Guest Editorial for the Special Section on Antenna Systems and Propagation for Cognitive Radio

COGNITIVE radio systems are quickly reshaping the future of wireless communications, sensing, and data sharing. Today, research in cognitive radio is aimed at developing efficient wireless communication strategies to make use of under-used spectrum. The idea is to make smart wireless devices that can observe their RF environment and detect unused frequency bands in real time. That way, more wireless devices can operate in the same frequency band, enabling more efficient use of the spectrum. Therefore, it is desirable to develop devices that can learn from observations and make decisions about when and how to transmit without disrupting any existing wireless connections.

These new modes of operation create a need for antennas, algorithms, and communication schemes that can make a cognitive radio (CR) system work with other devices across multi-bands, multi-standards or multi-channels. Various research communities, however, have differing definitions of cognitive radio (CR) and each community has unique views as the defining features of CR. Communication theorists view CR as primarily about dynamic spectrum sharing, while networking/IT researchers interpret CR as a device capable of cross-layer optimization. Computer scientists picture CR as a device capable of learning and adapting, with assumed capabilities, while the hardware/RF community often views it as an evolutionary step from Software Defined Radio. Amid all of these conceptions of cognitive radio, the possibilities for antenna systems and related propagation issues to play a more active role in system-level performance are often ignored.

The focus of this Special Section is to showcase a unified vision for future cognitive radios, with an emphasis on antennas and RF front ends, and the algorithms for learning and controlling the RF/antenna front-end of any future cognitive radios as well as the sensing and integration of the propagation environment into the system configuration. More specifically, the initial announcement encouraged emphasis in the following areas:

- Spectrum sensing and analysis algorithms coupled with antennas and RF front ends to sense, classify, and respond to the RF environment.
- Real-time frequency reconfigurable antennas linked with agile RF front ends that can sense the RF environment and, in turn, adjust to communicate in the detected available spectrum, thereby avoiding any interfering signals.

TABLE I
CLASSIFICATION OF VARIOUS APPLICATION AREAS COVERED IN THIS SPECIAL SECTION AND SPECIFIC TOPICS ADDRESSED IN EACH GROUP

Group A: Reconfigurable Antenna Design	• Frequency / Radiation Pattern / Polarization Reconfigurable Antennas • Compact Antennas • Algorithms and Optimization Approaches • Various Configuration Mechanisms and Miniaturization
Group B: MIMO Applications	• Beam Space MIMO • Dynamically Reconfigurable Systems • Spectrum Interweave Applications • Spectrum Underlay Applications • Beam Steering Capabilities and BER Performance
Group C: Phased Array Applications	• Dynamic Tethering of Phased Arrays Android Smartphones • Tracking and Beamsteering • Multiple Channel Communication • Multiple Harmonic Beamforming • Software-based Configurability
Group D: Hardware Requirements and System Considerations	• Basic Design Challenges and Hardware Requirements • Spatial Filtering • Channel Selectivity and Receiver Sensing Architecture • Intermodulation and Harmonic Distortion Suppression • Benefits of Polarization for Fixed Area Television White Space Devices

- Pattern and polarization reconfigurable antenna systems designed to avoid interference through spatial rather than frequency means.
- MIMO and other reconfigurable systems in cognitive radio to increase throughput in crowded regions of the electromagnetic spectrum.
- Inferential propagation models leveraging spectrum sampling or spectrum databases.
- Propagation modeling and channel estimation with a particular focus on information extraction and exploitation for cognitive radio system configuration.
- Propagation-channel-based techniques for security and assurance.

This Special Section achieved most of its goals, especially in the area of new antenna design and related systems, and we encourage readership of the entire section to gain an overview of the diverse antenna design approaches, system architectures, and algorithms available in the area of cognitive radio. We thank

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all authors who submitted their work for consideration in this Special Section and regret that many could not be accepted. Papers were selected based on detailed peer review and relevance to the topic. Table I provides a guide to follow the topics discussed in this Special Section. Papers were grouped into four main categories that cover specific cognitive radio issues. All four groups have some overlap with each other since several papers address more than one specific issue related to CRs.

