and the resultant congestion of the spectrum, future radar systems will be required to perform their ever-critical societal and military functions in a frequency-flexible, cognitive manner. To facilitate this new paradigm, this research involves investigation of an adaptive radar transmitter with jointly optimizable circuit and waveform to operate within a dynamically varying spectral mask based on locations of nearby communication nodes. The specific intellectual and scientific aims of this research are to (1) create a useful circuit optimization approach for linearity and efficiency, (2) innovate an approach to optimize the radar waveform for spectral compliance and desired detection/ambiguity properties, (3) simultaneously optimize the waveform and matching networks in the reconfigurable radar transmitter, (4) investigate sources of additional information to speed the search, and (5) recommend an approach for dynamic radar spectral mask construction based on the relative locations of the radar transmitter and communication nodes. The proposed work will provide enabling technology for cognitive radar systems to exist in a dynamic spectrum access environment with changes in radar operating frequency, and will also allow optimization of radar detection capabilities and power efficiency based on the surrounding environment and potential victims of interference. This work is interdisciplinary, fusing work in areas of RF/microwave circuitry and robust intelligence/optimization to accomplish a transformative paradigm shift in radar/communications coexistence. Broader Impacts: For the purpose of garnering expert input from policy and economic perspectives, the principal investigator, along with a multidisciplinary steering committee, will add a Spectrum Forum to their already successful Texas Symposium on Wireless and Microwave Circuits and Systems. The research team has constructed collaborations to channel outcomes of this research into relevant regulatory efforts and already underway involvement in the North Atlantic Treaty Organization Research Task Group on Spectrum Engineering. The principal investigator also will continue successful efforts in educating high school students about spectrum issues and science, technology, engineering, and math careers by partnering with schools in the Central Texas region. The research group of the PI has a history of significant female and minority representation in his research group, and the placement of this research at a university with significant female involvement in engineering will allow this grant to continue to involve underrepresented groups in research	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Charles Baylis / Charles_Baylis@baylor.edu	Baylor University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Modeling and Analysis of Radar / Communications Spectrum Sharing Opportunities	1343306	This research effort focuses on the impact that 4G/LTE wireless devices (e.g. cell towers and smart phones) may have on radar altimeters operating in the 4200-4400 MHz spectral band. Based on the identification of this band by the government as a potential candidate for commercial cellular use, the spectral characteristics and potential impact to the operation of these airplane landing radars has become extremely important to a broad audience. The recent crash of the Asiana Airlines flight has added to the focus on the operation of these radars.To obtain this understanding, a significant spectrum measurement campaign will be undertaken focused on appropriate radar altimeter systems and on 4G/LTE systems. The measurements will quantify the effects of 4G/LTE on radar altimeter performance using actual and/or simulated equipment. These measurement results will provide a basis for performing the detailed analysis work required to gauge the level of impact that would be expected under a variety of conditions. This information will need to be quickly and effectively disseminated to others in the wireless research community and importantly to various decision-makers in the telecommunications policy realm.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dennis Roberson / dennis.roberson@iit.edu	Illinois Institute of Technology	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Signal processing techniques for enhancing spectrum access in wireless networks using coupled antenna arrays	1443958	networks using coupled antenna arraysThe current spectrum crunch calls for innovative approaches to utilize the available frequency spectrum more efficiently. This proposal aims at addressing this issue by introducing a new class of antenna arrays called coupled antenna arrays (CAAs). The unique nature of the CAAs allows for placing the antenna elements closely resulting in very small arrays that are suitable for mobile radios. The performance of CAAs should be assessed with proper models and analysis tools. Also, utilizing CAAs for different applications requires proper signal processing techniques. The proposed research is expected to result in achieving performance levels and spectrum efficiencies that far exceed the current wireless technologies. In the short term, the expected research findings will lead to the development of multi-antenna receivers with offered spectral efficiencies that cannot be easily achieved using any other existing technology today. This will profoundly impact the efficiency of spectrum utilization of future wireless systems. In the long term, these concepts are expected to revolutionize how we solve problems in a variety of areas ranging from wireless communications and signal processing to antenna theory and radar systems. In addition to these positive societal, economic, and technological impacts, the proposed work integrates research and education through a carefully planned series of activities. These will facilitate the engineering-oriented professional development of K-12 science teachers; integrate research activities into the teaching of science/engineering at the K-12, undergraduate, and graduate levels; improve recruitment and retention of under-represented minority and female students in research activities at the pre-college, undergraduate, and graduate levels; and result in development and broad dissemination of research based educational materials through both traditional and non-traditional means of dissemination.The overall objective of the proposed interdisciplinary research project is to use recent advances in the areas of multi-antenna wireless communication systems and signal processing and coupled antenna array (CAA) technology to fundamentally enhance the efficiency of spectrum utilization of mobile wireless communication systems. Specifically, the PI and the Co-PI plan to develop a new class of electrically-small CAAs and investigate their applications for: 1) Spectrum co-existence and capacity enhancement of wireless systems operating in strong interference environments; 2) Capacity-enhancement of multi-input multi-output (MIMO) communications systems; and 3) Capacity enhancement and complexity reduction of multi-cell cooperative networks. The proposed work bridges the gaps between two traditionally separate areas of research to develop viable solutions for enhancing the spectrum efficiency of future wireless systems. This work particularly emphasizes on small mobile wireless devices that cannot accommodate large antenna arrays, and work at frequencies below 5.0 GHz where the propagation conditions are most suitable for achieving wide-area coverage that many mobile wireless systems rely on. This project involves two fundamental thrusts of investigation that are expected to significantly advance our	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hamid Bahrami / hrb@uakron.edu	University of Akron	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Spectrum Sharing for Short-Latency Immersive Wireless Applications	1343398	This project will develop the key technologies needed for interactive wireless applications operating in shared spectrum. Sharing is the new spectrum paradigm, and interactive applications are the most demanding in terms of the quality-of-service they require. Thus, they are the perfect vehicle to push the frontiers of our understanding of sharing. This project will explore new high-reliability coding techniques to protect interactive applications while meeting tight latency constraints and explore how to coexist with neighboring disparate systems through explicit and implicit signaling. The project will contribute the fundamental understanding required to define the correct regulatory structure for spectrum sharing. Broadly speaking, the interactive applications that this project will study are the key to the next growth phase in commercial wireless - as machines need to interact with each other to improve the performance of real-world systems. Because industrial control is a critical use case, this project can help invigorate the agile manufacturing sector of the economy. Efficiently shared spectrum is much more economical than exclusive-use spectrum and hence could help innovative high-skill manufacturing where the United States has an advantage over low-wage countries. While developing this technology, the project will train students in a way that encourages cross-fertilization of ideas between wireless communication, circuit implementation, control theory, and coding theory. These ideas will be brought into the classroom, including our new M.Eng. courses aimed at educating innovative technical leaders. The project will also broaden participation in the technical workforce by mentoring students from underrepresented groups.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Borivoje Nikolic / bora@eecs.berkeley.edu	University of California-Berkeley	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Medium: Collaborative Research: GOALI: Adaptive and Flexible Spectrum Optical Networking	1302719	This project will study and develop technology for Elastic Optical Networks (EONs). In EONs flexible amounts of spectral bandwidth may be allocated to each data channel without requiring adherence to a fixed wavelength grid. Such an approach is well-suited for supporting a wide range of dynamic traffic demands in a bandwidth-efficient manner. Key enabling technologies, optical arbitrary waveform generation(OAWG) and optical arbitrary waveform measurement (OAWM), will enable elastic optical networking over a large spectrum by dividing the spectrum into spectral slices and dynamically processing information at lower rates compatible with CMOS electronics. The project will leverage these technologies as a basis for innovative hardware and software solutions for EON technology, architectures, protocols, network control and management, system integration, and testbed integration. Advances in the basic architecture and technology for optical networking is important for US competitiveness. The project will work with several US-based industrial organizations as a means of technology transfer. The research results and publications will likely to impact standardization activities of flexible grid networking (e.g. International Telecommunication Union ITU-T SG15 on flex grid). The project will link education and research and serve as a rich platform for crossdisciplinary education in optical and higher-layer networking, and in computer engineering.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	S.J.Ben Yoo / yoo@ece.ucdavis.edu	University of California-Davis	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Distributed Robust Spectrum Sensing and Sharing in Cognitive Radio Networks	1318748	The future Cognitive Radio Networks (CRNs) will consist of heterogeneous devices such as smartphones, tablets and laptops moving dynamically. Accurate and robust spectrum sensing and identification of unauthorized spectrum usage are essential components of spectral efficiency in future radio systems. This project aims to utilize consensus-based cooperation featuring self-organizable and scalable network structure to capture the swarming behaviors of spectrum users and providing cooperative spectrum sensing in a fully distributed manner. By using a combination of control theory and machine learning techniques, the project designs secure weighted average consensus for cooperative spectrum sensing that can not only capture the swarming behaviors in CRNs with heterogeneous devices, but also is robust to practical channel conditions. Robust localization approaches are developed grounded on dynamic signal strength mapping, which have the capability to localize multiple malicious users. Additionally, the new techniques are validated using an actual testbed with on-campus deployment and system demonstration to industrial collaborators. The integration of control theory with dynamic spectrum access will enable a new revolution in the way for enhancing spectrum efficiency in CRNs. The project serves as a pioneer in exploiting multi-disciplinary knowledge (e.g., control systems and machine learning techniques) to achieve a more efficient spectrum usage in future radio systems, aiming to alleviate the increasing crowdness of the spectrum occupancy and support the co-existence of heterogeneous devices. This project also carries out a broad range of education and outreach activities to encourage students to pursue careers in the fields of science and engineering. Research results will be disseminated to academia and industry through presentations and publications in meetings, conferences and journals.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yingying Chen / yingying.chen@stevens.edu	Stevens Institute of Technology	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Efficient Spectrum Access for Gbps WLANs in a Crowd of Legacy Networks	1317411	Next-generation WLAN protocols will rely heavily on spectrum aggregation to achieve Gbps throughput. But the aggregated wideband spectrum may be severely underutilized and even starved when it overlaps with legacy narrowband channels. As WLAN protocols continue their expansion and diversification, such heterogeneous spectrum sharing becomes increasingly prevalent, raising coexistence as a fundamental problem and practical problem. The objective of this research is to gain insights into coexistence of Gbps and legacy WLANs through measurement studies, develop optimization-driven protocols to enable efficient spectrum sharing between them, and validate the protocols in a medium-scale software-radio testbed. The proposed solutions improve the MAC layer`s awareness of heterogeneous spectrum sharing, and enforce intelligent control over the PHY layer through fine-grained spectrum access and opportunistic spectrum aggregation. They have the potential to realize Gbps wireless networking even in a crowd of low-rate legacy networks/devices.By addressing the key issues of heterogeneous spectrum sharing, the proposed research helps accelerate the deployment of Gbps WLANs which will, in turn, improve the quality of experience for billions of WiFi end-users. It will also train graduate students with a balanced mix of theory and hands-on experiences, and synthesize their knowledge in both computer science and communications engineering. Undergraduate students will also participate in this project, with the complementary support from the undergraduate research programs in the PI`s institutions. The PIs will interact closely with industry for possible transitioning of the research results.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kang Shin / kgshin@eecs.umich.edu	University of Michigan Ann Arbor	no-value

National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Unleashing Spectrum Effectively and Willingly: Optimization and Incentives	1420881	An intriguing fact emerges during the study of spectrum usage. On one hand, the proliferation of wireless devices, e.g. smartphones, laptops, and tablets, and bandwidth-hungry applications has resulted in the problem of spectrum scarcity. On the other hand, a recent report by FCC reveals that the licensed users are extremely underutilizing the allocated spectrum. To remove the barriers to efficient spectrum utilization, this project aims to 1) design effective spectrum allocation algorithms to allow as many secondary users (SUs) to coexist with the primary user (PU) as possible while taking into account the interference generated by both SUs and PU; and 2) develop incentive mechanisms for enticing spectrum licensees to share or license their under-utilized spectrum for better utilization. While designing spectrum allocation schemes, the physical interference model is adopted to characterize the interference closely to reality. Joint optimization of spectrum allocation and power control is explored to further improve the spectrum utilization. This can lead to efficient approximation algorithms with guaranteed performance comparing with the optimum, as well as effective heuristic algorithms. Another major task of this project is to design incentive auctions for enticing spectrum licensees to share their spectrum with unlicensed users in exchange for the proceeds from the auction. Three different application scenarios are investigated: 1) the spectrum holder is willing to coexist with the unlicensed users under the condition that the cumulative interference caused by them does not interrupt its own transmission; 2) small network operators are allowed to form groups for collective buying power to increase their chances of winning the spectrum; and 3) the competition among multiple spectrum licensees is considered. This research can help ensure wireless networks in the USA keep pace with the continuously increasing demand for spectrum, so that they can support activities that increasingly rely on them, including public safety and health-care. The designed group-buying based incentive auctions can provide opportunities for small businesses to compete against big brand companies and win the access to desired spectrum that is essential to the success of their business. These small businesses are the engines of job creation and economic growth for the country. This project involves under-represented and minority students, as well as K-12 students to inspire their interests in science and engineering.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dejun Yang / djyang@mines.edu	Colorado School of Mines	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Unleashing Spectrum Effectively and Willingly: Optimization and Incentives	1421685	An intriguing fact emerges during the study of spectrum usage. On one hand, the proliferation of wireless devices, e.g. smartphones, laptops, and tablets, and bandwidth-hungry applications has resulted in the problem of spectrum scarcity. On the other hand, a recent report by FCC reveals that the licensed users are extremely underutilizing the allocated spectrum. To remove the barriers to efficient spectrum utilization, this project aims to 1) design effective spectrum allocation algorithms to allow as many secondary users (SUs) to coexist with the primary user (PU) as possible while taking into account the interference generated by both SUs and PU; and 2) develop incentive mechanisms for enticing spectrum licensees to share or license their under-utilized spectrum for better utilization. While designing spectrum allocation schemes, the physical interference model is adopted to characterize the interference closely to reality. Joint optimization of spectrum allocation and power control is explored to further improve the spectrum utilization. This can lead to efficient approximation algorithms with guaranteed performance comparing with the optimum, as well as effective heuristic algorithms. Another major task of this project is to design incentive auctions for enticing spectrum licensees to share their spectrum with unlicensed users in exchange for the proceeds from the auction. Three different application scenarios are investigated: 1) the spectrum holder is willing to coexist with the unlicensed users under the condition that the cumulative interference caused by them does not interrupt its own transmission; 2) small network operators are allowed to form groups for collective buying power to increase their chances of winning the spectrum; and 3) the competition among multiple spectrum licensees is considered. This research can help ensure wireless networks in the USA keep pace with the continuously increasing demand for spectrum, so that they can support activities that increasingly rely on them, including public safety and health-care. The designed group-buying based incentive auctions can provide opportunities for small businesses to compete against big brand companies and win the access to desired spectrum that is essential to the success of their business. These small businesses are the engines of job creation and economic growth for the country. This project involves under-represented and minority students, as well as K-12 students to inspire their interests in science and engineering.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Guoliang Xue / xue@asu.edu	Arizona State University	no-value
National Science Foundation (NSF)	COMPUTING RES INFRASTRUCTURE	Collaborative Research:II-NEW: RUI: ROAR- A Research Infrastructure for Real-time Opportunistic Spectrum Access in Cloud based Cognitive Radio Networks	1405681	This project focuses on the development of a real-time opportunistic spectrum access testbed for cognitive radio networks, called ROAR.The information gained from this project will provide a platform to assess maturity of spectrum-sensing technology and identify areas that need further research for real-time opportunistic dynamic spectrum access in a heterogeneous cognitive network environment, and will support enhancement of our national wireless infrastructure and capacity. ROAR will have a broad societal impact as wireless networks touch every aspect of our society. Project-based learning will be incorporated in related undergraduate and graduate courses to integrate research and education. Focused efforts will be undertaken to interest underrepresented minorities (including females) in the proposed research field.This project will setup a cloud-based cognitive network for real-time opportunistic spectrum access across diverse RF bands (e.g., 9 kHz ? 6000 MHz) including cellular, IEEE 802.11 a/b/g/n, IEEE 802.15.4, DSRC/WAVE and Bluetooth networks, in order to study the implementation, evaluation and development of future wireless systems. This project also enables experimental investigations in a number of other research projects, including secure dynamic spectrum access design, cognitive radio enabled opportunistic spectrum access in highly mobile vehicular networks, primary user security emulation, energy management techniques for mobile devices, cross-layer based protocol design, security for cyber-physical system design, interference mitigation techniques and wireless resource management schemes.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Sachin Shetty / sshetty@tnstate.edu	Tennessee State University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Secure Crowdsourcing-Based Cooperative Spectrum Sensing	1320906	Crowdsourcing-based cooperative spectrum sensing (CCSS) refers to a spectrum-sensing service provider (SSP) outsourcing the spectrum-sensing tasks over a large geographic region to distributed mobile users referred to as mobile detectors. The promise and feasibility of CCSS are deeply rooted in the ubiquitous penetration of increasingly powerful mobile devices into everyday life and in the anticipated prevalence of dynamic spectrum access (DSA) in future mobile communication systems. CCSS is expected to be much more cost-effective than deploying a large-scale dedicated network of distributed spectrum sensors. This research is to investigate a secure and privacy-preserving CCSS architecture. The research tasks include: (1) incentive-aware and reputation-aware selection of mobile detectors whereby the SSP can select an optimal set of mobile detectors for a sensing task; (2) secure combination which enables the SSP to minimize the impact of false sensing reports on the final detection result; (3) a reputation system which records the past sensing performance of mobile detectors and provides crucial input into the selection of mobile detectors and the secure combination of sensing reports; and (4) spectrum-misuse detection to enable the real-time detection of unauthorized spectrum use. This research will expand the fundamental understanding of security, privacy, and incentive issues in CCSS. Materials of this project will be made publicly available online as tutorials, talks, publications, and software toolkits. The education plan of this project is to develop new cross-disciplinary teaching materials on DSA and involve undergraduates, underrepresented students, and graduates in networking and security research.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yanchao Zhang / yczhang@asu.edu	Arizona State University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Spectrum Sensing and Resource Allocation for Cognitive Radio Networks	1421869	industry and the rapid proliferation of wireless devices over the past couple of decades. Ironically, studies of spectrum usage have shown that much of the available spectrum is highly underutilized, due to the current policy of static allocation, which partitions the spectrum into various licensed bands. The main goal of this project is to develop a cost-effective solution to the spectrum scarcity issue based on emerging cognitive radio technology, which has the potential to allow unlicensed users to reclaim unused spectrum in the licensed bands. A cognitive radio is capable of detecting unused or idle spectrum and dynamically tuning its transmission and reception activities to the so-called spectrum holes. A group of unlicensed users equipped with cognitive radios can form a network and communicate with each other via such spectrum holes. This research focuses on developing efficient and accurate methods for cognitive radios to identify spectrum holes and allocate this spectrum to enable communications among unlicensed users without causing harmful interference to the licensed users of a spectrum band. A major challenge of this work lies in how to perform spectrum sensing and resource allocation in a cognitive radio network to maximize its capacity while managing the additional interference and overhead incurred by the cognitive radios. If the project is successful, the research results should have a significant impact on increasing the capacity and performance of future wireless networks. The research is expected to advance the field of cognitive radio and contribute towards its adoption in commercial applications. The results of this research will be applicable to future infrastructured wireless networks, as well as wireless communications in emergency scenarios such as disaster relief. An experimental platform will be developed to prototype and evaluate the effectiveness of the proposed dynamic spectrum access approach in practical wireless environments. Students, including some from underrepresented groups, will gain practical experience from working with the cognitive radio testbed. New course materials will be developed to teach the basics of cognitive radio technology to students at the graduate level. The technical approach of this research centers on a joint consideration of spectrum sensing and resource allocation, taking into account the three main dimensions of spectrum holes, i.e., time, space, and frequency. A multidimensional characterization of spectrum holes will be developed, which incorporates a bivariate Markov chain to model temporal dynamics, power control in the context of spatial spectrum sensing, and frequency-domain search for spectrum holes in the wideband regime. A model of a cognitive radio network based on simplicial homology will be developed to allocate spectrum resources among cognitive radio nodes, as well as the communication and computational resources required for spectrum sensing, to optimize performance from a networking perspective. Interference modeling and management for the cognitive radio network will be addressed in conjunction with resource allocation. The project will study tradeoffs among communications and computational resources within the proposed framework for dynamic spectrum access. An important	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Brian Mark / bmark@gmu.edu	George Mason University	no-value

National Science Foundation (NSF)	NETWORK SCIENCE & ENGINEERING	NetSE: Medium: Collaborative Research: Promoting Secondary Spectrum Markets via Profitability-Driven Methods and Algorithms	964170	Wireless telecommunications are undergoing substantial policy reforms in pursuit of better spectral efficiency. A key element in these reforms entails granting full property rights to spectrum license holders, thereby paving the way to secondary spectrum markets. Spectrum markets hold a remarkable potential to increase spectrum utilization by making it available to a larger fraction of public at lower cost. Yet, although a favorable regulatory framework has been in effect in the last few years, liquidity of spectrum markets is inhibited due to uncertainties perceived by spectrum license holders. These uncertainties stem from complex relationships between effects of electromagnetic interference and economic considerations. This research involves a constructive study of viability of spectrum markets by establishing methods and algorithms that render such markets profitable for their participants. The investigators focus on analytical study of profitability of spectrum markets, and its empirical verification. Main thrusts of the research program are: (i) fundamental elements of pricing and interference externalities for efficient and economically viable use of spectrum; (ii) algorithms for spot market use and real-time measurement-based pricing policies; (iii) empirical techniques for testing demand model specification, and formative models of demand-price relationships via experimental studies. This research is interdisciplinary and it is based on identifying incarnations of both novel and classical notions in economics in the specific context of wireless communications and spectrum markets. The research impacts legal and economic policies for the future wireless industry and provides a tool for assessing potentials of the secondary spectrum market.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Assaf Zeevi / assaf@gsb.columbia.edu	Columbia University	no-value
National Science Foundation (NSF)	NETWORK SCIENCE & ENGINEERING	NetSE: Medium: Collaborative Research: Promoting Secondary Spectrum Markets via Profitability-Driven Methods and Algorithms	964652	Wireless telecommunications are undergoing substantial policy reforms in pursuit of better spectral efficiency. A key element in these reforms entails granting full property rights to spectrum license holders, thereby paving the way to secondary spectrum markets. Spectrum markets hold a remarkable potential to increase spectrum utilization by making it available to a larger fraction of public at lower cost. Yet, although a favorable regulatory framework has been in effect in the last few years, liquidity of spectrum markets is inhibited due to uncertainties perceived by spectrum license holders. These uncertainties stem from complex relationships between effects of electromagnetic interference and economic considerations. This research involves a constructive study of viability of spectrum markets by establishing methods and algorithms that render such markets profitable for their participants.The investigators focus on analytical study of profitability of spectrum markets, and its empirical verification. Main thrusts of the research program are: (i) fundamental elements of pricing and interference externalities for efficient and economically viable use of spectrum; (ii) algorithms for spot market use and real-time measurement-based pricing policies; (iii) empirical techniques for testing demand model specification, and formative models of demand-price relationships via experimental studies. This research is interdisciplinary and it is based on identifying incarnations of both novel and classical notions in economics in the specific context of wireless communications and spectrum markets.The research impacts legal and economic policies for the future wireless industry and provides a tool for assessing potentials of the secondary spectrum market.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Murat Alanyali / alanyali@bu.edu	Trustees of Boston University	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Optimal Joint Spectrum Allocation and Scheduling for Cognitive Radio Networks	1523965	Objective:The objective of this project is to significantly improve spectrum utilization through conducting optimal or near-optimal joint spectrum allocation and scheduling in cognitive radio networks. The PIs address critical and practical challenges for spectrum allocation and scheduling in cognitive radio networks, in particular multi-hop cognitive radio networks, such as dynamic traffic demands and pattern, unpredictable primary user activity, wireless interference, and coexistence. A test-bed will be set up to extensively evaluate the designed algorithms and protocols.Intellectual merit:The intellectual merits of this project are: 1) this project develops creative models and algorithms in the framework of restless multi-armed bandit to address the critical challenges for spectrum allocation and scheduling in cognitive radio networks; 2) the proposed methodology is novel in that it intelligently combines the networked multi-armed bandit modeling, graph theory, and communication scheduling theories; 3) this project significantly advances the fundamental knowledge and understanding of cognitive radio networks; and 4) the developed algorithms, models, and protocols significantly improves spectrum utilization in future wireless communication systems.Broader impacts:This project significantly improves the design, deployment, and operation of future wireless communication systems. The proposed algorithms, protocols, and models enable future wireless systems to share spectrum much more efficiently than today`s systems, which will result in significant economical, societal, and public safety impacts. In addition, the proposed research is integrated into education and training for both undergraduate and graduate students. This project also significantly broadens the participation of underrepresented minority groups, e.g., the Native Americans in South Dakota.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiaohua Xu / xiaohuax@mtu.edu	Michigan Technological University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Policies for Cellular Television	1343359	There is growing demand for spectrum that cannot be met without new and more efficient approaches to spectrum use. Professors Jon Peha and Pedro Ferreira of Carnegie Mellon University are examining the technical, economic, and policy issues of cellular television, an unconventional approach to the delivery of over-the-air broadcast television that some believe could free up vast amounts of spectrum for other purposes while fundamentally transforming the television industry. Cellular television includes both single frequency networks (SFNs), and networks using efficient multicast over cellular data services for delivery of broadcast over-the-air television. This project is assessing the potential of cellular television, and its implications for policymakers and regulators. Using models that consider the propagation of wireless signals and realistic demand distributions for video content, researchers are investigating the infrastructure required to efficiently support cellular TV, and the corresponding short and long-term engineering-economics of providing broadcast services with this new approach. They are looking at how these architectures could affect spectrum availability and performance of other wireless systems, such as broadband cellular systems and TV white space devices. Researchers will use data on actual user behavior derived through empirical observation of a cable TV system to develop and assess algorithms that allow even greater spectrum sharing and efficiency by considering the programs that users watch, and how these vary in popularity over time and space. Researchers are also examining a variety of laws and regulations that could affect or be affected by the emergence of cellular TV.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jon Peha / peha@cmu.edu	Carnegie-Mellon University	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Reconfigurable Bandpass Sampling Receivers for Software-Defined Radio Applications	1444086	California-DavisThe last few decades have seen tremendous progress in the development of wireless communication technologies. Wireless technologies are tightly woven into every facet of today`s society and have significantly contributed to the advancement of human civilization. Future wireless systems are expected to have even more functionality, longer battery life, smaller size and more importantly, lower cost. At the same time, a proliferation of vastly different wireless standards, devices, and systems has continued to challenge us to make better use of the already congested radio spectrum. One example is the 4G cellular networks, which have been allocated more than 40 different bands worldwide, causing significant implementation problems for cellular infrastructure providers and mobile handset manufacturers. To overcome these challenges, concepts such as software defined radios and cognitive radios have been proposed. In these systems, both software and hardware (analog and radio frequency front-end circuits) can be reconfigurable adaptively to make the most efficient use of the available spectrum. Although much research has been done in this area, making truly reconfigurable radio front-end circuit remains a challenge. In this research, we propose a band-pass sampling receiver architecture that is reconfigurable in terms of operating frequency, bandwidth, and signal waveforms. The proposed research will have a transformative impact on future wireless communication systems. The highly reconfigurable wireless receivers made available through this research will enable not only highly versatile mobile systems but also a significantly more economical and environmentally friendly telecommunication infrastructure. Such infrastructure and systems will result in more efficient utilization of and public access to the radio spectrum.In contrast to a low-pass sampling receiver, the proposed receiver samples at a much lower frequency with respect to the center frequency of the signal. The analog-to-digital converter (ADC) in the band-pass sampling radio therefore operates at a much lower bandwidth, resulting in a significant reduction in power consumption. The I/Q separation and baseband processing (channel filtering, base-band AGC, etc) can be carried out entirely in the digital domain. This will improve flexibility in terms of adapting to different waveforms and wireless standards. The use of high-Q tunable RF band-pass filters ensures that minimum distortion is introduced by out of band interferers. Compared with existing solutions, the proposed architecture pushes digitization closer to the antenna as possible without having to sacrifice the dynamic range. The proposed receiver has the potential to significantly increase the utilization of the ever more crowded radio frequency spectrum.The outcome of this research will be widely disseminated through academic and trade journals/conferences and the PIs` research group websites. The PIs plan to establish a summer outreach program on wireless technology to promote interests in STEM subjects, engineering in particular for high-school students and teachers. The outcome of the research will also be integrated into the graduate and undergraduate courses the PIs have developed. In addition, the PIs plan to engage	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiaoguang Liu / lxgliu@ucdavis.edu	University of California-Davis	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Spectral Tweets: A Community Paradigm for Spatio-temporal Cognitive Sensing and Access	1247885	Advances in wireless communication, networking, and computation using miniaturized devices have come to a confluence that has greatly improved productivity even in traditionally "low-tech" sectors of the economy. The flip side is that demand for radio spectrum is on track to outpace advances in spectral efficiency. Innovative and pragmatic dynamic spectrum sensing and measurement-based spectrum access modalities are needed to bridge the gap, and support demand and the national economy in the not-so-distant future. It is now widely accepted that effective spectrum sensing must be a collaborative endeavor, involving many sensors taking relatively sparse measurements across space, time, and frequency. The vision and starting point of this project is that today`s smart phones and tablets are ideal platforms for crowdsourcing spectrum sensing, and this is a viable way to create a spectrum sensing web that spans across much of our living and working space. But can all these devices be coordinated to produce local spectrum maps, reveal transmission opportunities, and enable intelligent dynamic access. An appealing idea is to employ Twitter as a service model to multicast short "spectral tweets." Devices will hook up to local communities based on GPS information, and set up "bots" to follow tweets from other devices in the neighborhood.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Nikolaos Sidiropoulos / nikos@ece.umn.edu	University of Minnesota-Twin Cities	no-value

