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A tree routing protocol for cognitive radio network

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ABSTRACT

Cognitive Radio (CR) technology is an agile solution for spectrum congestion and spectrum access utilization problems that result from the legacy fixed spectrum management policies. CR technology can exploit unused licensed band to meet the increasing demand for radio frequency. The routing process faces many challenges in CR Network (CRN) such as the absence of centralized infrastructure, the coordination between the routing module and spectrum management module, in addition to the frequent link failure due to the sudden appearance of PUs. In this paper we propose a Tree routing protocol for cognitive radio network (C-TRP) that jointly utilizes the tree routing algorithm with a spectrum management module in routing decisions, and also we proposed a new metric used in taking the best route decisions. In addition, we enhance the traditional tree routing algorithm by using a neighbor table technique that speeds up the forwarding data packets. Moreover, we add a robust recovery module to C-TRP to resume the network in case of the link failure. The main motivation in the design of C-TRP is quick data transmission and maximization of date rates. The performance evaluation is carried out in NS2 simulator. The simulation results proved that C-TRP protocol achieves better performance in terms of average "PDR", "end-to-end delay" and "routing overhead ratio "compared to "CTBR" and "STOD-RP" routing protocols.

1. Introduction

The radio spectrum is a natural resource regulated by international governmental agencies and assigned to licensed operators on a term basis using a fixed spectrum assignment policy [1].

This fixed assignment policy which was adequate in the past. But due to the rapid development of wireless applications and devices, that policy became inadequate according to federal communications commission (FCC) reports [2]. These recent reports [3,4] have shown that the usage of spectrum band is quite low due to waste valuable resources (spectrum bands) in some places. FCC highlights that many spectrum bands, allocated through fixed assignment policies, have the average utilization of such bands varying between 15% and 85% [5].

We can overcome this problem and utilize the unused radio frequency band efficiently by applying the concept of cognitive radio (CR) that has been proposed by Mitola [6]. Mitola has proposed that spectrum holes can be best used by permitting unlicensed users to access the spectrum band when the licensed users are not available. The licensed users are called Primary Users (PUs), whereas the unlicensed users are called Secondary Users (SUs) or CR nodes. The PU is the user that has absolute authority and higher priority to use the spectrum band at any time and any place. The SU is the user that uses the spectrum band as a visitor only at the time that PU is not available.

In CR network, a node is equipped with a spectrum agile radio that can monitor, scan the available channels (spectrum sensing), change its configuration parameters and tune its transmitter to a suitable free available channel to use it in the time that PUs are not available and release it when the PUs return back [7].

In this paper, we focus on the routing module in Cognitive Radio Network (CRN). The routing process is the process of finding the best route from a source node to destination node. The routing in multi-hop CRN faces many challenges. First one is the coordination between the routing module and spectrum management module [8]. The second challenge is the frequent link failure [9] due to the sudden appearance of PUs. Therefore, the routing protocol in CRN must have a robust recovery module to resume the network stability.

Any routing protocol consists of three main components: the first one is the routing metric which means the criteria that how

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to choose the best route from source to destination, the second one is the data structure that contains the routing information and third is the messages that exchange between neighboring nodes to share routing information.

Many routing protocols have been proposed for CRN in the last years. Besides the main goal of protecting PU transmissions [10], each protocol is proposed based on different design goals which change the types of previous components. Some protocols seek to decrease "end to end delay" such as [11], other protocols want to increase the throughput such as [12,13], some protocols are designed to maintain the route stability such as [14,15], and others minimize the cost of route recovery/maintenance [16].

In this paper, our contributions are as follows: first we introduce a tree routing protocol for cognitive radio network (C-TRP) that can deal with the previous challenges. C-TRP effectively coordinates between tree routing module and channel assignment module. Second, we enhance the tree routing algorithm that is used in C-TRP by adding a neighbor table technique. C-TRP employs a neighbor table to reduce the overhead of the routing process in the traditional tree algorithm. The nodes consult the neighbor table before sending packets, up (parents) or down (children) in the tree. If the node finds the destination node in the neighbor table, it will forward packets directly to it; otherwise, it will send packets up or down the tree according to the routing table's data. Third, we also propose the new routing metric that is path-delay. A path-delay includes both switching and queuing delay. A routing metric is used to rank the channels available from end to end. Last, we provide our routing protocol with a robust recovery module to deal with frequent link failure due to PUs activities on channels.

The rest of the paper is organized as follows. Section two describes the related work, section three describes the C-TRP in details, section four presents our performance evaluations and simulation results while section five concludes the paper and future work.

