Computers and Electrical Engineering 52 (2016) 293–306

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Combined channel assignment and network coded opportunistic routing in cognitive radio networks☆,☆☆

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ARTICLE INFO

Article history:
Received 29 October 2014
Revised 1 June 2015
Accepted 1 June 2015
Available online 27 June 2015

Keywords:
Opportunistic routing
Channel assignment
Network coding
Cognitive radio networks

ABSTRACT

In this paper, we investigate the joint opportunistic routing and channel assignment problem in multi-channel multi-radio (MCMR) cognitive radio networks (CRNs) for improving the aggregate throughput of the secondary users. We first present the nonlinear programming optimization model for this joint problem, taking into account the feature of CRNs-channel uncertainty. In order to reduce the computational complexity of the problem, we present a heuristic algorithm to select forwarding candidates and assign channels in CRNs, including candidate selection algorithm considering the queue state of a node and expected transmission count (*ETX*), and channel assignment algorithm taking into account the transmission time and the available time of a given channel. Our simulation results show that the proposed scheme Channel Assignment and Network Coded Opportunistic Routing, (CANCOR) performs better than the traditional routing and classical opportunistic routing in which channel assignment strategy is employed.

1. Introduction

The cognitive radio principle has introduced the idea to exploit spectrum holes (i.e., bands) which result from the proven underutilization of the electromagnetic spectrum by modern wireless communication and broadcasting technologies [1]. Cognitive radio networks (CRNs) have emerged as a prominent solution to improve the efficiency of spectrum usage and network capacity. In CRNs, secondary users (SUs) can exploit channels when the primary users (PUs) currently do not occupy the channels. The set of available channels for SUs is instable, varying over time and locations, which mainly depends on the PU's behavior. Thus, it is difficult to create and maintain the multi-hop paths among SUs through determining both the relay nodes and the available channels to be used on each link of the paths.

Taking the advantage of the broadcast nature and spatial diversity of the wireless medium, a new routing paradigm, known as opportunistic routing (OR) [2], has been proposed in the ExOR protocol. Instead of first determining the next hop and then sending the packet to it, a node with OR broadcasts the packet so that all neighbors of the node have the chance to hear it and assist in forwarding. OR provides significant throughput gains compared to traditional routing. In

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. M. Rehmani.
☆☆ Part of the works will present at IEEE Globecom 2014 (Qin et al., 2014).
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http://dx.doi.org/10.1016/j.compeleceng.2015.06.002
0045-7906/

CRNs, it is hard to maintain a routing table due to dynamic spectrum access. The pre-determined end-to-end routing does not suit for CRNs. Since opportunistic routing does not need prior setup of the route, it is more suitable for CRNs with dynamic changes of channel availability depending on the PU's behavior. However, it is not easy to extend the previous studies [2,3] of OR in multi-hop CRNs. On the one hand, in CRNs, SU can only opportunistically explore the spectrum holes for communications. These spectrum holes are usually uncertain. On the other hand, the sender and forwarder should have a common available channel for communications. How to detect and choose a good candidate is not trivial for multi-hop CRNs.

In our previous work [4], we have studied network coded opportunistic routing in multi-channel CRNs while considering channel assignment, which only considers the nonlinear programming optimization for the joint OR and channel assignment problem. In this paper, we further explore the OR and channel assignment in CRNs, and present a heuristic algorithm to solve the optimization problem, including candidate selection algorithm and channel assignment algorithm. The contributions of our work can be summarized as follows.

First, we propose a new metric to select proper forwarding candidates for opportunistic routing, which considers the queue state of a node, packet loss rate and channel availability. Also, we present a method for dynamically calculating the threshold of the new metric, which depends on the number of the one-hop neighboring nodes and the value of the metric. It does not discuss in [4], which is more suitable for multi-hop CRNs.

Second, a new algorithm for calculating the forwarding probability of any packet at a node is proposed, which is used to calculate the number of packets a forwarder should send.

Third, we formulate an optimization problem for combining opportunistic routing and channel assignment in CRNs, and propose a heuristic algorithm to solve the complicated joint problem, including candidate selection algorithm and channel assignment algorithm, which does not mention in [4].

Finally, different from [4], in this paper, we compare the performance of our scheme, CANCOR-Channel Assignment and Network Coded Opportunistic Routing, with theoretical results (found by solving the linear programming problem), and with shortest path routing (SINGLE), MORE [3], MaxPoS [5,6], and ExOR [2] in CRNs under different scenarios, and the extensive simulation results are presented to demonstrate the effectiveness of the CANCOR.

The rest of this paper is organized as follows. Section 2 presents related works. In Section 3, we describe the CRNs model used in this paper. In Section 4, we formulate an optimization problem for joint opportunistic routing and channel assignment for CRNs. The heuristic algorithm is proposed in Section 5. The simulation results are presented in Section 6. Finally, Section 7 concludes this paper.

2. Related works

The effects of opportunistic routing on the performance of CRNs have been investigated in [5–11]. In 2008, Pan et al. [7] proposed a novel cost criterion for OR in CRNs, which leverages the unlicensed CR links to prioritize the candidate nodes and optimally selects the forwarder. In this scheme, the network layer selects multiple next-hop SUs and the link layer chooses one of them to be the actual next hop. The candidate next hops are prioritized based on their respective links' packet delivery rate, which in turn is affected by the PU activities. At the same time, Khalife et al. [8] introduced a novel probabilistic metric toward selecting the best path to the destination in terms of the spectrum/channel availability capacity. Considering the spectrum availability time, Badarneh and Salameh [5,6] gave a novel routing metric that jointly considers the spectrum availability of idle channels and the required CR transmission time over those channels. This metric aims at maximizing the probability of success (PoS) for a given CR transmission, which consequently improves network throughput. Lin and Chen [9] proposed a spectrum aware opportunistic routing for single-channel CRNs that mainly considers the fading characteristics of highly dynamic wireless channels. The routing metric takes into account transmission, queuing and link-access delay for a given packet size in order to provide guarantee for end-to-end throughput requirement. Taking heterogeneous channel occupancy patterns into account, Liu et al. [10] introduced opportunistic routing into the CRNs where the statistical channel usage and the physical capacity in the wireless channels are exploited in the routing decision. Liu et al. [11] further discussed how to extend OR in multi-channel CRNs based a new routing metric, referred to as Cognitive Transport Throughput (CTT), which could capture the potential relay gain of each relay candidate. The locally calculated CTT values of the links (based on the local channel usage statistics) are the basis for selecting the next hop relay with the highest forwarding gain in the Opportunistic Cognitive Routing (OCR) protocol over multi-hop CRNs.

However, none of the above schemes systematically combines the channel assignment with OR to model CRNs. The number of candidate forwarders and the performance of OR will decrease, if using existing channel assignment algorithms for multi-channel multi-radio (MCMR) OR. A Workload-Aware Channel Assignment algorithm (WACA) for OR is designed in [12]. WACA identifies the nodes with high workloads in a flow as bottlenecks, and tries to assign channels to these nodes with high priority. WACA is the first static channel assignment for OR. However, it deals with channel assignment for single flow. Assuming that the number of radios and the number of channels are equal, a simple channel assignment for opportunistic routing (SCAOR) is proposed in [13]. It selects a channel for each flow. SCAOR is for multiple flows, but assumes that the number of radios and the number of channels are equal in SCAOR.