Journal of Network and Computer Applications 45 (2014) 79–95

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

Review

Clustering algorithms for Cognitive Radio networks: A survey

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ARTICLE INFO

Article history:
Received 16 August 2013
Received in revised form
17 June 2014
Accepted 21 July 2014
Available online 1 August 2014

Keywords:
Cognitive Radio
Software defined radio
Topology management
Clustering
Routing

ABSTRACT

Cognitive Radio (CR) networks enable unlicensed or Secondary Users (SUs) to sense for and operate in the underutilized spectrum (or white spaces) owned by licensed or Primary Users (PUs) without causing unacceptable interference to the PUs' activities. Clustering, which is a topology management mechanism, organizes nodes into logical groups in order to provide network-wide performance enhancement. Clustering aims to achieve network scalability and stability, as well as to support cooperative tasks, such as channel sensing and channel access, which are essential to CR operations. While clustering has been well investigated in traditional networks such as mobile ad hoc networks, similar investigations in CR networks remain in the infancy stage. New clustering algorithms must be designed to address new challenges associated with the intrinsic characteristics of CR, namely the dynamicity of channel availability that changes with time and location. This article reviews clustering algorithms, and they are characterized by clustering objectives, metrics and the number of hops in each cluster. We also present complexity analysis, performance enhancements achieved by the clustering algorithms, as well as open issues, in order to establish a foundation for further research and to spark new research interests in this area.

Contents

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http://dx.doi.org/10.1016/j.jnca.2014.07.020
1084-8045/

1. Introduction

Cognitive Radio (CR) (Akyildiz et al., 2006) enables unlicensed users (or Secondary Users, SUs) to sense for licensed users' (or Primary Users, PUs) underutilized channels (called white spaces), and subsequently uses the channels in an opportunistic manner conditional on the interference to the PUs being below an acceptable level. IEEE 802.22 is a standard for CR networks that uses white spaces in the television frequency bands; and it is designed for centralized networks comprised of base stations and wireless hosts (or Customer Premise Equipment (CPE)) (Fan and Rocky, 2009). A distributed Cognitive Radio network is comprised of a number of SUs who communicate with each other in the absence of fixed network infrastructure such as an access point or a base station. This article focuses on clustering in distributed CR networks.

Clustering organizes nodes into clusters in order to provide network-wide performance enhancement. Generally speaking, there are three main advantages brought about by clustering to CR networks, namely scalability, stability, and supporting cooperative tasks, such as channel sensing and channel access, which are essential to CR operations, and these advantages have led to the use of clustering in CR networks. An intrinsic characteristic of CR networks that warrants further investigation on clustering is *dynamicity of channel availability* in which the channel availability (or white spaces) of each SU is different, and it changes with the level of PU activities, time and location. Popular traditional clustering algorithms, such as lowest ID (Ephremides et al., 1987) and maximum node degree (Jeng and Jan, 2007), may not be suitable, and so various new clustering algorithms have been proposed. The lowest ID clustering algorithm selects a node with the lowest ID as the leader of a cluster (or clusterhead); while the maximum node degree clustering algorithm selects a node with the highest number of neighbor nodes as the clusterhead. There are three reasons why traditional clustering algorithms applied to wireless ad hoc and sensor networks (Peiravi et al., 2013; Lee and Lee, 2013; Khan et al., 2011) are not suitable for CR networks. Firstly, the algorithms do not adapt to the channel dynamics in CR networks. Secondly, the algorithms may not achieve objectives specific to CR networks. For instance, a common channel may not be established due to the lack of white spaces, so some nodes in a cluster may not be able to communicate with the clusterhead. Thirdly, the algorithms may not enhance network performance pertinent to CR networks such as achieving a higher number of common channels in a cluster, and application-specific network performance, such as achieving lower error probability in channel sensing outcomes.

The main contribution of this article is to present an extensive review on the various aspects of clustering algorithms in distributed CR networks, including clustering objectives, clustering characteristics (i.e. metrics and intra-cluster distance), performance enhancements, complexity analysis (i.e. time and message complexities), as well as open issues. It focuses on clustering algorithms, particularly clustering metrics and how these metrics have been applied to form clusters in CR networks, rather than application schemes that apply the cluster structure such as cluster-based routing that focuses on the enhancement of routing rather than clustering (Talar and Altilar, 2011), and it does not focus on the traditional coordination mechanisms for clustering algorithms because there has been a considerable amount of literature being published in the context of mobile and static ad hoc (or mesh) networks. Since clustering algorithms have been traditionally incorporated into the network layer to form clusters, which help to limit the flooding of routing overheads (e.g. Route Request and Route Reply) throughout the entire network (Ephremides et al., 1987; Jeng and Jan, 2007), the other layers such as the application and physical layers are not discussed in this article. Additionally, the contributions are to The purposes of this article are to establish a foundation and to spark new interests in this emerging research area. Note that, for simplicity, the terms *SUs* and *nodes* are used interchangeably throughout the entire article. The organization of this article is as follows. The rest of Section 1 presents an overview of CR networks, as well as an overview, advantages and challenges of clustering in CR networks. Section 2 presents taxonomy of the attributes of clustering algorithms in CR networks. Section 3 presents various clustering algorithms in CR networks, as well as to relate them to the attributes of clustering algorithms presented in Section 2. Section 4 presents performance enhancements achieved by clustering algorithms. This section also presents complexity analysis of the clustering algorithms. Section 5 presents open issues. Section 6 presents conclusions.

1.1. Cognitive radio: an overview

The traditional spectrum allocation policy has been partitioning radio spectrum into smaller ranges of licensed and unlicensed frequency bands (also called channels). The licensed channels, which are auctioned off by the government, provide exclusive channel access to PUs. SUs, such as the popular wireless communication systems IEEE 802.11, are forbidden to access any of the licensed channels. Instead, they access unlicensed channels without incurring any monetary cost.

Cognitive Radio enables SUs to sense radio spectrum and use white spaces whilst minimizing interference to PUs. The purpose is to improve the availability of bandwidth at each SU, and hence improving the overall utilization of radio spectrum, which is one of the scarcest resources in wireless communications. The main difference between CR and the traditional wireless networks is the presence of PU activities in CR networks; hence the main