Networking over Multi-Hop Cognitive Networks


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Current wireless networks feature fixed spectrum assignment policies, according to which licensees are granted the rights for the use of frequency bands on a long-term basis over vast geographical regions. Moreover, the huge success of wireless applications has prompted the exponential growth of unlicensed band usage, thus causing possible wireless spectrum shortage. Part of the problem is that spectrum usage is not uniform (according to FCC, only 15 to 85 percent of the licensed spectrum is utilized on average).

This situation has motivated and pushed forward the concept of dynamic spectrum access (DSA), according to which unlicensed users may use licensed spectrum bands opportunistically in a dynamic and noninterfering manner. The recent achievements in the field of software-defined radios (SDRs) [1] have provided the technological background for the realization of novel low-power wireless cognitive radio transceivers with the capability of changing their transmitter parameters (operating spectrum, modulation, transmission power, and communication technology) based on interaction with the surrounding environment. Cognitive radio networks (CRNs) based on nodes equipped with cognitive transceivers have consequently emerged as viable architectural solutions to solve current wireless network problems resulting from limited available spectrum and inefficiency in spectrum usage by exploiting the existing wireless spectrum opportunistically [2].

Most of the research on CRNs to date has focused on single-hop scenarios, tackling physical (PHY) layer and/or medium access control (MAC) layer issues, including the definition of effective spectrum sensing, spectrum decision, and spectrum sharing techniques. Only very recently has the research community started to realize the potentials of multihop CRNs, which can open up new and unexplored service possibilities enabling a wide range of pervasive communication applications [3, 4]. To fully unleash the potentials of such a networking paradigm, new challenges need to be addressed and solved. Unlike CRNs where single-hop access to an infrastructure access point is the aim, multihop CRNs' responsibility is not limited to the discovery and allocation of wireless resources while avoiding service disruption for primary users; additional tasks must be accomplished to sustain end-to-end communication, including identifying a set of relay nodes, ensuring that required bandwidth is available over all necessary links, and regulating resource sharing among all flows in the network. Most important, these goals must be achieved while coping with negative effects of frequent link outages due to primary user access. Preferably, the multihop CRN must also ensure that flow requirements such as bandwidth, delay, and jitter bounds are met.

Considering the points above, multihop CRNs bear similarities to mobile ad hoc networks (MANETs), where the problem of designing effective communication protocols has been studied extensively over the last two decades. Several existing proposals for MANETs assume node mobility to be the primary reason for topological changes and provide solutions for adaptation to medium rates of topological changes. Furthermore, resource allocation in MANETs at the MAC level aims at sharing dedicated wireless resources among contending nodes. The dynamic nature of channel availability in multihop CRNs not only becomes important for point-to-point connection establishment, which necessitates specific solutions at the MAC layer, but also creates rapidly changing network topologies that rival the effects of extremely high nodal mobility. As such, existing MAC, routing, and transport protocols and solutions designed for MANETs are rendered ineffective as those solutions cannot handle high rates of change of resource availability in the network.

Resource discovery and allocation problems are also significantly different in multihop CRNs from those in single-hop CRNs. In multihop CRNs the local view of available resources is not necessarily identical in all nodes of the network due to the physical separation of nodes. The correlation between resource availability observations diminishes as peer nodes move further away from each other. This observation leads to two important effects. First, resource availability information must be disseminated at least between neighboring nodes, and possibly beyond that, to ensure that point-to-point and end-to-end connectivity can be established. Second, establishment and maintenance of end-to-end paths, whether performed centrally or in a distributed manner, must have tight couplings with resource availability views and allocation decisions. Consequently, resulting communication solutions are most likely to be based on cross-layer interactions.

This special issue aims to consolidate and disseminate the latest developments and advances in the emerging area of multihop CRNs. The five articles selected to be part of this special issue address recent research issues/advances at different layers of the cognitive protocol stack, shedding light on different aspects related to the design of effective multihop CRNs.

The first article in this issue, "Spectrum Management in Cognitive Radio Ad Hoc Networks" by I. F Akyildiz, W. Lee, and K. Chowdhury, provides a comprehensive overview of the challenges of and solutions to the problem of designing effective building blocks for the *cognitive cycle* in cognitive radio ad hoc networks (CRAHNs). The authors focus on the four issues of spectrum sensing, decision, sharing, and mobility, providing an overview of the most promising approaches in these fields and commenting on future research roadmaps.

In the second article, "Channel Access Protocols for Multihop Opportunistic Networks: Challenges and Recent Developments," Salameh, and Krunz focus on the design of MAC schemes for multihop CRNs. The different solutions are evaluated and classified according to protocol-oriented aspects, including the specific control channel used to coordinate among cognitive devices, and technology-oriented aspects, including the specific degrees of freedom in the transmission phase.

The next article, "Multihop Cognitive Radio Networks: To Route or Not to Route" by Khalifé, Malouch, and Fdida, climbs one layer up the communication stack to address the issue of routing in CRNs. The authors start off by observing that the topological features of multihop cognitive radio networks may be extremely heterogeneous, depending on the variability pattern in the activity of PUs. As a consequence, they argue that a unique routing solution suited to all network conditions can hardly be achieved. Finally, they focus on the design of opportunistic routing mechanisms for CRNs highlighting the requirements and design rationale.

In their article "A Distributed Network Coded Control Channel for Multihop Cognitive Radio Networks," Asterjadhi, Baldo, and Zorzi consider the problem of implementing distributed spectrum sharing techniques for multihop cognitive radio networks. The authors show how to leverage network coding techniques to achieve distributed coordination among cognitive devices in the spectrum access phase.

Finally, the last thought-provoking article, "Cognitive Radio Sensor Networks" by Akan *et al.*, overviews the possibility of leveraging the cognitive networking paradigm in the field of wireless sensor networks. To this extent, the applicability to wireless sensor networks of standard techniques of spectrum sensing, decision, sharing, and mobility is thoroughly assessed and evaluated.

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