National Science Foundation (NSF)	STTR PHASE II	STTR Phase II: SpiderRadio: Enabling Cognitive Dynamic Spectrum Access Wireless Communications	1353340	This Small Business Technology Transfer (STTR) Phase II project targets a practical dynamic spectrum management (DSM) architecture and a corresponding suite of innovative multi-layer algorithms, development of a DSM enabled multi-radio router and pilot trials for public safety communications. Dynamic spectrum management and access are two important areas of interest to wireless communications researchers, spectrum regulators, and international standardization bodies. DSM plays several important roles, including: (a) improving spectrum efficiency to alleviate the wireless spectrum crunch; (b) providing prioritized, inter-operable communications for first responders during emergencies; and (c) reducing cost for wireless access, and (d) improving the reliability and security of wireless communications. In this project, statistical estimation and decision algorithms are proposed for measurement driven real-time spectrum management at the physical/medium access control (PHY/MAC), network and application layers. Using agile software stack implementation and hardware integration a completely working DSM system will be demonstrated based on these ideas. The broader impact/commercial potential of this project will be a better understanding of DSM related applications, regulatory policies and technical challenges in real-life mobile wireless networks. Impact on state-of-the-art technologies for resilient and interoperable public safety communications, especially during emergencies, is also expected. Findings from the pilot trials will contribute to the body of knowledge in interference mitigation, spectrum sharing, mobile data offloading and supporting reliable mobile multimedia applications. Taken together, these markets constitute a multi-billion dollar opportunity for DSM technologies.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-5	Medium	ongoing	Vijay Kumar / vijaypkumar@yahoo.com	Dynamic Spectrum Limited Liability Company	no-value
National Science Foundation (NSF)	SECURE & TRUSTWORTHY CYBERSPACE	TWC SBE: Medium: Collaborative: Dollars for Hertz: Making Trustworthy Spectrum Sharing Technically and Economically Viable	1314598	The critical role of spectrum as a catalyst for economic growth was highlighted in the 2010 National Broadband Plan (NBP). A challenge for the NBP is realizing optimal spectrum sharing in the presence of interference caused by rogue transmissions from any source, but particularly secondary users who share the spectrum. This complex problem straddles wireless technology, industrial economics, international standards, and regulatory policy.This interdisciplinary, multi-university collaborative project studies the many dimensions of the problem from algorithms to law enforcement. The investigators study (1) ex-ante spectrum rule enforcement mechanisms (i.e., preventive) such as spectrum access control via policy reasoners, (2) ex-post spectrum rule enforcement schemes (i.e., punitive) with policy conformance monitoring that employ cryptographic commitments, (3) ex-post enforcement schemes that can uniquely identify rogue transmitters, and (4) the economic viability of spectrum sharing with different enforcement schemes.The project provides a broad range of education and industry outreach activities in order to rapidly insert research advances into curriculum and university-industry partnerships. Specifically, the investigators will present short courses and tutorials at the annual Virginia Tech Wireless Symposium and Summer School, and widely disseminate findings through NSF Industry & University Collaborative Research Centers (I/UCRC) at the Virginia Polytechnic Institute and State University.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jung-Min Park / jungmin@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	SECURE & TRUSTWORTHY CYBERSPACE	TWC SBE: Medium: Collaborative: Dollars for Hertz: Making Trustworthy Spectrum Sharing Technically and Economically Viable	1314589	The critical role of spectrum as a catalyst for economic growth was highlighted in the 2010 National Broadband Plan (NBP). A challenge for the NBP is realizing optimal spectrum sharing in the presence of interference caused by rogue transmissions from any source, but particularly secondary users who share the spectrum. This complex problem straddles wireless technology, industrial economics, international standards, and regulatory policy. This interdisciplinary, multi-university collaborative project studies the many dimensions of the problem from algorithms to law enforcement. The investigators study (1) ex-ante spectrum rule enforcement mechanisms (i.e., preventive) such as spectrum access control via policy reasoners, (2) ex-post spectrum rule enforcement schemes (i.e., punitive) with policy conformance monitoring that employ cryptographic commitments, (3) ex-post enforcement schemes that can uniquely identify rogue transmitters, and (4) the economic viability of spectrum sharing with different enforcement schemes.The project provides a broad range of education and industry outreach activities in order to rapidly insert research advances into curriculum and university-industry partnerships. Specifically, the investigators will present short courses and tutorials at the annual Virginia Tech Wireless Symposium and Summer School, and widely disseminate findings through NSF Industry & University Collaborative Research Centers (I/UCRC) at the Virginia Polytechnic Institute and State University.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Nelson Sa / nesa@vassar.edu	Vassar College	no-value
National Science Foundation (NSF)	SECURE & TRUSTWORTHY CYBERSPACE	TWC SBE: Medium: Collaborative: Dollars for Hertz: Making Trustworthy Spectrum Sharing Technically and Economically Viable	1314468	The critical role of spectrum as a catalyst for economic growth was highlighted in the 2010 National Broadband Plan (NBP). A challenge for the NBP is realizing optimal spectrum sharing in the presence of interference caused by rogue transmissions from any source, but particularly secondary users who share the spectrum. This complex problem straddles wireless technology, industrial economics, international standards, and regulatory policy. This interdisciplinary, multi-university collaborative project studies the many dimensions of the problem from algorithms to law enforcement. The investigators study (1) ex-ante spectrum rule enforcement mechanisms (i.e., preventive) such as spectrum access control via policy reasoners, (2) ex-post spectrum rule enforcement schemes (i.e., punitive) with policy conformance monitoring that employ cryptographic commitments, (3) ex-post enforcement schemes that can uniquely identify rogue transmitters, and (4) the economic viability of spectrum sharing with different enforcement schemes.The project provides a broad range of education and industry outreach activities in order to rapidly insert research advances into curriculum and university-industry partnerships. Specifically, the investigators will present short courses and tutorials at the annual Virginia Tech Wireless Symposium and Summer School, and widely disseminate findings through NSF Industry & University Collaborative Research Centers (I/UCRC) at the Virginia Polytechnic Institute and State University.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Michelle Connolly / connolly@econ.duke.edu	Duke University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Collaborative Research: Joint Network and Market Design for Content and Spectrum Sharing in Future 5G Networks (JoiNtMaCS)	1456806	Future wireless networks, as represented by the 5G concept and associated set of future standards, are expected to meet a diverse range of new requirements, leverage technological and regulatory advancements, and overcome the spectrum scarcity challenges. However, the success of a new technology is not only determined by its technical strengths but also by an intricate interplay between the economic considerations of the consumers/users, competing service and content providers, and governing/regulating public agencies. This project explores new wireless spectrum and content sharing concepts from both technological and business perspectives for future 5G networks. The overall objective of this project is to investigate and develop fundamental technological and business aspects of new spectrum/content sharing for 5G networks, that potentially could lead to significant technical performance improvements as well as revolutionize future wireless markets and operators business. The intellectual merits of the research can be described around its four research thrusts: (i) new, potentially transformative, business models for future 5G markets, and in particular new business models for mobile operators, (ii) in-network dynamic spectrum and content sharing and pricing mechanisms under various possible future architectures that take into account the new business models and bridge the gap between technological and economic considerations, (iii) collaborative content distribution that could lead to win-win relationships for wireless stakeholders, and (iv) intelligent content caching for improved performance for different network and business scenarios. A unique aspect of the research plan is that it stresses business and economic implications of various architectural choices, with formal models that capture technology performance as well as business/economic considerations. The research leverages the complementary expertise of the investigators to build a cohesive multi-disciplinary international team between the five PIs in the three institutions. It also leverages significant contacts with industry and start-ups to guide the research directions of the project as well as influence future technologies and markets.The broader impacts of this project include (1) the development of course projects that prepare students to understand the market/economic aspects of networking and the future architectural choices regarding content and spectrum sharing, (2) the development of a tutorial on this subject to be offered at summer schools and conferences, (3) K-12 outreach, (4) enhancement of student diversity and increase of number of women and under-represented groups in engineering, (5) technology transfer through collaboration with industry, and (6) development of dual-degree PhD programs.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Atilla Eryilmaz / eryilmaz.2@osu.edu	Ohio State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Measurement-Augmented Spectrum Databases for White Spaces	1443923	The recent wave of radio spectrum deregulation encourages shared use of underutilized spectrum (so-called `white spaces`) where licensed users (primary) co-exist with unlicensed or lightly licensed users (secondary). Federal Communications Commission (FCC) has recommended use of online spectrum databases to ensure that primary communications are protected against interference coming from secondary communications. However, these databases provide notoriously poor estimates of whether a primary communication is active as they are based on empirically driven radio propagation modeling. This accuracy issue ultimately weakens the business case for white space networks, particularly in urban regions where the demand of both primary and secondary use is high.The core intellectual merit of the project is a fundamental rethinking of the current approach to spectrum databases. The project develops a functional system architecture that improves the spectrum database estimates by integrating the current modeling-based approach with distributed spectrum measurement data. The project delivers the key components necessary to realize such measurement-augmented database system: (i) open access spectrum observatory tool backed by models and databases, (ii) a spatial statistics-based approach to integrate modeling and measurement data, (iii) practical methods to collect large-scale, distributed spectrum measurement data to feed into the database. Success in the project will revitalize the interest in white spaces among commercial operators and also will help FCC in future spectrum policy formulation. The open access spectrum observatory tool will provide researchers with significant data sets and models. The project also plans technology transfer and cross-disciplinary educational efforts in wireless systems.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Sumit Roy / roy@ee.washington.edu	University of Washington	no-value

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Enhancing Spectral Access via Directional Spectrum Sensing Employing 3D Cone Filterbanks: Interdisciplinary Algorithms and Prototypes	1247940	NSF Proposal No. 1247940Dr. A. Madanayake (PI)Intellectual MeritThis NSF EARS project proposes a new spectrum sensing architecture combined with joint link scheduling and routing to significantly enhance access to the radio spectrum. Traditional non-directional sensing algorithms do not offer information about the direction of primary and secondary signals, directional information on interference, and information on network node location, and hence significantly limit the potential of cognitive radio technology in terms of spectrum utilization. This project envisions a generalized framework leading to the determination and subsequent utilization of spatio-temporal vacancies in time, frequency, position and direction. New mathematical, hardware, and software algorithms and techniques will be pioneered toward enabling low-complexity digital radios. Multi-dimensional sensed information will drive the innovation of cross-layer link scheduling and routing schemes aimed at boosting the cognitive radio network performance. The proposed innovations will be accomplished through mathematical formulation and modeling of directional sensing algorithms based on multi-dimensional signal processing concepts. The project will also investigate low-complexity fast algorithms for enabling real-time realization leading to new types of (i) digital integrated circuits, (ii) new design techniques for cognitive radios, and (iii) highly agile radio frequency component models all leading to an integrated directional spectrum sensor.Broader ImpactsThis proposal entails tightly integrated research and educational activities at four universities including an HBCU and an undergraduate institution. Spectrum-aware education is pursued as one of the key components of the project because wireless system designers and policy makers alike urgently need this knowledge for pioneering new innovations in this upcoming area of technology. Scientific findings enabled by the proposed research in the cognitive radio networks will serve as a tangible tool-box for engineering transformational technologies such technologies could, in turn, lead to mushrooming of businesses and services that directly benefit from intellectual property (e.g. patents). This research will foster startup firms manufacturing new devices that will potentially improve today`s wireless infrastructure. Distinct and diverse applications in education, energy, environment, healthcare, infrastructure, and public-safety will be studied from a unified perspective, i.e. spectrum scarcity, with the objective of maximizing the untapped economic potential of such scientific findings. The project will involve minorities, underrepresented groups, and women in research, while inspiring spectrum-aware educational concepts through new laboratory modules. Participation of underrepresented groups and women will be encouraged and promoted through mentorship and outreach, aimed at inspiring them to take up graduate studies in engineering and computer science.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Habarakada Madanayake / arjuna@uakron.edu	University of Akron	no-value
National Science Foundation (NSF)	INFORMATION TECHNOLOGY RESEARCH	Collaborative Research: A Multi-Layer Approach Towards Reliable Cognitive Radio Networks	1443434	The development of radio technologies that support efficient and reliable spectrum sharing is an enabler for utilizing the spectrum being made available through the National Broadband Plan. Software defined radios represent a promising technology that supports spectrum sharing as evidenced by the large amount of algorithms and protocols that allow for cognitive radio networks (CRNs) to be deployed. Unfortunately, the economic promise of dynamic spectrum access is easily undermined if cognitive radio users act dishonestly or maliciously, thereby subverting protocols that are founded on the cooperation of users. It is therefore important that mechanisms are developed that ensure the trustworthy operation of CRNs in the presence of potentially malicious or malfunctioning wireless nodes. The objective behind the project`s research activities is to develop technological solutions that ensure that cognitive radios operate in trustworthy manner in spite of potential security threats. As a result of this research effort, it is possible for radio spectrum to be more reliably utilized, thereby ensuring that the economic opportunities associated with the radio spectrum are fairly utilized by everyone. The educational impact of the work comes from its multi-disciplinary foundation, broadening student views of wireless system design, and guiding the next generation of wireless engineer to include security and reliability in the design process. Wireless technologies are an enabler for economic growth in the United States, and cognitive radio networks are an emerging form of wireless system that make spectrum access more available to the broader population. Unfortunately, cognitive radio systems are susceptible to threats that undermine the correct operation of their algorithms and protocols, and thus solutions that support the secure operation of cognitive radio networks are needed. This project ensures the trustworthy operation of cognitive radio networks by: 1) developing algorithms that ensure the correct operation of spectrum sensing procedures upon which spectrum access protocols rely; 2) developing traffic monitoring tools that identify improper communication activity by cognitive radio devices; and 3) developing new forms of interference-resistant communications that ensure that cognitive radio communication continues reliably in the face of interference. The research effort is inter-disciplinary, pulling from statistical tools to network traffic analysis to communications theory to support the secure operation of cognitive radio networks. The algorithms and protocols developed in this project are complemented by a systems prototyping and experimentation effort aimed at guaranteeing that the technologies developed are suitable for deployment in real wireless systems.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Wade Trappe / trappe@winlab.rutgers.edu	Rutgers University New Brunswick	no-value
National Science Foundation (NSF)	INFORMATION TECHNOLOGY RESEARCH	EARS: CogCloud: A Spectrum-Efficient and Green Cloud Platform for Radio-As-A-Service Over a Cognitive Radio Substrate	1443966	Virtualization has been widely used in cloud computing to achieve performance isolation among multiple tenants, and to improve resource utilization and energy efficiency. However, research on wireless virtualization is still in its infancy. Due to the rapid growth in wireless networks in the last two decades and the fact that much of the prime wireless spectrum has already been allocated for specific service providers or services for exclusive use, the scarcity in the spectrum has become a serious concern. On the other hand, recent measurements have shown that the licensed spectrum is severely under-utilized. This has led to significant interest in cognitive radio transmission strategies.The objective of this project is to develop a spectrum-efficient cloud platform, namely CogCloud, to enable Radio-as-a-Service (RaaS) over a cognitive radio substrate, and minimize its energy consumption by designing a two-level closed-loop control framework that leverages cloud-level and BS-level optimization for coarse-grained and fine-grained control respectively over radio resources and wireless users. CogCloud is expected to have the following desirable properties: 1) RaaS for multiple independent Mobile Virtual Network Operators (MVNOs): Radio resources in a cognitive radio substrate are provided as a service to multiple independent MVNOs; 2) performance isolation: Changes in an MVNO (such as the number of wireless users, their traffic load, etc) do not affect the performance of wireless users of other MVNOs; 3) spectrum efficiency: spectrum availability is fully exploited by cognitive radios and efficiently managed by the cloud to support QoS-enabled wireless communications; 4) energy efficiency: the cognitive radio substrate and its radio resources are operated in the most energy-efficient way. To achieve these goals, the project is organized into four cohesive research thrusts: 1) system architecture design and implementation; 2) cloud-level optimization; 3) BS-level optimization for fine-grained control; and 4) validation and performance evaluation.The project is expected to make a significant impact on the advancement of cloud computing, cognitive radio networking and green communications, and advance public understanding of emerging research areas, such as wireless virtualization and cloud-based radio access networks (RANs), via publications, seminars, workshops and international collaborations. Special efforts are made to engage students from under-represented groups.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jian Tang / jtang02@syr.edu	Syracuse University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Crowdsourcing-Based Spectrum Etiquette Enforcement in Dynamic Spectrum Access	1444059	The radio spectrum is becoming an increasingly valuable natural resource nowadays, while it has been shown that much of the spectrum is underutilized in existing licensed bands. To enhance spectrum utilization, dynamic spectrum access (DSA) has been envisioned as a set of promising new spectrum management paradigms, such as spectrum trading/auction and opportunistic spectrum access. While DSA and programmable cognitive radios enable a much higher flexibility of spectrum access, due to the openness of wireless medium, it is also susceptible to various forms of misuse or abuse. For example, unauthorized transmissions without a valid license, or secondary transmissions that intentionally disobey the interference constraints set by the primary users (radios). The misusers will not only gain higher throughput for themselves, but also harm the efficiency of spectrum access operations of normal users (radios). Therefore, enforcing spectrum access rules or etiquettes is crucial to ensuring the ultimate success of the DSA paradigm. This project develops a framework for etiquette and rule enforcing in dynamic spectrum sharing environments. The main idea of the proposed research is to engage community users (radios) to detect misuse, and identify and punish unruly devices. By crowdsourcing the tasks of monitoring neighborhood radio access behaviors to many cognitive radio devices, multiple benefits can be gained: 1) the potentially large number of participating devices can result in much larger detection coverage and accuracy; 2) no pervasive dedicated trusted infrastructure or hardware is needed; and 3) the fact that every device could possibly be a monitoring device leads to a much stronger deterrence to misbehaviors. The interdisciplinary research plan consists of four major components: 1) an optimized crowdsourced passive radio traffic monitoring framework to detect access misbehavior in the vast DSA spectrum; 2) techniques to identify misbehaving cognitive radio devices using physical layer identification, even when the signal waveform can be adaptively modified; 3) techniques for immediate punishment of spectrum misuse through adaptive friendly jamming which exploits multi-functional re-configurable antennas; and 4) incentive mechanism design via auctions to ensure user participation in each task of crowdsourced etiquette enforcement. The success of this project will benefit multiple current and future application domains deploying DSA, especially those that require critical information protection, such as healthcare, transportation, energy, public services, emergency, and military services.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dejun Yang / djyang@mines.edu	Colorado School of Mines	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Intelligent and Cross-Layer Attack and Defense in Spectrum Sharing	1444009	equivalently for wireless bandwidth, keeps an exponential growth. Unfortunately, all our wireless vision needs to be realized through the public radio spectrum, which cannot be further created but has to be efficiently shared among various wireless systems and devices. While significant progress has been made in efficient spectrum access and sharing technologies, their successful deployment towards fulfilling the national broadband plan relies crucially on the development of adequate security mechanisms. Such security mechanisms should be able to protect the welfare of all stakeholders in the spectrum sharing systems, in particular the federal government and military users; meanwhile, they should also be able to address the new challenges brought about by the advanced technologies and new access paradigms that have enabled innovative spectrum sharing. At the current stage, an effective security mechanism for spectrum sharing systems is lacking, which significantly impedes their practical deployment and consequently the realization of the anticipated wireless broadband revolution. This proposal constitutes a solid step towards filling this gap, seeking to obtain a deeper understanding of the emerging attacking strategy and behavior in this new arena, and develop a holistic view and solution to the security of spectrum access and sharing. The expected outcome will be valuable to all players in wireless industry, as well as to all sectors of the national economy that benefit from wireless innovation. The inter-disciplinary nature of the proposed research will naturally help promote cross-disciplinary education and well-rounded training of future IT workforce.The proposed research will be focused on the security aspects of the dynamic spectrum access (DSA) paradigm and cognitive radio (CR) technology, which receive major research interest and also impose foremost research challenges. It is comprised of two thrusts. First, cross-layer attack and defense in CR networks will be addressed. Current research on CR security mainly focuses on attacks and defenses at individual protocol layers, but cross-layer attack naturally fits the CR setting and can lead to unprecedented detrimental effect. In this project, a general class of cross-layer attacks will be investigated. In response to cross-layer attacks, a cross-layer defense framework is subsequently proposed, for which two research tasks will be focused on: advance in individual detection modules for attacks unique to CR functionalities, and metrics-driven cross-layer fusion. In existing studies, the assumed capabilities at CR are rather modest. With the further development of CR technology, wireless devices will grow in reasoning and learning capabilities. Meanwhile, such technology progress can also be exploited by the adversaries to launch more sophisticated malicious attacks. In the second thrust, assuming more intelligence and growing reasoning and learning capabilities for both the CR user and the adversary, the arms race between them will be explored through the stochastic game modeling and multi-agent reinforcement learning (MARL) methodologies. The proposed research will be evaluated through theoretical analysis, numerical and network simulation, prototype implementation, and experimentation on real testbeds.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Huaiyu Dai / huaiyu_dai@ncsu.edu	North Carolina State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	A Modern Evolvable Architecture for Spectrum Regulation	1444078	This project will study how to engineer modern spectrum sharing systems. Wireless spectrum is now recognized as a key national resource that has to be managed appropriately to support innovation and economic growth. Traditional wireless rules were written by a combination of lawyers and engineers in legal English, and read/interpreted by lawyers and engineers. The emerging revolution in wireless regulation is that the core rules will be embedded in automated Spectrum Access Systems (SASs) that are implemented in a combination of hardware, software, and interaction protocols. Moreover, the SASs will support diverse wireless systems ranging from legacy federal users to traditional cellular carriers to emerging new innovative wireless systems. The ideas developed in this project will be disseminated to industry as well as brought into the classroom, including our new Masters of Engineering courses aimed at educating innovative technical leaders. The project will also broaden participation in the technical workforce by mentoring students from underrepresented groups. At its technical core, this project will help create a modern theory of how to make scalable and robust SASs by bringing together a combination of software engineering, mathematical wireless theory, as well as an understanding of the policy tradeoffs that we want to support. The key realization is that making scalable systems is about robustly approximating what we want in a safe manner while supporting flexibility. Ideas from virtualization, software-defined-networking, and cloud computing will play an important role. In addition to getting a handle on what the overall architecture should be of our SAS-enabled wireless future, the project will also take insights and embody them into easy-to-use prototype tools that can be adapted by federal regulators and spectrum managers to explore and navigate the design tradeoffs.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Anant Sahai / sahai@eecs.berkeley.edu	University of California-Berkeley	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Fundamental Limits of Spectrum Sensing	1343210	Objective:Ubiquity of wireless connectivity and its constant growth in application and scale necessitate extremely efficient usage of spectrum as the main commodity in wireless industry. Highly regulated spectrum access policies and growing demands for spectrum access have promoted the notion of accommodating the needs of unlicensed services when the license-holding ones under-utilize the spectrum. The goal of this proposed project is to characterize the fundamental limits of spectrum sensing while recognizing the system-level and physical-level limitations imposed by costs of information acquisition, data traffic demands, and model uncertainties with sound guarantees on agility, responsiveness, and adaptability to the geo-temporal spectral occupancy variations. Intellectual merit:The proposed research lies at the crossroad of wireless communication, sequential statistics, and stochastic optimization. It aims to find the fundamental limits of spectrum sensing and delineates the interplay among the performance guarantees on the decisions about spectral activities, cost of sensing, communication delay tolerance, and the uncertainty level about model dynamics. This leads to novel spectrum sensing procedures in which an optimal balance among can be struck among different aspects based on the operational needs. Broader impact:The research has multiple technological and societal impacts. It furnishes a baseline for assessing the competency of different available spectrum sensing procedures within the same framework, and also provides novel sensing procedures that yield performance levels that match the theoretical fundamental limits. The theoretical models and concepts that are developed in this project have the potential to impact adjacent research domains, especially those involving experimental design and hypothesis testing for high-dimensional data.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Harold Vincent Poor / poor@princeton.edu	Princeton University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Medium: Collaborative Research: Integrated Dynamic Spectrum Access for Throughput, Delay, and Fairness Enhancement	1162296	The central theme of this project is to investigate methodologies and theories to enhance throughput, delay, and fairness of cognitive radio networks via integrated dynamic spectrum access. The research will develop new methods to:1) Extend spectrum sensing beyond just the presence and absence of the primary spectrum users` activities at certain spectrum bands/channels, but also their locations and transmit powers 2) Predict the primary spectrum user`s activity and its interval using game theoretic and statistical learning approaches 3) Perform delay-aware spectrum management with a very comprehensive delay model considering all the factors that may affect the delivery latency of a packet, including the spectrum sensing delay, the transmission delay, the queuing delay, and the spectrum negotiation and scheduling delay 4) Share spectrum in a fair manner considering the tradeoff between fairness and throughput5) Propose a delay-aware fair routing protocol for throughput optimization which jointly considers throughput, delay, and fairness along with dynamic spectrum management.The project`s focus on dynamic spectrum access is of high national interest and can create significant impact on spectral usage policies and related industries in the telecommunication and information technology sectors. The project will also encourage and include under-represented and minority students to be part of this activity, while extending education and outreach plans to undergraduates and K-12 students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Wireless Security; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Bechir Hamdaoui / hamdaoui@eecs.oregonstate.edu	Oregon State University	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS	CCF: Small: Sensing-Based Dynamic Spectrum Access Networks: Modeling, Algorithms, and Experimental Validation	1117365	The FCC released its National Broadband Plan citing the exponentially growing demand for mobile data services and the critical need to better utilize the radio spectrum. Beyond retargeting certain frequency bands, the FCC is considering a paradigm shift of dynamic spectrum access (DSA) technology and policy. DSA allows `secondary` radios to transmit in underutilized `white space` provided they create minimal interference to `primary` radios. Significant white space, as much as 85%, has been observed across time, frequency, and location. However, even in the TV bands, the challenge of inconspicuous utilization of white spaces has not yet been achieved by the two leading solutions, distributed spectrum sensing and centralized emitter databases.This project focuses on a comprehensive approach to DSA based upon spectrum sensing that combines the following in a feedback loop: novel modeling of primary and secondary transmissions; design of optimal spectrum sensing algorithms and secondary access protocols based upon these models; and experimental validation within a testbed of software-defined radios. Preliminary results develop primary Markov models and optimal sequence detection algorithms for spectrum sensing that build upon the well-known Viterbi and forward-backward algorithms and expose fundamental limitations due to primary mismatch for the commonly used energy detector. The connections to trellis- and graph-based algorithms from the channel coding community should introduce a sizable new toolbox to DSA researchers. Secondary access protocols that take advantage of Markov process models for the primary users similarly exhibit improved performance tradeoffs between primary interference and secondary throughput. Collaborators in industry and regulatory bodies will be kept informed of the research results with an aim toward impacting DSA technology and policy development at national and international levels.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	J. Nicholas Laneman / jnl@nd.edu	University of Notre Dame	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	CCSS:Collaborative Research: Stochastic Modeling and Optimization for Cognitive Radio Networks	1128768	The objective of this research is to develop network protocols and optimizationtechniques to efficiently utilize the spectrum white spaces for cognitive radio networks.The proposed approach is based on a novel cognitive radio network (CRN) networkarchitecture under which effective design methodologies can be developed to take betteradvantage of cognitive radio technologies in harvesting and managing unutilizedspectrum for better service provisioning.The PIs will first study the proposed CRN architecture to enable collective spectrumsensing and let the secondary service provider manage the harvested spectrum for betterspectral efficiency while shifting the design complexity from the user side to the systemside. They will then investigate how to split traffic over harvested spectral bands tobalance the risk and reward, how to optimally utilize the spectral resource by jointlydesigning frequency allocation and routing while supporting traffic demands, and how tomaximize the throughput by joint link scheduling and routing. The proposed researchoutcome will lay the solid foundation for practical implementation of CRNs, which could potentially revolutionizes the way how cognitive radios should be more effectively used.The research outcome will significantly advance the state of the art in CRNs, opening anew avenue to designing smart living environments for public safety, disaster rescue,mobile healthcare and online social networks to improve peoples quality of life.Research findings will be disseminated through publications and talks, and in classroomteaching. This project will also actively recruit and train minority students for futureworkforce and mentor junior faculty.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Pan Li / li@ece.msstate.edu	Mississippi State University	no-value

