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Time-efficient distributed layer-2 auto-configuration for cognitive radio networks ☆

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Abstract

Cognitive radios (CR) have the ability to dynamically adapt to local spectrum availability. In a network comprised of CR-enabled devices, layer-2 auto-configuration involves determining a common set of channels to facilitate communication among participating nodes. This is a unique challenge as nodes in the CR network may be unaware of (a) their neighbors and (b) the channels on which they can communicate with a neighbor. In this paper, we propose a time-efficient distributed algorithm for layer-2 auto-configuration for a CR network. Our algorithm finds the globally common channel set in $2MN + O(DN)$ timeslots, where each node is assigned a unique identifier from the range $[1, \ldots, N]$, M is the maximum number of channels available for communication, and D is the diameter of the network. All nodes know M and N. We present both diameter-aware and diameter-unaware versions of the algorithm. We then show that the proposed algorithms are efficient by proving a matching lower bound. Finally, we investigate a special case when nodes have more knowledge available at their disposal and discuss how the time-complexity of our algorithm can be improved under this case.

Keywords: Cognitive radio; Multiple channels; Neighbor discovery; Distributed algorithm

1. Introduction

With the unprecedented proliferation of wireless communication devices in recent times, it is being claimed that there will be an acute shortage of bandwidth in the near future. This claim is seemingly supported by the observation that most of the available frequency bands have already been allocated to various applications (*e.g.*, television transmission, microwave communication, cellular communication, etc.) [5]. However, it has been noted that a significant portion of the allocated spectrum is underutilized [6,3]. For example, in several urban areas many of the television channels in the VHF and UHF bands are unassigned.

Cognitive radio (CR) technology [19] allows wireless devices to dynamically adapt to spectrum

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availability in their geographical region. The owner of a (licensed) channel is referred to as *primary user* and all other users of the channel as *secondary users* [3]. CR technology enables secondary users to scan and identify unused channels in a frequency spectrum. A channel is said to be *available* if the secondary user can send and receive messages on the channel without interfering with the primary user(s). Such a communication infrastructure based on CR technology has applications in defense and relief and rescue operations. Since the usage of spectrum varies widely from one region to another [6], communication among users (soldiers in a platoon or relief personnel in a disaster-prone area) must rely on a dynamic channel assignment scheme. Also, in military applications and disaster recovery scenarios such as the shuttle recovery effort in east Texas or hurricane affected areas, significant parts of the spectrum are likely to be available for use by secondary users. When a secondary user (hereafter, referred to as a node in the CR network) independently scans the spectrum usage and maintains the set of (locally) available channels, the following layer-2 auto-configuration issues arise:

1. How do nodes detect their neighbors and collectively form a communication infrastructure in the absence of a central authority?
2. How do nodes decide on the set of channel(s) that can be used for communication?

Note that the CR nodes may be turned on at different times. Wireless communication among neighbors is possible if the source and destination nodes tune to a common channel at the same time. In the layer-2 auto-configuration problem in a CR network, a *common set of channels* (referred to as the *globally common channel set*, $\mathcal{G}_0$, in this paper) needs to be determined. The motivations behind finding $\mathcal{G}_0$ are:

a. There may be multiple groups of nodes deployed in a geographical area, say in a military operation (there may be many platoons, with each platoon being a group) or at the site of a natural disaster (firemen, paramedics, police being three groups). It is important that each group chooses a unique channel for communication among the group members with few nodes acting as gateways between groups.
b. Node mobility leads to frequent changes in network topology. For such systems, communication over a *globally common* channel provides a simple and effective solution ([7,17]).
c. Since a globally common channel is available at all the nodes, and the nodes may be distributed over a wide geographical region, using such a channel leads to a fairly stable communication infrastructure.

Finding a common set of available channels (that is, globally common channel set) for communication is non-trivial because of the divergence in the sets of available channels at individual nodes and the absence of a central authority. This is because communication infrastructures in military and relief operations are usually ad hoc in nature. The complexity of the problem is further increased due to the following reasons:

i. Nodes do not have prior knowledge about the number and identities of other nodes in their neighborhood.
ii. Although two nodes may be physically close, their channel availability sets may be different. Thus, nodes are unaware of the existence of a common channel in their one-hop neighborhood.
iii. Changes in neighborhood due to node mobility can play a significant role in computing $\mathcal{G}_0$. So, it is very important that the distributed computation terminates quickly.

1.1. Our Contributions

Let each node be assigned a unique identifier from the range $[1, \ldots, N]$, and $\mathcal{A}_{\text{univ}}$ be the set of M possible channels all the nodes are capable of operating on. In this paper, we propose a 2-phase auto-configuration algorithm that enables the nodes to dynamically compute the globally common channel set, $\mathcal{G}_0$ in a distributed manner. All nodes know $\mathcal{A}_{\text{univ}}$[1] and the value of N. We present a fully distributed algorithm to determine $\mathcal{G}_0$ in $2MN + O(DN)$ timeslots, where D is the diameter of the network. The algorithm consists of two phases. Phase 1 (*neighbor discovery and configuration*) of the algorithm consists of $2MN$ timeslots split equally between *neighbor discovery* and *conveying locally common broadcast channel*. Phase 2 consists of $O(DN)$ timeslots and is used for the computation of $\mathcal{G}_0$. If D is known, then the

[1] When the radios are built, they have a range of frequencies they can operate on.