Mobile Netw Appl (2008) 13:411–415
DOI 10.1007/s11036-008-0077-x

Guest Editorial: Special Issue on Cognitive Radio Oriented Wireless Networks and Communications

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Published online: 18 June 2008
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Keywords cognitive radio · wireless networks

1 Background

In recent years, there has been an exponential rise in the number of wireless standards such as 802.11 a,b,g,n (and more), 802.15 (Bluetooth, Zigbee, UWB), WCDMA (and several modes), CDMA 2000 (1xEV-DV, 1xEVDO), Wireless USB, and 802.16 (various modes) to name just the most prominent standards. The abundance of standards today is the result of a desire in the industry to support new applications, with each standard custom-tailored to a specific operating environment and spectrum. It is not hard to envision that wireless coverage will be pervasive in the future and will support a variety of applications that are undreamed of today.

On the other hand, wireless spectrum access has been regulated with static spectrum allocation since the early 1920s, which assigns a fixed block of spectrum to each new wireless service for its exclusive use. Over the years, the remaining useful spectrum available for new wireless services is being exhausted. This is a serious problem since new wireless services and devices are now rolling out at an unprecedented pace. This trend will continue as wireless becomes pervasive in the future.

Recent studies sponsored by the FCC have shown that traditional fixed allocation policy is becoming inadequate in addressing today's rapidly evolving wireless communications. Studies show that many allocated spectrum blocks are used only in certain geographical areas and are idle most of the time. These frequency bands are called the spectrum "white space" (or "hole"). Measurements conducted by the Shared Spectrum Company [1] find that even in the most crowded area near downtown Washington, DC, where both government and commercial spectrum use is considered intensive, 62% of the spectrum remain white space.[1] Another measurement (funded by NSF), also conducted by the Shared Spectrum Company [2], shows

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[1] A bandwidth is considered white space if it is wider than 1 MHz and remains unoccupied for at least 10 min [1].

that even during the 2004 Republican National Convention in New York City (perhaps the most heavily-congested area in the USA at that time), there was still significant white space available in the public sector spectrum.

These studies have prompted the FCC to explore new innovative policies to encourage dynamic access to the under-utilized spectrum, provided that interference on licensed users (also called *primary users*) of the spectrum is under control and not excessive [3–5]. Wireless devices are allowed to sense and explore a wide range of the frequency spectrum and identify currently unused spectrum blocks for data communication, as long as such usage does not cause harmful interference to primary users. This approach is also called *dynamic spectrum access* (DSA).

On the radio technology front, the advancement of software-defined radio (SDR) and cognitive radio (CR) technologies makes DSA technically feasible. An SDR is a frequency-agile data communication device. SDR with spectrum sensing and learning/adaptation capabilities is called CR [6, 7]. Here we use CR to stand for programmable radio in the broadest sense (including SDR) when there is no confusion. CR capitalizes on advances in signal processing and radio technology, as well as recent advancements in spectrum policy [7–9]. A CR node constantly senses the spectrum to detect any change in white space. A frequency-agile radio module is capable of reconfiguring RF and switching to newly-selected frequency bands. Thus, a CR can be programmed to tune to a wide spectrum range and operate on any frequency bands in the range. From an application perspective, a CR allows a single radio to provide a wide variety of functions, acting as a cell phone, broadcast receiver, GPS receiver, wireless data terminal or node, etc.

The combination of wireless applications demand, FCC policy reform, and radio technology advances presages great potential for CRs and future generation wireless communications. CR-based wireless networks are expected to route messages through the network and interoperate with the larger Internet, manage spectrum resources dynamically, self-organize with a rapid initial configuration, accommodate mobility, support a variety of network services, use adaptation to ensure quality of service, and support multiple users and domains. The fundamental difference between shared spectrum networks and traditional wireless networks is that there is no statically allocated fixed spectrum for use. A white space in the spectrum may only be used at a specific time period, at a specified location or area, and under certain usage rules. Due to this fundamental difference in spectrum access, data communication for CR networks is substantially more interesting and challenging.

2 Outline of this special issue

The purpose of this special issue is to disseminate state-of-the-art approaches and novel technologies that will advance basic knowledge and understanding of CR oriented wireless communications and networks. The ten papers selected for this special issue address recent advances in this area at various layers of the protocol stack. Both theoretical and experimental (e.g., testbed) papers are included so that readers can have a comprehensive exposure on the state-of-the-art of CR based wireless networks.