National Science Foundation (NSF)	INFORMATION TECHNOLOGY RESEARCH	Collaborative Research: A Multi-Layer Approach Towards Reliable Cognitive Radio Networks	1443889	The development of radio technologies that support efficient and reliable spectrum sharing is an enabler for utilizing the spectrum being made available through the National Broadband Plan. Software defined radios represent a promising technology that supports spectrum sharing as evidenced by the large amount of algorithms and protocols that allow for cognitive radio networks (CRNs) to be deployed. Unfortunately, the economic promise of dynamic spectrum access is easily undermined if cognitive radio users act dishonestly or maliciously, thereby subverting protocols that are founded on the cooperation of users. It is therefore important that mechanisms are developed that ensure the trustworthy operation of CRNs in the presence of potentially malicious or malfunctioning wireless nodes. The objective behind the project´s research activities is to develop technological solutions that ensure that cognitive radios operate in trustworthy manner in spite of potential security threats. As a result of this research effort, it is possible for radio spectrum to be more reliably utilized, thereby ensuring that the economic opportunities associated with the radio spectrum are fairly utilized by everyone. The educational impact of the work comes from its multi-disciplinary foundation, broadening student views of wireless system design, and guiding the next generation of wireless engineer to include security and reliability in the design process. Wireless technologies are an enabler for economic growth in the United States, and cognitive radio networks are an emerging form of wireless system that make spectrum access more available to the broader population. Unfortunately, cognitive radio systems are susceptible to threats that undermine the correct operation of their algorithms and protocols, and thus solutions that support the secure operation of cognitive radio networks are needed. This project ensures the trustworthy operation of cognitive radio networks by: 1) developing algorithms that ensure the correct operation of spectrum sensing procedures upon which spectrum access protocols rely; 2) developing traffic monitoring tools that identify improper communication activity by cognitive radio devices; and 3) developing new forms of interference-resistant communications that ensure that cognitive radio communication continues reliably in the face of interference. The research effort is inter-disciplinary, pulling from statistical tools to network traffic analysis to communications theory to support the secure operation of cognitive radio networks. The algorithms and protocols developed in this project are complemented by a systems prototyping and experimentation effort aimed at guaranteeing that the technologies developed are suitable for deployment in real wireless systems.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Thomas Hou / thou@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Overcoming Technological Challenges for Spectrum Trading	1443894	The dynamic and uneven wireless network traffic load at different time instants and geographical locations has led to substantial underutilization of some spectrum bands while severely crowding others. This project investigates a number of fundamental and challenging technical issues that arise from broadband spectrum trading for achieving superior technical, economic, and social values of spectrum use. The project is an interdisciplinary research effort across mathematics and wireless network technologies. With respect to wireless technologies, this research project outcomes can significantly improve spectrum efficiency and user experience, while benefiting many real-life needs, such as public safety, telemedicine, and social services. On mathematics, the research effort will lead to the formulation of more interesting problems with real world applications and the discovery of new tools for solving such problems. As a comprehensive investigation to overcome technical challenges that arise from broadband spectrum trading, the project tasks focus on three inter-related key research directions: 1) new graph theory problems, 2) new graph-based resource allocation and utility optimization, and 3) physical layer techniques and utility design. Specifically, the project considers new problems on judicious partitions of graphs and new problems on optimal disjoint paths in weighted graphs using minimum-edge-weight path utility. New solutions and tools developed for such problems can then be applied and generalized for solving various resource allocation and utility optimization problems in broadband spectrum trading. Furthermore, the project addresses new fundamental physical layer issues that arise from spectrum trading. These implementation issues include broadband channel estimation, dynamic pilot placement, interference limited pilot power control, and low complexity broadband spectrum sensing. To establish utility functional curves and to develop means for modeling parametric effects in fine-granularity for more effective broadband spectrum trading, the project applies group-theory-based methodologies to design and carry out detailed tests and analysis in order to fine-tune effective utility functions that incorporate user experience and satisfaction. The research results are also expected to lead to strong social impacts and to provide better technical insights and effective guidelines on governmental regulatory policymaking and technological development regarding broadband spectrum trading for wireless communications.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Geoffrey Ye Li / liye@ece.gatech.edu	Georgia Tech Research Corporation	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Spectrum Efficient Waveform Design with Application to Wireless Networks	1247848	Spectrum efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized. In this project, innovative spectrum efficient waveform designs are studied towards narrower mainlobe and lower sidelobe in spectrum. It has been recognized that judicious use of properly designed waveforms, coupled with advanced receiver strategies, is fundamental to fully utilizing the capacity of the electromagnetic spectrum. This project seeks innovative approaches on nested and co-prime samplers for spectrum efficiency, and subsequently applies it to wireless networks. Different waveforms designs and diversities are studied based on nested and co-prime samplers. Co-prime samplers are used for Multi-Input Multi-Output communication system. In the application to spectrum efficient wireless networks, nodes exchange information over a common wireless channel. Under different traffic scenarios and different constraints, e.g., bandwidth and signal to noise and interference ratio, the amount of data exchanged among these nodes may vary. A key question then is how the throughput capacity of wireless network improves with the new waveform design schemes and different network setup and how it grows with the number of nodes in the network. This project seeks to help reach the nation`s broadband goals and the larger objective of alleviating growing pressure on limited spectrum resources. This project will attract minority and woman students to participate in the project.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Qilian Liang / liang@uta.edu	University of Texas at Arlington	no-value
National Science Foundation (NSF)	INFORMATION TECHNOLOGY RESEARCH	Collaborative Research: Virtualized Wireless Networks and Their Impact on Capacity Markets	1443796	This project develops a new vision for wireless networks, predicated on the creation of service-driven virtual networks constructed from a pool for resources that belong to a variety of stakeholders. The resources include spectrum, physical infrastructure, and control and management support, and the stakeholders include traditional mobile operators, operators of WiFi access networks, businesses and households that support wireless connectivity through small cell deployment, traffic aggregators (such as Mobile Virtual Network Operators [MVNOs]), and regulators. The resulting architecture separates the consumer-facing service provision from the technologies used to construct the network, enabling the disintermediation of current wireless service provision systems. Moving the point at which network access transactions take place up the value chain (or the protocol stack) means that a greater range of service types can be provided to consumers without requiring large up-front capital investments on the part of the (consumer-facing) service providers. This will have profound impact on both industry and society, affecting the way that these networks are designed and built, spectrum and infrastructure resources are managed, and pricing structures for services provided over the network.This project first defines a new architecture that enables the virtualization of a wireless network over a combination of spectrum licensed under different regimes and infrastructure with different ownership. Relying on game theoretic and market models of virtual network construction, new resource management mechanisms are designed to select the appropriate set of resources to build a virtual wireless network with given coverage and capacity requirements. Combinatorial auctions for multiple objects are practical mechanisms for the dynamic allocation and aggregation of resources for such a virtualized wireless network. In analyzing the impact of the proposed architecture on spectrum markets, a key question is whether the incorporation of a virtualized spectrum commodity influences the viability of these markets (as measured by the liquidity outcome), and how this compares to previous scenarios in which the traded commodity was the physical spectrum resource or `naked spectrum;. Finally, this project explores how markets in virtual wireless capacity would work when implemented in current wireless networks, in the context of LTE-Advanced and expected 5G developments.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Martin Weiss / mbw@pitt.edu	University of Pittsburgh	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: Collaborative Proposal: Global RF Spectrum Opportunity Assessment	1265351	In order to apply emerging technologies (e.g. dynamic spectrum sharing) to address the wireless spectrum shortage problem, there is a critical need to understand global RF spectrum usage trends. To accomplish this, a three-pronged approach is being pursued: 1) deployment of geographically dispersed, temporally coordinated RF spectrum observatories in multiple U.S. locations, and through international collaboration, in Finland. The spectrum observatories use a common platform generating a single RF spectrum measurement dataset. 2) Development of empirically validated, statistical models of spectrum utilization for different wireless application types based on this dataset. 3) Use of "big data" analytical techniques to mine the dataset to discover temporal and spectral correlations not obvious using traditional approaches. As the models and relationships are refined, they will enable temporal and spectral occupancy predictions to support spectrum sharing for various circumstances and wireless applications.The generation of a high-resolution, multi-location, multi-national spectrum usage dataset using a common, consistent measurement and storage approach is unique and allows direct, unambiguous comparisons of spectrum usage across geographies and demographics. The statistical models of spectrum utilization and the identified similarities and differences between regions and wireless services are unique and inform dynamic spectrum sharing research and related regulatory action with "real-world" data. Importantly, this is the first time that "big data" analytic approaches are being systematically applied to RF utilization data providing new insights motivating novel dynamic spectrum sharing approaches and improved spectrum efficiency.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dennis Roberson / dennis.roberson@iit.edu	Illinois Institute of Technology	no-value

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Enhancing Spectral Access via Directional Spectrum Sensing Employing 3D Cone Filterbanks: Interdisciplinary Algorithms and Prototypes	1418013	NSF Proposal No. 1247853Xin, Chunsheng Intellectual MeritThis NSF EARS project proposes a new spectrum sensing architecture combined with joint link scheduling and routing to significantly enhance access to the radio spectrum. Traditional non-directional sensing algorithms do not offer information about the direction of primary and secondary signals, directional information on interference, and information on network node location, and hence significantly limit the potential of cognitive radio technology in terms of spectrum utilization. This project envisions a generalized framework leading to the determination and subsequent utilization of spatio-temporal vacancies in time, frequency, position and direction. New mathematical, hardware, and software algorithms and techniques will be pioneered toward enabling low-complexity digital radios. Multi-dimensional sensed information will drive the innovation of cross-layer link scheduling and routing schemes aimed at boosting the cognitive radio network performance. The proposed innovations will be accomplished through mathematical formulation and modeling of directional sensing algorithms based on multi-dimensional signal processing concepts. The project will also investigate low-complexity fast algorithms for enabling real-time realization leading to new types of (i) digital integrated circuits, (ii) new design techniques for cognitive radios, and (iii) highly agile radio frequency component models all leading to an integrated directional spectrum sensor.Broader ImpactsThis proposal entails tightly integrated research and educational activities at four universities including an HBCU and an undergraduate institution. Spectrum-aware education is pursued as one of the key components of the project because wireless system designers and policy makers alike urgently need this knowledge for pioneering new innovations in this upcoming area of technology. Scientific findings enabled by the proposed research in the cognitive radio networks will serve as a tangible tool-box for engineering transformational technologies such technologies could, in turn, lead to mushrooming of businesses and services that directly benefit from intellectual property (e.g. patents). This research will foster startup firms manufacturing new devices that will potentially improve today`s wireless infrastructure. Distinct and diverse applications in education, energy, environment, healthcare, infrastructure, and public-safety will be studied from a unified perspective, i.e. spectrum scarcity, with the objective of maximizing the untapped economic potential of such scientific findings. The project will involve minorities, underrepresented groups, and women in research, while inspiring spectrum-aware educational concepts through new laboratory modules. Participation of underrepresented groups and women will be encouraged and promoted through mentorship and outreach, aimed at inspiring them to take up graduate studies in engineering and computer science.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Chunsheng Xin / cxin@odu.edu	Old Dominion University Research Foundation	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative: Comprehensive Network State Inference for Robust and Policy-Cognizant Spectrum Access	1343256	Objective: The objective of this project is a compendious cognition infrastructure enabling robust, cross-layer protocol designs under governance policy constraints, so as to maximize the cognitive radio (CR) network performance and end-user satisfaction, notwithstanding the challenges associated with dynamic and opportunistic radio-spectrum access, as well as the incomplete, corrupt and sporadic data reflecting the cost and restrictions in acquiring network state measurements.Intellectual merit: The intellectual merit is to transform state-of-the-art learning tools for comprehensive and resource-aware cognition of the "global" network state (which includes interference, any-to-any link gains, band occupancies, queue lengths, and path delays), jointly with stochastic, state-cognizant optimization of CR networks with policy implications, to pioneer transformative adaptation approaches to routing, medium-access, and physical-layer designs of wireless CR networks endowed with the much needed robustness to state uncertainty.Broader impacts: The broader impacts include tangible implications to mobile ad hoc, smart grid, intelligent transportation networks, as well as medical telemetry, geo-monitoring, and surveillance systems. Advances in the foundations of kernel-based learning, kernel matrix completion, inference on graphs, and sampling-based scenario optimization, will benefit a gamut of research areas including social analytics, bio-informatics, medical imaging, and surveillance using sensor networks. Policy research integrated with technical components will encourage community embracing of novel CR technologies and open up investment and business opportunities yielding greater economic impact.Undergraduate Design Projects and Botball Competition, facilitated by the proposed Cognitive Spectrum Operations Testbed, will also benefit student training with hands-on experience in state-of-the-art learning, wireless systems on mobile robots, and network optimization subjects.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Brett Walkenhorst / brett.walkenhorst@gtri.gatech.edu	Georgia Tech Applied Research Corporation	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative: Comprehensive Network State Inference for Robust and Policy-Cognizant Spectrum Access	1343248	Objective: The objective of this project is a compendious cognition infrastructure enabling robust, cross-layer protocol designs under governance policy constraints, so as to maximize the cognitive radio (CR) network performance and end-user satisfaction, notwithstanding the challenges associated with dynamic and opportunistic radio-spectrum access, as well as the incomplete, corrupt and sporadic data reflecting the cost and restrictions in acquiring network state measurements.Intellectual merit: The intellectual merit is to transform state-of-the-art learning tools for comprehensive and resource-aware cognition of the "global" network state (which includes interference, any-to-any link gains, band occupancies, queue lengths, and path delays), jointly with stochastic, state-cognizant optimization of CR networks with policy implications, to pioneer transformative adaptation approaches to routing, medium-access, and physical-layer designs of wireless CR networks endowed with the much needed robustness to state uncertainty.Broader impacts: The broader impacts include tangible implications to mobile ad hoc, smart grid, intelligent transportation networks, as well as medical telemetry, geo-monitoring, and surveillance systems. Advances in the foundations of kernel-based learning, kernel matrix completion, inference on graphs, and sampling-based scenario optimization, will benefit a gamut of research areas including social analytics, bio-informatics, medical imaging, and surveillance using sensor networks. Policy research integrated with technical components will encourage community embracing of novel CR technologies and open up investment and business opportunities yielding greater economic impact.Undergraduate Design Projects and Botball Competition, facilitated by the proposed Cognitive Spectrum Operations Testbed, will also benefit student training with hands-on experience in state-of-the-art learning, wireless systems on mobile robots, and network optimization subjects.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Georgios Giannakis / georgios@umn.edu	University of Minnesota-Twin Cities	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS); GRANT OPP FOR ACAD LIA W/INDUS; COMMS, CIRCUITS & SENS SYS	EARS: GOALI: Low-Power, Multi-Tiered, Shared-Spectrum Access Terminals using Compressive Scanning and On-Top-of-CMOS BAW Filter Banks	1343282	Cognitive mobile devices that sense and exploit available spectral resources have the potential for very broad societal impact, from business and government to the education and non-profit sectors.The proposed research leverages the interdisciplinary nature of the team and the industry-academic partnership towards realizing the cognitive radio vision to enhance access to the radio spectrum. The industrial partnership will specifically provide the essential system and application context to facilitate faster translation of the research into practice. Three graduate students will be trained in this highly cross-disciplinary area. The PIs will further develop Research Experience for Undergraduates (REU) projects as part of the program to expand undergraduate participation. As wireless systems continue to proliferate and the demand for instantaneous, over-the-air access to large volumes of content continues to grow, radio spectrum (especially in the 500MHz-6GHz range) is an increasingly scarce resource. Most of the useful spectrum has been licensed. A few license-free bands are crowded to capacity, while many licensed bands are underutilized. Cognitive radios propose to scan and opportunistically share spectrum. They have the potential for expanding the available spectrum through opportunistic use, if conflict can be sensed and avoided by continuously monitoring higher priority traffic. This requires agile, low-power solutions for spectrum scanning and bandwidth aggregation receivers. This project studies these challenges in the context of a multi-tiered shared-spectrum access communication system. It focuses on tier-3 cognitive radio terminals that scan and dynamically use radio spectrum that is underutilized by higher tier users. It proposes novel bandpass compressed spectrum scanner architectures and recovery algorithms, that promise to substantially reduce power consumption and scan time compared to existing solutions. To enable interference-robust, reconfigurable receiver architectures with noncontiguous bandwidth aggregation, reconfigurable arrays of bulk acoustic wave devices fabricated on top of CMOS will be investigated. The industrial partnership is key to provide system and application knowledge, as well as system integration expertise to test and evaluate the innovations. The cross-disciplinary research questions are important for broadband RF systems in general, and the proposed solutions will have impact beyond multi-tiered cognitive radio systems.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Peter Kinget / kinget@ee.columbia.edu	Columbia University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Spectrum Efficiency Analysis using Multisite Spectrum Observatory Network	1248000	The need for increased RF spectrum access for wireless broadband applications continues within the commercial and government user domains. Since the usable RF spectrum is fully allocated, the only options available are to: a) increase the efficiency of current spectrum uses; b) re-purpose spectrum to higher value uses; or c) institute spectrum sharing. While the FCC has a database of authorized, licensed spectrum users, the ultimate success of any of these options depends on knowledge of actual RF spectrum utilization in time, frequency, and space. While snap-shot surveys of RF utilization have been performed, and long-term observations of RF use have been made at single locations, the impact of incorporating the spatial dimension to both improve the accuracy of these estimates and model medium-scale geographic variations has not been fully explored. Given the need to obtain mappings and models of the temporal and spatial variations of the RF environment with sufficiently high fidelity to estimate, characterize, and model spectrum utilization, the resulting research objectives are: 1) create a sufficiently low-cost and scalable approach to generating and accessing the necessary high quality RF dataset; 2) provide new methods for analyzing, modeling, and visualizing the resulting large, multi-dimensional information base; and 3) model spectrum activity to test the feasibility of spectrum sharing in candidate bands in order to facilitate decision making and innovation in spectrum repurposing and sharing.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dennis Roberson / dennis.roberson@iit.edu	Illinois Institute of Technology	no-value

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Economically-Robust and Secure Auctions for Heterogeneous Secondary Spectrum Market	1407986	both the primary and secondary users in a spectrum market. The major design objective of these auctions focuses on truthfulness (economic-robustness) to prevent market manipulation, i.e., to ensure that buyers and sellers cannot obtain more utility by cheating on bid prices. This objective is typically realized by adapting classic auctions, such as Vickrey-Clarke-Groves (VCG), McAfee, and Myerson`s Optimal Mechanism (MOM), for spectrum reuse in homogeneous spectrum markets. There are unaddressed challenges with this approach in a heterogeneous spectrum market, which is characterized by bid diversity in both the spatial and temporal domains, i.e., buyers and sellers can bid different units of the spectrum bands with different channel properties at different locations and in different times. VCG, MOM, and McAfee all lose their truthfulness when bid diversity is considered for heterogeneous spectrum markets. This phenomenon has been largely overlooked by the current research. Additional challenges are that bidders and the auctioneer may have an incentive to collude for profit maximization, and that the disclosure of the bids to the auctioneer may reveal private information of the bidders, resulting in economic espionage and other security concerns. The recent research on secure auctions is sporadic, missing an in-depth study to address the unique challenges of secure auctions in heterogeneous spectrum markets. This project aims to address the challenges mentioned above. The proposed research may foster the development of novel techniques and methodologies toward secure, robust, and efficient spectrum access.The desired properties of an auction in a heterogeneous secondary spectrum market will incent buyers and sellers to use spectrum efficiently. These include: i) truthfulness, collusion-resistance, cheating prevention, and privacy preservation to encourage users to join the market and discourage them from predicting others` bids for market manipulation; ii) high revenues for sellers/buyers and the auctioneer to incent them to participate; and iii) high spectrum utilization. The objective of this project is to design economically-robust and secure auctions that transform current auction models to achieve these properties for heterogeneous secondary spectrum markets. The proposed research can be summarized by the following activities: the design of economically-robust auctions based on virtual valuations for fairness, efficiency, and optimality to prevent market manipulation when addressing the challenges brought on by bid diversity and spectrum reuse; the design of collusion-resistant auctions based on the concept of virtual bidders and novel pricing functions when bidder-bidder and bidder-auctioneer collusions exist; and the design of privacy-preserving auctions based on Homomorphic encryption, secure multi-party computation, and secret-sharing, under the assumption that the auctioneer is not trust-worthy. The expected results of this project include novel auction mechanisms, algorithms, and theories. The research findings will be disseminated through high-quality publications, presentations in focused workshops, and conferences. The project outcomes will provide guidance to industry and may be adopted for market-based short-term spectrum allocations.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiuzhen Cheng / cheng@gwu.edu	George Washington University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	NeTS: Medium: Collaborative Research: Integrated Dynamic Spectrum Access for Throughput, Delay, and Fairness Enhancement	1162159	The central theme of this project is to investigate methodologies and theories to enhance throughput, delay, and fairness of cognitive radio networks via integrated dynamic spectrum access. The research will develop new methods to:1) Extend spectrum sensing beyond just the presence and absence of the primary spectrum users` activities at certain spectrum bands/channels, but also their locations and transmit powers 2) Predict the primary spectrum user`s activity and its interval using game theoretic and statistical learning approaches 3) Perform delay-aware spectrum management with a very comprehensive delay model considering all the factors that may affect the delivery latency of a packet, including the spectrum sensing delay, the transmission delay, the queuing delay, and the spectrum negotiation and scheduling delay4) Share spectrum in a fair manner considering the tradeoff between fairness and throughput5) Propose a delay-aware fair routing protocol for throughput optimization which jointly considers throughput, delay, and fairness along with dynamic spectrum management.The project`s focus on dynamic spectrum access is of high national interest and can create significant impact on spectral usage policies and related industries in the telecommunication and information technology sectors. The project will also encourage and include under-represented and minority students to be part of this activity, while extending education and outreach plans to undergraduates and K-12 students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Taieb Znati / znati@cs.pitt.edu	University of Pittsburgh	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Social Tie Aware Spectrum Sharing: Physical-Social Game and Cloud-Based Cooperative Sensing	1422277	To meet the rapidly growing demand of wireless applications, there is an urgent need to develop innovative spectrum sharing techniques that enable cognitive radio devices to dynamically sense the communication environment and adapt their transmission schemes. One key observation is that wireless devices are carried by human beings and people typically behave with rationality in social interactions. Indeed, social trust is built upon human relationship, and altruistic behaviors are often observed in many human activities. With this insight, in this project a cognitive radio network is viewed as an overlay/underlay system where a "virtual social network" (i.e., the social tie structure among users) overlays the physical communication network. Then, the social tie structure is leveraged to facilitate cooperative sensing and spectrum sharing, and such cooperation has potential to achieve substantial gains in spectral efficiency. This project serves as an excellent example for exploring innovative research on the interplay among engineering, social sciences, and economics for improving spectrum efficiency. The findings on exploiting social tie structure for spectrum sharing contribute to advancing the state-of-the-art of cognitive radio network design, and have great potential to open a new avenue for enhancing spectrum sharing and hence benefit the society at large.With an innovative agenda, this project focuses on developing social tie aware spectrum sharing mechanisms, while taking into account both physical coupling and social coupling among cognitive radio users. Specially, under this common theme, this project is organized into two well coordinated thrusts: 1) Thrust I focuses on database assisted spectrum access when primary user activities change relatively slowly; and social-aware channel allocation among secondary users is cast in a manner in which each user carries out channel selection to maximize its social group utility, defined as the weighted sum of its own utility and the utilities of other users having social ties with it. Then, social group utility maximization (SGUM) for the physical-social game is investigated and distributed algorithms are devised to achieve social tie aware Nash equilibrium. 2) Thrust II is centered around devising a social-aware spectrum sensing framework when primary user activities change fast, in which a cloud-based platform is employed to incentivize secondary users to participate in sensing tasks by leveraging social trust among them. Intuitively, by leveraging the wisdom of crowds, cooperative sensing enables secondary users to overcome the challenges due to incomplete information and limited capability of individual users, leading to more accurate detection of spectrum opportunities. Besides extensive simulation studies, the devised techniques will be evaluated in a realistic wireless network testbed. Overall, this project aims to develop a social group utility maximization framework to capture complex social structure among mobile users, consisting of diverse positive social ties (e.g., between friends and allies) and negative social ties (due to malicious behavior).	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Junshan Zhang / junshan.zhang@asu.edu	Arizona State University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	NeTS: Small: Spectrum Sensing, Allocation, and Charging for Cognitive Radio Networks	1320453	The objective of this project is to conduct a holistic protocol design for large-scale cognitive radio networks. To support a large number of wireless devices as secondary users that able to dynamically access available channels, it is necessary to design decentralized architecture and solutions for cognitive radio networks. Based on the decentralized architecture, this project addresses important problems in spectrum sensing, spectrum allocation and pricing, and spectrum usage monitoring and charging in dynamic spectrum access networks. More specifically, this project focuses on three research thrusts: (1) A robust collaborative spectrum sensing algorithm to tolerate arbitrary false data reports from adversaries, (2) An efficient spectrum allocation and pricing scheme for a large number of secondary users to share spectrum resources based on localized and approximation algorithms, and (3) A scheme for monitoring and charging the spectrum usage of secondary users without sacrificing secondary users` privacy. The proposed architecture and the solutions to the relevant problems have the potential to significantly advance the state-of-the-art of cognitive radio networking research, in particular, in improving the efficiency of spectrum sharing. The technology developed in this project will facilitate a wide variety of scientific and engineering applications and result in a significant impact on the society. The project will perform a wide range of education and outreach activities, including integration of research findings into courses and curricula, and involving under-represented students in research projects. Research results will be broadly disseminated through conference and journal publications, research talks, and via the Internet.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Qun Li / liqun@cs.wm.edu	College of William and Mary	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small:Spatio-Temporal Spectrum Sensing	1117600	This project aims to develop a comprehensive approach for characterization of RF environment in terms of spatial and temporal features including: i) the number of active transmitters, ii) their power, direction of arrival and location, and iii) modulation class. Spatio-temporal spectrum sensing requires novel multi-dimensional parameter estimation algorithms as opposed to conventional spectrum sensing that uses hypothesis testing based detection algorithms. In this work, the Bayesian estimation approach using angle-of-arrival measurements is applied to create the probabilistic map of the transmitter presence in a given region taking into account measurement noise and uncertainties. The tools from random matrix theory are applied to perform joint detection and parameter estimation, and analytically derive performance bounds. The methods for modulation classification are based on goodness-of-fit statistical tests with reduced sampling complexity, and provide the unified classification framework for a wide range of modulation classes. The results of this research will impact the design of novel medium access and routing protocols that manage the interference through awareness of the location and link quality of other transmitters in the region. The developed technologies could potentially apply for monitoring of RF transmissions within wireless infrastructure, and for the defense and national security applications.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Danijela Cabric / danijela@ee.ucla.edu	University of California-Los Angeles	no-value
National Science Foundation (NSF)	TRUSTWORTHY COMPUTING	TC: Small: Security Provisioning for Cognitive Radio Networks	1252643	The emerging wireless paradigm of dynamic spectrum access via cognitive radio technology has been increasingly recognized for its great potential in drastically enhancing spectrum utilization efficiency. The basic requirements of cognitive radio networks (CRNs) are to protect licensed primary users and provide reliable dynamic spectrum access to secondary cognitive users, which give rise to a new fundamental issue in spectrum access related security. This project develops a comprehensive security system that lays down a secure backbone for CRNs that coexist with primary networks under various network architectures and spectrum coexistence paradigms. The developed security measures are coherently embedded into the entire CRN, from the very beginning of the spectrum sensing stage to the dynamic spectrum access process until the data communication stage. Targeting three main sources of CRN security vulnerability, our research objectives and thrusts include: 1) systematically identify the unique primary user related attacks in CRNs and develop a suite of attack detection and defense mechanisms; 2) develop secure and robust strategies of dynamic spectrum access for benign cognitive users; 3) design confidential and anonymous mechanisms to solve the distinct challenges in privacy protection, taking full advantage of the unprecedented flexibility that CRNs offer in dynamic spectrum utilization. This project lays out the foundation for the development of enabling security technologies for the new paradigm of dynamic spectrum sharing, which in turn can substantially improve the spectrum utilization efficiency of wireless networks, offering a multitude of new cognitive radio devices and wireless services with secure and reliable spectrum access.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Chunxiao Chigan / Tricia_Chigan@uml.edu	University of Massachusetts Lowell	no-value

