Modified AODV Routing Protocol for Multi-hop Cognitive Radio Ad Hoc Networks

Melvin Mathew, G. Shine Let and G. Josemin Bala

Abstract Cognitive radio network (CRN) is a next generation network which has been studied and receiving significant research due to the underutilization and congestion in radio spectrum. Cognitive radio technology possesses self-adaptivity, and routing is one of the key issues for designing a self-adaptive networks. It has been received greater attention due to the tremendous growth in spectrum utilization there by reusing the spectrum efficiently and sharing the licensed band in the absence of primary users (PUs). In this paper, we have proposed a modified AODV routing protocol which can be used for multi-hop cognitive radio ad hoc networks that can efficiently utilizes the spectrum in an intelligent manner. The proposed routing method selects the best path to transmit the packets considering the PUs activity and switches to new route if there is any interference of PUs present. In this method, the routing table periodically updates its information and can be used to find the optimal route.

Keywords Cognitive radio network · Secondary users · Multi-hop · Routing · Radio spectrum

1 Introduction

With rapid growth of wireless network applications, nowadays there is a great demand for spectrum radio resources. The fixed radio spectrum is allocated by government agencies for various applications. The unlicensed band or ISM band is widely utilized and congested. As per the report by Federal Communications

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Commission (FCC), the usage of licensed spectrum varies between 15 and 85 % as time and location vary [1]. To overcome this scenario, cognitive radio is introduced as the next generation wireless technology in [2]. Cognitive radio is an intelligent radio which can change its transmitter and receiver parameters depending on the spectrum environment. A node integrated with cognitive radio technology can sense different spectrum range (Hz) and transmit the data based on the available bandwidth.

The main aim of cognitive radio is to select the best available licensed radio spectrum without giving interference to the licensed users. The temporally vacant licensed radio spectrum is called white space or spectrum hole or spectrum opportunities [2, 3]. Figure 1 shows the spectrum opportunity concept.

Cognitive radio network (CRN) is the collection of two or more devices equipped with wireless communication, networking and cognitive radio capability. In CRN, the unlicensed users are called cognitive users or secondary users (SUs), and the licensed users are called primary users (PUs). For SUs, no fixed spectrum will be allocated [4], and they will be using licensed spectrum when PUs are not using it. Guaranteed quality of service (QoS) is provided to PUs, and best effort QoS is given to SUs in CRN. Based on the architecture of cognitive network, it is classified as infrastructural CRN and infrastructureless CRN [5]. In infrastructural CRN, cognitive users communicate each other in centralized manner through fixed infrastructure or base station. Infrastructural CRN is also called as centralized CRN. In infrastructureless CRN, SUs communicate each other in ad hoc manner. The infrastructureless CRN is also called as cognitive radio ad hoc network.

For efficient communication between various cognitive users, various routing protocols are used. Section 2 gives an overview of the existing routing protocols in CRNs. Section 3 presents the proposed modified AODV routing protocol for cognitive radio ad hoc network. Next, Sect. 4 presents the performance evaluation, and finally, conclusion and remarks are presented in Sect. 5.

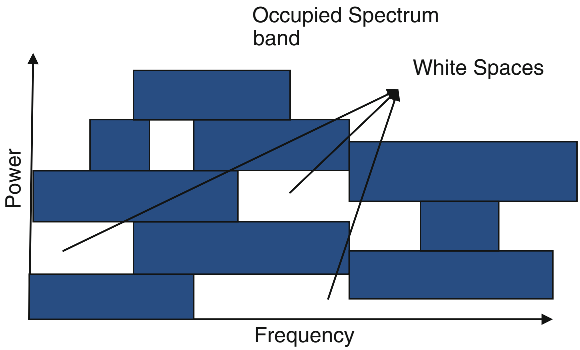

Fig. 1 Spectrum opportunity concept (*source* Elsevier computer networks 50, p. 2130)

2 Related Work

Routing in CRN is difficult task because of its dynamic variation of the available channels, data rates, and bandwidth. The routing protocols in CRN can be classified as proactive, reactive, hybrid, and adaptive per hop, and the routing model can be centralized or distributed [6]. Depending upon the protocol operation, the routing protocols for CRN can be classified as spectrum-aware-based, multi path-based, local coordination-based, reactive source-based, and tree-based [7]. In [8–11], route discovery is incorporated with spectrum sensing. Sampath et al. [8] have proposed high-throughput packet transmission using spectrum-aware routing (SPEAR) protocol. SPEAR is an on demand routing protocol, and it makes routing decisions based on the collaboration of physical and MAC layers. Ma et al. [9] modify AODV protocol, and route decision is done by intermediate SU node such that it increases the available time for data transmission between SU source and destination in order to reduce switching delay. This routing protocol introduces extra overhead of broadcasting RREQ messages, and deafness introduces extra delay to RREQ messages.

