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Common control channel design for cognitive radio wireless ad hoc networks using adaptive frequency hopping

Claudia Cormio [a], Kaushik R. Chowdhury [b,*]

[a] Telematics Lab., Dipartimento di Elettronica ed Elettrotecnica, Politecnico di Bari, Italy
[b] School of Electrical and Computer Engineering, Northeastern University, Boston, MA 02115, United States

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ABSTRACT

Cognitive radio (CR) technology enables the opportunistic use of the portions of the licensed spectrum by the CR users, while ensuring low interference to the primary user (PU) activity in the licensed bands. The spectrum is sensed locally by the CR users, and a specific channel that is acceptable to both the end nodes of the communication link is chosen. However, this necessitates a common control channel (CCC) for exchanging the sensing information and reserving the channel before actual data transfer. In this paper, a common control channel design for CR ad hoc networks is proposed, called as adaptive multiple rendezvous control channel (AMRCC) based on frequency hopping. Our scheme is scalable, and allows continuous connectivity between the CR users under dynamic PU activity. The contribution made in this paper is threefold: (i) a frequency hopping scheme is proposed that allows altering the hopping sequence based on the PU activity in the channels, (ii) a simple and low-overhead procedure is developed to aid new node-join and leave events, and (iii) a slot duration optimization is given that avoids a significant performance degradation with the number of available channels. Performance evaluation proves that our solution achieves better performance than the other classic CCC solutions in terms of time to rendezvous (TTR) and the resulting throughput, specifically in CR ad hoc networks.

1. Introduction

Cognitive radio networks allow the CR users to share the wireless channel with licensed or primary users (PU) of the spectrum in an opportunistic manner. Such a radio is equipped with dynamic spectrum access capability, thereby allowing it so identify portions of the spectrum that are currently available for transmission. This technology is envisaged to solve the problem of spectrum scarcity in the unlicensed 2.4 GHz ISM bands, and the inefficient spectrum utilization that exists in some licensed frequency bands.

One of the key considerations in using CR technology is ensuring that the PU transmission is always protected. To achieve this, it is essential to exchange the information pertaining to the spectrum availability between a given node pair before starting data transmission. This functionality is generally provided at the link layer, and several works have addressed the problems of medium access control (MAC) for CR networks [6]. The MAC protocols assume either a dedicated control channel with reserved frequencies within the licensed band, or the explicit use of the unlicensed band to exchange the control information [1]. These messages exchanges over the common control channel (CCC) may be related to the (i) channel access and contention, (ii) neighbor discovery, and (iii) spectrum management. While the first two approaches are common to classical wireless ad hoc networks, there are several spectrum related functions that are unique to CR networks. Specifically, the spectrum sensing information has to be exchanged over a channel that is always available before data can be transmitted. Moreover, once a PU reclaims

* Corresponding author. Tel.: +1 404 510 9089.
E-mail addresses: c.cormio@poliba.it (C. Cormio), krc@ece.neu.edu (K.R. Chowdhury).

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the spectrum, the new channel must be quickly determined for the affected link, and this link recovery information cannot be transmitted over the previously used spectrum. In either case, a CCC is used to facilitate the continuous operation of the CR users without any disruption.

Most of the current works implicitly assume the presence of such a control channel and hence, formalizing such a CCC design idea is very important. In this work, we propose a frequency shifting design for a CCC, called as AMRCC that can adaptively change the sequence of the channels based on the sensing results. Our design is motivated by the fact that strict synchronization is difficult to achieve in an ad hoc network, and the CCC design must be scalable. Moreover, we assume a single radio network, where the CR users may be mobile and operate under the standard concern of minimizing the interference to the active licensed users in the vicinity.

The research community has proposed several schemes for setting up and maintaining a reliable CCC in CR networks, while addressing the challenges posed by (i) saturation of the channel reserved for the CCC [9], (ii) robustness to PU activity [1], (iii) jamming attack [10], and (iv) limited control channel coverage [1]. We describe some of the related works in the following discussion.

