## Cognitive Radio: A path in the Evolution of Public Wireless Networks

The concept of cognitive radio has arisen as a generalization of the principle of multiple access in radio channels initially developed in the late sixties and early seventies including the pioneering methods of channel sharing depicted in the ALOHA and CSMA protocols. The intent is to go beyond the context of a single homogeneous system or network with a number of terminals that operate according to a well defined and known physical layer including fixed modulation and error control coding algorithms. The cognitive radio is supposed to be a "smarter radio" in the sense that it can sense channels that contain signals from a large class of heterogeneous signals, networks, and services, and that based on this sensing the radio will implement sophisticated algorithms to share the channel as an additional user, in order to achieve the goals of efficient communication over a shared wireless medium which is ultimately spectrum limited. Included in these concepts is the idea that devices belonging to different systems will have different priorities in accessing the spectrum. One example is the well known classification of users as primary or secondary in the case of the TV spectrum being opened up to new uses. From this standpoint we may view cognitive radio as generalizing the area of multiple access involving devices in a single homogeneous system, from the physical layer standpoint, to multiple access involving devices in different systems. We may view it as inter-system multiple access as opposed to the more traditional intra-system multiple access.

There is another more general use of the term "cognitive radio" that sometimes appears in the literature where the concept is viewed as a sort of evolution of the field of adaptive systems and adaptive signal processing and as a topic within a larger field of cognitive systems. In this case analogies are drawn to the human brain. Clearly the term "cognitive" is meant as an evolution to the concept of "channel sensing" in the field of multiple access communications of the seventies. It is also clear that the term "radio" in "cognitive radio" is referring to a sophisticated radio receiver that somehow is to mimic the human brain. However there are two main limitations of radio receivers: first, they can only sense signals in their own geographical environment and if this sensing is to result on some additional use of the channel, a transmission, then the possible consequences of such a transmission will occur at a different location, where the signals present may be very different; secondly in terms of communication the most that we can expect from such a "cognitive" device is to separate a number of signals on the channel using algorithms such as those developed in the field of multi-user detection. It is therefore clear that the evolution of the field must involve more than one individual radio. It must involve many radios sensing channels and the sensed information must be processed by some kind of global processor that will then be in a position to dictate conditions under which further transmissions in to the wireless media are to be allowed, or there must be a distributed algorithm that runs under the input of sensed information from a number of terminals. From a wireless communications perspective the evolution is clearly away from the focus on a single radio to a network of radios – it is towards a cognitive radio networks rather than a cognitive radio terminal.

The key is not necessarily the transceivers and sophisticated algorithms that merit the historical use of the term "cognitive", but these receivers, as sensors, along with the network infrastructure consisting of servers, or the distributed terminals themselves as a group, that run algorithms to determine policy for the additional use of spectrum by any individual terminal. It is this infrastructure that has the capability to determine interference consequences at receivers that are well away from a particular sensing radio. Our intention for this special issue was to concentrate on the aspect of "cognitive radio" that relates to the evolution of wireless networks that provide connectivity to a wider communication infrastructure.

In this special issue, we have selected nine articles from a total of thirty-five submissions, which were received through an open call-for-papers. The articles went through a rigorous peer-review process. Seven of the papers were deemed to be outside the scope of the issue and were referred to regular issues of JCN. The papers included address issues that cover, among other issues, terminal functions of sensing, network functions of co-operative sensing, transmission scheduling, and evolution applications in a cellular networking context. We have arranged them into three categories: Spectrum Sensing; Spectrum Access, Scheduling, and Resource Allocation; and Networking among Cognitive Radios.

In the paper entitled "Cognitive Radio Based Spectrum Sharing: Evaluating Channel Availability via Traffic Pattern Prediction", by X. Li, and S. A. Zekavat, a technique is proposed where secondary users estimate the utilization of channels by predicting the traffic pattern of primary users, and selecting an appropriate channel for transmission. The proposed technique reduces the channel switching rate of secondary users and the interference on primary users.