The authors in [10] have proposed a routing protocol called SAMER which considered spectrum availability and quality. SAMER protocol enhances route robustness and improves throughput performance of the network. This protocol establishes route based on periodically collected information, and best path is selected depending on minimum hop count and spectrum availability. Cheng et al. [11] have also proposed an on demand routing protocol for CRN called spectrum-aware on demand routing protocol (SORP), where the best channel is selected based on minimum channel switching delay and back-off delay. In local coordination-based routing, nodes choose the flow direction based on neighborhood interaction. The authors in [12] have presented a routing protocol, which minimizes channel switching delay for SUs and help to minimize channel contention among SUs. This protocol improves the end-to-end performance of the network.

The [13, 14] considers multipath routing in CRN. Multipath routing discovers multiple routes between source and destination. This minimizes inter-path contention and interference and enhances route reliability. The authors in [15, 16] proposed a tree-based routing protocol. In this type of routing protocols, a tree structured network is enabled by configuring a root. The tree-based algorithm works along with channel selection mechanism. The tree-based scheme suffers from scalability problems because of overhead incurred in establishing and maintaining tree structure. Gymkhana, a distributed routing protocol proposed in [17], collects key parameters for routing between source and destination, and mathematical framework is modeled and evaluated to find the connectivity of different paths by considering PUs activity. The authors in [18] considered AODV as a pure on demand route acquisition system, as nodes do not maintain routing information or participate in exchange of routing tables. In ad hoc network, AODV routing protocol minimizes the number of required broadcasts for creating the routes. So, the modification of AODV routing protocol for CRN is considered in this paper.

3 Modified AODV Routing Protocol

In this paper, we are using a modified form of AODV routing protocol. In AODV routing protocol, the network remains in a idle state if there is no other communication. If it needs a connection to other node, which is the destination node, it broadcasts a message to its neighboring nodes to update the routing table. After updating the routing table, each node contains the neighboring node information, and a route is established to the destination node. AODV routing protocol is a combination of DSDV and DSR routing protocol. In this proposed work, that is modified form of AODV, there consists of detecting any obstacle in its path. In cognitive radio, the PU has the full access to the spectrum. Even in the absence of the PU, the SU can access the spectrum and transmits the information. Here, we are mainly focusing on routing in the cognitive radio between the SU. In this, route between the SU can be established in the absence of PUs. If there is a need for the connection between two SUs in the network, at first, it broadcasts the message to its neighboring nodes and updates the routing table. The route is established based upon the path where there are no PUs active. After the route is established between the SUs, it can transmit information to the destination nodes.

In the proposed method, it also checks whether there are any PUs active during the routing. If any PUs detected along the routing path, the route to the destination is changed since the PUs have full control to the spectrum. The PUs and the licensed users in the spectrum cannot be interfered under any circumstances. When a PU is detected along the routing, the nodes can broadcast the messages to the neighboring nodes and update the routing table. The new routing table contains the information to the destination where there are no PUs present. The new route can transfer packets to the destination. The main idea behind is that it continuously checks the presence of PUs in the routing path, and if any PUs activated, the route can be diverted to another one in which there is no PUs interference.

Algorithm

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begin
if a packet exists to send from source to destination then
broadcasts the messages to all other nodes in network.
routing table updated which contains information of all  neighbouring nodes.
route has been established by checking the absence of the primary users in the path.
if there is any primary user interference then
   broadcasts the messages to all nodes to update the routing table
   new route has been established without interfering the primary users
end endend
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4 Simulation Results

In this, simulations are carried out using ns2 software. Table 1 shows the simulation parameters set in the simulation software. Figures 2 and 3 show the simulation results running at different times. The simulations process has been implemented

Table 1 Simulation parameters

Scenario dimension	1,000 × 1,000
Traffic application	CBR
Routing protocol	AODV
Antenna type	Omni antenna
Wireless MAC interface	IEEE 802.11
Propagation model	Two ray ground
Number of nodes	50
Number of primary users	25
Number of secondary users	25
Number of channels per radio	2