National Science Foundation (NSF)	COMM & INFORMATION THEORY	CIF: Small: Collaborative Research: Cooperative Sensing and Communications for Cognitive Radio Networks	1336123	The emerging cognitive radio network (CRN) paradigm has a great potential to solve what seems to be a spectrum crisis, by allowing the unlicensed or secondary users (SUs) to opportunistically and dynamically utilize the white spaces within the licensed bands, without causing harmful interference to the licensed or primary users (PUs). This research investigates two essential components of CRNs: spectrum sensing and spectrum access and sharing. More specifically, the PIs study: 1) novel integrated signal processing and communication designs for data fusion in cooperative spectrum sensing, and 2) novel cooperative spectrum sharing and communication schemes that benefit both PUs and SUs.In contrast to the existing data fusion rules that assume error-free communication channels with capacity constraints, this research involves novel integrated designs that consider the deteriorating effects of communication channels between the radios and the fusion point and therefore are robust against channel errors and provide higher detection reliability. The robustness can further be improved by employing distributed space-time coding and harvesting diversity gain. Novel cooperative communication schemes are developed based on modern coding and enable SUs to relay PUs' rateless coded data packets in a fashion that is completely seamless to PUs. The schemes have mutual benefits for both PUs and SUs and differ from the existing ones in which SUs are silent during PUs' transmission. Broader impacts include (1) bonding the research groups from OSU and the UR and enhancing research and education through this partnership, (2) making a significant impact on the theory and practice of CRNs, (3) increasing the participation of under-represented students in PIs' research groups and promoting engineering among high school students, and (4) integrating research and education through development of new courses.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Azadeh Vosoughi / azadeh@ucf.edu	University of Central Florida	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Wideband Silicon-Based Receivers for RF/Microwave Spectrum Sensing	1230274	AbstractIntellectual MeritCognitive radio systems offer the opportunity to use dynamic spectrum management techniques to adapt to immediate local spectrum availability over huge swaths of spectrum when the primary users are not present. The objective of this research is to develop a unique wideband silicon-based spectrum sensing receiver for cognitive radios. With respect to intellectual merit, the proposed receiver enables spectrum sensing over multi-octave radio/microwave frequency range without the need for any complex tunable image-reject filter and a broadband frequency synthesizer to drastically reduce the power consumption and the complexity of the receiver. The realization of this receiver is possible by two-step down conversion and employing a narrowband frequency synthesizer, an integer frequency divider and switchable harmonic mixers in the front-end architecture. Given the wide variations in signal bandwidth and formats that must be reliably sensed, a type of programmable energy detection method is employed to further relax challenging requirements for cognitive radio front-ends.Broader ImpactWith respect to broader impact, simple implementation, miniaturization and low power consumption of wideband spectrum sensing receivers are essential features for cognitive radios operating in a battery-powered environment for applications including man-portable military radios, avionics, electronic warfare, eavesdropping, surveillance and commercial wireless mobile systems. The results of the project will advance microwave integrated circuits and wireless communication fields. The proposed project allows talented students to train in microwave integrated circuits and wireless communications through a variety of research, and educational/outreach activities. Educational opportunities for under-represented groups will be explored by (1) attending annual Electrical and Computer Engineering, Unplugged program and Society of Women Engineers summer camp to inspire high school and women students to join the engineering program, and (2) collaborating with Enrichment Experience Engineering program at Texas A&M University to provide workshops for minority high school teachers in engineering.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kamran Entesari / kentesar@ece.tamu.edu	Texas A&M Engineering Experiment Station	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Achieving Efficient Spectrum Usage in Active and Passive Sensing Through a Market-Based Approach	1247840	Opportunities for time-sharing spectrum use could allow for significant improvements in spectrum efficiency. Two large users of spectrum bandwidth -- radar and remote sensing -- are also two applications that might best be able to allow time sharing. For example, radar usually sweeps in direction, which may allow use of the radar frequency in directions not being scanned at any one instant. Remote sensing applications, which often use Dicke switching to switch between the observed source and an internal calibration source, could also allow time sharing during the calibration cycle. The research will investigate the incorporation of a time dimension to spectral allocations, and will also investigate relevant market assessments of the value of spectrum made available through temporal sharing.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Joel Johnson / johnson.1374@osu.edu	Ohio State University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: Collaborative Research: Global RF Spectrum Opportunity Assessment	1265266	In order to apply emerging technologies (e.g. dynamic spectrum sharing) to address the wireless spectrum shortage problem, there is a critical need to understand global RF spectrum usage trends. To accomplish this, a three-pronged approach is being pursued: 1) deployment of geographically dispersed, temporally coordinated RF spectrum observatories in multiple U.S. locations, and through international collaboration, in Finland. The spectrum observatories use a common platform generating a single RF spectrum measurement dataset. 2) Development of empirically validated, statistical models of spectrum utilization for different wireless application types based on this dataset. 3) Use of "big data" analytical techniques to mine the dataset to discover temporal and spectral correlations not obvious using traditional approaches. As the models and relationships are refined, they will enable temporal and spectral occupancy predictions to support spectrum sharing for various circumstances and wireless applications.The generation of a high-resolution, multi-location, multi-national spectrum usage dataset using a common, consistent measurement and storage approach is unique and allows direct, unambiguous comparisons of spectrum usage across geographies and demographics. The statistical models of spectrum utilization and the identified similarities and differences between regions and wireless services are unique and inform dynamic spectrum sharing research and related regulatory action with "real-world" data. Importantly, this is the first time that "big data" analytic approaches are being systematically applied to for utilization data providing new insights motivating novel dynamic spectrum sharing approaches and improved spectrum efficiency.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Allen MacKenzie / mackenab@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	CAREER: SpecMax: Spectrum Trading and Harvesting Designs for Multi-Hop Communications in Cognitive Radio Networks	1350230	Cognitive radio (CR) is a revolutionary paradigm that releases spectrum and enables secondary users (SUs) to opportunistically access under-utilized spectrum. Due to the great economic value of spectrum, CR technology has also promoted many spectrum-trading designs in cognitive radio networks (CRNs). Unfortunately, most existing designs rely on the premise that the SUs hand-held devices have powerful CR capability, which may not be easily embedded into lightweight small-sized radios of SUs˙ devices. Besides, existing designs mainly focus on per-user based spectrum trading for single-hop communications, and lack deep understanding of multi-hop end-to-end service provision. Moreover, the prevalent idea of choosing the best band makes secondary services vulnerable to interruption due to the returns of primary users. Finally, to facilitate spectrum trading, more accurate information of spectrum availability should be provided. Motivated by these facts, this project aims to construct a framework to investigate the spectrum trading in multi-hop CRNs, which includes the study of (1) designing a novel CRN architecture to facilitate the accessing of SUs without CR capability, (2) extending spectrum trading for multi-hop CR communications, (3) harvesting spectrum under spectrum uncertainty, and (4) constructing a fine-grained mobile spectrum map. The results of this project can advance the state of the art in spectrum trading designs and enrich the scientific knowledge of network designs and network economics. The project is thus crucial to the success of CRNs, which can provide great opportunities for job creation, greater productivity, and economic growth. This project also involves research publications/talks, curriculum development, minority student recruitment, training and mentoring, and outreach to K-12 students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Miao Pan / panm@tsu.edu	Texas Southern University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	CAREER: Towards Seamless Mobility in Cognitive Radio Wireless Networks	953644	The cognitive radio technology is a promising technology to overcome the imbalance between the increase in the spectrum access demand and the inefficiency in the spectrum usage by allowing dynamic spectrum access. Seamless mobility is considered as a critical component to ensure the success of cognitive radio network (CRN) deployment, but unfortunately, is under-explored in the literature. The research objective of this project is to develop new policies and algorithms for providing seamless mobility support in cognitive radio wireless networks (CRNs). The approach involves identifying the new issues in the mobility support caused by the changing spectrum environment in CRNs, exploiting the varying spectrum opportunities in time and space domains, proactively utilizing the spectrum opportunities for mobility preparations, and optimizing the performance via spectrum-adaptive mobility management schemes.This project will provide innovative mobility support techniques to numerous applications of the CRN technology. It will also have significant impacts on research in emerging technologies with high mobility scenarios, such as vehicular networks, and opportunistic interconnections of heterogeneous wireless networks. This project provides an excellent opportunity for graduate and undergraduate research students to gain valuable educational training and research experiences. The research results will be presented at IEEE journals and international conferences. In addition, the PI plans to organize a workshop and a journal special issue to enhance the understanding and promote research discussions on seamless mobility in wireless networks.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jiang (Linda) Xie / Linda.Xie@uncc.edu	University of North Carolina at Charlotte	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Cognitive and Efficient Spectrum Access in Autonomous Wireless Networks	1247955	The objective of this project is to enable more efficient and reliable operation of autonomous femtocell networks with agile spectrum access, autonomous interference control, as well as intelligent network self-organization and self-optimization. This project falls into four interacted thrusts: 1) Incorporate cognition into the femtocell networks to cognitively reuse the available spectrum sensed; 2) Develop distributed, dynamic and cooperative interference management schemes exploiting antenna techniques and based on sensed environmental conditions; 3) Investigate the scenarios and schemes that femtocells can be exploited to facilitate macrocell transmissions, and the potential gains in capacity, coverage and reliability; 4) Incorporate interference cancellation for data multicast, and develop techniques to support multiuser video streaming. The project also develops a testbed with open source programmable wireless platforms, for prototyping and evaluating the effectiveness of various techniques developed. The proposed research has the potential to significantly increase the capacity and resilience of existing and future wireless networks. The agility and resilience of the system will also make it instrumental to support communications and applications that are important for national security and economy. The PIs will facilitate technology transfer through their industrial partners and industry affiliate programs. Complementary to the research agenda, the project will carry out a broad range of education and outreach activities, including integration of research findings into the courses, promoting underrepresented and undergraduate populations, and engaging with the K-12 schools to raise the level of student interests in pursuing advanced education and career in the areas of engineering and mathematics.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Shiwen Mao / smao@auburn.edu	Auburn University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Enhancing Spectral Access via Directional Spectrum Sensing Employing 3D Cone Filterbanks: Interdisciplinary Algorithms and Prototypes	1247935	NSF Proposal No. 1247935Vemuru, Srinivasa R. Intellectual MeritThis NSF EARS project proposes a new spectrum sensing architecture combined with joint link scheduling and routing to significantly enhance access to the radio spectrum. Traditional non-directional sensing algorithms do not offer information about the direction of primary and secondary signals, directional information on interference, and information on network node location, and hence significantly limit the potential of cognitive radio technology in terms of spectrum utilization. This project envisions a generalized framework leading to the determination and subsequent utilization of spatio-temporal vacancies in time, frequency, position and direction. New mathematical, hardware, and software algorithms and techniques will be pioneered toward enabling low-complexity digital radios. Multi-dimensional sensed information will drive the innovation of cross-layer link scheduling and routing schemes aimed at boosting the cognitive radio network performance. The proposed innovations will be accomplished through mathematical formulation and modeling of directional sensing algorithms based on multi-dimensional signal processing concepts. The project will also investigate low-complexity fast algorithms for enabling real-time realization leading to new types of (i) digital integrated circuits, (ii) new design techniques for cognitive radios, and (iii) highly agile radio frequency component models all leading to an integrated directional spectrum sensor.Broader ImpactsThis proposal entails tightly integrated research and educational activities at four universities including an HBCU and an undergraduate institution. Spectrum-aware education is pursued as one of the key components of the project because wireless system designers and policy makers alike urgently need this knowledge for pioneering new innovations in this upcoming area of technology. Scientific findings enabled by the proposed research in the cognitive radio networks will serve as a tangible tool-box for engineering transformational technologies such technologies could, in turn, lead to mushrooming of businesses and services that directly benefit from intellectual property (e.g. patents). This research will foster startup firms manufacturing new devices that will potentially improve today`s wireless infrastructure. Distinct and diverse applications in education, energy, environment, healthcare, infrastructure, and public-safety will be studied from a unified perspective, i.e. spectrum scarcity, with the objective of maximizing the untapped economic potential of such scientific findings. The project will involve minorities, underrepresented groups, and women in research, while inspiring spectrum-aware educational concepts through new laboratory modules. Participation of underrepresented groups and women will be encouraged and promoted through mentorship and outreach, aimed at inspiring them to take up graduate studies in engineering and computer science.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Srinivasa Vemuru / s-vemuru@onu.edu	Ohio Northern University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Extreme Densification of Wireless Networks	1343383	Network densification - where a multitude of base-stations and access points with overlapping wireless footprints and disparate capabilities pervade the physical domain - is the way forward towards meeting the tremendous demand for mobile data. The main objective of this project is to reevaluate the manner in which wireless networks are engineered and spectrum usage is managed so as to exploit dense access infrastructure. The project is expected to make contributions in three areas: 1) Design, analysis and prototyping of communications and network protocols to enable unprecedented fine grain control over transmissions over shared spectrum without requiring high coordination overheads, by leveraging emerging agile access techniques; 2) Design and analysis of novel, simple and sparse-state algorithms that leverage the large flexibility in such systems to achieve near-optimal resource allocations; 3) Modeling and analysis of extreme dense wireless networks to both evaluate the performance of resource sharing between providers in this regime, as well as evaluate economic and policy incentives to deploy a range of contractual structures.The proposed research activity relies heavily on the development of sound theory and analysis of extremely dense networks, algorithmic development, simulation for large-scale systems and finally prototyping small-scale regimes. The research will serve as a catalyst towards changing traditional wireless networking paradigm, from one where infrastructure points connect to many mobiles, to one where a mobile connects to a large number of infrastructure nodes. The research will be disseminated broadly to researchers, practitioners and policy makers, leveraging in particular, a strong industry focused research center, as well as in efforts reaching out to public high school students, parents and teachers.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Gustavo de Veciana / gustavo@ece.utexas.edu	University of Texas at Austin	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Extreme Densification of Wireless Networks	1343253	Network densification - where a multitude of base-stations and access points with overlapping wireless footprints and disparate capabilities pervade the physical domain - is the way forward towards meeting the tremendous demand for mobile data. The main objective of this project is to reevaluate the manner in which wireless networks are engineered and spectrum usage is managed so as to exploit dense access infrastructure. The project is expected to make contributions in three areas: 1) Design, analysis and prototyping of communications and network protocols to enable unprecedented fine grain control over transmissions over shared spectrum without requiring high coordination overheads, by leveraging emerging agile access techniques; 2) Design and analysis of novel, simple and sparse-state algorithms that leverage the large flexibility in such systems to achieve near-optimal resource allocations; 3) Modeling and analysis of extreme dense wireless networks using mean field games to both evaluate the performance of resource sharing between providers in this regime, as well as evaluate economic and policy incentives to deploy a range of contractual structures.The proposed research activity relies heavily on the development of sound theory and analysis of extremely dense networks, algorithmic development, simulation for large-scale systems and finally prototyping small-scale regimes. The research will serve as a catalyst towards changing traditional wireless networking paradigm, from one where infrastructure points connect to many mobiles, to one where a mobile connects to a large number of infrastructure nodes. The research will be disseminated broadly to researchers, practitioners and policy makers, leveraging in particular, a strong industry focused research center, as well as in efforts reaching out to public high school students, parents and teachers.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ramesh Johari / rjohari@stanford.edu	Stanford University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Measurement-Augmented Spectrum Databases for White Spaces	1443951	The recent wave of radio spectrum deregulation encourages shared use of underutilized spectrum (so-called `white spaces`) where licensed users (primary) co-exist with unlicensed or lightly licensed users (secondary). Federal Communications Commission (FCC) has recommended use of online spectrum databases to ensure that primary communications are protected against interference coming from secondary communications. However, these databases provide notoriously poor estimates of whether a primary communication is active as they are based on empirically driven radio propagation modeling. This accuracy issue ultimately weakens the business case for white space networks, particularly in urban regions where the demand of both primary and secondary use is high.The core intellectual merit of the project is a fundamental rethinking of the current approach to spectrum databases. The project develops a functional system architecture that improves the spectrum database estimates by integrating the current modeling-based approach with distributed spectrum measurement data. The project delivers the key components necessary to realize such measurement-augmented database system: (i) open access spectrum observatory tool backed by models and databases, (ii) a spatial statistics-based approach to integrate modeling and measurement data, (iii) practical methods to collect large-scale, distributed spectrum measurement data to feed into the database. Success in the project will revitalize the interest in white spaces among commercial operators and also will help FCC in future spectrum policy formulation. The open access spectrum observatory tool will provide researchers with significant data sets and models. The project also plans technology transfer and cross-disciplinary educational efforts in wireless systems.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Samir Das / samir@cs.stonybrook.edu	SUNY at Stony Brook	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Multi-Input Multi-Output (MIMO) Aware Cooperative Dynamic Spectrum Access	1443858	[illegible] framework, termed McDysa, which enables multiple primary users and multiple secondary users to cooperate in dynamic spectrum sharing. By exploiting the underlying cognitive radio and MIMO techniques, McDysa is expected to achieve significant gains on spectrum efficiency while providing substantial enhancements to physical layer security as well. The technical merit and impact of this project are both fundamental and applied, including new problems, algorithms, and methodologies. The McDysa architecture considers multiple simultaneous primary- and secondary-user transmissions by exploiting MIMO techniques. A number of problems studied in the project may foster the development of novel techniques and methodologies toward MIMO-aware dynamic spectrum access. Examples include the novel problem of MIMO-enabled relay selection, insightful analysis of McDysa transmission capacity, and the consideration of secrecy capacity enhancement via friendly jamming. As many of the methodologies in McDysa leverage knowledge from other domains such as game theory, the research outcomes of this project may also motivate advancements of the corresponding domain-specific research. The broader impact of this project also extends to education. The project contains a detailed plan for disseminating the research results and for outreaching to students from underrepresented groups via various channels established in the past years. It also includes a plan for integrating undergraduate and graduate education with research through curriculum development and student involvement. Specifically, the testbed validation of McDysa can offer undergraduate and graduate students valuable hands-on experience, and is therefore an excellent educational vehicle to broaden the participation of students, especially those from underrepresented groups, in computer science research. Technically, this project defines novel problems and develops new performance-optimization techniques in the following three thrusts that are critical to MIMO-aware cooperative dynamic spectrum access: (i) Relay selection and resource sharing, which focuses on developing novel centralized and distributed relay selection and resource management algorithms based on game theory to enable multiple MIMO-empowered primary and secondary users to cooperate for joint optimization. (ii) Achievable transmission capacity analysis, which investigates the achievable transmission capacity of secondary networks and secrecy capacity of the primary network, and the usage of beamforming optimization to maximize such capacities. (iii) Secrecy capacity enhancement, which studies the usage of two friendly jamming mechanisms, cooperative jamming and artificial interference, in the design of novel beamforming techniques and interference signals for nulling the interference at the receivers, in order to enhance the secrecy capacity of the primary network. Besides the three thrusts, this project also includes the design and validation of a testbed that supports a number of experimental tasks for validating the effectiveness of approaches and methodologies developed in the project. This project also has strong societal impact as the rigorously proven solutions developed in the project can serve as guidelines and backbone for	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiuzhen Cheng / cheng@gwu.edu	George Washington University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS); COMMS, CIRCUITS & SENS SYS	EARS: Providing Predictable Service and Spectrum Access With Realtime Decision in Cognitive Multihop Wireless Networks	1247944	The objective of this project is to design real-time temporal-spatial spectrum sharing, trading and accessing schemes to improve the network performances by fully exploiting the channel availability (e.g., spatial, temporal, and spectral) and quality (e.g., signal to interference plus noise ratio and data rate) diversities. PIs focus on 1) designing a rigorous mathematical model for spectrum sharing; 2) designing efficient auction-based real-time spectrum allocation methods; 3) studying the schedulability of periodic channel usage requests, and the robustness of the designed protocols; 4) designing effective distributed real-time channel sensing, probing, accessing and routing strategies using online optimization techniques for multihop cognitive radio networks; 5) evaluating and testing the performances of proposed algorithms and methodologies using cognitive radio network testbeds.The intellectual merit is that the proposed research offers both theoretical and systematic methods to address some not well-understood key problems (e.g., zero-regret online spectrum sensing and accessing, robustness of protocols), and propose novel approaches (e.g., networked multi-armed bandit) to tackle these challenging problems. This project further enhances the understanding and designing of efficient real-time algorithms for multihop cognitive radio networks using resources opportunistically with unpredictable online requests and external disturbances.The broader impacts are that solutions proposed in this study alleviate the spectrum shortage problem and take advantage of the remarkable strength of cognitive radio technology. The proposed research rigorously integrates and thus sheds light on theory, algorithm design and analysis, protocol design and system implementation of cognitive radio networks.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiang-Yang Li / xli@cs.iit.edu	Illinois Institute of Technology	no-value
National Science Foundation (NSF)	INDUSTRY/UNIV COOP RES CENTERS	I/UCRC FRP: Collaborative Research: Coexistence of Heterogeneous Secondary Networks for Shared Spectrum Access	1431244	Spectrum sharing plays a key role in realizing plans to make available new swaths of spectrum for wireless applications. The benefits of spectrum sharing cannot be fully realized without addressing interference among coexisting heterogeneous secondary networks. Although coexistence issues in the ISM bands have been studied before, the situation in the TV bands and other shared access spectrum (e.g., 3.5 GHz band) is more complex and challenging due to the signal propagation characteristics, incumbent protection rules, and the disparity of PHY/MAC strategies of secondary systems. To date, most research efforts have focused on incumbent protection, and little attention has been given to the coexistence of secondary systems in the context of spectrum sharing. The proposed research aspires to fill this void by 1. studying the viability of using stochastic neural networks for modeling and solving the CDM problem and 2. developing novel rendezvous techniques for unicast and multicast scenarios.The group plans to integrate project findings in relevant graduate courses at their respective institutions. In the second year of the project, the investigators will jointly organize a session on heterogeneous coexistence and spectrum sharing at the Virginia Tech annual Symposium and Wireless Summer School, which is an educational outreach event that serves the wireless industry. The group also proposes to give a tutorial presentation on heterogeneous coexistence and spectrum sharing at relevant conferences, including the IEEE DySPAN Conference, the flagship conference on dynamic spectrum access and spectrum sharing technologies. The group will also collaborate with our industry partners from Raytheon and Space Micro to demonstrate a sample of the proposed solutions on their spectrum-agile radio platforms.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Jung-Min Park / jungmin@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	MAJOR RESEARCH INSTRUMENTATION; SPECIAL PROJECTS - CISE; INDUSTRY/UNIV COOP RES CENTERS	MRI: Development and Deployment of an Operational and Programmable Diverse-Spectrum Access Network	1126478	Project Proposed:This project, SPAN, a system for Spectrum-Programmable Access for Next-generation Deployments, proposes a novel instrument and testbed environment with wireless access in diverse spectral ranges, which is open, disruptive and unconstrained by any standard. This project will yield three key developments, including the SPANnode, SPANscope, and SPANnet, which include the wireless node, unique network scale monitoring systems, and a wireless networks, respectively. SPANnode is a programmable wide-band node, with a unique level of high performance, spanning 100 times more spectrum and aggregate multiple bands to yield 4 times greater transmission bandwidth than any currently available open-source platform. SPANnode will yield the world's first full-duplex transit node and first multi-user beam-forming gateway. SPANscope is a unique network-scale monitoring tool across vast spectral, spatial, and temporal scales. Finally, SPANnet is a wireless network comprising SPANnodes, SPANscope monitors, SPANscope-compliant smartphones, and community-owned legacy 802.11 clients. SPAN enables research in- Spectrum Aggregation: The project will develop and experimentally evaluate an algorithmic toolkit that enables network operators to aggregate diverse spectral bands to best meet their service objectives. - Networked Multi-antenna Services: The project will exploit a novel multi-antenna features to develop new communication modes including multi-user beam-forming backhaul, full-duplex transit nodes, and enhanced security via a managed spatial footprint. - Network-Scale Energy Optimization: The project will study energy efficiency performance tradeoffs brought by dynamic spectrum access and multi-antenna transceivers to reduce the operational cost of high-performance wireless network infrastructure and improve the battery lifetime.Broader Impacts: This project, unique in its goals and expected results, carries potential for large broader impacts in the areas of spectrum policy, standards, industry, and the research community. The measured data sets collected by in the project will be shared with the broader research community. The researcher is potentially transformational. SPANnet will serve primarily Hispanic community, and the project includes outreach to high schools in the underserved community. The project team actively engages multiple Hispanic and under-represented Ph.D. students. All code will be open-source and proposed are the community events that will promote wide usability of the SPANnodes which will be made available to the research community.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Large	ongoing	Edward Knightly / knightly@ece.rice.edu	William Marsh Rice University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Efficient Spectrum Access for Gbps WLANs in a Crowd of Legacy Networks	1318292	Next-generation WLAN protocols will rely heavily on spectrum aggregation to achieve Gbps throughput. But the aggregated wideband spectrum may be severely underutilized and even starved when it overlaps with legacy narrowband channels. As WLAN protocols continue their expansion and diversification, such heterogeneous spectrum sharing becomes increasingly prevalent, raising coexistence as a fundamental problem and practical problem. The objective of this research is to gain insights into coexistence of Gbps and legacy WLANs through measurement studies, develop optimization-driven protocols to enable efficient spectrum sharing between them, and validate the protocols in a medium-scale software-radio testbed. The proposed solutions improve the MAC layer`s awareness of heterogeneous spectrum sharing, and enforce intelligent control over the PHY layer through fine-grained spectrum access and opportunistic spectrum aggregation. They have the potential to realize Gbps wireless networking even in a crowd of low-rate legacy networks/devices.By addressing the key issues of heterogeneous spectrum sharing, the proposed research helps accelerate the deployment of Gbps WLANs which will, in turn, improve the quality of experience for billions of WiFi end-users. It will also train graduate students with a balanced mix of theory and hands-on experiences, and synthesize their knowledge in both computer science and communications engineering. Undergraduate students will also participate in this project, with the complementary support from the undergraduate research programs in the PIs` institutions. The PIs will interact closely with industry for possible transitioning of the research results.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xinyu Zhang / xyzhang@ece.wisc.edu	University of Wisconsin-Madison	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS; EXP PROG TO STIM COMP RES	Optimal Joint Spectrum Allocation and Scheduling for Cognitive Radio Networks	1310562	Objective:The objective of this project is to significantly improve spectrum utilization through conducting optimal or near-optimal joint spectrum allocation and scheduling in cognitive radio networks. The PIs address critical and practical challenges for spectrum allocation and scheduling in cognitive radio networks, in particular multi-hop cognitive radio networks, such as dynamic traffic demands and pattern, unpredictable primary user activity, wireless interference, and coexistence. A test-bed will be set up to extensively evaluate the designed algorithms and protocols.Intellectual merit:The intellectual merits of this project are: 1) this project develops creative models and algorithms in the framework of restless multi-armed bandit to address the critical challenges for spectrum allocation and scheduling in cognitive radio networks; 2) the proposed methodology is novel in that it intelligently combines the networked multi-armed bandit modeling, graph theory, and communication scheduling theories; 3) this project significantly advances the fundamental knowledge and understanding of cognitive radio networks; and 4) the developed algorithms, models, and protocols significantly improves spectrum utilization in future wireless communication systems.Broader impacts:This project significantly improves the design, deployment, and operation of future wireless communication systems. The proposed algorithms, protocols, and models enable future wireless systems to share spectrum much more efficiently than today`s systems, which will result in significant economical, societal, and public safety impacts. In addition, the proposed research is integrated into education and training for both undergraduate and graduate students. This project also significantly broadens the participation of underrepresented minority groups, e.g., the Native Americans in South Dakota.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yanxiao Zhao / yanxiao.zhao@sdsmt.edu	South Dakota School of Mines and Technology	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Techno-Economic Models of Secondary Spectrum Use	1247546	Dynamic Spectrum Access (DSA) technologies have been proposed and researched for 15 years, yet only some relatively experimental systems are in operation today. This research explores some essential but unexplored techno-economic aspects of DSA that are crucial if these systems are to come to commercial reality. One major thrust is an exploration of how substitutable different frequency bands that these systems might use are with each other. Another major thrust is how a firm that might be considering the use of DSA technologies can manage the technical and financial risk inherent in them. To accomplish this, a fungibility score based on mathematical models and agent-based simulations are developed to evaluate the substitutability among spectrum bands to assist firms as well as policymakers in assessing candidate bands for use in a DSA system. For risk management, the project employs real options analysis to develop a set of risk measures and mitigation strategies for technical and financial risk to assist secondary users in DSA systems. This work will help policymakers develop better guidelines for the industry. It will also help firms seeking to use DSA technologies reason more clearly about which technical and financial choices are best and why, providing guidelines for growth and job creation. The expected outcomes of this project will include a set of tools that will enable entrants into a secondary spectrum market to make decisions as well as for policy makers to evaluate the factors that may influence their regulatory guidelines in order to promote viable DSA markets.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Martin Weiss / mbw@pitt.edu	University of Pittsburgh	no-value

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: Full-Duplex Cognitive Radio: Theory and Hardware	1509006	[illegible] to increase 1000-fold within the next decade, the wireless spectrum has become a scarce commodity. This proposal aims at the development of novel theory and hardware that will significantly improve the ability to reuse the crowded spectrum by leveraging the capabilities of full-duplex mobile users in sensing the spectrum while they are transmitting. The concept of a fully passive full-duplex radio front-end in this proposed research is a fundamental shift from the conventional full-duplex radio designs that shall provide significant power and complexity advantages. The use of the proposed design in cognitive networks to intelligently detect unused radio spectrum is expected to lead to more efficient use of the spectrum and significant capacity enhancement that is not easily achievable using existing technologies. In the long term, the proposed concept has the transformative potential to improve wireless systems in a variety of aspects, ranging from high-capacity distributed multiple-input multiple-output solutions, efficient network protocols to support intelligent interference coordination, and management to reduce latency in multi-hop wireless networks. Besides these societal and technical contributions, this project will also advance discovery and understanding via integrating with both graduate and undergraduate education, and enhance infrastructure for research and education via an interdisciplinary, inter-institutional collaboration. The education and collaboration plans will additionally broaden the participation of underrepresented groups, including those from a predominantly undergraduate institution and female students. Through a collaboration between two experts in different areas (i.e., antenna design and communication theory), the overall objective of the proposed interdisciplinary research project is to develop new architectures and algorithms for full-duplex cognitive radio wireless communications to significantly improve reuse of the crowded spectrum. The specific aims of the project include the following: 1) to design and develop fully passive full-duplex hardware architectures suited for cognitive mobile devices, which significantly cancel the self-interference without the need for adaptive analog cancellation at the 5 Ghz band or below; 2) to investigate the applications of the proposed full-duplex hardware architectures in enhancing white spectrum usage and increasing capacity of cognitive radio links under the context of opportunistic spectrum access; and 3) to investigate the applications of the proposed full-duplex hardware architectures in multiuser cognitive networks for further sensing performance improvement and capacity enhancement. For Aim 1, the merit of the approach is in the use of novel antenna configurations that provide a considerable amount of isolation from self-interference. The design is based on obtaining two identical out-of-phase components of self-interference signals. The design is fully passive and can be used in wideband applications. For Aims 2 and 3, the approach to the information-theoretical characterization of the full-duplex cognitive radio link and network is founded on capacity calculation techniques using novel results in real and complex analysis, probability theory, and optimization theory. The full-duplex capability will be [illegible] radically transform its basic properties on-the-fly. A key step is deployment of infrastructure and client nodes that can access diverse spectral ranges spanning from MHz to GHz. This unique capability in spectrum access enables revisiting the foundations of network assessment, design, and access. This experimental approach capitalizes on an unprecedented opportunity in an urban community within Houston: In Pecan Park, an underserved community, the project team will serve as researchers, the wireless network service provider, the network equipment and protocol designers, and community-technology educators and advocates. In a coordinated effort using this urban testbed, the project addresses the following three inter-related research thrusts:CACTUS: cross sectional assessment of community and technology usage: development of a first-of-its-kind network assessment tool that integrates three new methods with existing network trace collection capabilities: (i) sociological assessment of community-technology wireless access objectives from perspectives of both usage and contribution to a collective good; (ii) in-situ user experience assessment via end-user reporting; and (iii) concurrent in-situ client performance tests instantiated remotely by the network operator.PAWN: polymorphic architecture for wireless networks: employing an urban deployment of nodes that can access spectrum spanning an order of magnitude from 5 GHz to 500 MHz in the Digital TV white spaces range, the project will (i) develop foundations and tools for dynamic network architecture based on assessment of community objectives and usage; (ii) develop foundations and tools for 'green wireless', energy-efficient architectures which power down low-usage nodes but retain coverage through spectrum adaptation; and (iii) develop foundations and tools for spectrum-driven mobility management, in which highly mobile clients exploit nodes with large spatial footprints (enabled by low spectral ranges) to obtain a performance-velocity profile that was previously impossible.CODA: context-driven network access: exploiting CACTUS and context awareness, the project will (i) develop context-driven quality estimation of current and future association choices to a polymorphic wireless network and devise client-directed policies for a client to optimize efficiency, performance, and mobility of association; and (ii) design and realize a polymorphic aggregate network interface that dynamically aggregates packets from multiple network interfaces of multiple spectral bands. Using this mechanism and context-awareness, we will study interface selection and traffic allocation for a client to obtain its required performance with unprecedented efficiency.Broader Impact. With a strong interdisciplinary nature, this project will develop new research methods and yield foundational findings for areas spanning wireless networking to social sciences. The deployment in a low-income community provides access to information technologies for its residents. It will produce lessons and insights for future deployments of wireless infrastructures in other urban communities, including underserved ones, both nationally and internationally. The unique use of DTV white spaces can guide future FCC policy decisions. The project will provide research [illegible]	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Huu Nghi Tran / nghi.tran@uakron.edu	University of Akron	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; NETWORK SCIENCE & ENGINEERING	NetSE: Large: Urban-Scale Polymorphic Wireless Networks: Community-Driven Assessment, Design, and Access	1012831	to increase 1000-fold within the next decade, the wireless spectrum has become a scarce commodity. This proposal aims at the development of novel theory and hardware that will significantly improve the ability to reuse the crowded spectrum by leveraging the capabilities of full-duplex mobile users in sensing the spectrum while they are transmitting. The concept of a fully passive full-duplex radio front-end in this proposed research is a fundamental shift from the conventional full-duplex radio designs that shall provide significant power and complexity advantages. The use of the proposed design in cognitive networks to intelligently detect unused radio spectrum is expected to lead to more efficient use of the spectrum and significant capacity enhancement that is not easily achievable using existing technologies. In the long term, the proposed concept has the transformative potential to improve wireless systems in a variety of aspects, ranging from high-capacity distributed multiple-input multiple-output solutions, efficient network protocols to support intelligent interference coordination, and management to reduce latency in multi-hop wireless networks. Besides these societal and technical contributions, this project will also advance discovery and understanding via integrating with both graduate and undergraduate education, and enhance infrastructure for research and education via an interdisciplinary, inter-institutional collaboration. The education and collaboration plans will additionally broaden the participation of underrepresented groups, including those from a predominantly undergraduate institution and female students. Through a collaboration between two experts in different areas (i.e., antenna design and communication theory), the overall objective of the proposed interdisciplinary research project is to develop new architectures and algorithms for full-duplex cognitive radio wireless communications to significantly improve reuse of the crowded spectrum. The specific aims of the project include the following: 1) to design and develop fully passive full-duplex hardware architectures suited for cognitive mobile devices, which significantly cancel the self-interference without the need for adaptive analog cancellation at the 5 Ghz band or below; 2) to investigate the applications of the proposed full-duplex hardware architectures in enhancing white spectrum usage and increasing capacity of cognitive radio links under the context of opportunistic spectrum access; and 3) to investigate the applications of the proposed full-duplex hardware architectures in multiuser cognitive networks for further sensing performance improvement and capacity enhancement. For Aim 1, the merit of the approach is in the use of novel antenna configurations that provide a considerable amount of isolation from self-interference. The design is based on obtaining two identical out-of-phase components of self-interference signals. The design is fully passive and can be used in wideband applications. For Aims 2 and 3, the approach to the information-theoretical characterizationof the full-duplex cognitive radio link and network is founded on capacity calculation techniques using novel results in real and complex analysis, probability theory, and optimization theory. The full-duplex capability will be	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Large	ongoing	Edward Knightly / knightly@ece.rice.edu	William Marsh Rice University	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Collaborative Research: Full-Duplex Cognitive Radio: Theory and Hardware	1509052	The design is fully passive and can be used in wideband applications. For Aims 2 and 3, the approach to the information-theoretical characterizationof the full-duplex cognitive radio link and network is founded on capacity calculation techniques using novel results in real and complex analysis, probability theory, and optimization theory. The full-duplex capability will be	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Tutku Karacolak / tutku.karacolak@vancouver.wsu.edu	Washington State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Overcoming Technological Challenges for Spectrum Trading	1443870	The dynamic and uneven wireless network traffic load at different time instants and geographical locations has led to substantial underutilization of some spectrum bands while severely crowding others. This project investigates a number of fundamental and challenging technical issues that arise from broadband spectrum trading for achieving superior technical, economic, and social values of spectrum use. The project is an interdisciplinary research effort across mathematics and wireless network technologies. With respect to wireless technologies, this research project outcomes can significantly improve spectrum efficiency and user experience, while benefiting many real-life needs, such as public safety, telemedicine, and social services. On mathematics, the research effort will lead to the formulation of more interesting problems with real world applications and the discovery of new tools for solving such problems. As a comprehensive investigation to overcome technical challenges that arise from broadband spectrum trading, the project tasks focus on three inter-related key research directions: 1) new graph theory problems, 2) new graph-based resource allocation and utility optimization, and 3) physical layer techniques and utility design. Specifically, the project considers new problems on judicious partitions of graphs and new problems on optimal disjoint paths in weighted graphs using minimum-edge-weight path utility. New solutions and tools developed for such problems can then be applied and generalized for solving various resource allocation and utility optimization problems in broadband spectrum trading. Furthermore, the project addresses new fundamental physical layer issues that arise from spectrum trading. These implementation issues include broadband channel estimation, dynamic pilot placement, interference limited pilot power control, and low complexity broadband spectrum sensing. To establish utility functional curves and to develop means for modeling parametric effects in fine-granularity for more effective broadband spectrum trading, the project applies group-theory-based methodologies to design and carry out detailed tests and analysis in order to fine-tune effective utility functions that incorporate user experience and satisfaction. The research results are also expected to lead to strong social impacts and to provide better technical insights and effective guidelines on governmental regulatory policymaking and technological development regarding broadband spectrum trading for wireless communications.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Zhi Ding / zding@ucdavis.edu	University of California-Davis	no-value