2. Related work

In this paper, we apply a Tree Routing Protocol for cognitive Radio Network (C-TRP). A tree-based routing is used before for large-scale wireless networks. For example, it is used in IEEE 802.16j [17] in which the wireless network type was used in Japan, and the wireless land type operates on 2.4 GHZ band and The ZigBee standard [18] for sensor wireless network.

In the Tree-based Routing protocols (TRPs), the links between nodes are controlled by Parent-Child relationships only. The TRP builds a hierarchical and logical map of nodes in the form of a tree from a physical mesh network topology as shown in Fig. 1. The TRP is a hierarchical model routing protocol that has one root node connected by parents' nodes and the children that connected to the root node through its parents. This topology eliminates path search [26] and avoids the extensive broadcast message that occurs in many routing protocols such as "Ad hoc On-Demand Distance Vector (AODV)" [19].

AODV is the most famous routing protocol in the ad hoc wireless network in general. AODV uses a hop count as routing metric. AODV [20] has two message types. First one is a route request message (RREQ) which is broadcast when a node requires a route. The second message is a route reply (RREP) that is sent from the destination node or intermediate node that has a route to the destination.

The main disadvantage of TRP is that it increases the end to end hop count. We mitigate this disadvantage by using a neighbor table. The neighbor table is not fully utilized in most TRP that used in wireless networks, and also not used in all TRP which is used in

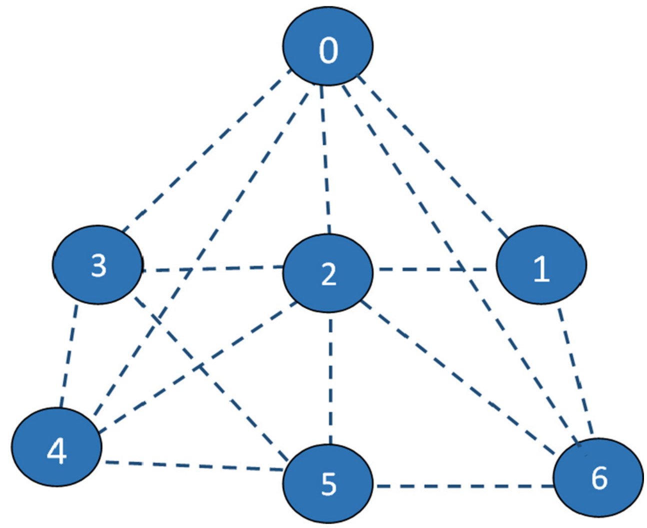

Fig. 1. Physical mesh topology.

CRN such as "spectrum-tree based on demand routing protocol for multi-hop cognitive radio networks (STOD-RP)" [21] and "Cognitive Tree-based Routing (CTBR) protocol" [22]. The neighbor table is built once a node starts to join the tree. The node first discovers all surrounding nodes (parents, some other adjacent nodes). The node searches for all available neighbors and finds the best parent to join the tree. The neighbor table must be refreshed periodically. The AODV [20] updates its neighbor table information by exchanging a hello message with neighbors at a specific period.

In this paper, we implement a C-TRP and compare it with the other two related routing protocols for multi-hop multi-channel CRN STOD-RP [21] and CTBR [22] protocols.

In a STOD-RP protocol, the authors proposed the "spectrum Tree Based On Demand Routing protocol (STOD-RP)". The STOD-RP addresses the problem of the integration between the routing's module with spectrum decision management module. In the STOD-RP, protocol builds one tree for each spectrum and selects one CR node from existing nodes to become the root node. The root node contains all information about the spectrum band (busy - free) states. The root node is selected based on the node which has the largest number of spectrum bands and has the longest period of spectrum availability. The STOD-RP uses statistical PUs activities and SU Quality of Service (QoS) requirements as a metric for route selection.

The drawbacks of STOD-RP: first it runs a proactive tree based routing to establish a route from the node to the root node, and then uses on demand routing discovery to search the destination node, which may cause processing overhead and longer delay. The second drawback is that STOD-RP does not use a dedicated common control channel (CCC) and uses one available channel in each spectrum tree to transmit the data and control messages, which decrease the end-to-end throughput and packet delivery ratio, and does not maintain the stability of network topology due to the dynamic nature of available channels.

Another approach that extends a tree routing algorithm is a cognitive tree based routing (CTBR). A CTBR has enhanced tree based routing to adapt multiple wireless systems. In CTBR, the tree is built by configuring a base station as a tree root node. The root node sends periodically a root announcement (RANN) messages to all nodes. When a node receives RANN message, it caches the parent that sends this message as a potential parent. Then, each node selects one parent from potential parents based on the best path metric from the node to the root node.

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