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Fault tolerant backbone construction in cognitive radio networks

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ABSTRACT

A cluster based backbone formation protocol is proposed for cognitive radio networks, where nodes are allowed to use the channels not occupied by primary users. It is based on the idea of finding the neighbors, choosing the best nodes as cluster heads and connecting clusterheads with the help of intermediate nodes to construct the backbone. We have proposed an efficient approach for neighbor discovery as well as cluster formation in cognitive radio network. We present the analytic as well as simulation study of the protocol. In the end, we indicate a method to handle the dynamic changes in the constructed backbone.

1. Introduction

Nowadays, the vast growth in mobile devices has led to the scarcity of bandwidth that necessitates the new paradigm of spectrum management, such as spectrum sensing, spectrum allocation, spectrum decision and spectrum mobility [1]. A cognitive radio network (CRN) is a collection of mobile nodes (a.k.a. secondary users) and has all the functionalities related to spectrum management. The secondary users can sense the available spectrum, and they can switch to other channels or vacate them in case, the primary user appears. A channel is said to be available if not occupied by primary user. The communication between two nodes can only occur if they are in transmission range of each other and tuned to a common channel. Such nodes are called neighbors. Cognitive radio networks are more challenging as compared to mobile ad hoc networks because it needs to address both the mobility as well as dynamic channel availability. Due to the uncertainty of channel availability, if a node wants to communicate with the other node that is multiple hops away, then it faces two difficulties. First, it needs to find the route from source to destination, and second, if a route is computed, it may not be stable [3] because once the link becomes unavailable, the route is broken. Hence, to work with the opportunistic networks, one must have the ability to handle the node mobility as well as channel management.

The proposed protocol creates clusters, and each cluster has a unique clusterhead. The clusterheads are responsible for inter cluster communication. The clusterheads are joined together with the help of intermediate nodes (a.k.a. gateway nodes) to form the virtual backbone. Once the backbone is formed, the nodes that belong to different clusters can communicate with each other using backbone nodes. There are various applications of virtual backbone like routing, channel management, failure handling, and topology managements [2]. The protocol involves following phases:

(1) *Neighbour discovery*: Initially, each node discovers its one hop neighbors that are tuned to different channels.
(2) *Cluster head selection* – Once the neighbor discovery is over, each node possesses the information about its one hop neighbors. Such information is useful for selection of clusterheads.
(3) *Cluster formation* – After the declaration of cluster heads, nodes get associated with suitable clusterheads.
(4) *Virtual backbone formation* – It is the final phase of the algorithm, where all clusterheads are connected through gateway nodes to construct the virtual backbone.

Furthermore, we also propose a method for failure handling in cognitive radio network. In the end, correctness proof and simulation result are presented.

2. Related work

Numerous research articles have been published towards virtual backbone construction in wireless ad hoc networks; however, we mention here only the works [3–5] that may be adapted in cognitive radio networks. As these research papers do not address the node mobility and dynamic availability of channels, it may lead to instability if applied straightforward in cognitive radio networks. In [3], the authors have proposed a technique to construct connected dominating set (CDS) in wireless ad hoc networks, which serves as a virtual backbone. Further, in [4], an algorithm based on weakly connected dominating set (WCDS) is proposed where the computation is based on finding a

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maximal independent set. A cluster formation protocol is presented in [5], where clusterheads are selected using the concept of weight. An energy efficient clustering techniques are discussed in [6,7] for routing in wireless sensor networks; however, these are not applicable in cognitive radio networks.

Some papers [8–12,1], present the algorithms to construct the clusters in mobile ad hoc networks (MANETs). In [5], the authors have proposed distributed mobility–adaptive clustering (DMAC) and distributed clustering algorithm (DCA) for wireless networks. The techniques proposed in [8,9] follow a traditional approach for cluster formation that is based on two phases: (1) clusters formation, and (2) connecting the clusters with the help of cluster heads. The algorithm in [10] is quite different from the traditional approach, where the node, selected as a clusterhead, has the highest number of connected nodes in d-hop neighborhood. In [11], a node is selected as a cluster head if it satisfies the following two conditions: (1) It has higher priority in its one hop neighborhood, and (2) it has higher priority in the neighborhood of at least one of its neighbors. In [12], the authors have proposed a tree based cluster formation algorithm. In [13], the algorithm is based on the concept of connected dominating set to form the virtual backbone.