In **Group A**, the reader will find a novel compact and low-profile microstrip antenna design as a suitable radiating device for a software defined radio system. Another paper shows that by using online learning and the *multi-armed bandit algorithm*, a sequential decision policy can be employed to learn the optimal reconfigurable antenna states without *a priori* knowledge of any channel statistics. This work is also implemented in a 2×2 array design that supports the validity of the proposed approach. The next paper shows how to achieve pattern reconfiguration by rotating parasitic structures using *Electro-Active Polymer (EAP) Actuators* in an idealized multipath propagation environment and how to achieve miniaturization based on a composite right/left-handed (CRLH) resonator. Also, a paper on the design methodology of reconfigurable antennas, with *RF-MEMS* switches, using the *Particle Swarm Optimization* approach is included and a detailed design, as applied to cognitive radio, is presented.

In **Group B**, the emphasis is on applying MIMO antenna systems for cognitive radio. One of the papers discusses the design and deployment of *beam-space MIMO* in future wireless applications. The approach targeted is based on integration in small wireless devices, where the antenna is made of a single integrated radiator rather than an array of physically separated dipoles. This approach can simplify the implementation of variable loads and DC bias circuits for BPSK modulated signals, and does not make use of any external reconfigurable matching circuits. Next, in this segment, the two types of cognitive radio configurations (*spectrum interweave* and *spectrum underlay*) are presented. Reconfigurable *filtennas* are proposed as communicating antennas in a MIMO environment for the two configurations. Also here, an approach for the design and evaluation of *pattern reconfigurable antennas* for MIMO applications is presented. Their performance is estimated using simulations, and the effect of uniform beam steering on MIMO system performance is evaluated for a real indoor channel using two Electrically Steerable Passive Array Radiator (ESPAR) antennas.

In **Group C**, some innovative approaches to phased array applications in CR are highlighted. One of the papers discusses an interactive framework for CR applications in which an *Android smartphone* and a phased array controller are *wirelessly tethered*. The smart phone serves as a communications bridge between the phased array's control system and a remote network server that handles bi-directional communication of system health monitoring data, state information, and other control signals. Another paper presents the idea of using *time-modulated arrays*, called *4D arrays*, to implement a secure communication scheme directly at the physical layer using software-based reconfigurability and multiple harmonic beamforming. Examples of these time-modulated 4D arrays and their effectiveness as an enabling technology for future CR systems are presented and discussed.

In **Group D**, some of the hardware and system architecture challenges in designing CRs that can concurrently and continuously sense the spectrum while transmitting in the same frequency band are presented. In this section the reader will find a new approach, based on spatial filtering to achieve CRs with simultaneous transmission and sensing capabilities. The idea behind this concept is to use redundant transmit antennas to form an adaptive spatial filter that can selectively null the transmit signal in the sensing direction and achieve a wideband isolation for concurrent receive and transmit modes of operation. In another paper, an investigation of the effects of intermodulation and harmonic generation due to the non-linearities of PIN diodes in frequency reconfigurable antennas is detailed. The paper includes suggestions on how intermodulation can be lowered and how particular spurious frequency products can be suppressed. Within this group, the advantage of utilizing horizontal polarization within available TV frequency white spaces is proposed in order to reduce interference with primary users. Also within this group, a channel cognitive wireless sensor system, for low-power sensor network applications, is presented. The proposed receiver, based on an RF spectrum sensing technology, is implemented at the ISM band of 2.4–2.5 GHz and features excellent channel selectivity for the allocated channels.

Finally, the Guest Editors would like to thank the authors and the reviewers for their efforts in making this Special Section a timely one and hope that it will serve as a well-referenced publication in this rapidly evolving topic. They also express their gratitude to the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION Editors-in-Chief, Prof. Michael Jensen and Dr. Kwok Wa Leung for their support, advice, and encouragement during the completion of this publication.