National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; COMPUTING RES INFRASTRUCTURE	Collaborative Research:II-NEW: RUI: ROAR - A Research Infrastructure for Real-time Opportunistic Spectrum Access in Cloud based Cognitive Radio Networks	1405670	This project focuses on the development of a real-time opportunistic spectrum access testbed for cognitive radio networks, called ROAR.The information gained from this project will provide a platform to assess maturity of spectrum-sensing technology and identify areas that need further research for real-time opportunistic dynamic spectrum access in a heterogeneous cognitive network environment, and will support enhancement of our national wireless infrastructure and capacity. ROAR will have a broad societal impact as wireless networks touch every aspect of our society. Project-based learning will be incorporated in related undergraduate and graduate courses to integrate research and education. Focused efforts will be undertaken to interest underrepresented minorities (including females) in the proposed research field.This project will setup a cloud-based cognitive network for real-time opportunistic spectrum access across diverse RF bands (e.g., 9 kHz ? 6000 MHz) including cellular, IEEE 802.11 a/b/g/n, IEEE 802.15.4, DSRC/WAVE and Bluetooth networks, in order to study the implementation, evaluation and development of future wireless systems. This project also enables experimental investigations in a number of other research projects, including secure dynamic spectrum access design, cognitive radio enabled opportunistic spectrum access in highly mobile vehicular networks, primary user security emulation, energy management techniques for mobile devices, cross-layer based protocol design, security for cyber-physical system design, interference mitigation techniques and wireless resource management schemes.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Danda Rawat / drawat@georgiasouthern.edu	Georgia Southern University Research and Service Foundation, Inc	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	EAGER: CDRIVE: Cognitive Radio Enabled Spectrum Aware Intelligent Vehicular Networks	1265166	Transferring high bandwidth content is a challenge in vehicular and mobile networks that are limited by spectrum scarcity in the unlicensed bands, short connection times, and the cost of cellular data plans. These observations motivate the use of frequency agile cognitive radios as part of the project called CDRIVE (for Cognitive raDio enabled spectRum-aware Intelligent Vehicular nEtworks). CDRIVE involves the use of theoretical analysis tools and exploration of correlation functions. A major contribution lies in creating a new ns-2 based simulation tool that combines spectrum-related functions in a cognitive radio within a vehicular environment. CDRIVE makes advances towards developing a holistic framework for vehicular cognitive radios networks for allocating roadside base station locations that have spectrum database access capability, enhancing the science of collecting spectrum measurements under different topographical conditions, surrounding urban structures and speeds, and devising a new rate control mechanism that anticipates network and correlated road congestions, and intermittent disruptions due to spectrum outages. CDRIVE will yield insights on integrating cognitive radios with spectrum databases, especially for mobile networks, which are now mandated by the FCC. It will provide the theory and practical validation of the best mobility-aware spectrum-sensing strategies, and tightly couple the external environment with the sensing method. It will also shape future safety-related messaging in vehicles, support real-time telemetry analysis, and allow high-bandwidth communication for emergency response personnel.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kaushik Chowdhury / krc@ece.neu.edu	Northeastern University	no-value
National Science Foundation (NSF)	INFORMATION TECHNOLOGY RESEARCH; ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	A New Dimension in Radio Spectrum Sharing through Network Cooperation	1343222	Existing spectrum-sharing paradigms have set clear boundaries between primary and secondary networks. There is very limited node-level cooperation between primary and secondary networks. This project develops a new and bold paradigm that explores policy-based network cooperation as a new dimension for spectrum sharing between primary and secondary networks. The benefits of this paradigm are numerous, as it allows integrating resources from two networks. To move this new paradigm from concept to reality, this project aims to (1) develop fundamental understanding of policy-based cooperation through mathematical models and optimization, (2) explore new achievable rate regions through the use of advanced physical layer technologies, and (3) develop distributed optimization algorithms that can offer performance approaching the theoretical limits. For prototype, the project implements the policy-based cooperation on a 48-node testbed.The project investigates a new paradigm and technologies that enable more flexible and efficient sharing of the radio spectrum. New mathematical models developed in this research will help gain fundamental understanding of the benefits of the new paradigm. The use of advanced physical layer technologies will further push the performance envelopes of achievable rate regions. New textbooks will be developed and used in classrooms at Virginia Tech and other universities. Special efforts to broadening participation by female and underrepresented students are planned through an on-going NSF REU site for cognitive radio communications and Virginia Tech`s participation in Pacesetters, a program organized by the National Center for Women and Information Technology.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Large	ongoing	Jeffrey Reed / reedjh@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: Spectrum Situational Awareness-Understanding the Data	1454835	The key resource shared by all wireless systems is the electromagnetic spectrum, which is challenged by temporal and spatial congestion, interference, and increasing security threats. This project investigates the hypothesis that building a resilient always-on wireless network, capable of meeting ever-increasing performance and security requirements, necessitates not only innovations in radio design but also innovations in the management and exploitation of vast amounts of radio spectrum knowledge. Such knowledge is referred to as spectrum situational awareness - the amount of actionable intelligence and understanding that a wireless network (or individual radio) has about its RF spectrum environment. This research work formally studies the nature of big spectrum data and investigates several critical issues, e.g., how should data from heterogeneous sources be prioritized or weighted, and what are the effects of inaccurate or sparse data measurements.The scientific goals of this project are to provide foundational principles and insights for developing innovative and scalable spectrum situational awareness architectures, and to enable more efficient and effective uses of the data as well as the improved protocol and system designs. Using formal statistical methods (e.g., regression analysis and response surface methodology) and new big data analytics tools, the research team fully characterizes big spectrum data, its potential impact on spectrum utilization and system performance, and its interaction with the plethora of influential radio, network, and environmental factors. The empirical work is based on experimental scenarios that reflect realistic networking environments, comprising multiple wireless access technologies, interconnected high-speed backhaul networks, and distributed cloud-based technologies. Two testbed instruments are used to design and execute large-scale simulation and emulation experiments: the Distributed Computing and Visual Analytics Sandbox for High Volume Data Streams combined with the Wireless Systems and Performance Engineering Research (WiSPER) laboratory. Additionally, the research team develops a multilayer spectrum situational awareness framework and is deriving performance indices that can be used to quickly quantify and compare the spectrum situational awareness capabilities of network systems. The project engages students from underrepresented groups via ongoing partnerships with Historically Black Colleges and Universities.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dmitri Perkins / perkins@cacs.louisiana.edu	University of Louisiana at Lafayette	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Big Bandwidth: Finding Anomalous Needles in the Spectrum Haystack	1247298	Objective:The objective of the proposed project is to explore the problem of scanning large amounts of spectrum in order to detect anomalous usage of that spectrum. The project will examine spectrum scanning using a single spectrum sensor and using multiple spectrum sensors. The approach will involve using game theoretic formulations that allow for the determination of scanning strategies that give an optimal likelihood of detecting an adversarial or accidental misuse of spectrum in terms of the bandwidth that can be scanned in a single scan and the bandwidth that an anomalous activity might involve. The optimization of strategies are complemented by techniques that increase the amount of spectrum that can be scanned in a single scan, and spectrum mapping algorithms that estimate the received power levels at arbitrary spatial locations.Intellectual merit:The intellectual merit of the proposed effort stems from the pulling together of a mixture of technologies from different fields, including game theory, signal processing, security, wireless communications, and RF photonics to address the challenging problem of detecting and preventing anomalous spectrum activity across a wide swath of bandwidth. Broader impacts:The broader impacts of the proposed effort will include the cross-pollination between different disciplines, such as game theory, security, photonics and signal processing. Additionally, the project will guide the development of graduate and undergraduate students at both participating institutions, giving the students new tools with which to contribute to wireless and optical communications. Finally, new interdisciplinary curricula will be developed as part of the effort.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Paul Prucnal / prucnal@ee.princeton.edu	Princeton University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Crowdsourcing-Based Spectrum Etiquette Enforcement in Dynamic Spectrum Access	1444076	The radio spectrum is becoming an increasingly valuable natural resource nowadays, while it has been shown that much of the spectrum is underutilized in existing licensed bands. To enhance spectrum utilization, dynamic spectrum access (DSA) has been envisioned as a set of promising new spectrum management paradigms, such as spectrum trading/auction and opportunistic spectrum access. While DSA and programmable cognitive radios enable a much higher flexibility of spectrum access, due to the openness of wireless medium, it is also susceptible to various forms of misuse or abuse. For example, unauthorized transmissions without a valid license, or secondary transmissions that intentionally disobey the interference constraints set by the primary users (radios). The misusers will not only gain higher throughput for themselves, but also harm the efficiency of spectrum access operations of normal users (radios). Therefore, enforcing spectrum access rules or etiquettes is crucial to ensuring the ultimate success of the DSA paradigm. This project develops a framework for etiquette and rule enforcing in dynamic spectrum sharing environments. The main idea of the proposed research is to engage community users (radios) to detect misuse, and identify and punish unruly devices. By crowdsourcing the tasks of monitoring neighborhood radio access behaviors to many cognitive radio devices, multiple benefits can be gained: 1) the potentially large number of participating devices can result in much larger detection coverage and accuracy; 2) no pervasive dedicated trusted infrastructure or hardware is needed; and 3) the fact that every device could possibly be a monitoring device leads to a much stronger deterrence to misbehaviors. The interdisciplinary research plan consists of four major components: 1) an optimized crowdsourced passive radio traffic monitoring framework to detect access misbehavior in the vast DSA spectrum; 2) techniques to identify misbehaving cognitive radio devices using physical layer identification, even when the signal waveform can be adaptively modified; 3) techniques for immediate punishment of spectrum misuse through adaptive friendly jamming which exploits multi-functional re-configurable antennas; and 4) incentive mechanism design via auctions to ensure user participation in each task of crowdsourced etiquette enforcement. The success of this project will benefit multiple current and future application domains deploying DSA, especially those that require critical information protection, such as healthcare, transportation, energy, public services, emergency, and military services.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ming Li / lim@email.arizona.edu	Utah State University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Enhancing Spectral Access via Directional Spectrum Sensing Employing 3D Cone Filterbanks: Interdisciplinary Algorithms and Prototypes	1247946	NSF Proposal No. 1247946Devabhaktuni, Vijaya KumarIntellectual MeritThis NSF EARS project proposes a new spectrum sensing architecture combined with joint link scheduling and routing to significantly enhance access to the radio spectrum. Traditional non-directional sensing algorithms do not offer information about the direction of primary and secondary signals, directional information on interference, and information on network node location, and hence significantly limit the potential of cognitive radio technology in terms of spectrum utilization. This project envisions a generalized framework leading to the determination and subsequent utilization of spatio-temporal vacancies in time, frequency, position and direction. New mathematical, hardware, and software algorithms and techniques will be pioneered toward enabling low-complexity digital radios. Multi-dimensional sensed information will drive the innovation of cross-layer link scheduling and routing schemes aimed at boosting the cognitive radio network performance. The proposed innovations will be accomplished through mathematical formulation and modeling of directional sensing algorithms based on multi-dimensional signal processing concepts. The project will also investigate low-complexity fast algorithms for enabling real-time realization leading to new types of (i) digital integrated circuits, (ii) new design techniques for cognitive radios, and (iii) highly agile radio frequency component models all leading to an integrated directional spectrum sensor.Broader ImpactsThis proposal entails tightly integrated research and educational activities at four universities including an HBCU and an undergraduate institution. Spectrum-aware education is pursued as one of the key components of the project because wireless system designers and policy makers alike urgently need this knowledge for pioneering new innovations in this upcoming area of technology. Scientific findings enabled by the proposed research in the cognitive radio networks will serve as a tangible tool-box for engineering transformational technologies such technologies could, in turn, lead to mushrooming of businesses and services that directly benefit from intellectual property (e.g. patents). This research will foster startup firms manufacturing new devices that will potentially improve today's wireless infrastructure. Distinct and diverse applications in education, energy, environment, healthcare, infrastructure, and public-safety will be studied from a unified perspective, i.e. spectrum scarcity, with the objective of maximizing the untapped economic potential of such scientific findings. The project will involve minorities, underrepresented groups, and women in research, while inspiring spectrum-aware educational concepts through new laboratory modules. Participation of underrepresented groups and women will be encouraged and promoted through mentorship and outreach, aimed at inspiring them to take up graduate studies in engineering and computer science.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Vijaya Kumar Devabhaktuni Vijay.Devabhaktuni@utoledo.edu	University of Toledo	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Enabling local spectrum markets for enhanced access and flexible service	1247958	Licensed spectrum services today are offered by a few large providers with a national presence, and market competition is realized only at the national scale. Typical provider-customer contracts are relatively long term with few standard contract choices, which does not lead to the best value realization for the customer. Furthermore, mobile users are often restricted to using long range communication to the provider's base stations, even when they are in the range of access points of other users that are currently under-loaded but closed for public use.This project attempts to address those limitations. Firstly, it studies the viability of regional wholesale spectrum markets, and the role that should be played by regional spectrum providers with secondary licenses and localized operation. Secondly, it investigates the design and pricing of flexible provider-customer spectrum service contracts that would enable both contracting parties to operate at their desired risk-return tradeoff points. Thirdly, this project studies access, security and incentive mechanism design questions that can enable users to serve as micro-providers, or share their spectrum contracts with others in their "community". These explorations are conducted using economic/business theories of investment analysis, financial engineering, risk management, control and optimization, and network game theory, as well as small-scale user surveys and simulation experiments.The broader goal of the project is to facilitate a more layered market structure that will increase the number of regional players in the spectrum service contracting business, and also involve the users in providing spectrum services to others. More local competition would allow more competitive prices for spectrum usage, better local expansion and coverage, and therefore better access for users. Sharing of unused spectrum by users with each other would enable better spectrum access and rates, and revenue to users who share their unused spectrum. Spectrum service innovations that this project explores, along with presence of regional providers, would allow users to have individualized spectrum contracts with more flexible terms and conditions than what exist today.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Koushik Kar / koushik@ecse.rpi.edu	Rensselaer Polytechnic Institute	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Paving the way to dynamic spectrum sharing: Understanding regulatory and enforcement mechanisms	1247928	Objective: The objective of this program is to help eliminate key barriers to implementing new spectrum sharing policies though the development of regulatory and enforcement mechanisms that protect incumbents users. The proposed research develops needed enforcement mechanism though developing algorithms for rapid identification and location of users, developing metrics appropriate for enforcement systems, and determining fundamental limits for density of nodes to achieve reliable detection for enforcement. The technology development will be guided by considering legal issues surrounding privacy and whether the technology requires changes to existing telecommunication policy.Intellectual merit: The intellectual merit is the discovery of novel approaches to transmitter identity and location verification, and the development of metrics that regulators can use to help determine compliance of future spectrum sharing systems.Broader impacts: The broader impacts are elimination of roadblocks to spectrum sharing mechanisms. The President's Council of Advisors on Science and Technology identified nearly 1GHz of spectrum that can be shared to spur the economy and establish the United States as the leading technology innovator for dynamic spectrum access. Understanding the technical viability, legal feasibility, and system costs of spectrum sharing enforcement will eliminate fear, uncertainty, and doubt on the part of spectrum owners about moving into a spectrum sharing mode. Our approach also proactively reaches out to the regulatory community and educates them on the new regulatory approaches and enforcement mechanisms made possible by this research.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jeffrey Reed / reedjh@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Distributed Robust Spectrum Sensing and Sharing in Cognitive Radio Networks	1464092	The future Cognitive Radio Networks (CRNs) will consist of heterogeneous devices such as smartphones, tablets and laptops moving dynamically. Accurate and robust spectrum sensing and identification of unauthorized spectrum usage are essential components of spectral efficiency in future radio systems. This project aims to utilize consensus-based cooperation featuring self-organizable and scalable network structure to capture the swarming behaviors of spectrum users and providing cooperative spectrum sensing in a fully distributed manner. By using a combination of control theory and machine learning techniques, the project designs secure weighted average consensus for cooperative spectrum sensing that can not only capture the swarming behaviors in CRNs with heterogeneous devices, but also is robust to practical channel conditions. Robust localization approaches are developed grounded on dynamic signal strength mapping, which have the capability to localize multiple malicious users. Additionally, the new techniques are validated using an actual testbed with on-campus deployment and system demonstration to industrial collaborators. The integration of control theory with dynamic spectrum access will enable a new revolution in the way for enhancing spectrum efficiency in CRNs. The project serves as a pioneer in exploiting multi-disciplinary knowledge (e.g., control systems and machine learning techniques) to achieve a more efficient spectrum usage in future radio systems, aiming to alleviate the increasing crowdness of the spectrum occupancy and support the co-existence of heterogeneous devices. This project also carries out a broad range of education and outreach activities to encourage students to pursue careers in the fields of science and engineering. Research results will be disseminated to academia and industry through presentations and publications in meetings, conferences and journals.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jie Yang / jyang5@fsu.edu	Florida State University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Dynamic Spectrum Access under Uncertainty: Theory, Algorithm Development, and Evaluation	1421576	The demand for wireless spectrum is projected to continue growing well into the future, and will only worsen the currently felt spectrum crunch. Rigid licensing policies that give exclusive and permanent right of use of wireless spectrum to lessees further exacerbate this scarcity. This shortcoming has been identified in the famous 2002 FCC study, which estimates the utilization of licensed spectrum between 15-85% depending on time and location, thus, underscoring the critical need for new methods of spectrum sharing. Development of these new methods, coined as Dynamic Spectrum Access (DSA) techniques, is very challenging due to the inherent uncertainty in user traffic demand, spectrum availability, wireless channel conditions, and user locations. Thus, the overarching goal of this project is to efficiently manage dynamic spectrum access in the presence of these uncertainties. The algorithms developed in this project ultimately encourage both federal and commercial spectrum holders to participate in DSA systems. Additional wireless bandwidth is being freed up for essential services to be migrated to the wireless domain, significantly lowering the cost of access to wireless networks for a significant fraction of the society currently shut out of this market. These emerging systems also create new communication-based business models, develop community resources, and improve public safety.Managing dynamic spectrum access faces three major challenges induced by: (1) the dynamics and the possibly correlated nature of spectrum resource from a secondary provider/user's perspective; (2) uncertainty about spectrum availability in terms of long-term channel statistics and real-time channel states; (3) uncertainty of secondary traffic and heterogeneous performance/pricing requirements of secondary users. In this project, efficient information sharing, spectrum sensing, and scheduling policies are designed that take all these three aspects into account. Since jointly optimizing across the three dimensions outlined above is a daunting challenge, the project is organized across two inter-related thrusts. In the first thrust, a given level of spectrum uncertainty is assumed, and efficient scheduling policies are designed for a secondary provider to meet various QoS requirements. In the second thrust, the case where a secondary provider can control information inaccuracy by coordinating SUs to sense channels is considered and the joint sensing and scheduling problem investigated. The developed algorithms are validated through simulations and via testbed implementations. The effect of uncertainties is investigated by developing analytical techniques that combine stochastic optimization, approximation algorithms and game theory. The resulting joint sensing and resource allocation policies are low-complexity and provably efficient. This project will engage underrepresented students and K-12 students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ness Shroff / shroff@ece.osu.edu	Ohio State University	no-value

National Science Foundation (NSF)	INDUSTRY/UNIV COOP RES CENTERS	I/UCRC FRP: Collaborative Research: Coexistence of Heterogeneous Secondary Networks for Shared Spectrum Access	1432880	Spectrum sharing plays a key role in realizing plans to make available new swaths of spectrum for wireless applications. The benefits of spectrum sharing cannot be fully realized without addressing interference among coexisting heterogeneous secondary networks. Although coexistence issues in the ISM bands have been studied before, the situation in the TV bands and other shared access spectrum (e.g., 3.5 GHz band) is more complex and challenging due to the signal propagation characteristics, incumbent protection rules, and the disparity of PHY/MAC strategies of secondary systems. To date, most research efforts have focused on incumbent protection, and little attention has been given to the coexistence of secondary systems in the context of spectrum sharing. The proposed research aspires to fill this void by 1. studying the viability of using stochastic neural networks for modeling and solving the CDM problem and 2. developing novel rendezvous techniques for unicast and multicast scenarios.The group plans to integrate project findings in relevant graduate courses at their respective institutions. In the second year of the project, the investigators will jointly organize a session on heterogeneous coexistence and spectrum sharing at the Virginia Tech annual Symposium and Wireless Summer School, which is an educational outreach event that serves the wireless industry. The group also proposes to give a tutorial presentation on heterogeneous coexistence and spectrum sharing at relevant conferences, including the IEEE DySPAN Conference, the flagship conference on dynamic spectrum access and spectrum sharing technologies. The group will also collaborate with our industry partners from Raytheon and Space Micro to demonstrate a sample of the proposed solutions on their spectrum-agile radio platforms.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Marwan Krunz / krunz@ece.arizona.edu	University of Arizona	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	NeTS: Small: RUI: On-Demand Spectrum Access: Application-Oriented Dynamic Spectrum Access	1418012	With the proliferated growth of wireless communication services, the radio spectrum has become a precious resource. On the other hand, many licensed spectrum bands are considerably under-utilized in both time and spatial domains. This situation has motivated dynamic spectrum access to increase spectrum utilization. This project proposes a novel application-oriented dynamic spectrum access model, termed on-demand spectrum access (ODSA), to capitalize on recent spectrum policies evolution, while eliminate technical barriers bothering the existing dynamic spectrum access model. We consider a spectrum service provider to offer on-demand spectrum services to users, such that users can dynamically set up application-oriented virtual topologies to carry out specific applications. This project will develop optimal or near-optimal spectrum allocation algorithms, and novel techniques to improve spectrum sharing and increase spectrum utilization. The developed algorithms, techniques, and architectures have the potential to affect the spectrum authorities on policy reform of spectrum management, and affect the design, deployment, and operation of future wireless communication systems, to result in significant economical, societal, and public safety impacts. This project also offers an excellent opportunity to promote broadening participation of underrepresented minority students in research and education, by directly supporting underrepresented minority students and outreach activities.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Chunsheng Xin / cxin@odu.edu	Old Dominion University Research Foundation	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; SPECIAL PROJECTS - CCF	WiFiUS: Collaborative Research: Sequential Inference and Learning for Agile Spectrum Use	1456793	A key imperative to expanding future wireless services is to overcome the spectral crunch. At present, static allocation and rigid regulation lead to underutilization of available spectral resources. Flexible spectrum use aims at exploiting under-utilized spectrum. Available spectrum opportunities may be non-contiguous, scattered over a large bandwidth, and are available locally and for a limited period of time due to the highly dynamic nature of wireless transmissions. This fuels the need to understand how to discover, assess and utilize the time-frequency-location varying spectral resources efficiently and with minimal delay. Moreover, it is critical to access identified idle spectrum in an agile manner.This project will design sequential inference and learning algorithms for agile spectrum access when the state of the spectrum varies rapidly. The key advantage of sequential algorithms, as compared to block-wise algorithms, is that they typically lead to significantly reduced decision delays. The overarching goal of this project is to design sequential inference and learning algorithms for agile spectrum utilization. In particular, this project will employ advanced sequential inference and learning methods for the following three interconnected yet increasingly sophisticated and demanding tasks: 1) to employ sequential reinforcement learning and sequential inference algorithms to design sensing policies for rapid spectrum opportunities discovery; 2) to design sequential algorithms for fast and accurate spectrum quality assessment; and 3) to build, maintain and exploit an interference map of the area where our network operates and represent it as a spatial potential field. The proposed research is expected to make substantial contributions to both applications and theory. On the application level, the proposed research has the potential to substantially improve spectral efficiency by introducing novel tools from sequential analysis, machine learning and statistical inference for the design of spectrum discovery, assessment and exploitation policies. On the theoretical level, the proposed project will advance the state of the art in sequential analysis and contribute new approaches to the general methodological base for optimal stopping, control and machine learning problems. Furthermore, new methods and theory of modeling and exploiting knowledge of interference using spatial potential fields, sequential statistics and advanced propagation modeling will be developed.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Harold Vincent Poor / poor@princeton.edu	Princeton University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Social Structure for Cooperative Mobile Networking	1457278	To meet the rapidly growing demand of mobile data traffic, regulatory agencies around the world are actively working on policies and regulations for dynamic spectrum access that are mutually beneficial to the cognitive devices and the licensed spectrum users of the under-utilized spectrum. One of the primary contributors to the explosive mobile traffic growth is the rapid proliferation of mobile social applications. One key observation is that, since mobile networks are designed and deployed to meet the social needs of humans, connections and behaviors of people in the social domain shape the ways in which they access mobile services. With this insight, this project advocates a social-aware approach to enable shared spectrum access, cooperative spectrum sensing and intelligent device-to-device (D2D) communications, by leveraging the social structure among mobile users. Such social trust-based cooperation among mobile devices enables self-organizing networking, and has the potential to achieve substantial gains in spectral efficiency and lead to significant increases in network capacity. By combining theoretical studies with practical applications, this project aims to integrate social elements into the design of cooperative mobile networks, thereby accelerating the evolution of future mobile networks.Under the common theme of exploiting the social structure for cooperative mobile networking, this project is organized into four well-coordinated thrusts: 1) Thrust I focuses on social recommendation-aided dynamic spectrum access by exploring the collective wisdom of secondary users for distributed spectrum sharing; 2) Thrust II investigates social-enhanced D2D communications; 3) Thrust III designs and analyzes collaboration protocols among secondary users; 4) Thrust IV studies social assisted information dissemination in mobile networks. The proposed research is expected to enable a paradigm shift from traditional approaches to social-aware approaches to enable shared spectrum access, cooperative spectrum sensing and intelligent device-to-device (D2D) communications, via exploiting the social structure among mobile users. The broader impacts also include educational elements, such as promoting diversity by providing research opportunities to woman and underrepresented students.	Technologies and applications for efficient spectrum use or legacy transformation; Spectrum access policy and regulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Lei Yang / lyang55@asu.edu	Arizona State University	no-value
National Science Foundation (NSF)	ADVANCED NET INFRA & RSCH; RES IN NETWORKING TECH & SYS	CAREER: Towards Cognitive Communications in Wireless Networks	845812	Today`s cognitive radio is characterized by its capability to perceive the existence of spectrum holes through spectrum sensing, and then transmitting on these unutilized frequencies. While each individual cognitive radio is very capable and can make independent decisions, lack of user coordination and network control raises serious issues in efficiency, security and resource waste in wireless environments. These problems call for fundamental changes in cognitive communication network design. In this research, we introduce and develop the concept of cognitive network, which is defined as an intelligent wireless system that can collect and analyze the current network conditions, and then make real-time corresponding changes in network operating parameters, such as modulation scheme, transmission power, carrier frequencies, data frame structure, coding schemes, resource allocation and security management. We provide a comprehensive framework for the development of cognitive networks from a network-centric perspective. More specifically, we plan to: (i) Introduce a novel architecture for cognitive network; (ii) Design efficient and secure resource management protocols; (iii) Develop highly efficient and resilient anti-interference/interception systems through multi-layer diversity; (iv) Develop cryptographic algorithms and protocols for anonymous routing and network integrity.The proposed research on cognitive networks introduces innovative methodologies on architecture development, system design, secure and efficient network management. It will significantly improve spectral efficiency, security and interoperability of communications between versatile wireless devices, and therefore provides an ideal human-technology platform for e-commerce, national security, environmental protection, health monitoring, as well as many future applications that can benefit from fast and reliable information exchange.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jian Ren / renjian@egr.msu.edu	Michigan State University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Future Wireless Broadband Access: Cross-Optimizing Hardware, Physical and Network Layers	1444060	wireless access impacts virtually all sectors of society and economy including education, healthcare, transportation, and security. In a vast and mixed urban/rural country such as the United States, providing high-speed broadband data access through the wired infrastructure can be costly. On the other hand, wireless can cover large areas and reach a large number of people very effectively. In addition, wireless is the preferred medium through which we connect to the Internet and enjoy a whole wealth of services such as entertainment, education, healthcare, e-commerce, social networking, and remote working. In this context, the ability to handle the predicted dramatic increase of demand for wireless data has become crucial not only for the wireless industry but, more in general, for the growth of our economy. While wireless connectivity has significantly improved over the past few decades, it is quite behind the theoretical and technological achievable limits and it cannot address future demand. With this in mind, this project develops an innovative multi-tier hierarchical infrastructure for next-generation cellular networks with densely deployed base stations, along with a set of well-integrated cross-layer design techniques for interference management and system optimization. This proposed approach may considerably improve the rate performance and user capacity, and is promising in bridging the gap between theory and practice for broadband wireless access. To support the drastically increased mobile data traffic in wireless broadband services, this work focuses on a systematic cross-layer system optimization approach that relies on three major pillars: 1) at the physical layer, base stations with massive multiple-input multiple-output antenna systems are used; 2) at the wireless network architecture level, a multi-tier heterogeneous network approach is selected, achieving unprecedented spatial spectrum reuse; 3) at the cross-layer optimization level, a holistic network utility maximization approach is proposed, that systematically obtains layered protocol architectures from the structure of the global optimization solution. In relation to the above pillars, the fundamental challenges that will be addressed in this project are: 1) the design of integrated and power-efficient reconfigurable massive multiple-input multiple-output front-end antenna systems based on the concept of hybrid beamforming, i.e., on the optimal splitting of multiuser precoding and inter-cell interference management functions between digital baseband processing and analog radio frequency beamforming; 2) the design of hybrid beamforming schemes that exploit long-term channel statistics for inter-cell coordinated interference management, and instantaneous channel state information to achieve spatial multiplexing gain in each cell; 3) a user partitioning and scheduling approach based on clustering the user space according to quality of experience requirements, channel statistics and mobility, assigning network utility functions to the different user groups, solving the combined network utility maximization problem and systematically deriving a layered protocol architecture from the structural properties of the optimization solution. In addition, the work will significantly extend current mathematical performance analysis of wireless	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Konstantinos Psounis / kpsounis@usc.edu	University of Southern California	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Enabling High-Speed Communication over Turbulent Free-Space Optical Links by Employing Spectral-Spatial Schemes	1500170	field of optical communication systems operating through free space. Free-space optical communication systems emerged as the most promising alternative and supplement to high-speed radio frequency data links by offering several key advantages, such as higher security, operation over unlicensed frequency spectrum, and higher information capacity. Such systems can be remarkably well-suited for rapidly establishing high-speed communication in disaster recovery areas or over difficult terrains, linking Earth stations and low-orbit satellites, providing ultra-secure inter vessel connections, or supporting high-speed data links in urban areas. Although the information capacity of free-space optical communications is inherently higher since information is carried by frequencies from optical domain, there is need to investigate more comprehensive solutions for additional information capacity increase in order to advance high-speed free-space optical communication capabilities towards their full potential.It is well known that higher information capacity can be enabled by exploiting fundamental optical parameters (time, frequency, polarization, and space) contained in a highly directed light beam. While the time, frequency, and polarization properties have been analyzed and understood in detail, theoretical and practical use of the spatial dimension is not fully explored. The goal of this project is to investigate free-space optical communication schemes by utilizing both frequency and space properties through their parallel employment within a single propagating light beam. Although this approach is highly promising, propagation through the turbulent atmosphere can drastically degrade the signal quality and thus reduce the information capacity. Therefore, an innovative approach is needed to advance solutions that can increase the information capacity and compensate for these turbulence effects. The principal technical objective of the proposed project is advancement of technologically innovative multidimensional schemes that increase the information capacity of free-space optical communication systems. For that purpose, creation and propagation of spatial orbital angular momentum-based modes to carry an optimized number of spectral components will be explored. In parallel, modulation, coding, detection, and compensation schemes and algorithms that would maximize the information capacity of free-space optical communication channel will be investigated. This approach is transformative in nature since it brings multidimensional character to design of free-space optical communication channels. The key challenge in this task will be suppression and minimization of the mutual interaction between spatial modes due to the impact of air turbulence, which would otherwise cause unacceptable crosstalk and limit the channel capacity. For this purpose, a rigorous theoretical framework for the multidimensional free-space optical communication channel will be developed and experimentally verified. It will be used to lay down the crosstalk mitigation research tasks in both optical and electrical domains to counter the effects of long-term temporal correlation. A novel architecture that combines adaptive compensation of wave-front phase distortions with advanced detection and coding	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Milorad Cvijetic / milorad@optics.arizona.edu	University of Arizona	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	High-Efficiency Wireless Transmitters Employing RF Pulse-Width Modulation	1509615	wireless systems such as cellular telephony and wireless local area networks (WLAN), and the widespread availability of communication devices, has had a profound impact on multiple aspects of modern life over the recent decades. Examples of this include commerce, entertainment, healthcare, navigation, safety and security, social-media, transportation and workspace productivity, in addition to basic person-to-person communication. In the foreseeable future, the emergence of applications driven by the "internet-of-things", wherein a significantly larger number of devices, such as household and industrial appliances, will require wireless connectivity, will place even greater demands on the wireless infrastructure. Power efficiency of communication links, and compatibility with technologies such as advanced semiconductor processes that enable miniaturization and low-cost deployment, will be critical to future proliferation of wireless systems. Efficiency is important in both mobile and stationary devices for minimizing energy wastage. With potentially billions of wireless communication devices being deployed over the coming years, the need for efficient operation is in fact, fundamental. Power efficiency is also critical in mobile devices since it directly impacts the available operating time of the device. The proposed research will investigate design techniques for significantly enhancing the efficiency of wireless communication transmitters through innovative architectures that leverage advanced Complementary Metal "Oxide" Semiconductor (CMOS) processes. The research will also include an investigation of transmitter architectures that can be easily reconfigured to operate in different end environments, and on techniques that reduce the spurious interference generated by transmitters, that can degrade the performance of other devices. A key part of the proposed research will be an investigation of Pulse-Width Modulation (PWM) signaling schemes, as applied to the problem of wireless transmitters. Techniques that reduce noise in the transmitter spectrum will be explored. To avoid the noise caused by quantization in the time-domain, analog-PWM techniques will be investigated. Techniques for efficient generation of PWM directly at the desired RF band without the need for frequency upconversion will be employed. This will help reduce the out-of-band spurs that can be a significant limitation in upconverted baseband PWM due to co-existence considerations. The use of phase-locked loop (PLL) based PWM generator, which allows for generation of high-speed analog PWM will be studied. The use of efficient class-D output stages to drive output loads over broad bandwidths with minimal reconfiguration will be investigated. Such transmitters can be an enabler for techniques such as channel-bonding, wherein data rates can be increased multiple-fold by combining data streams that are transmitted over multiple bands concurrently. A practical design to validate and verify the proposed circuit techniques will be implemented in a modern CMOS technology. A practical wireless system, such as 4G-LTE will be employed for this investigation. The work will form the core of the doctoral research of one graduate student researcher, who will gain expertise in theoretical, design-related and	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Ranjit Gharpurey / ranjitg@mail.utexas.edu	University of Texas at Austin	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Enabling Robust Communication in Cognitive Radio Networks with Multiple Lines of Defense	1318948	Opportunistic spectrum access (OSA) is at the core of the cognitive radio technologies with the focus on improving spectrum utilization efficiency and reliability. Despite the benefits, existing OSA protocols suffer from their deterministic nature and cannot prevent an ill-intended jammer from disrupting legitimate communications. A cognitive jammer can always effectively jam the idle channels by exploiting public-available channel statistics and causes serious spectrum underutilization. This project addresses the challenge of establishing robust anti-jamming communication in cognitive radio networks (CRNs) through a multiple-line of defense approach. The research considers a variety of network environments and integrates defense technologies from different dimensions, including adaptive uncoordinated frequency hopping (AUFH), power control, and signal processing. The defense approach enables both reactive and proactive protections, from evading jammers to competing against jammers, and to expelling jamming signals, and thus ensures robust user communications in CRNs. The research in this project has a potential to significantly advance the state-of-the-art and develop innovative and sophisticated defense strategies using the proposed multiple lines of defense approach. The proposed solutions will contribute towards eventually building robust and dependable CRNs that are critical to the future communication systems. The project will also contribute directly to the curriculum development, teaching, student supervising and future security engineer training. Major results of this project will be disseminated through presentations, publications, as well as online materials in the forms of tutorials and software packages.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kui Ren / kuiren@buffalo.edu	SUNY at Buffalo	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Collaborative Research: Enabling Robust Communication in Cognitive Radio Networks with Multiple Lines of Defense	1318594	Opportunistic spectrum access (OSA) is at the core of the cognitive radio technologies with the focus on improving spectrum utilization efficiency and reliability. Despite the benefits, existing OSA protocols suffer from their deterministic nature and cannot prevent an ill-intended jammer from disrupting legitimate communications. A cognitive jammer can always effectively jam the idle channels by exploiting public-available channel statistics and causes serious spectrum underutilization. This project addresses the challenge of establishing robust anti-jamming communication in cognitive radio networks (CRNs) through a multiple-line of defense approach. The research considers a variety of network environments and integrates defense technologies from different dimensions, including adaptive uncoordinated frequency hopping (AUFH), power control, and signal processing. The defense approach enables both reactive and proactive protections, from evading jammers to competing against jammers, and to expelling jamming signals, and thus ensures robust user communications in CRNs. The research in this project has a potential to significantly advance the state-of-the-art and develop innovative and sophisticated defense strategies using the proposed multiple lines of defense approach. The proposed solutions will contribute towards eventually building robust and dependable CRNs that are critical to the future communication systems. The project will also contribute directly to the curriculum development, teaching, student supervising and future security engineer training. Major results of this project will be disseminated through presentations, publications, as well as online materials in the forms of tutorials and software packages.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Peng Ning / pning@ncsu.edu	North Carolina State University	no-value

