Chapter 89
A Graph-Intersection-Based Algorithm to Determine Maximum Lifetime Communication Topologies for Cognitive Radio Ad Hoc Networks

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ABSTRACT

The authors propose a generic graph intersection-based benchmarking algorithm to arrive at upper bounds for the lifetimes of any communication topology that spans the entire network of secondary user (SU) nodes in a cognitive radio ad hoc network wherein the SUs attempt to access the licensed channels that are not in use. At any time, instant t when we need a stable communication topology spanning the entire network, the authors look for the largest value of k such that the intersection of the static SU graphs from time instants t to t+k, defined as the mobile graph Gt...t+k(SU) = Gt(SU) ∩ Gt+1(SU) ∩ .... ∩ Gt+k(SU), is connected and Gt...t+k+1(SU) is not connected. The authors repeat the above procedure for the entire network session to determine the sequence of longest-living instances of the mobile graphs and the corresponding instances of the topology of interest such that the number of topology transitions is the global minimum. They prove the theoretical correctness of the algorithm and study its effectiveness by implementing it to determine a sequence of maximum lifetime shortest path trees.

INTRODUCTION

A cognitive radio is a software-defined radio that can dynamically adapt its transmission parameters to the channels (frequencies) available for use in the operating environment (Akyildiz et. al., 2006). A cognitive radio network (CRN) is thus a network of wireless devices embedded with cognitive radios that can sense the available channels in the neighborhood and switch the communication channel, if

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needed. Cognitive radios have been considered as a promising solution to alleviate the spectrum scarcity problem (Zhao & Sadler, 2007). Accordingly, CRNs typically comprise of two categories of users: primary users (PUs) who own licensed channels and secondary users (SUs) who do not own any licensed channel (Akyildiz et. al., 2006). The SUs use the licensed channels of the PUs when the latter do not use them. When the PUs of the currently used channels become active, an SU relinquishes the channel and switches to any other available PU channel.

In this chapter, we target a well-known category of CRNs called the cognitive radio ad hoc networks (CRAHNs) - a self-organized ad hoc network of the licensed PU nodes and the unlicensed SU nodes (Akyildiz et. al., 2009). Depending on the activity status of the PU nodes, the set of common PU channels in the neighborhood of the SU nodes changes dynamically with time. Thus, even in a static network of SU nodes and PU nodes, communication topologies (like paths and trees) that connect the SU nodes may have to be frequently reconfigured depending on the availability of the PU channels in the SU-SU neighborhoods. Not much work has been done on determining stable paths or trees that could exist for a longer time in a CRAHN. Specifically, to the best of our knowledge, there has been no work done to determine stable sequence of a communication topology that spans (i.e., connect all the SU nodes) the entire CRAHN network of SU nodes.

Our focus in this chapter is to develop a generic benchmarking algorithm that can be used to arrive at upper bounds for the lifetime of any communication topology that spans the entire network of SU nodes. Referred to as the Maximum Lifetime Communication Topology (MLCT) algorithm, the algorithm can be used to determine a stable sequence of instances of any communication topology that spans the entire network of SU nodes (say, shortest path tree, minimum spanning tree, connected dominating set, etc) for the lifetime of the network as long as there is a polynomial-time algorithm or heuristic to determine that topology.

BACKGROUND

Most of the work done so far in the CRAHN literature focused on developing routing solutions that are either full spectrum knowledge based or local spectrum knowledge based. The full spectrum knowledge based solutions assume each SU node to be completely aware of all the available PU channels in the network and choose optimal routes with respect to either minimum number of hops per SU-SU path (Xin et. al., 2005), maximum conflict-free assignment (Zhou et. al., 2009) of PU channels or minimum number of channel switches per SU-SU path (Xin et. al., 2008); there is bound to be switching of channels when none of the common available PU channels for the end nodes of an SU-SU link are the same as the preferred PU channels for one or both the end nodes to which they stay tuned by default for transmission and reception. Such full spectrum knowledge-based solutions take a centralized approach like we took in this chapter; however, the full spectrum knowledge for the current time instant alone cannot be used to arrive at benchmarks for the routing metric, if one intends to stay with a route as long as it exists.

The local spectrum knowledge based routing solutions are distributed in nature and rely only on the spectrum information gathered in the neighborhood through the common control channel (Lo, 2011). The local spectrum knowledge based routing solutions proposed so far could be classified into sub classes that target at optimizing a particular metric in a distributed fashion. The minimum power routing protocol (Pyo & Hasegawa, 2007) is designed to discover SU-SU paths that incur lower energy consumption by taking into consideration the energy loss incurred due to transmission, reception, broadcast route discov-