The first paper in this issue, Budiarjo, Nikookar, and Ligthart's "Cognitive Radio with Single Carrier TDCS and Multicarrier OFDM Approach with V-BLAST Receiver in Rayleigh Fading Channel" compares a single carrier with TDCS with multi-carrier OFDM in terms of computational complexity, bit error rate (BER) and bit rate. Through computer simulations, the authors conclude that multi-carrier OFDM with interference avoidance capability is the preferred method for CR.

In the second paper in this issue, "Cognitive Radio Design on an MPSoC Reconfigurable Platform", Zhang, Kokkeler and Smit present a system level design methodology for mapping CR onto an MPSoC platform. The design methodology is based on a task transaction level interface (TTL) to partition the application into communicating tasks. By making the communication explicit, the computation (task) is implemented separately from the communication. The authors show a design case and conclude that TTL is a suitable design methodology for mapping CR on a reconfigurable MPSoC.

In the next paper, "Bio-Inspired Algorithms for Dynamic Resource Allocation in Cognitive Wireless Networks," T. Renk et al. present three bio-inspired approaches for distribution and sharing processes in CR networks. The first one deals with the detection of spectrum holes and the second one describes resource allocation in OFDM access based systems. The third one is concerned with distributed resource auctioning.

In their paper "Population Adaptation for Genetic Algorithm-based Cognitive Radios," Newman et al. aim to reduce the computational time for genetic algorithms when they are applied to address problems in CRs. They present a population adaptation technique for genetic algorithms that takes advantage of the information from previous cognition cycles in order to reduce the time required to reach an optimal decision.

The paper on "Distributed Scheduling and Resource Allocation for Cognitive OFDMA Radios" by Bazerque and Giannakis considers scheduling spectrum access and allocating power and rate resources in CR networks. They present a primal-dual optimization framework to schedule any-to-any CR communications based on OFDM access and allocate power so as to maximize the weighted average sum-rate of all users. The framework leads to an iterative channel-adaptive distributed algorithm whereby nodes rely only on local information exchanges with their neighbors to attain global optimality.

Xin, Ma, and Shen investigate channel assignment for CR wireless networks in their paper entitled "A Path-centric Channel Assignment Framework for Cognitive Radio Wireless Networks." Their proposed algorithm takes a different approach from traditional channel assignment algorithms for multi-channel wireless networks. They couple both routing and channel assignment, and determine the channel assignment for each node by the routing protocol to achieve globally optimized performance, rather than focusing on the local node with non-coordinated channel assignment.

The paper by Cao and Zheng, "Understanding the Power of Distributed Coordination for Dynamic Spectrum Management," studies the efficiency and complexity of a distributed spectrum allocation algorithm using explicit user coordination. Users self-organize into coordination groups and adjust spectrum assignments in each local group to approximate an optimal assignment. Compared to the conventional topology-based optimizations, local coordination can reduce the computation and communication overhead required to adapt to topology variations.

In the next paper, Sengupta and Chatterjee investigate possible auction mechanisms for dynamic spectrum allocation in their paper entitled "Designing Auction Mechanisms for Dynamic Spectrum Access." The authors focus on the scenario where there are multiple spectrum bands in the common pool of auction but each bidder is allocated at most one spectrum band. Through analysis and simulation, the authors show that the popular conception of concurrent auction is not beneficial and show that sequential auction proves to be the better choice for DSA auctions.

In their paper "Potential Cognitive Radio Denial-of-Service Vulnerabilities and Protection Countermeasures: A Multi-dimensional Analysis and Assessment," Brown and Sethi examine the denial of service vulnerabilities for CRs and explore potential protection remedies that can be applied. An analysis of how vulnerable are victim CRs to potential denial of service attacks is presented along different axis, namely the network architecture employed, the spectrum access technique used and the spectrum awareness model. The goal is to assist CR designers to incorporate effective security measures in the early stages of CR development.

The final paper in this issue, by Miljanic et al. presents an experimental CR hardware platform. In this paper, entitled "The WINLAB Network Centric Cognitive Radio Hardware Platform - WiNC2R," the authors described the architecture and hardware implementation of a network-centric experimental CR prototype platform under development at WINLAB. The system is based on the "CogNet" protocol architecture running on either GNU/USRP or the WiNC2R hardware board. Initial hardware design work and component level protocol evaluations are presented.

As guest editors of this special issue, we wish to thank Professor Imrich Chlamtac, Editor-in-Chief of this journal, for his advice and support in this effort. We also wish to thank all the reviewers who contributed their valuable time and expertise during the paper selection process.

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