National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	Secure Communications in Fading Cognitive Radio Networks with Finite-Alphabet Signaling	1231848	Objective:The objective of this program is to establish transformative methodology and novelalgorithms for secure communications in spectrum sharing cognitive radio networks tosimultaneously maximize the secrecy throughput of secondary users under securitythreats, ensure the quality of service for primary users, and keep information secret toeavesdroppers.Intellectual merit:The intellectual merit is: 1) to propose a unified network model to describe the fadingcognitive radio network that has multiple primary users, secondary users andeavesdroppers, all connected by wireless fading channels; 2) to formulate the securecommunication of secondary users into direct maximization of mutual information orthroughput with finite-alphabet (rather than Gaussian) signaling and channel statisticsconstraints; 3) to present a novel approach to solving the neither concave nor convexoptimization problem.Broader impacts:The broader impacts include: 1) this project will bridge the gap between networkinformation theory and practical network implementation by employing finite-alphabetsignaling and channel statistics to optimize linear precoders which maximize thepractically achievable data rates or throughput; 2) it will establish a transformativemethodology that effectively tackles difficult non-concave, non-convex, and nondeterministicpolynomial-time (NP) hard optimization problems in cognitive radio networks. This methodology can be well applicable to other wireless network settingssuch as cooperative relay networks, cellular networks, and wireless sensor and meshnetworks; 3) The research will be timely integrated to collaborations with industrialpartners and education of undergraduate and graduate students, particularly, underrepresentedminority students, thus enhancing the impact to the society via technology innovation.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Yahong Zheng / zhengyr@mst.edu	Missouri University of Science and Technology	no-value
National Science Foundation (NSF)	STTR PHASE II	STTR Phase II: Universal Wireless Channel Selection Filter for Enhanced Access to RF Spectrum	1353180	This Small Business Technology Transfer Research (STTR) Phase II project will extend the basic science of linear interference delay effect filters, enabling ultra-wideband tunable RF filters for all types of RF receivers and instrumentation. It will also extend the engineering science of implementing such filters as integrated circuits. And, its distortion filtering aspect will enable signal agnostic,adaptive cancellation of wideband, and in-band, interference, for anti-jamming applications as well as to enhance signal quality for the consumer.The broader impact/commercial potential is that it will help achieve the national goal of expanding access to RF spectrum by maximizingspectral efficiency with its continuous tuning. Second, it reduces filter cost and space requirements while increasing reliability by eliminating increasingly complex filter banks. This will result in smaller, cheaper and more dependable phones for consumers, which will help drive industry growth. Third, the results of this project will deliver Smartphone GPS accuracy rivaling commercial units, as well as enabling protection of GPS-dependent infrastructure against inadvertent or intentional disruption. Fourth, it will enable precise, jamming resistant GPS navigation by aerial drones used by first responders, homeland security and the military, helping prevent crashes that place people at risk.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-5	Medium	ongoing	Vrinda Haridasan / vrinda@physicaldevices.com	Physical Devices LLC	no-value
National Science Foundation (NSF)	SECURE & TRUSTWORTHY CYBERSPACE	TWC SBE: Medium: Collaborative: Incentive Compatible Wireless Security	1314620	Wireless connectivity has become the primary way most users access cyberspace. The wide use of the internet on wireless and mobile devices is further encouraged with new services that simultaneously engage and connect a large number of users. As a result, the society at large is quickly getting comfortable with the idea of conducting everyday lives on mobile devices most of which require communicating sensitive and confidential information over the wireless medium. Consequently, secure access to cyberspace necessitates wireless security. Wireless, being an open medium, is more prone to malicious cyber acts as compared to wired connectivity. On the other hand, this medium also presents unique opportunities to provide security guarantees through the interaction of nodes and advanced physical layer techniques. In particular, information theoretic security emerges with design insights that provide guaranteed security against computationally unlimited adversaries. In order to do so, information theory assumes a network of altruistic nodes and looks for fundamental performance limits which usually come with complex interaction and coordination requirements. The premise of this project is that this idealistic set-up can be successfully transformed into a practical one by amalgamating information theory with the theory of incentives in order to provide secure wireless cyber access.Specific research topics being addressed include the development of: (1) mechanisms to incentivize non-altruistic cognitive nodes to participate in information theoretic security protocols; (2) incentive mechanisms for scenarios where all nodes have equal access to spectrum and need confidentiality, even from each other; (3) techniques for providing security to groups of cooperative nodes and the associated trust issues; (4) incentive mechanisms for combating active attacks; (5) strategies for combating colluding adversaries; and (6) mechanisms to ensure that nodes have the incentive to adopt a given security protocol.Broader impacts of this work include: (1) providing secure access to cyberspace via the wireless medium; (2) new design insights for practical security protocols; and (3) amalgamating information theory and game theory via incentive mechanisms. Educational broader impacts include: (1) dissemination of research results in the form of tutorials and short courses; (2) enhancing graduate-student research experiences via a three-university research exchange program; (3) incorporating the research results into graduate and undergraduate communications courses; and (4) recruitment of and mentorship for women in engineering and science.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Randall Berry / rberry@ece.northwestern.edu	Northwestern University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Cognitive Mesh: Making Cellular Networks More Flexible	1343220	Innovative use of wireless devices such as smartphones in various mobile applications has exacerbated the congestion over cellular spectrum. On the other hand, many licensed spectrum blocks are left unused. Although cognitive radios (CR) technology has emerged as an enabler for unlicensed users to opportunistically access the unused licensed spectrum, most previous works commonly assume that each user is equipped with a CR which can operate across a wide range of spectrum. This may be possible in theory, but may not be practical for light-weight devices such as cell phones. How to effectively utilize the CR technology to build more flexible networks so that even non-CR capable devices can benefit from the opportunistic access to the unused spectrum is therefore in dire need.In this project, the PIs propose a novel cognitive mesh assisted cellular network (CMCN) and investigate: 1) the architectural design of CMCN so that unoccupied licensed spectrum can be efficiently utilized and non-cognitive cellular devices can benefit from the CR technology, 2) spectrum and energy efficient CR mesh router placement under uncertain spectrum availability, 3) how to construct a fine-grained spectrum map to facilitate efficient spectrum allocation and intelligent traffic delivery, and 4) experimental validation and implementation for the proposed design. The research outcome provides a viable solution to the spectrum congestion in cellular systems. Moreover, with this flexible architecture, telecommunication industries can be rejuvenated with new innovations, leading to further development of cellular networks with high capacity and better support of new applications such as mobile healthcare, which has significant impact on individuals' lives and further provides greater opportunities for job creation and economic growth. The results of the project will be disseminated through publications and presentations. Finally, this project will actively recruit and train minority students for the future workforce and mentor junior faculty.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Pan Li / li@ece.msstate.edu	Mississippi State University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Intelligence Measure of Cognitive Radio Networks	1464487	Research on spectrum sharing has generated a large amount of spectrum measurement data and many spectrum sharing techniques. Most of the techniques are based on cognitive radio networks (CRNs) because the cognition capability is necessary for optimizing spectrum efficiency and guaranteeing safe coexistence in the presence of the spectrum uncertainty. Such cognitive capabilities collectively defines the intelligence of CRNs. Although cognition and intelligence are vital for CRNs, their quantitative specification is largely open. This project addresses this open question by developing a framework for investigating quantitatively the cognitive capabilities and the intelligence of CRNs. This project develops both a theoretical approach and an empirical approach to construct a CRN intelligence model. This model is inspired from the Cattell-Horn-Carroll human intelligence model. On the other hand, the pioneering theoretical approach is in sharp contrast to conventional human intelligence research that is mainly empirical. In addition, this project develops a CRN testing battery to measure the intelligence as CRN IQ (intelligence quotient) following psychometric practices. Finally, this project initiates innovative research in IQ-based multi-hop routing and IQ-based immunity to Denial-of-Service attacks, where innovative CRN techniques are developed with the aim of enhancing important cognitive capabilities. This project adopts a big data approach to exploit the vast amount of existing spectrum measurement data and CRN research results. Psychometric techniques are exploited to resolve challenges involved in this big data application.This project impacts society by expediting the commercial success of spectrum sharing technology. It integrates three traditionally disparate areas: wireless communications, psychology, and big data. The framework for constructing intelligence measure is useful to many other systems such as cognitive computing, cognitive control and cognitive radar. This project enhances the value of the spectrum measurement data and leads to a new direction for big data utilization. This project impacts education in many aspects, such as stimulating student research via the human intelligence analogy, supporting hands-on curriculum with the CRN testing battery, setting up CRN IQ competition projects, and outreaching to under-represented students and high school students.This project impacts society by expediting the commercial success of spectrum sharing technology. It integrates three traditionally disparate areas: wireless communications, psychology, and big data. The framework for constructing intelligence measure is useful to many other systems such as cognitive computing, cognitive control and cognitive radar. This project enhances the value of the spectrum measurement data and leads to a new direction for big data utilization. This project impacts education in many aspects, such as stimulating student research via the human intelligence analogy, supporting hands-on curriculum with the CRN testing battery, setting up CRN IQ competition projects, and outreaching to under-represented students and high school students.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kai Zeng / kzeng2@gmu.edu	George Mason University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Cognitive and Efficient Spectrum Access in Autonomous Wireless Networks	1247924	The objective of this project is to enable more efficient and reliable operation of autonomous femtocell networks with agile spectrum access, autonomous interference control, as well as intelligent network self-organization and self-optimization. This project falls into four interacted thrusts: 1) Incorporate cognition into the femtocell networks to cognitively reuse the available spectrum sensed; 2) Develop distributed, dynamic and cooperative interference management schemes exploiting antenna techniques and based on sensed environmental conditions; 3) Investigate the scenarios and schemes that femtocells can be exploited to facilitate macrocell transmissions, and the potential gains in capacity, coverage and reliability; 4) Incorporate interference cancellation for data multicast, and develop techniques to support multiuser video streaming. The project also develops a testbed with open source programmable wireless platforms, for prototyping and evaluating the effectiveness of various techniques developed. The proposed research has the potential to significantly increase the capacity and resilience of existing and future wireless networks. The agility and resilience of the system will also make it instrumental to support communications and applications that are important for national security and economy. The PIs will facilitate technology transfer through their industrial partners and industry affiliate programs. Complementary to the research agenda, the project will carry out a broad range of education and outreach activities, including integration of research findings into the courses, promoting underrepresented and undergraduate populations, and engaging with the K-12 schools to raise the level of student interests in pursuing advanced education and career in the areas of engineering and mathematics.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xin Wang / xwang@ece.sunysb.edu	SUNY at Stony Brook	no-value
National Science Foundation (NSF)	COMMS, CIRCUITS & SENS SYS	EARS: Enhancing Spectrum Efficiency of Autonomous and Agile Hybrid FSO/RF Systems	1343372	The objective of this project is to develop a highlybandwidth-efficient and autonomous hybrid free-space optical/radiofrequency (FSO/RF) system based on several innovative and agiletechnologies in forward error correction (FEC) coding, modulation, andswitching.Intellectual Merit: The intellectual merit lies in the development ofa solid construction for super fast, highly practical, and highlyspectrum efficient dual-pulse pulse position modulation (D-PPM); theproposition of a novel iterative decoding/demodulation method that caneffectively explore D-PPM with powerful rate-compatible FEC codes toachieve adaptive coding and modulation; and the design of autonomousand agile monitoring and switching technologies. The research entailstheoretic, algorithmic, and simulation activities, that will combinethe various aspects of information and communication, signalprocessing, networking, and optics into a cohesive framework ofautonomous and agile FSO/RF systems.Broader Impacts: RF spectrum is a precious commodity that is rapidlybecoming scarce, and FSO presents an effective alternative to theovercrowding RF spectrum. FSO offers many unique advantages includingunlicensed access to high bandwidth, interference-free andelectromagnetic pollution-free, high data rates, high security, andeasiness to set-up, tear-down and re-configure. With the backup RF toprovide a carrier grade availability, and with effectivecommunication, signal-processing and optical technologies to furtherenhance its bandwidth-/power-efficiency and robustness, hybrid FSO/RFhas the potential to provide applications in a wide range of verticalmarkets, from finance to healthcare, government, military, education,and enterprise connectivity.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jing Li / jingli@ece.lehigh.edu	Lehigh University	no-value
National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS; COMM & INFORMATION THEORY	An Efficient Framework for Channel State Dissemination and Network Synchronization	1319458	With the rapid proliferation of wireless devices in the last decade, it has become increasingly important to efficiently utilize limited spectrum resources through close coordination of devices in the network. While several advanced techniques have been developed recently to address this problem, these techniques require an accurate and consistent view of the channel states as well as some degree of synchronization among the devices in the network to be effective. The research plan in this project is focused on developing an analytical framework and efficient techniques for channel state dissemination and network synchronization to enable close coordination of devices in a network and efficient utilization of the channel resources. The proposed research is based on the view that, in order to determine the best use of the spectral and temporal resources available to the network, channel state estimation and dissemination should be performed continuously as part of the normal network operation. By estimating and disseminating network channel state information continuously through existing network traffic, devices in the network can adaptively determine an appropriate network structure and mitigate the effects of interference to facilitate efficient communication under current and predicted channel states.The foundational nature of the research plan makes it broadly applicable in a wide range of wireless communication systems such as cellular networks, wireless local area networks, vehicular networks, and emergency communication systems. The analytical framework and techniques for efficient channel state dissemination and network synchronization developed on this project will impact emerging wireless communication systems such as informed-transmitter multi-input multi-output (MIMO), cognitive radio, cooperative relaying, distributed transmission, and interference alignment. The proposed research will establish a solid theoretical foundation for understanding the limits of minimum-staleness channel state dissemination and clock synchronization in wireless networks and will also include experimental verification through testbed implementations of the channel state dissemination and network synchronization techniques.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Donald Brown / drb@ece.wpi.edu	Worcester Polytechnic Institute	no-value
National Science Foundation (NSF)	CAREER: FACULTY EARLY CAR DEV; SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS; EXP PROG TO STIM COMP RES	CAREER: Towards Rich Multimedia Experience in Emerging Cognitive Radio Networks	953513	A cognitive radio (CR) is a frequency-agile wireless communication device with intelligent control and a monitoring interface that enables dynamic spectrum access. The CR concept represents a paradigm change in spectrum regulation and utilization. As basic understandings gained, there is a compelling need to fully capitalize CR`s high potential for supporting new applications. This CAREER project investigates the problem of enabling rich multimedia services in emerging CR networks. Although highly rewarding, the new dimension of dynamics on channel availability, sensing, and access brings about a whole level of technical challenges. To address these challenges, a novel cross-layer optimization and control approach is employed, complemented with distributed algorithm design and development of an open source CR video testbed. The manifold design trade-offs, multifarious dynamics, scarce resources and, on the other hand, video`s tight QoS constraints make the optimization and control approach highly suited for "squeezing" the most out of CR video networks. The three research thrusts include: cross-layer optimization of CR video networks, classical and modern control theory based analysis and design of CR video networks, and experimental research with a CR video testbed and field experiments.This project will serve a critical need by enabling video communications in emerging CR networks for commercial and mission-critical applications. Open source software, a CR video testbed, and experimental data will be distributed in the wireless community. The research outcomes will be integrated with course development, textbook writing, involving graduate and undergraduate students in cutting-edge research, promoting diversity, and outreach to K-12 students.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Shiwen Mao / smao@auburn.edu	Auburn University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: Collaborative Research: Cross-Layer Modeling and Design of Energy-Aware Cognitive Radio Networks	1265332	Minimization of energy consumption is critical to developing green, sustainable technologies for cognitive radio terminals that can connect to networks that operate on different frequency bands with a variety of air interfaces. The intellectual merit of this project is a unified and coherent consideration of RF components, communication system algorithms, baseband computation platforms, and design tools, to greatly increase spectrum sharing efficiency. Dataflow methodologies are a promising candidate for the modeling, analysis and verification of cognitive radio systems. As dataflow models are abstract and platform independent, the same model can be used to generate implementations for very different devices from low-power sensor nodes to high-end mobile terminals. The key novelty is in the development of systematic methods for design, implementation, and integration of configurable RF chains, and in the development of dataflow methods for formal analysis and optimization of these new capabilities. The expected results are: (1) Energy consumption models and a design framework for computation, control and configuration of future radio devices, leveraging the investigators` existing experimental testbeds, (2) Configurable radio architectures for wide-scale cognitive access of noncontiguous RF spectrum, and (3) Design methodologies for flexible, energy-efficient cognitive wireless networks. The broader impact includes international collaboration through the WiFiUS program creating a holistic design for configurable frequency agile terminals. A novel interdisciplinary approach is enabled by the unique international team, which builds upon collaborations between experts at the Tampere University of Technology and University of Oulu in Finland, and Rice University and the University of Maryland in the US.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Joseph Cavallaro / cavallar@rice.edu	William Marsh Rice University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Laying the Foundations of Social Network-Aware Cellular Device-to-Device Communications	1443905	Providing ubiquitous access to the rapidly expanding suite of mobile social applications has strained modern-day wireless networks, motivating the need for new technologies to optimize the usage of the scarce radio resources. Device-to-device (D2D) communications between mobile devices over the reliable and pervasive cellular network infrastructure constitutes one of the most promising technologies for further accelerating the penetration of mobile social services. As compared to conventional D2D over short-range and limited-capacity technologies such as Bluetooth, D2D over cellular provides longer transmission ranges, improved spectrum sharing, higher capacities, guaranteed quality-of-service, and a broader range of applications and services. Owing to its promising potential, D2D is now viewed by both academia and standardization bodies as a cornerstone technology in emerging 5th generation (5G) wireless systems.Leveraging cellular D2D for mobile social applications requires addressing a variety of technical challenges that are characterized by a strong interplay between social factors such as content correlation, and wireless features such as network-controlled resource allocation and interference management. This project addresses these challenges by introducing a novel network optimization framework, cognizant of both social and wireless realms, suitable for ensuring the delivery of high-speed, high-quality social networking services over cellular D2D communications. Specifically, new D2D-oriented socio-technological metrics and novel semi-distributed resource allocation and content delivery algorithms will be developed to optimize the quality-of-service of social network-aware D2D systems. In addition, hierarchical resource allocation tools will be introduced to optimize the distribution of social content over D2D while maximizing the spread of data over multiple D2D connections. The results will be evaluated and deployed on two platforms: a large-scale testbed based on open-source Android devices for validating the approach and exploring new social metrics, and a software defined radio platform to analyze the performance of the proposed schemes within a realistic cellular setting.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	My Thai / mythai@cise.ufl.edu	University of Florida	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS); COMMS, CIRCUITS & SENS SYS	EARS: Novel Beam Steering Apertures and Waveforms for High Capacity Broadband Wireless Nodes	1247503	Proposal Summary - Novel Beam Steering Apertures and Waveforms for High Capacity Broadband Wireless Nodes Intellectual MeritThe demand for broadband wireless has put existing systems to their limits. In not so distant future mobile Gb/s portable and wearable wireless nodes will be required which will necessitate significant improvements in spectral efficiency. This work proposes an integrated research concept which brings together innovations in beam steering antenna arrays and interference immune waveforms and algorithms. To date most of the antennas and arrays that have been developed for portable and wearable wireless applications have fixed broad beams. This makes them very inefficient because much of the radiated radio frequency power is absorbed by the head or the body resulting in wasted battery power. In this work led by USC significantly smaller form factor antenna arrays will be developed by exploiting the steerable parasitic array concept. The dependency of the array gain and angular coverage on array parameters will be studied to develop new design rules. From a systems perspective, efforts have been devoted to maximize spectral efficiency within heterogeneous networking strategies. However, conventional spectrum utilization strategies which are developed for homogeneous networks are being integrated to the heterogeneous networks, which stand as the bottleneck of the heterogeneous network. To break that bottleneck the concept of enhanced partial overlapping domains is proposed by the USF team. For the first time, beam steering approaches at the mobile will be combined with time-frequency utilization considering enhanced partially overlapped domains. A system level testbed will be developed to evaluate the performance of the proposed arrays and waveforms. Broader ImpactsThe broader impact of this work includes its potential for new fundamental knowledge generation in the field of beam steering antenna arrays and interference immune waveforms/algorithms for future high capacity portable/wearable wireless applications. This will have effects on commercial and military communication domains. Immediate tangible outcome will be a system level testbed that will provide results, outcomes, and design guidelines to prospective designers. This research also involves a team from Benedict College, Columbia, SC, an HBCU (Historically Black Colleges and Universities) Institution. The Benedict team will conduct research and educational activities that will lead to the development of demonstration modules that will enhance future outreach and recruitment efforts of undergraduate students, high school students, and female and minority students	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Mohammod Ali / alimo@engr.sc.edu	University South Carolina Research Foundation	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Medium: Collaborative Research: GOALI: Adaptive and Flexible Spectrum Optical Networking	1302645	This project will study and develop technology for Elastic Optical Networks (EONs). In EONs flexible amounts of spectral bandwidth may be allocated to each data channel without requiring adherence to a fixed wavelength grid. Such an approach is well-suited for supporting a wide range of dynamic traffic demands in a bandwidth-efficient manner. Key enabling technologies, optical arbitrary waveform generation(OAWG) and optical arbitrary waveform measurement (OAWM), will enable elastic optical networking over a large spectrum by dividing the spectrum into spectral slices and dynamically processing information at lower rates compatible with CMOS electronics. The project will leverage these technologies as a basis for innovative hardware and software solutions for EON technology, architectures, protocols, network control and management, system integration, and testbed integration. Advances in the basic architecture and technology for optical networking is important for US competitiveness. The project will work with several US-based industrial organizations as a means of technology transfer. The research results and publications will likely to impact standardization activities of flexible grid networking (e.g. International Telecommunication Union ITU-T SG15 on flex grid). The project will link education and research and serve as a rich platform for crossdisciplinary education in optical and higher-layer networking, and in computer engineering.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Jason Jue / jjue@utdallas.edu	University of Texas at Dallas	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	NeTS: Small: Collaborative Research: OSTARA: An Optically-based Simultaneous Transmit and Receive Architecture for Enhancing Wireless Communications	1217435	Improving the usage of communication spectrum resources is critical to future wireless systems. The OSTARA project focuses on the development of RF photonic techniques that support the ability to simultaneously transmit and receive in wireless devices. The effort involves a mix of theoretical development (specifically investigating potential improvements in capacity), as well as systems validation efforts involving building an opto-cancellation circuit capable of cancelling out co-site interference associated with simultaneous transmission and reception. . Specifically, the theoretical component of the effort will involve using ray-tracing to understand the role of cancelation of multipath components on communication rate, as well as an investigation into the impact of idealized cancellation on network capacity using graph coloring. The systems component of the effort will involve developing photonic circuits that subtract off the transmitted signal from the receiver chain, as well as potential multipath images of the transmitted signal. Validation will involve field testing the opto-canceller by setting up test scenarios on the ORBIT testbed at WINLAB.Broader Impact: The proposed research will improve the spectrum utilization of future wireless systems, an issue of critical national importance. Additionally, the project will educate students and post-doctoral fellows in the inter-disciplinary area of RF-photonics as applied to advanced radio systems.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Paul Prucnal / prucnal@ee.princeton.edu	Princeton University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: End-User Behavior and Prospect Pricing in Wireless Data Networks	1421961	is approaching 7B, even creating a reality that in some parts of the world, there are more people with access to a phone than with access to electricity at home. The advent of machine-to-machine communications adds increased pressure on wireless system capacity. In fact, there is a recognition and push in both industry and academia towards the goal of achieving "1000x" capacity for wireless. The solution approaches range from spectrally agile cognitive radios with novel spectrum sharing, to use of higher frequency electromagnetic spectrum as well as smaller and denser cell deployments referred to as heterogeneous networks (HetNets). While this is a much needed activity with many challenges to overcome, providing a spatially high density of wireless/wired backhaul as required for HetNets is expensive and the overwhelming demands on wireless capacity fundamentally remain, in that state-of-the-art systems are nowhere near the 1000x capacity target goals and perhaps even an order of magnitude or two away. Wireless service providers (SPs) in recent times have therefore resorted to control access and services being provided to end-users via differentiated and hierarchical monetary pricing. As such, end-users may have to make decisions on data rate and price offerings that may be presented to them when they need service in high user-density dynamic spectrum settings. A complementary approach termed "prospect pricing" is proposed as a way to support data demand and relies on influencing end-user (human) behavior using dynamic pricing algorithms when technological solutions by themselves cannot satisfy the demands of wireless data. The research agenda seeks to design and study wireless network pricing from a cognitive psychology perspective, thereby presenting a novel framework to understand how wireless networks can be influenced by end-user behavior and vice-versa. The successful completion of this research will serve up useful pointers to how prospect pricing can be used by the SPs to manage the ever increasing demand for data.Policing mechanisms that influence wireless device behavior and thereby drive systems to better operating points have been addressed amply in the radio resource management literature. These mechanisms essentially are borne out of expected utility theory (EUT) based microeconomics approaches, and implemented via engineered system design, i.e., embedding these strategies in the link layer and network layer protocols that are executed by wireless devices. When a SP controls access to end-users via differentiated and hierarchical monetary pricing, then the performance of the network is directly subject to end-user decision-making that has shown to deviate from EUT. Prospect Theory, a Nobel prize winning theory that explains real-life decision-making and its deviations from EUT behavior, is used to design "prospect pricing" for wireless networks. Specifically, dynamic pricing algorithms for wireless data are designed to enable HetNets to manage the ever increasing demand for data, especially when both spectrum and infrastructure resources are constrained. Using a mix of theory, algorithm development and experimentation, the research agenda proposed by a team comprised of a wireless networking/systems researcher and a	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Narayan Mandayam / narayan@winlab.rutgers.edu	Rutgers University New Brunswick	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Enhanced Interference Alignment for Networks using Reconfigurable Antennas	1422964	pervasive in our everyday lives. The traditional approach of dealing with interferenceis to share limited resources, such as spectrum, among many users such that a given resource is used byonly one user at a time. The recent notion of interference alignment (IA) proposes a new paradigm whereseveral users can simultaneously send information by sharing the same resource. This new approachresults in increased network capacity where every user gets half the interference-free throughput. In thisresearch, the project team will leverage reconfigurable antenna systems to design and enhanceinterference alignment techniques for multi-user wireless networks. Reconfigurable antennas are capableof electronically switching between different radiation patterns (or `states`) in response to the needs ofthe overlying communication link and network. In this regard, reconfigurable antenna systems represent asignificant new degree of freedom for developing interference management techniques. The project teamproposes new ways of using the antennas to enable more practical solutions for future multi-usernetworks and also provide a software defined radio platform to enable further research within thecommunity.While the vast majority of existing research in this area considers an antenna to be a monolithic `blackbox`, the project team will develop and demonstrate new compact form-factor electronicallyreconfigurable antenna technologies that are capable of providing pattern agility. This additional degreeof freedom allows for the dynamic selection of radiation patterns to seamlessly integrate with, and extendinterference alignment techniques. The first objective is to demonstrate how electrically reconfigurableantennas can greatly enhance the sum capacity achieved via distributed interference alignment, especiallyat low SNR, by improving the subspace design. The second objective is to demonstrate how blindinterference alignment can be practically achieved by combining antenna state selection algorithms withmultiple physical layer transmission schemes. The additional channel diversity provided byreconfigurable antennas comes with an overhead to acquire information about the state of all the channels,revealing a need for a strategy to select the optimal state and most importantly an ability to learn thechanges in the channel state in order to adapt. With these goals in mind, the project team will utilizeonline learning based on multi-armed bandit theory to design algorithms to control and adapt the state of areconfigurable antenna system. For the multi-user network, the team will analyze the cost of learningunder an unknown statistical model of the channel and compare it with the oracle with full priorknowledge. Finally, the team will focus on implementing the developed interference alignment algorithmson Drexel`s Software Defined Communications (SDC) testbed. The SDC testbed is based upon a ScalableOFDM physical layer, which operates close to many different standards. The project team will developnew blocks for precoding and decoding, cross-transmitter symbol-timing synchronization, as well asimplement more efficient synchronization techniques that require less data overhead. The proposedcombination of the Drexel SDC testbed with IA algorithms will result in a product	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kapil Dandekar / dandekar@coe.drexel.edu	Drexel University	no-value

