Improvement of physical-layer communication technology at the mobile-user level with reconfigurable antennas

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Background: The electromagnetic spectrum is a critical resource for wireless communications. However, its portions used in modern communication systems (e.g., radio, microwave) are of finite extent. The continuous expectation for higher performance mobile data connections in consumer, military, and government sectors is at odds with the traditional fixed-spectrum access (FSA) policy under which current communications currently operate. Under FSA policy, a chart of the radio spectrum appears crowded with pre-allocated bands for commercial mobile, government applications, and other licensed uses. Recent studies have found, however, that out of all of the licensed spectrum very little is being used at any given time [1].

From this observation comes the motivation toward dynamic spectrum access (DSA) using *cognitive radios* in which a more efficient strategy is used to arbitrate communications in the radio spectrum. Implementing such a cognitive radio (CR) which can understand its surroundings and cooperatively arbitrate communications with other users is a very complex task [1, 2]. Before designing a cognitive radio network, several technologies must be developed in order for a device to actively and intelligently base its actions on other users and the physical world around it. These technologies include:

- A wideband sensing antenna and radio to determine the current use of the spectrum in the local area of the CR
- Intelligent software to learn use-patterns, movement, and capabilities of users around the CR.
- Cooperative protocols for efficiently accomplishing communications errands not possible by a single user.
- Flexible physical-layer hardware that allows both mobile users and stationary hubs to facilitate robust, cooperative, and non-interfering communication links in diverse environments.

Together these topics represent open problems which have been of recent interest in the fields of signal processing, remote sensing, communications, radio frequency (RF) hardware design, and antenna design. Our work here at the University of Illinois at Urbana-Champaign (UIUC) focuses on the last two tasks, particularly designing antenna systems intended for advanced communications protocols on mobile user platforms.

Proposed future work: We propose the investigation of antenna technologies for the mobile user with the special needs of cognitive radio in mind. Instead of developing antenna designs that accomplish specific functionality needed for only stationary users, we propose to: **1)** Determine the new communication tasks to be carried out by mobile users in a cognitive radio network. **2)** Incorporate the "human aspect" of mobile communications, e.g., how patterns in the movement and activity of mobile users could be beneficial to communication functionality **3)** Assess the unique hardware needs of mobile users to accomplish the tasks from above **4)** Based on findings in the previous stages, develop adaptive, flexible antenna platforms for various types of mobile users and applications using modern antenna design concepts such as pattern, polarization, and frequency reconfigurability in order to maximize physical-layer functionality.

Current mobile devices use small antennas with limited functionality. The literature is rich with research on the basic nature and limitations of such electrically small antennas. The same is true for larger reconfigurable antennas. In order to advance the state of cooperative networking (on the way to cognitive radio), these fields need to be merged at their intersection with modern communication schemes.

For example, a recent modulation scheme was suggested in [3] which uses a multiple-in multiple-out (MIMO) antenna array using symbol-specific pre-coding matrices to make demodulation difficult in directions other than that of the intended receiver. This directional modulation can also be used to reduce interference in adjacent spatial channels as is done with traditional MIMO beamforming. In both directional modulation and traditional MIMO beamforming, the ability to create orthogonal communication channels relies on diverse physical channels between sets of transmitters and receivers. Introduction of reconfigurable antennas on either side of a link could provide further diverse channels as well as open the door for cooperative MIMO between mobile users. Consider multiple mobile users in proximity working cooperatively to transfer data to and from a stationary, MIMO-equipped router. With estimated knowledge of relative location and the channels used they could together form an ad-hoc MIMO transceiver operating with minimal interference to other users. The question arises then, what kinds of mobile antennas could best perform this task? What are the specific performance needs in different environments, such as an office, a highway, or an urban canyon? Could the mobile users in such ad-hoc cooperative networks benefit from the incorporation of reconfigurable antennas? Would reconfigurable antennas provide more flexibility for implementations of directional modulation? Could information regarding the movement and behavior of mobile users be used in the design of hardware for these ad-hoc networks? How can automated adjustments be applied to the system to maintain performance in a changing physical environment?

The aim of this work is to focus on the real and impactful antenna functionality that is necessary to fully deliver on the promises of cognitive radio. In particular, attention will be given to leveraging reconfigurable antennas which are able learn, adapt, and respond to their environments in ways that best suit the needs of contemporary physical-layer communications. Our work will be of value in the fields of communications, remote sensing, distributed sensor networks, and antenna design.

References

[1] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 2, pp. 201-220, Feb 2005.

[2] J. Mitola *et al*., "Cognitive radio: Making software radios more personal," *IEEE Pers. Comm.*, vol. 6, no.4 pp. 13-18, Aug. 1999.

[3] M. P. Daly and J. T. Bernhard, "Directional modulation technique for phased arrays," *IEEE Trans. on Antennas and Propagation*, vol. 57, no. 9, pp. 2633-2640, Sept. 2009.