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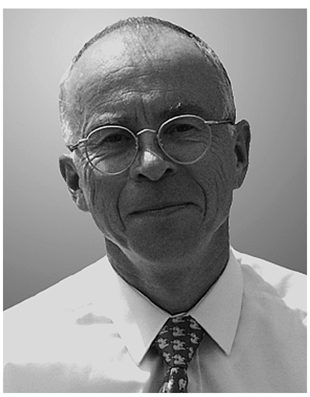
Prof. Bernhard is a Fellow of the IEEE. In 2008–2009, she was a member of the Defense Science Study Group, sponsored by DARPA. In addition to the NSF CAREER Award, the IEEE Antennas and Propagation Society H. A. Wheeler Prize Paper Award and other research recognitions, she has been honored with a number of teaching and advising awards. In 2008, she served as the President of the IEEE Antennas and Propagation Society.



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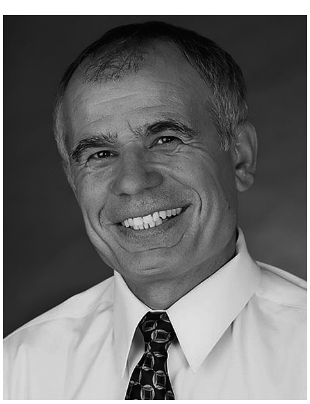
Prof. Bonek is a past Chairman of Commission C of URSI and a past Chairman of the Antennas and Propagation Working Group in the European research initiatives COST 259 and COST 273. Upon his initiative, a Center of Excellence in Telecommunications Research, Forschungszentrum Telekommunikation Wien (ftw), was established in Vienna, Austria. From 1985 to 1990, he served the IEEE Austria Section as a Chairman. Recently, he served as a reviewer of grant proposals to European Research Council, in Physical Sciences and Engineering.



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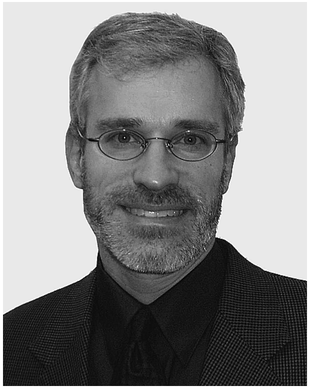
Prof. Christodoulou is a Fellow of IEEE, a member of Commission B of URSI, and a Distinguished Professor at UNM. He is the recipient of the 2010 IEEE John Krauss Antenna Award for his work on reconfigurable fractal antennas using MEMS switches, the Lawton-Ellis Award, and the Gardner Zemke Professorship at the University of New Mexico. He was appointed as an IEEE AP-S Distinguished Lecturer (2007–2010) and elected as the President for the Albuquerque IEEE Section in 2008. He served as an Associate Editor for the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION for six years, as a Guest Editor for a Special Issue on Applications of Neural Networks in Electromagnetics in the *Applied Computational Electromagnetics Society (ACES) Journal*, and as the co-editor of a Special Issue on Synthesis and Optimization Techniques in Electromagnetics and Antenna System Design in the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION (March 2007).



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Kathleen L. Melde (previously Kathleen L. Virga) (F'12) received the Ph.D. degree in electrical engineering from the University of California, Los Angeles (UCLA), Los Angeles, CA, USA, in 1996.

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Dr. Melde is a Fellow of the IEEE and a member of the Antennas and Propagation (AP-S) and Microwave Theory and Techniques (MTT) Societies. She was named a University of Arizona College of Engineering Teaching Fellow in 2012. In 2010, she received the "Excellence at the Student Interface" award from the University of Arizona, College of Engineering. From 1999–2001 she served on the Administrative Committee (AdCom) for the IEEE AP-S Society. She was an Associate Editor for the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION and the IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS. She is on the organizing committee for the 2014 Antenna Measurement Techniques Association (AMTA) conference and the 2016 Antennas and Propagation Symposium.