National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; RES IN NETWORKING TECH & SYS	REU Site: Cognitive Communications	1156503	This award provides funding to renew the existing successful CISE Research Experiences for Undergraduates Site at Virginia Tech University. The REU Site will provide undergraduate students with immersive, high-quality learning and interdisciplinary research experience in cognitive communications, an emerging wireless communications technology. The students will implement their projects on the Virginia Tech Cognitive Radio Network testbed (VT-CORNET). The students will participate in professional development activities that make them more aware of graduate school and professional aspects of a computing career. The students will join a variety of funded research projects ongoing at the Wireless@VT center and work with a faculty team with outstanding experience and expertise to direct the intellectual component of each project. Cognitive communications is an emerging and exciting field that promises to transform the wireless communications industry. The focus will be on topics such as spectrum management for wireless networks, public safety interoperable radios, rural broadband access, usability and human factors principles for cognitive engines and interface design that are important and timely. Thus the project has the potential to contribute to the advancement of research and discovery in an important and timely area of computing.The broader impacts of the project include providing a quality research experience to undergraduate students, particularly students from underrepresented groups and from institutions with limited research environments. Thus this project has the potential to produce new computer science graduate students and faculty members and to advance discovery and understanding while promoting learning.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Carl Dietrich / cdietric@vt.edu	Virginia Polytechnic Institute and State University	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Collaborative Research: Future Small-Cell Networks Using Reconfigurable Antennas	1457306	The future proliferation of wireless systems and services is dependent on the design of flexible radio architectures that can adapt to the rapidly changing wireless environment. Since usable spectrum is limited, and modulation and coding techniques are approaching their Shannon capacity limitation, improving capacity through increased spectrum reuse and interference mitigation has become a high priority in future cellular networks. Industry leaders have focused on a multi-tiered heterogeneous network structure, where small-cell (e.g., pico-cell, femto-cell) base stations are deployed to meet capacity demand. Among the technical challenges making full-scale deployment of small-cell base stations possible, interference management still looms the largest. This project focuses on providing wireless systems with the available hardware and algorithmic tools to make intelligent decisions about antenna configuration for small-cell base stations to mitigate interference and improve network capacity and coexistence in a heterogeneous network environment.This project is composed of three main research thrusts: i.) Algorithm and System Design; ii.) Antenna and Transceiver Design; and iii.) Testbed Implementation. The first focus is on the mathematical modeling and overall system design of small-cell networks making use of reconfigurable antennas. A vital component of this overall system design is the development of efficient and effective analytical tools and algorithms for downlink transmission, focusing on directional network design, algorithms for directionality selection, and base station user association. The second thrust includes the development of practical reconfigurable antennas and transceiver processing techniques for small-cell base stations. The project team is adapting reconfigurable metamaterial and alford loop antenna designs to provide new, compact reconfigurable antenna architectures with both beam steering and variable beam width capabilities. Using these new antenna technologies this research enhances direction of arrival and digital pre-distortion techniques for enhanced small-cell uplink and downlink. The cornerstone of this research is the design of a fully implemented, programmable across-the-stack SDR platform with integrated reconfigurable antennas. This project makes use of open-source technologies and will result in the deployment of a fully functional cellular backbone system, consisting of both macro-cell and small-cell base stations.This project leverages collaboration between Drexel University and WPI, along with a strong international collaboration with the University of Oulu, VTT Technical Research Centre and Tampere University of Technology. This ongoing collaboration with Finnish institutions continues to provide novel international research experiences for undergraduate and graduate students as well as pilot testing for dissemination of the developed testbed.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Kapil Dandekar / dandekar@coe.drexel.edu	Drexel University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Pervasive Spectrum Sharing for Public Safety Communications	1444077	Next-generation public safety communication (PSC) systems must deliver high-capacity wireless services to public safety personnel and users in disaster-affected areas, with little reliance on infrastructure. Remarkably, modern-day PSC systems have yet to catch up with the past decade`s wireless revolution, as they still rely on technologies of yesteryears that fall short on delivering high-speed wireless access. Indeed, coping with the foreseen stringent service requirements in future PSC systems mandates major innovations that can increase spectral efficiency. This, in turn, requires tackling multidisciplinary challenges: 1) developing incentive mechanisms for government agencies, providers, and users to share their precious spectrum resources; 2) dynamically managing interdependent spectrum markets; and 3) efficiently modeling and operating sustainable communication protocols that can function with little infrastructure support. This project brings together researchers in wireless communications and networking, game theory, mathematics, and public safety administration to address these challenges and boost the efficiency of PSC by introducing a novel framework that provides the necessary analytical tools for modeling, designing, analyzing, and operating large-scale spectrum sharing in disaster and emergency situations. The overarching scientific merit of this research is to initiate the much-needed leap towards a more open, highly participatory, and pervasive sharing of the wireless spectrum for PSC. This project offers an array of spectrum sharing innovations: 1) new economic approaches and PSC mechanisms that provide incentives for government agencies, providers, and end-users, to effectively subsidize the scarce radio spectrum and facilitate novel public safety and spectrum allocation policies; 2) a foundational framework that tightly integrates tools from game theory and auction theory for enabling a dynamic operation of co-existing spectrum sharing markets with multi-hop capabilities; 3) novel realistic models for characterizing wireless channels, traffic, topology, user behavior, and mobility in PSC; and 4) effective and accelerated transition of theoretical results to practice via a new PSC testbed for extensive validation and close collaboration with several major industry partners and local public safety agencies. In a nutshell, the project provides a new generation of PSC systems and protocols that expedite the response to disasters, save lives, and reduce economic costs.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Murat Yuksel / yuksem@unr.edu	Board of Regents, NSHE, obo University of Nevada, Reno	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	ECCS - EARS: Collaborative Research: Enhanced Radio Spectrum via Information Acquisition and Learning	1247995	This research focuses on the problem of information acquisition in the context of spectrum sensing and utilization where a (set of) decision maker(s), by carefully controlling a sequence of actions with uncertain outcomes, dynamically refines his/her belief about stochastically time-varying parameters of interest such as spectrum availability and quality, in order to communicate over that spectrum as efficiently as possible.The research represents a new theoretical framework for stochastic learning and decision-making in such settings termed Information Acquisition and Utilization Problems (IAUP). Motivated by a synthesis of the researchers` prior works on adaptive sampling, active hypothesis testing, and restless multi-armed bandits, this framework is particularly apt for problems of spectrum sensing and access for several reasons. First, unlike more general stochastic control frameworks such as partially observable Markov decision problems (POMDP`s), the IAUP is a purely informational problem in that the actions of the decision maker change only its information state, but not the state of the underlying environment (spectrum quality). Second, in an IAUP there is a conceptual distinction between two kinds of actions: those taken to obtain/refine the information state, and those taken to utilize the current information state, potentially allowing for tractable solutions in many cases where a separation theorem can be proved between these two sets. Finally, an IAUP can explicitly capture the tradeoff between the cost of spectrum sensing and the accuracy and completeness of the information that can be obtained.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Tara Javidi / tara@ece.ucsd.edu	University of California-San Diego	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Efficient Temporal-Spatial Spectrum Sharing through Voluntary Exchange	1343380	The goal of this project is to develop more efficient and flexible access to radio spectrum. Typically radio spectrum bands are allocated by the FCC to commercial and noncommercial users who can be thought of as "primary users." Such a user may not need to utilize the spectrum all of the time. This has led to the existence of "secondary users" who access the spectrum opportunistically. However, such secondary usage can bring interference to other secondary users and primary users. Furthermore, primary users have little motivation to permit this type of secondary use as there is no benefit to them and only risk.To encourage spectrum sharing and enhance spectrum efficiency, it is important to have a mechanism or solution concept that creates the correct incentives for both primary and secondary users. However, there are significant communication costs as well as limitations involved in the sale or exchange of spectrum bands. Therefore, spectrum sharing through voluntary exchange is proposed to address these challenges for efficient spectrum access. The research project outlined here will determine which type of spectrum sharing mechanisms would be better for primary users, secondary users, and for society.More specifically, voluntary exchange mechanisms including monetary exchange and barter are examined to promote spectrum sharing between primary and secondary users where both the communication costs and constraints for information exchange are reflected in the spectrum sharing models. Moreover, new ways to avoid interference for users located in different regions are examined to further enhance spectrum efficiency.Sharing spectrum and improving spectrum efficiency are current priorities of lawmakers and spectrum regulators, as evidenced through the National Broadband Plan (2010), the PCAST report on sharing spectrum between the federal government and non-government users (2012), the Spectrum Act of 2012, and two presidential memoranda on the topic (2010 and 2013). Clearly, development and application of appropriate economic theories to foster more opportunities for spectrum sharing is a desirable outcome with significant broader impact to all stakeholders, including commercial broadband providers, public safety, homeland security, and national defense.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiangwei Zhou / xzhou@engr.siu.edu	Southern Illinois University at Carbondale	no-value

National Science Foundation (NSF)	COMM & INFORMATION FOUNDATIONS	CIF: Small:Toward a Stochastic Geometry for Cellular Systems	1525904	scarce. As a result, novel architectures and transmission techniques are needed for cellular networks to improve their spectral efficiency and provide consistent and high-speed wireless service for all users. The two key approaches to achieve this goal are increased network density and heterogeneous network architectures, where multiple tiers of base stations are deployed with different capabilities, depending on the user density and traffic demands. For such networks, new mathematical models and techniques are needed that capture their inherent randomness and heterogeneity. Stochastic geometry is a mathematical theory that is ideally suited for such problems. It provides both the models and the theory for the analysis of the network performance and user experience. This project focuses on the development of stochastic geometry-based tools tailored to the fifth generation of cellular systems (5G), which will result in novel design insights and help identify promising network architectures without the need for extensive and expensive simulations. Hence it will have a significant impact on the discussions on 5G that currently dominate the wireless industry and academic research and may even influence the standardization process. In addition, the project devises novel analytical techniques and makes theoretical contributions that are applicable beyond cellular networks, and it helps train future generations of students in emerging wireless technologies and analysis techniques.As cellular networks become denser and more heterogeneous, the locations of the base stations become more irregular due to restrictions on the placement and adaptation to users and traffic. As a result, classical network models such as lattices become outdated and need to be replaced by models that capture the inherent randomness in the base station locations. Recently, researchers have applied techniques from stochastic geometry for the analysis of some of the key metrics of cellular systems, most notably the signal-to-interference ratio, which determines the quality of the wireless connections. However, the underlying model was mostly restricted to the Poisson point process, which is analytically convenient but not very realistic. The analysis of more accurate models and of advanced transmission schemes such as base station cooperation and multi-antenna transmission has proven rather difficult. Hence there is an urgent need to devise new models that accurately describe current and future cellular networks and to significantly extend the set of tools for their analysis. This proposal aims at meeting this need by applying novel ideas and recent insights to develop new theoretical methods that expand the currently available ones in three main directions: (1) efficient ways to obtain highly accurate approximate results for diverse network models; (2) fine-grained and sharp results on the experience of individual users; (3) fundamental insight into the impact of the temporal dependence of the interference in cellular systems. The analytical methods used include Palm theory, Tauberian theorems, series and factorial moment expansions, and general probability theory, and the models will be validated with actual data.	Technologies and applications for efficient spectrum use or legacy transformation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Martin Haenggi / haenggi.1@nd.edu	University of Notre Dame	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Cognitive and Efficient Spectrum Access in Autonomous Wireless Networks	1247929	The objective of this project is to enable more efficient and reliable operation of autonomous femtocell networks with agile spectrum access, autonomous interference control, as well as intelligent network self-organization and self-optimization. This project falls into four interacted thrusts: 1) Incorporate cognition into the femtocell networks to cognitively reuse the available spectrum sensed; 2) Develop distributed, dynamic and cooperative interference management schemes exploiting antenna techniques and based on sensed environmental conditions; 3) Investigate the scenarios and schemes that femtocells can be exploited to facilitate macrocell transmissions, and the potential gains in capacity, coverage and reliability; 4) Incorporate interference cancellation for data multicast, and develop techniques to support multiuser video streaming. The project also develops a testbed with open source programmable wireless platforms, for prototyping and evaluating the effectiveness of various techniques developed. The proposed research has the potential to significantly increase the capacity and resilience of existing and future wireless networks. The agility and resilience of the system will also make it instrumental to support communications and applications that are important for national security and economy. The PIs will facilitate technology transfer through their industrial partners and industry affiliate programs. Complementary to the research agenda, the project will carry out a broad range of education and outreach activities, including integration of research findings into the courses, promoting underrepresented and undergraduate populations, and engaging with the K-12 schools to raise the level of student interests in pursuing advanced education and career in the areas of engineering and mathematics.	Technologies and applications for efficient spectrum use or legacy transformation; Wireless Security; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Harish Viswanathan / harish.viswanathan@alcatel-lucent.com	Lucent Technologies Bell Laboratories	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Cognitive Networking for Wireless Communication in Rural Areas: A Directional Antennas and Propagation Modeling Approach with Low Cost Implementation	1443875	coverage due to inaccessibility in rural areas. Availability of such services is essential to education, jobs, health care, and the economic development of these areas. The objective of the proposed work is to develop a practical and affordable wireless communication system that covers and best fits the needs of rural areas. The proposed technology is particularly suitable for applications in areas with vast coverage requirements, rough terrain, and sparse access nodes and base stations. The project involves the development of an integrative approach based on the utilization of "advanced" slow moving (or stationary but strategically placed based on sight planning) mobile nodes with extended monitoring and control capabilities to facilitate the use of advanced antennas and propagation technologies while not requiring changes in existing Medium Access Control (MAC) standards and upper layers of the ISO communications model. The proposed affordable wireless communication and connectivity technology in rural areas will have significant educational, job creation, health care, and economic development impact on minorities and underrepresented communities in the US and throughout the world. It represents a solution that fits the long unaddressed needs of these communities. Demonstrating the proposed technology and its use in rural areas in Hawaii, and perhaps beyond, will have significant economic, educational, and health care (remote patient monitoring) benefits to these communities. As wireless protocols and implementation standards continue to expand with additional capabilities to meet fast growing demands, it is also becoming more difficult to interface and integrate special needs such as those of rural areas with set protocols and standards in the ISO communication model. The proposed work addresses this issue, and an affordable, expandable, and effective system will be developed that utilizes innovative technology and research advances without requiring changes and adjustments in the MAC and upper layers of the ISO model. The proposed procedure is based on the use of the so called "advanced" nodes which include the use of "directional antennas," beam steering capabilities, integration of propagation modeling, implementation of cognitive spectrum sensing capabilities, and also providing networking topology controls in each of these nodes. Specific innovations include development of new broadband, dual polarization and low cost directional antenna array designs with beam steering capabilities and the implementation of multi-level details propagation modeling to enhance receivers performance while minimizing required computation time and resources. The proposed cognitive network system and the associated introduction of the "advanced" nodes, not only provide communication advantages such as extended range and area coverage using high gain antennas and the relatively lower power requirements when directional (rather than omnidirectional) antennas are used, but the integration of the communication channel links controls in these units facilitates interfaces between the proposed directional physical layer with the MAC and other upper layers in the ISO model without modification or alteration of set standards and protocols. A team of investigators with	Technologies and applications for efficient spectrum use or legacy transformation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Magdy Iskander / iskander@spectra.eng.hawaii.edu	University of Hawaii	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	NeTS: Small: Networking at Terahertz Frequencies	1217994	annual growth in demand range from 71% in Japan to over 117% in the U.S. Projecting this ahead a decade implies per-user wireless bandwidth needs of tens of gigabits per second, which is at least two orders of magnitude greater than what most users see today.Applications driving such a relentless thirst for bandwidth are quite diverse. From a consumer standpoint, key drivers include the evolution of applications such as ultra high-definition television while in the business domain applications include networking hundreds of thousands of computers together in data centers or delivering very high quality multimedia for medical and other similar applications. This project seeks to exploit a relatively unexplored part of the wireless spectrum to deliver data at rates of terabits/sec. The spectrum in question is called the terahertz spectrum and extends in frequency from 300 GHz to 3.1 THz.The challenges of delivering terabit data rates over the terahertz spectrum are many and range from a limited understanding of communication at these frequencies to utilizing the vast bandwidth available for establishing communication links to understanding networking at these frequencies. This project will provide answers to some of the larger open questions including channel characterization and modulation for achieving terabit rates. Techniques used for high speed communications today cannot be logically extrapolated to the terahertz band due to the massive amount of bandwidth involved which constrains devices and has complex unknown propagation properties. This project proposes an innovative way of exploiting the terahertz bandwidth to manufacture pulses, each of which carry large amounts of data. As a result, a terabit of information can be transmitted per second while using a relatively slow clock and inexpensive devices. The feasibility of this technique will be studied in a systematic way by first performing detailed terahertz channel measurements followed by the development of channel impulse response models at these frequencies. The measurements will consider distances of up to the dimensions of a small room and will serve as input to a terahertz simulator that will be built as part of this work. Using the measurements in conjunction with detailed simulations, the project will answer questions about the expected channel capacity when using these types of pulses. In parallel with these studies, the project will experimentally characterize pulse behavior over varying distances and environmental conditions. The project thus seeks to fill in important holes in our understanding of terahertz communications and will pave the way for future development of terahertz communication systems.The broader impact of this work ranges from fundamentally influencing research directions in wireless communications to enabling the development of novel technologies for future generation communications. Furthermore, the terahertz measurement database developed as part of this project will be made public and will serve as a valuable resource to the broader scientific community. The project will also enhance the training of the future workforce via the development of new classes and including students in hands on measurement. Finally, the outcome of this work (terabit/sec data delivery) will ultimately influence the way	Technologies and applications for efficient spectrum use or legacy transformation; Modeling and Simulation;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Suresh Singh / singh@cs.pdx.edu	Portland State University	no-value