Very few articles [14,15] have been published towards virtual backbone formation in cognitive radio networks. The authors in [14] have assigned an initial home channel (IHC) to each node, and each node finds out the available common channels with other nodes by using channel hoping. Once the status of other nodes is known, the clusters are formed. In [15], the authors have assumed two types of zones: first interference zone (affected by primary users), and second non-interference zone (not affected by primary users). A node is selected as a clusterhead in potential interference zone that has less probability to encounter with interference.

Additionally, a node having higher stability has higher priority to get elected as a clusterhead or gateway node in non interference zone.

In this paper, we propose a backbone formation algorithm in CRN. It is based on the idea of cluster formation like [16]; however, unlike [16], we do not find the neighbors on a single channel rather we find the neighbors of a node on all available channels in its channel list.

3. The system model

In this section, we present the preliminary assumptions, notations (Table 1), types of messages (Table 2), and data structures (Table 3).

3.1. Network structure

We represent the network by communication graph $CG = (V, E)$, where V represents the set of SUs and E represents the set of links (edges) connecting the SUs. An undirected edge between any pair of cognitive radio nodes (SUs) represents a bidirectional link, and these links are not necessarily FIFO.

Table 1
Notations.

Notation	Meaning
C_j	Channel C is available on node j
C_{ij}	A channel C is available between node CR_i and CR_j
CR_i	It represents a cognitive radio node with unique identifier i
CG	Communication graph
E	A set of edges
N	Total number of cognitive radio nodes
NV	A set of new nodes that appear in the network after virtual backbone formation
PU	Primary user
rtt	Round trip time
SU	Secondary user
Ch	Cluster head

3.2. Cognitive radio nodes

We consider the cognitive radio network as a collection of N CRs ($CR_1, CR_2, CR_3, \ldots, CR_N$). Each node is assigned a unique identifier [1, 2, 3, …, N], e.g., CR_i denotes a cognitive radio node with unique id i. In our illustration CR_i, and node i have been used interchangeably. CRs are capable enough to sense the available channel(s) and keep track of occupancy status of the channels by PUs. The spectrum availability can be sensed using techniques discussed in [17,18]. Further, the nodes in the network are equipped with carrier sense multiple access/collision avoidance (CSMA/CA) protocol. The CSMA/CA has been used to avoid the collision because a CRN is a distributed system, where each node executes the protocol concurrently.

3.3. Communication channel

Each node in CRN maintains a list of channels not occupied by PUs. Two cognitive nodes i and j in the network can communicate with each other only if they have a common channel (C_{ij}) between them. Further, it is assumed that node has multiple interfaces to support multiple channels. Thus, it can listen on multiple channels at the same time.

3.4. Failure model

Failure in the network may occur because of following reasons [19].

- If a node has the only channel in its available list and suddenly PU appears on that channel. It causes disconnection of the node from the network.
- If a node does not have sufficient battery backup or computation capability, it may result in failure of the node.
- Frequent topology changes may also trigger failures.

4. The CVB-CRN protocol

We present a cluster based backbone formation protocol (called CVB-CRN, henceforth) that aims to provide virtual backbone without common control channel. It is based on the following steps (a) Neighbour discovery, (b) cluster head selection (c) cluster formation, and (d) virtual backbone formation. We discuss each phase in details with the help of algorithms.

4.1. Neighbor discovery

Neighbor discovery algorithm is described in Algorithm 1. It is tedious because secondary users operate on the channels whose availability is highly dependent on activities of primary users. There are various well-known existing algorithms based on the common control channel, channel hopping, and broadcasting techniques. All of these techniques have their pros and cons. Some papers have been published on neighbor discovery [20–25]. They use either time-based approach to access the channel or sequence

Algorithm 1. Neighbor Discovery

A1. Initialization
1. **For** $\forall\ j: j \in V$
2. **While** CL_j is not empty; **do**
3. select C_j: $C_j \in CL_j$
4. $Broadcast_j\ (ND_{request}, C_j)$
5. $CL_j \leftarrow CL_j \setminus \{C_j\}$
6. **done**
7. **End For**

A2. Action taken by node i on reception of $ND_{request}$ message from node j
1. **If** ($RMQstatus_i[j] == 0$) then