The paper entitled "A novel cooperative spectrum sensing algorithm in cognitive radio systems," by X. Zheng, J. Wang, Q. Wu, and L. Shen, considers a cooperative scheme for detection of a primary system with reduced communications requirements. Each node thresholds and quantizes its spectral energy estimate, and some nodes communicate to a base station for fusion. This method seeks to provide relaxed communications requirements with relatively small loss in joint detection performance.

In "Enhanced Robust Cooperative Spectrum Sensing in Cognitive Radio", by Feng Zhu and Seung-Woo Seo, the problem of cooperative spectrum sensing in the presence of malicious nodes that may report false sensing data to the fusion center on purpose is addressed. Several enhancements to existing techniques are proposed to solve this problem without excessive sampling overhead.

The paper entitled "Opportunistic spectrum access based on a constrained multi-armed bandit formulation", by J. Ai and A. Abouzeid, formulates channel sensing and opportunistic communications access as a constrained partially observable multi-armed bandit problem. This approach provides tradeoffs between complexity and optimality, especially when the statistics of the primary network traffic are known or slowly varying.

The paper entitled "Throughput and Delay Optimal Scheduling in Cognitive Radio Networks Under Interference Temperature Constraints", by D. Gozupek and F. Alagoz addresses the scheduling problem in time-division multiple access (TDMA)-based cognitive radio networks under interference temperature constraints in a centralized setting. Specifically, the throughput and delay-optimal scheduling problem is formulated as a two-stage binary integer programming problem, which is an NP-hard problem. To reduce the complexity of implementation, the authors propose two suboptimal schedulers with linear (in terms of number of cognitive radio nodes) complexity.

The paper entitled "Large-Scale Joint Rate and Power Allocation Algorithm Combined with Admission Control in Cognitive Radio Networks", by W. J. Shin, K. Y. Park, and D. I. Kim presents a centralized rate and power allocation method for secondary users radios in an orthogonal frequency division multiple access (OFDMA)-based wireless access scenario. The rate and power allocation problem is posed as an optimization problem with an objective to maximizing the transmission rates of the secondary users (i.e., cognitive radios) under large-scale signal-to-interference-plus-noise-ratio (SINR) constraints for the secondary users and large-scale interference temperature constraints for primary users. The optimization problem is transformed into a geometric program and then solved using three approximation methods. Subsequently, the rate and power control method is combined with an admission control method. The proposed model for resource allocation avoids the complexity of tracking instantaneous channel gains, and therefore, provides a more implementation-friendly solution to the resource allocation problem in a cognitive radio network.

In "Distributed Power and Rate Control for Cognitive Radio Networks", by W. Wang, W. Wang, Y. Zhu, and T. Peng, a distributed power and end-to-end rate control algorithm is proposed in the presence of licensed users. The optimal power and rate control solution is given for the unlicensed users while satisfying the interference temperature constraint on licensed users.

In "RawPEACH: Multi-Band CSMA/CA-Based Cognitive Radio Networks", by J. W. Chong, Y Sung, and D. K. Sung, a new medium access control (MAC) scheme embedding physical channels into multi-band carrier sense multiple access with collision avoidance (CSMA/CA) is proposed to provide strict quality of service (QoS) guarantee to high priority users. Two priority classes of users, primary and secondary users, are supported. For primary users physical channels are provided to ensure strict QoS, whereas secondary users are provided with best-effort service using CSMA/CA modified to multi-band operation.

Lastly, in "Ad-Hoc Behavior in Opportunistic Radio", by S. Mumtaz, P. M. A. Gameiro, and J. Rodriguez", a UMTS TDD opportunistic system is considered in the presence of the primary UMTS FDD cellular system. Issues of interference and routing are considered.

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## Organization of papers

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| **Spectrum Sensing** |
| Cognitive Radio Based Spectrum Sharing: Evaluating Channel Availability via Traffic Pattern Prediction |
| A Novel Cooperative Spectrum Sensing Algorithm in Cognitive Radio Systems |
| Enhanced Robust Cooperative Spectrum Sensing in Cognitive Radio |
| **Spectrum access, scheduling, and resource allocation** |
| Opportunistic Spectrum Access based on a Constrained Multi-Armed Bandit Formulation |
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