National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	CAREER: Towards Broadband and UAV-Assisted Heterogeneous Networks for Public Safety Communications	1453678	Public safety communication (PSC) can help save lives, property, and national infrastructure in case of incidents such as fires, terrorist attacks or natural disasters. Until recently, such communication has been mostly handled by wireless technologies operating in narrow spectrum bands. However, such technologies fall short of addressing public safety requirements, such as deep situational awareness features that necessitate video streaming capabilities. This research proposes the use of unmanned aerial vehicles (UAVs) along with cellular technologies within a novel and transformative framework that will serve as the pillar of next generation PSC systems. Reaping the benefits of the proposed architecture requires addressing several technical challenges including: 1) potentially damaged network infrastructure, as in the aftermath of an earthquake, causing severe connectivity problems; 2) dynamically varying interference between aerial and ground base stations as well as user equipment, hindering broadband throughput; 3) seamless connectivity problems, in the form of handover failures, exacerbated by dynamic interference and infrastructure mobility. For addressing these challenges, the proposed research will lay down an interdisciplinary research agenda that combines broadband wireless networks, UAV communications, software defined radios, reinforcement learning, and stochastic geometry, into an integrated and synergistic framework. The project will introduce several innovations that involve self organizing interference and mobility management techniques to achieve ubiquitous broadband connectivity for PSC networks. A comprehensive hardware/software PSC testbed with powerful UAV and radio equipment will be developed to validate, evaluate, and improve the proposed solutions. The theoretical and experimental outcomes will break new ground in PSC systems by enabling real-time wireless multimedia and deep situational awareness capabilities in mission-critical PSC scenarios. Close industrial collaboration will reinforce the proposed testbed, prototyping, and educational efforts, and allow training of undergraduate/graduate students in industrial labs. Outreach activities to local high-schools will attract underrepresented minorities, particularly Hispanics, into STEM areas and the field of wireless networks.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Ismail Guvenc / iguvenc@fiu.edu	Florida International University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Enhancement of Spectrum Decision through Probabilistic Graphical Models	1443861	The goal of this research is increase the consumer`s quality of service in environments where more and more services are competing for use of the radio spectrum. It is widely believed that future regulation of the spectrum will change from the current static environment, where opening new channels for communications takes years, to highly dynamic environment where smart radios will jump from frequency channel to frequency channel. In this dynamic environment, the consumer will share the spectrum with many different types of devices, including radars, other phones, Wi-Fi servers and a host of new smart devices. The new smart devices will constantly change their frequencies, data rates and modulation schemes, thereby creating a dynamic, more uncertain, environment. The scientists will explore how uncertainty influences the characterization of radio spectrum usage. The focus is on the sensing and decision-making aspects of the problem rather than management issues. The scientists will apply their experience with Artificial Intelligence and transfer techniques of dynamic problem solving from other domains. The proposed study has the potential to develop decision support models that will inform new policies for spectrum management in the future. This research project`s primary aim is to advance the knowledge and understanding of wireless communication scenarios to enrich the spectrum decision process in cognitive radio by evaluating the impact of uncertainty on the different cognitive cycle changes of adaptive radios. To achieve this goal, they propose to identify, classify, and characterize the random and deterministic variables present in a typical wireless scenario and model their causal relations, using probabilistic graphical models, such as Bayesian networks and influence diagrams.	Technologies and applications for efficient spectrum use or legacy transformation; Modeling and Simulation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Naima Kaabouch / naima.kaabouch@engr.und.edu	University of North Dakota Main Campus	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	CAREER: Cognitive Co-Existence in Heterogeneous Wireless Networks	1149981	Efficient spectrum sharing among disparate wireless systems without inter-system communication is the central problem in expanding existing and developing future wireless technologies. This proposal explores an integrated physical and network layer approach for spectrum sharing by developing algorithms and protocols that will allow heterogeneous networks to co-exist and maintain required interference constraints. The proposed framework is based on the novel idea of incorporating detailed real-time measurements and prediction of spectrum usage, including traffic parameters and network topology, into the design of cognitive protocols that respond to the actual spectrum occupancy in time, frequency, and space. The following critical enabling technologies of this framework are being developed: (i) identification of non-cooperative spectrally-overlapped transmitters based on location and modulation parameters; (ii) analysis and tracking of spectrum usage based on traffic estimation and prediction; (iii) cognitive co-existence protocols for spectrum sharing with combined traffic and location awareness. The objective of this research is to comprehensively analyze performance gains achieved by exploiting traffic and location awareness while taking into account estimation and prediction errors, physical limitations, and protocol overhead. The research approach is based on a closed loop between theoretical analysis, implementation, and experimental verification on the reconfigurable wireless testbed and network simulation tools. The algorithms, protocols and tools developed by this research will have practical impact on a broad range of wireless systems that share same spectrum resources including: current and future unlicensed bands, vehicular and safety networks, cellular infrastructure and femto cells, emergency and defense networks.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Danijela Cabric / danijela@ee.ucla.edu	University of California-Los Angeles	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: Collaborative Research: Holistically Application-Aware Multi-dimensional Cognitive Radio (HAMCR)	1352883	The overarching goal of the Holistically Application-Aware Multi-dimensional Cognitive Radio (HAMCR) research is to create a set of transformative and holistic technologies that enable substantial growth in the capacity of wireless networks, with support for diverse applications, but without increasing the available spectrum. The project is based on the observation that in today`s wireless networks the spectral allocation of resources is either independent of the applications` Quality of Service (QoS) requirements and of the user`s perceived QoS, or at best relies on a set of pre-defined fixed priorities. HAMCR maximizes spectrum utilization by trading off the spectral resource allocations of connections for the application-level QoS, while still maintaining acceptable levels of QoS for the individual users of the underlying applications, thus satisfying an increased number of users in times of shortage of spectral resources. Such an application-aware cognitive radio significantly advances spectrum utilization by intelligently supporting the expected traffic growth and by dynamically satisfying the changing demands in traffic. To achieve the above goal, the objectives of the proposed research are to: 1) Develop the fundamental design of middleware to optimize the allocation of the available physical resources by characterizing the applications` parameters and by trading off application-level QoS for spectral resources, while minimizing the degradation to the user-perceived QoS, thus maximizing the spectrum utilization; and 2) Design and implementation of a simulated wireless testbed to assess the feasibility of the application-based resources allocation by evaluating the complexity and the gain of the proposed approach for a number of realistic communication scenarios. The results of this project are expected to forge a new direction in the cognitive radio field, i.e., application-aware cognitive radio.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Richard Gitlin / richgitlin@usf.edu	University of South Florida	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Crowd-based Spectrum Monitoring and Enforcement	1443945	The scientists identify an important issue for a world of devices all communicating wirelessly: "How to identify malfunctioning devices or those not fairly sharing the spectrum with others?" The scientists explore scenarios for leveraging local, crowd-sourced mobile devices to detect and identify unauthorized transmitters. The goal of this technique is to reduce the cost of enforcement of network rules by adding the capability of some smart phones to sense the radio spectrum use and report back to a central database.The PIs propose to develop a Crowd-based Spectrum ENforcement System (CSENS), which takes a data-driven approach to spectrum enforcement. Specifically, the PIs propose to conduct 3 tasks: (i) real-time on-demand spectrum monitoring, which enables real-time responses to spectrum measurement tasks; (ii) utilizing physical layer features to embed cryptographic spectrum permits into transmissions, which enables reliably distinguish between authorized and unauthorized spectrum users; (iii) using a library of known signatures for network applications, unauthorized transmitters can be uniquely identified.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xia Zhou / Xia.Zhou@Dartmouth.edu	Dartmouth College	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Crowd-based Spectrum Monitoring and Enforcement	1443956	The scientists identify an important issue for a world of devices all communicating wirelessly: "How to identify malfunctioning devices or those not fairly sharing the spectrum with others?" The scientists explore scenarios for leveraging local, crowd-sourced mobile devices to detect and identify unauthorized transmitters. The goal of this technique is to reduce the cost of enforcement of network rules by adding the capability of some smart phones to sense the radio spectrum use and report back to a central database.The PIs propose to develop a Crowd-based Spectrum ENforcement System (CSENS), which takes a data-driven approach to spectrum enforcement. Specifically, the PIs propose to conduct 3 tasks: (i) real-time on-demand spectrum monitoring, which enables real-time responses to spectrum measurement tasks; (ii) utilizing physical layer features to embed cryptographic spectrum permits into transmissions, which enables reliably distinguish between authorized and unauthorized spectrum users; (iii) using a library of known signatures for network applications, unauthorized transmitters can be uniquely identified.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Haitao Zheng / htzheng@cs.ucsb.edu	University of California-Santa Barbara	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Large-Scale Statistical Learning based Spectrum Sensing and Cognitive Networking	1343156	As cognitive radio (CR) research advances to multihop and complex systems over large geographic regions, the spectrum utilization enhancement should be generalized to fully exploit the spectrum usage diversity in three dimensions (3D): time, frequency, and space, with new emphasis on the under-explored spatial dimension. Accordingly, this project focuses on the following three research objectives. The first one is to utilize the recent advancements in statistical learning over big data to develop efficient 3D spectrum sensing schemes, where a hierarchical approach is taken in developing novel finite-bit and single-bit learning techniques to efficiently explore the correlation structure across the three dimensions, with an advanced distributed approach also developed. The second one is to develop two key building blocks in large-scale CR networking based on the 3D spectrum sensing: 1) a novel multi-scale routing scheme to enhance the overall spectrum utilization, with a focus on exploiting the layered spectrum usage correlation structure in the spatial dimension; and 2) a reliable hierarchical common control channel identification scheme. The last research objective is to validate some key aspects in the proposed sensing and networking schemes via both intensive simulations and a concept-proving testbed. Throughout the project, an interdisciplinary approach is taken to combine the methods of statistical learning, signal processing, and wireless networking, with the core built upon the hierarchical treatment of both spectrum usage statistics and CR networking methodologies. The project provides both theories and algorithms for large-scale spectrum sensing and cognitive networking. Through a coherent education plan, the research findings will be incorporated into courses, and disseminated to the community via journal papers and conference presentations.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Tao Shu / shu@oakland.edu	Oakland University	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: EARS: Large-Scale Statistical Learning based Spectrum Sensing and Cognitive Networking	1343155	As cognitive radio (CR) research advances to multihop and complex systems over large geographic regions, the spectrum utilization enhancement should be generalized to fully exploit the spectrum usage diversity in three dimensions (3D): time, frequency, and space, with new emphasis on the under-explored spatial dimension. Accordingly, this project focuses on the following three research objectives. The first one is to utilize the recent advancements in statistical learning over big data to develop efficient 3D spectrum sensing schemes, where a hierarchical approach is taken in developing novel finite-bit and single-bit learning techniques to efficiently explore the correlation structure across the three dimensions, with an advanced distributed approach also developed. The second one is to develop two key building blocks in large-scale CR networking based on the 3D spectrum sensing: 1) a novel multi-scale routing scheme to enhance the overall spectrum utilization, with a focus on exploiting the layered spectrum usage correlation structure in the spatial dimension; and 2) a reliable hierarchical common control channel identification scheme. The last research objective is to validate some key aspects in the proposed sensing and networking schemes via both intensive simulations and a concept-proving testbed. Throughout the project, an interdisciplinary approach is taken to combine the methods of statistical learning, signal processing, and wireless networking, with the core built upon the hierarchical treatment of both spectrum usage statistics and CR networking methodologies. The project provides both theories and algorithms for large-scale spectrum sensing and cognitive networking. Through a coherent education plan, the research findings will be incorporated into courses, and disseminated to the community via journal papers and conference presentations.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Shuguang Cui / cui@tamu.edu	Texas A&M Engineering Experiment Station	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	NeTS: Small: Collaborative Research: OSTARA: An Optically-based Simultaneous Transmit And Receive Architecture for Enhancing Wireless Communications	1217517	Improving the usage of communication spectrum resources is critical to future wireless systems. The OSTARA project focuses on the development of RF photonic techniques that support the ability to simultaneously transmit and receive in wireless devices. The effort involves a mix of theoretical development (specifically investigating potential improvements in capacity), as well as systems validation efforts involving building an opto-cancellation circuit capable of cancelling out co-site interference associated with simultaneous transmission and reception. . Specifically, the theoretical component of the effort will involve using ray-tracing to understand the role of cancelation of multipath components on communication rate, as well as an investigation into the impact of idealized cancellation on network capacity using graph coloring. The systems component of the effort will involve developing photonic circuits that subtract off the transmitted signal from the receiver chain, as well as potential multipath images of the transmitted signal. Validation will involve field testing the opto-canceller by setting up test scenarios on the ORBIT testbed at WINLAB.Broader Impact: The proposed research will improve the spectrum utilization of future wireless systems, an issue of critical national importance. Additionally, the project will educate students and post-doctoral fellows in the inter-disciplinary area of RF-photonics as applied to advanced radio systems.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Wade Trappe / trappe@winlab.rutgers.edu	Rutgers University New Brunswick	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Multi-Input Multi-Output (MIMO) Aware Cooperative Dynamic Spectrum Access	1443916	[illegible] framework, termed McDysa, which enables multiple primary users and multiple secondary users to cooperate in dynamic spectrum sharing. By exploiting the underlying cognitive radio and MIMO techniques, McDysa is expected to achieve significant gains on spectrum efficiency while providing substantial enhancements to physical layer security as well. The technical merit and impact of this project are both fundamental and applied, including new problems, algorithms, and methodologies. The McDysa architecture considers multiple simultaneous primary- and secondary-user transmissions by exploiting MIMO techniques. A number of problems studied in the project may foster the development of novel techniques and methodologies toward MIMO-aware dynamic spectrum access. Examples include the novel problem of MIMO-enabled relay selection, insightful analysis of McDysa transmission capacity, and the consideration of secrecy capacity enhancement via friendly jamming. As many of the methodologies in McDysa leverage knowledge from other domains such as game theory, the research outcomes of this project may also motivate advancements of the corresponding domain-specific research. The broader impact of this project also extends to education. The project contains a detailed plan for disseminating the research results and for outreaching to students from underrepresented groups via various channels established in the past years. It also includes a plan for integrating undergraduate and graduate education with research through curriculum development and student involvement. Specifically, the testbed validation of McDysa can offer undergraduate and graduate students valuable hands-on experience, and is therefore an excellent educational vehicle to broaden the participation of students, especially those from underrepresented groups, in computer science research. Technically, this project defines novel problems and develops new performance-optimization techniques in the following three thrusts that are critical to MIMO-aware cooperative dynamic spectrum access: (i) Relay selection and resource sharing, which focuses on developing novel centralized and distributed relay selection and resource management algorithms based on game theory to enable multiple MIMO-empowered primary and secondary users to cooperate for joint optimization. (ii) Achievable transmission capacity analysis, which investigates the achievable transmission capacity of secondary networks and secrecy capacity of the primary network, and the usage of beamforming optimization to maximize such capacities. (iii) Secrecy capacity enhancement, which studies the usage of two friendly jamming mechanisms, cooperative jamming and artificial interference, in the design of novel beamforming techniques and interference signals for nulling the interference at the receivers, in order to enhance the secrecy capacity of the primary network. Besides the three thrusts, this project also includes the design and validation of a testbed that supports a number of experimental tasks for validating the effectiveness of approaches and methodologies developed in the project. This project also has strong societal impact as the rigorously proven solutions developed in the project can serve as guidelines and backbone for	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dechang Chen / dchen@usuhs.mil	Henry M Jackson Fdn for Advmt of Military Medicine	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS); SPECIAL PROJECTS - CISE	Collaborative Research: Spectrum Efficient Waveform Design with Application to Wireless Networks	1247694	Spectrum efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized. In this project, innovative spectrum efficient waveform designs are studied towards narrower mainlobe and lower sidelobe in spectrum. It has been recognized that judicious use of properly designed waveforms, coupled with advanced receiver strategies, is fundamental to fully utilizing the capacity of the electromagnetic spectrum. This project seeks innovative approaches on nested and co-prime samplers for spectrum efficiency, and subsequently applies it to wireless networks. Different waveforms designs and diversities are studied based on nested and co-prime samplers. Co-prime samplers are used for Multi-Input Multi-Output communication system. In the application to spectrum efficient wireless networks, nodes exchange information over a common wireless channel. Under different traffic scenarios and different constraints, e.g., bandwidth and signal to noise and interference ratio, the amount of data exchanged among these nodes may vary. A key question then is how the throughput capacity of wireless network improves with the new waveform design schemes and different network setup and how it grows with the number of nodes in the network. This project seeks to help reach the nation's broadband goals and the larger objective of alleviating growing pressure on limited spectrum resources. This project will attract minority and woman students to participate in the project.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Hyeong-Ah Choi / hchoi@gwu.edu	George Washington University	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS	EAGER: Cognitive Radio with 2-D Cognition: Dynamic Spectrum vs. Power Accesses	1265227	This project focuses on the fundamental tradeoff between spectrum efficiency and energy efficiency in cognitive radio systems by exploring the correlations across both spectrum and energy domains, in the notions of both frequency holes and energy holes. The considered application scenario is a spectrum sharing system with both legacy and cognitive radios, where the nodes are powered by either smart grids or environment energy harvesters or a mix of two. The three main research objectives are: develop joint 2-D sensing scheme to explore the correlation between frequency holes and energy holes; derive efficiency maximizing resource allocation schemes considering constraints in both energy and spectrum domains; and study performance enhancement mechanisms in the framework of collaborative clouds via node conferencing. Novel interdisciplinary approaches are applied to combine the methods of 2-D statistical signal processing, non-convex optimization, and analytical energy harvesting system modeling to study the unique problem considered for the newly defined cognitive radio systems with 2-D cognition. The project provides both theories and algorithms for energy-efficient operation of future cognitive radio systems with accesses to both spectrum and energy dynamics. The research findings will be incorporated into graduate courses; the results will be disseminated to the community via journal papers and conference presentations.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Shuguang Cui / cui@tamu.edu	Texas A&M Engineering Experiment Station	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Collaborative Research: Future Small-Cell Networks Using Reconfigurable Antennas	1457310	The future proliferation of wireless systems and services is dependent on the design of flexible radio architectures that can adapt to the rapidly changing wireless environment. Since usable spectrum is limited, and modulation and coding techniques are approaching their Shannon capacity limitation, improving capacity through increased spectrum reuse and interference mitigation has become a high priority in future cellular networks. Industry leaders have focused on a multi-tiered heterogeneous network structure, where small-cell (e.g., pico-cell, femto-cell) base stations are deployed to meet capacity demand. Among the technical challenges making full-scale deployment of small-cell base stations possible, interference management still looms the largest. This project focuses on providing wireless systems with the available hardware and algorithmic tools to make intelligent decisions about antenna configuration for small-cell base stations to mitigate interference and improve network capacity and coexistence in a heterogeneous network environment.This project is composed of three main research thrusts: i.) Algorithm and System Design; ii.) Antenna and Transceiver Design; and iii.) Testbed Implementation. The first focus is on the mathematical modeling and overall system design of small-cell networks making use of reconfigurable antennas. A vital component of this overall system design is the development of efficient and effective analytical tools and algorithms for downlink transmission, focusing on directional network design, algorithms for directionality selection, and base station user association. The second thrust includes the development of practical reconfigurable antennas and transceiver processing techniques for small-cell base stations. The project team is adapting reconfigurable metamaterial and alford loop antenna designs to provide new, compact reconfigurable antenna architectures with both beam steering and variable beam width capabilities. Using these new antenna technologies this research enhances direction of arrival and digital pre-distortion techniques for enhanced small-cell uplink and downlink. The cornerstone of this research is the design of a fully implemented, programmable across-the-stack SDR platform with integrated reconfigurable antennas. This project makes use of open-source technologies and will result in the deployment of a fully functional cellular backbone system, consisting of both macro-cell and small-cell base stations.This project leverages collaboration between Drexel University and WPI, along with a strong international collaboration with the University of Oulu, VTT Technical Research Centre and Tampere University of Technology. This ongoing collaboration with Finnish institutions continues to provide novel international research experiences for undergraduate and graduate students as well as pilot testing for dissemination of the developed testbed.	Technologies and applications for efficient spectrum use or legacy transformation; Test and Measurement;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Alexander Wyglinski / alexw@wpi.edu	Worcester Polytechnic Institute	no-value

National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: Collaborative Research: Cognitive Mesh: Making Cellular Networks More Flexible	1343361	Innovative use of wireless devices such as smartphones in various mobile applications has exacerbated the congestion over cellular spectrum. On the other hand, many licensed spectrum blocks are left unused. Although cognitive radios (CR) technology has emerged as an enabler for unlicensed users to opportunistically access the unused licensed spectrum, most previous works commonly assume that each user is equipped with a CR which can operate across a wide range of spectrum. This may be possible in theory, but may not be practical for light-weight devices such as cell phones. How to effectively utilize the CR technology to build more flexible networks so that even non-CR capable devices can benefit from the opportunistic access to the unused spectrum is therefore in dire need.In this project, the PIs propose a novel cognitive mesh assisted cellular network (CMCN) and investigate: 1) the architectural design of CMCN so that unoccupied licensed spectrum can be efficiently utilized and non-cognitive cellular devices can benefit from the CR technology, 2) spectrum and energy efficient CR mesh router placement under uncertain spectrum availability, 3) how to construct a fine-grained spectrum map to facilitate efficient spectrum allocation and intelligent traffic delivery, and 4) experimental validation and implementation for the proposed design. The research outcome provides a viable solution to the spectrum congestion in cellular systems. Moreover, with this flexible architecture, telecommunication industries can be rejuvenated with new innovations, leading to further development of cellular networks with high capacity and better support of new applications such as mobile healthcare, which has significant impact on individuals` lives and further provides greater opportunities for job creation and economic growth. The results of the project will be disseminated through publications and presentations. Finally, this project will actively recruit and train minority students for the future workforce and mentor junior faculty.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Miao Pan / panm@tsu.edu	Texas Southern University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS); SPECIAL PROJECTS - CISE	EARS: Collaborative Research: Intelligence Measure of Cognitive Radio Networks	1443885	Research on spectrum sharing has generated a large amount of spectrum measurement data and many spectrum sharing techniques. Most of the techniques are based on cognitive radio networks (CRNs) because the cognition capability is necessary for optimizing spectrum efficiency and guaranteeing safe coexistence in the presence of the spectrum uncertainty. Such cognitive capabilities collectively defines the intelligence of CRNs. Although cognition and intelligence are vital for CRNs, their quantitative specification is largely open. This project addresses this open question by developing a framework for investigating quantitatively the cognitive capabilities and the intelligence of CRNs. This project develops both a theoretical approach and an empirical approach to construct a CRN intelligence model. This model is inspired from the Cattell-Horn-Carroll human intelligence model. On the other hand, the pioneering theoretical approach is in sharp contrast to conventional human intelligence research that is mainly empirical. In addition, this project develops a CRN testing battery to measure the intelligence as CRN IQ (intelligence quotient) following psychometric practices. Finally, this project initiates innovative research in IQ-based multi-hop routing and IQ-based immunity to Denial-of-Service attacks, where innovative CRN techniques are developed with the aim of enhancing important cognitive capabilities. This project adopts a big data approach to exploit the vast amount of existing spectrum measurement data and CRN research results. Psychometric techniques are exploited to resolve challenges involved in this big data application.This project impacts society by expediting the commercial success of spectrum sharing technology. It integrates three traditionally disparate areas: wireless communications, psychology, and big data. The framework for constructing intelligence measure is useful to many other systems such as cognitive computing, cognitive control and cognitive radar. This project enhances the value of the spectrum measurement data and leads to a new direction for big data utilization. This project impacts education in many aspects, such as stimulating student research via the human intelligence analogy, supporting hands-on curriculum with the CRN testing battery, setting up CRN IQ competition projects, and outreaching to under-represented students and high school students.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiaohua Li / xli@binghamton.edu	SUNY at Binghamton	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	EARS: SAVANT - High Performance Dynamic Spectrum Access via Inter Network Collaboration	1247764	This project is aimed at achieving significant spectrum efficiency gains through inter network collaboration in radio resource management. The proposed SAVANT (spectrum access via inter network collaboration) architecture is based on a new protocol interface for dissemination of spectrum usage information, policies and algorithms between neighboring networks to enable spectrum coexistence algorithms that reduce interference and improve spectrum packing efficiency. A new inter-domain spectrum coordination protocol (ISCP) is being developed to enable independent networks to negotiate radio resource management policies and optionally merge radio resource controllers for joint optimization.The scope of research to be conducted includes ISCP protocol design/validation, evaluation of alternative algorithms involving network collaboration, prototype implementation and performance evaluation. The methodology for the project involves a mix of analysis, simulation and experimental prototyping. Generalized analytical models for radio localization, propagation and interference are developed and incorporated into simulation studies of inter-network cooperation using the ISCP protocol framework. These simulation models are expected to provide insight into the type of collaborative radio resource optimization algorithm to be used along with quantitative evaluation of ISCP overhead, complexity and performance. The project also includes an experimental prototyping track in which emerging software-defined network (SDN) technology is used to develop a proof-of-concept system with multiple collaborating networks. The proposed ISCP inter-network protocol has the potential for large gains in wireless spectrum utilization, and could thus influence future industry standards. The project will also produce educational materials for training of graduate students in software-defined networking and wireless systems.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Dipankar Raychaudhuri / ray@winlab.rutgers.edu	Rutgers University New Brunswick	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	ECCS - EARS: Collaborative Research: Enhanced Radio Spectrum via Information Acquisition and Learning	1248017	This research focuses on the problem of information acquisition in the context of spectrum sensing and utilization where a (set of) decision maker(s), by carefully controlling a sequence of actions with uncertain outcomes, dynamically refines his/her belief about stochastically time-varying parameters of interest such as spectrum availability and quality, in order to communicate over that spectrum as efficiently as possible.The research represents a new theoretical framework for stochastic learning and decision-making in such settings termed Information Acquisition and Utilization Problems (IAUP). Motivated by a synthesis of the researchers` prior works on adaptive sampling, active hypothesis testing, and restless multi-armed bandits, this framework is particularly apt for problems of spectrum sensing and access for several reasons. First, unlike more general stochastic control frameworks such as partially observable Markov decision problems (POMDP`s), the IAUP is a purely informational problem in that the actions of the decision maker change only its information state, but not the state of the underlying environment (spectrum quality). Second, in an IAUP there is a conceptual distinction between two kinds of actions: those taken to obtain/refine the information state, and those taken to utilize the current information state, potentially allowing for tractable solutions in many cases where a separation theorem can be proved between these two sets. Finally, an IAUP can explicitly capture the tradeoff between the cost of spectrum sensing and the accuracy and completeness of the information that can be obtained.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Bhaskar Krishnamachari / bkrishna@usc.edu	University of Southern California	no-value
National Science Foundation (NSF)	RES IN NETWORKING TECH & SYS; SPECIAL PROJECTS - CISE	NeTS: Medium: Collaborative Research: Integrated Dynamic Spectrum Access for Throughput, Delay, and Fairness Enhancement	1162057	The central theme of this project is to investigate methodologies and theories to enhance throughput, delay, and fairness of cognitive radio networks via integrated dynamic spectrum access. The research will develop new methods to:1) Extend spectrum sensing beyond just the presence and absence of the primary spectrum users` activities at certain spectrum bands/channels, but also their locations and transmit powers 2) Predict the primary spectrum user`s activity and its interval using game theoretic and statistical learning approaches3) Perform delay-aware spectrum management with a very comprehensive delay model considering all the factors that may affect the delivery latency of a packet, including the spectrum sensing delay, the transmission delay, the queuing delay, and the spectrum negotiation and scheduling delay 4) Share spectrum in a fair manner considering the tradeoff between fairness and throughput5) Propose a delay-aware fair routing protocol for throughput optimization which jointly considers throughput, delay, and fairness along with dynamic spectrum management.The project`s focus on dynamic spectrum access is of high national interest and can create significant impact on spectral usage policies and related industries in the telecommunication and information technology sectors. The project will also encourage and include under-represented and minority students to be part of this activity, while extending education and outreach plans to undergraduates and K-12 students.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Xiuzhen Cheng / cheng@gwu.edu	George Washington University	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Realtime GHz-Wide Spectrum Sensing and Acquisition Using the Sparse FFT	1343336	A GHz-wide radio spectrum sensing device capable of real-time, cheap, and low-power measurements will be made. The hardware will build on recent advances in the area of sparse Fourier transforms, which show that one can capture the frequency representation of a sparse signal without sampling it at the Nyquist rate. Preliminary results from a feasibility study show it is possible to recover GHz of bandwidth using a few low-speed low-power analog-to-digital converters similar to those used in inexpensive Wi-Fi cards.The research enables efficient spectrum utilization and scalable spectrum monitoring, and hence can help the government in managing this important resource. Further, realtime GHz spectrum sensing can help detecting radar signals, which are hard to detect using existing technologies. This could open up large swaths of spectrum for sharing, which would stimulate innovations in the mobile and wireless domain.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-3	Medium	ongoing	Dina Katabi / dina@csail.mit.edu	Massachusetts Institute of Technology	no-value

National Science Foundation (NSF)	SPECIAL PROJECTS - CISE	WiFiUS: Collaborative Research: Joint Network and Market Design for Content and Spectrum Sharing in Future 5G Networks (JoiNtMaCS)	1456887	Future wireless networks, as represented by the 5G concept and associated set of future standards, are expected to meet a diverse range of new requirements, leverage technological and regulatory advancements, and overcome the spectrum scarcity challenges. However, the success of a new technology is not only determined by its technical strengths but also by an intricate interplay between the economic considerations of the consumers/users, competing service and content providers, and governing/regulating public agencies. This project explores new wireless spectrum and content sharing concepts from both technological and business perspectives for future 5G networks. The overall objective of this project is to investigate and develop fundamental technological and business aspects of new spectrum/content sharing for 5G networks, that potentially could lead to significant technical performance improvements as well as revolutionize future wireless markets and operators business. The intellectual merits of the research can be described around its four research thrusts: (i) new, potentially transformative, business models for future 5G markets, and in particular new business models for mobile operators, (ii) in-network dynamic spectrum and content sharing and pricing mechanisms under various possible future architectures that take into account the new business models and bridge the gap between technological and economic considerations, (iii) collaborative content distribution that could lead to win-win relationships for wireless stakeholders, and (iv) intelligent content caching for improved performance for different network and business scenarios. A unique aspect of the research plan is that it stresses business and economic implications of various architectural choices, with formal models that capture technology performance as well as business/economic considerations. The research leverages the complementary expertise of the investigators to build a cohesive multi-disciplinary international team between the five PIs in the three institutions. It also leverages significant contacts with industry and start-ups to guide the research directions of the project as well as influence future technologies and markets.The broader impacts of this project include (1) the development of course projects that prepare students to understand the market/economic aspects of networking and the future architectural choices regarding content and spectrum sharing, (2) the development of a tutorial on this subject to be offered at summer schools and conferences, (3) K-12 outreach, (4) enhancement of student diversity and increase of number of women and under-represented groups in engineering, (5) technology transfer through collaboration with industry, and (6) development of dual-degree PhD programs.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Alhussein Abouzeid / abouzeid@ecse.rpi.edu	Rensselaer Polytechnic Institute	no-value
National Science Foundation (NSF)	SPECIAL PROJECTS - CISE; SPECIAL PROJECTS - CCF	WiFiUS: Collaborative Research: Sequential Inference and Learning for Agile Spectrum Use	1457076	A key imperative to expanding future wireless services is to overcome the spectral crunch. At present, static allocation and rigid regulation lead to under utilization of available spectral resources. Flexible spectrum use aims at exploiting under-utilized spectrum. Available spectrum opportunities may be non-contiguous, scattered over a large bandwidth, and are available locally and for a limited period of time due to the highly dynamic nature of wireless transmissions. This fuels the need to understand how to discover, assess and utilize the time-frequency-location varying spectral resources efficiently and with minimal delay. Moreover, it is critical to access identified idle spectrum in an agile manner.This project will design sequential inference and learning algorithms for agile spectrum access when the state of the spectrum varies rapidly. The key advantage of sequential algorithms, as compared to block-wise algorithms, is that they typically lead to significantly reduced decision delays. The overarching goal of this project is to design sequential inference and learning algorithms for agile spectrum utilization. In particular, this project will employ advanced sequential inference and learning methods for the following three interconnected yet increasingly sophisticated and demanding tasks: 1) to employ sequential reinforcement learning and sequential inference algorithms to design sensing policies for rapid spectrum opportunities discovery; 2) to design sequential algorithms for fast and accurate spectrum quality assessment; and 3) to build, maintain and exploit an interference map of the area where our network operates and represent it as a spatial potential field. The proposed research is expected to make substantial contributions to both applications and theory. On the application level, the proposed research has the potential to substantially improve spectral efficiency by introducing novel tools from sequential analysis, machine learning and statistical inference for the design of spectrum discovery, assessment and exploitation policies. On the theoretical level, the proposed project will advance the state of the art in sequential analysis and contribute new approaches to the general methodological base for optimal stopping, control and machine learning problems. Furthermore, new methods and theory of modeling and exploiting knowledge of interference using spatial potential fields, sequential statistics and advanced propagation modeling will be developed.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Medium	ongoing	Lifeng Lai / llai@wpi.edu	Worcester Polytechnic Institute	no-value
National Science Foundation (NSF)	ENHANCING ACCESS TO THE RADIO SPECTRUM (EARS)	Collaborative Research: Pervasive Spectrum Sharing for Public Safety	1443946	Next-generation public safety communication (PSC) systems must deliver high-capacity wireless services to public safety personnel and users in disaster-affected areas, with little reliance on infrastructure. Remarkably, modern-day PSC systems have yet to catch up with the past decade`s wireless revolution, as they still rely on technologies of yesteryears that fall short on delivering high-speed wireless access. Indeed, coping with the foreseen stringent service requirements in future PSC systems mandates major innovations that can increase spectral efficiency. This, in turn, requires tackling multidisciplinary challenges: 1) developing incentive mechanisms for government agencies, providers, and users to share their precious spectrum resources; 2) dynamically managing interdependent spectrum markets; and 3) efficiently modeling and operating sustainable communication protocols that can function with little infrastructure support. This project brings together researchers in wireless communications and networking, game theory, mathematics, and public safety administration to address these challenges and boost the efficiency of PSC by introducing a novel framework that provides the necessary analytical tools for modeling, designing, analyzing, and operating large-scale spectrum sharing in disaster and emergency situations. The overarching scientific merit of this research is to initiate the much-needed leap towards a more open, highly participatory, and pervasive sharing of the wireless spectrum for PSC. This project offers an array of spectrum sharing innovations: 1) new economic approaches and PSC mechanisms that provide incentives for government agencies, providers, and end-users, to effectively subsidize the scarce radio spectrum and facilitate novel public safety and spectrum allocation policies; 2) a foundational framework that tightly integrates tools from game theory and auction theory for enabling a dynamic operation of co-existing spectrum sharing markets with multi-hop capabilities; 3) novel realistic models for characterizing wireless channels, traffic, topology, user behavior, and mobility in PSC; and 4) effective and accelerated transition of theoretical results to practice via a new PSC testbed for extensive validation and close collaboration with several major industry partners and local public safety agencies. In a nutshell, the project provides a new generation of PSC systems and protocols that expedite the response to disasters, save lives, and reduce economic costs.	Technologies and applications for efficient spectrum use or legacy transformation; Education and outreach;	general	30 MHz - 6000 MHz	TRL-2	Small	ongoing	Naim Kapucu / kapucu@ucf.edu	University of Central Florida	no-value
National Telecommunications and Information Administration (NTIA)	NTIA INSTITUTE FOR TELECOMMUNICATION SCIENCES	5-GHz Rapid Response Capability	no-value	Develop and maintain a rapid response capability for testing, evaluation, and electromagnetic compatibility analyses of unlicensed 5-GHz devices to support spectrum sharing between unlicensed 5-GHz devices and Federal systems.	Technologies and applications for efficient spectrum use or legacy transformation	general	5150 MHz - 5850 MHz	TRL-5	Small	ongoing	John Carroll / jcarroll@its.bldrdoc.gov / 303-497-3367	Internal	http://www.its.bldrdoc.gov/publications/2548.aspx, http://www.its.bldrdoc.gov/publications/2554.aspx, http://www.its.bldrdoc.gov/publications/2677.aspx
National Telecommunications and Information Administration (NTIA)	NTIA INSTITUTE FOR TELECOMMUNICATION SCIENCES	Spectrum Monitoring Pilot Program	no-value	A pilot project to develop a spectrum monitoring capability. Its goals are to (1) develop an infrastructure to acquire and amass spectrum monitoring data and make it available to the spectrum community in near real time via the Internet, and (2) establish best practices for the acquisition of spectrum data.	Spectrum access policy and regulation; Modeling and Simulation;	general	Broadly applicable	TRL-6	Medium	ongoing	Mike Cotton / mcotton@its.bldrdoc.gov / 303-497-7346	NTIA/OSM, Coast Guard	Program description: http://www.its.bldrdoc.gov/programs/cac/spectrum-monitoring.aspx
National Telecommunications and Information Administration (NTIA)	NTIA INSTITUTE FOR TELECOMMUNICATION SCIENCES	Interference Protection Criteria simulation	no-value	Develop a Monte Carlo computer simulation model that estimates the most interference power a receiver can tolerate.	Spectrum access policy and regulation; Modeling and Simulation;	general	Broadly applicable	TRL-4	Small	ongoing	Robert Achatz / rachatz@its.bldrdoc.gov / 303-497-3498	NTIA/OSM, Coast Guard	Currently emulating radar into LTE and LTE into radio IPC measurements.
National Telecommunications and Information Administration (NTIA)	NTIA INSTITUTE FOR TELECOMMUNICATION SCIENCES	Aggregate Interference Modeling	no-value	Develop a Monte Carlo computer simulation model that predicts statistics of aggregate mobile device or basestation power at a victim receiver location.	Spectrum access policy and regulation; Modeling and Simulation;	aeronautical; terrestrial	< 6000 MHz	TRL-4	Small	ongoing	Joel Dumke / jdumke@its.bldrdoc.gov / 303-497-4418	Internal	Mobile device power control based on self-interference or CSMAC WG-1 universal cummulative distribution function.
National Telecommunications and Information Administration (NTIA)	NTIA INSTITUTE FOR TELECOMMUNICATION SCIENCES	Propagation Modeling and Measurement	no-value	Develop propagation models for compatibility analyses. Perform measurements to validate those models.	Spectrum access policy and regulation; Modeling and Simulation;	general	Broadly applicable	TRL-5	Small	ongoing	Paul McKenna / mckenna@its.bldrdoc.gov / 303-497-3474	Internal, NTIA/OSM, DOD	Currently focused on integrated clutter + terrain predictions
National Telecommunications and Information Administration (NTIA)	NTIA INSTITUTE FOR TELECOMMUNICATION SCIENCES	RFIMS Project	no-value	Develop specifications for an LTE uplink to satellite downlink radio interference monitoring and mitigation system and create a testbed to evaluate candidate systems.	Spectrum access policy and regulation; Modeling and Simulation;	aeronautical; terrestrial	1660 MHz - 1710 MHz	TRL-3	Medium	ongoing	John Carroll / jcarroll@its.bldrdoc.gov / 303-497-3367	NOAA	LTE aggregate interference waveforms, satellite tracking of polar orbiting satellites.