A swarm intelligence based dynamic control channel assignment is proposed in CogMesh [4]. It is a distributed and adaptive approach, which addresses the issue of the PU activity disrupting the use of the CCC, and the limited coverage of the control channel. This is the first work that applies a swarm intelligence-based algorithm, where higher efficiency is achieved if specialized workers perform specialized tasks in parallel. In response to the detected PU activity, the best channel chosen by the majority of the CR users is used as the CCC. Furthermore, the coverage is improved by reducing the number of control channels in the network, thereby decreasing overhead and switching delay. The maintenance of the proposed CCC incurs high overhead, especially in the presence of fast varying PU activity. Moreover, it assumes precise synchronization among the CR users.

The SYN–MAC is a slotted protocol that integrates the control channel access with the regular available data channel [8]. Each time slot is dedicated to a channel, which can be used both for control and data exchange. This also addresses the problems of control channel saturation and jamming. The main drawbacks here is that it disrupts the control channel operation whenever a PU occupies the control slot. The SRAC protocol addresses the control channel issue by exploiting the techniques of dynamic channelization and cross-channel communication [10]. The first technique refers to the capability to adapt the band for control signaling in order to prevent saturation, while the second allows a node to dynamically change the receiving channel in order to avoid jamming. However, this work is limited from the viewpoint of network-wide CCC coverage, and cannot easily recover from a sudden PU appearance.

The C-MAC protocol is characterized by in-band signaling [5]. It guarantees flexible control channel coverage, and it is robust to PU activity through the use of backup channels. The main drawbacks of this work are the high control overhead due to beacon exchange and the requirement of strict synchronization. The necessity for synchronization are more relevant to networks with special topologies, such as networks based on *clusters*. Such a solution is presented in [2], where the clusterhead assists in the choice of the channel. Moreover, several different clusters representing different CCCs may be integrated over time. This work may is limited in application as it assumes a special topology, and is also adversely affected in dynamically changing node locations.

A multiple rendezvous control channel (MRCC) is proposed in [7]. Here, the nodes hop over multiple channels till a common channel to the pair (rendezvous channel) is reached. The main problem of this work is that the hopping sequences between a node pair is static once the rendezvous condition is reached. If the PU activity is detected on a channel, the hopping on that particular channel is simply removed from the schedule. For dynamically changing PU activity, this may lead to inefficient hopping schedules. Moreover, there is no bounded time to achieve the rendezvous (TTR).

The adaptive multiple rendezvous control channel (AMRCC) scheme proposed in this paper maximally spreads control signalling and data transmission among channels by overcoming the limits of [7]. In fact, the AMRCC scheme builds the channel hopping sequences based on sensing information in order to hop across the different channels by minimizing the interference to licensed users. The main improvement of our work over [7] is that the sequences are chosen adaptively to combat the problem of PU interference. Similar to Bluetooth [3], the hopping sequences are built in such a way that the channels with minimum interference to other devices occur a higher number of times than the others. As opposed to this, [7] uses pre-defined sequences based on permutations of the available channels. The PU activity is taken into account by just removing a channel from the pre-defined sequence. This raises the concern that the sequences get progressively shorter. Additionally, AMRCC is completely asynchronous, unlike [7], where the start and stop times of each slot have to be rigidly synchronized.

An important contribution of this paper is a slot duration optimization of the AMRCC scheme. Here, the time for which the CR user stays on a given channel is also variable, and a function of the PU activity on the channel.

The rest of the paper is organized as follows: Section 2 the motivates our work. The design of our proposed AMRCC control channel design is explained, together with an optimization which assures scalability with the number of channels in Section 3. An optimization to the AMRCC design with differential slot times is described in Section 4. Section 5 gives a detailed performance evaluation of the AMRCC scheme and, finally, we conclude in Section 6.

2. Motivation for an adaptive MRCC

In this section we propose our adaptive MRCC (AMRCC) scheme for CR ad hoc networks, which achieves high performance by dynamically adapting the hopping sequences to the detected PU activity.