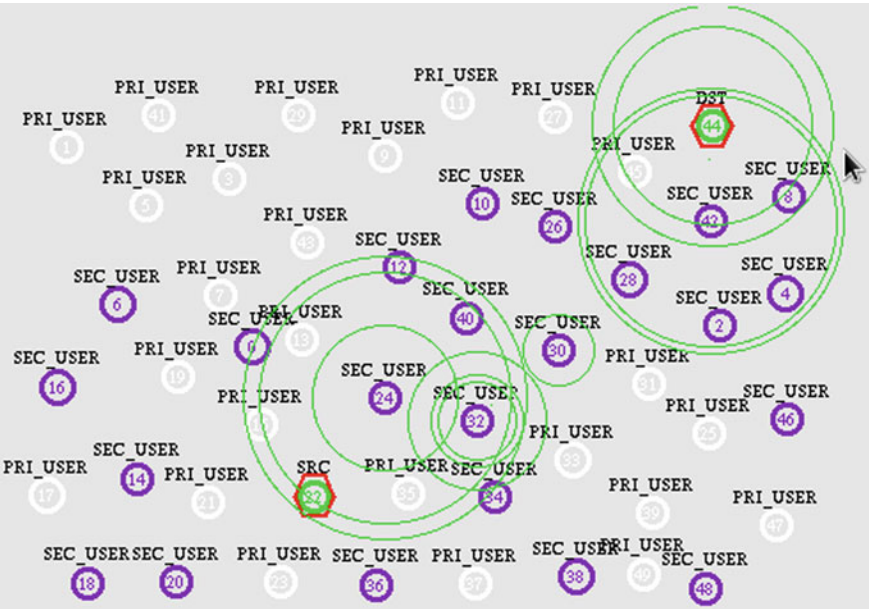


Fig. 2 Routing path established between source and destination

using ns2 software with tcl scripting language. We have considered 25 PUs and 25 SUs in the network to carry out the simulation. The protocol we have used in this scenario is modified AODV.

After starting, the simulation nodes will send the broadcast message to its neighboring nodes. The broadcast messages are useful to update the routing table. The routing table contains the information about its neighboring nodes and the distances from it. After routing table has been updated, the route has been established between the source and destination. Figure 2 shows the route which has been established between source and destination. The nodes are labeled as PR1_USER and SEC_USER in the simulation. The PUs are represented by white rounded

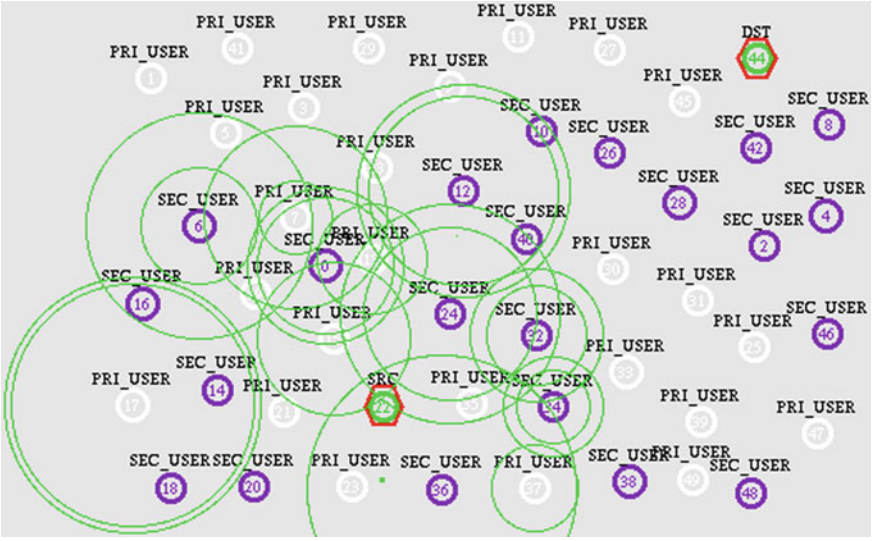


Fig. 3 Primary node *30* takes up its position, and secondary user *22* changes the routing path

nodes which are represented by odd numbers, and the SUs are represented in blue color, and they are in even numbers. In this scenario, route has been established between SU 22 which is the source and the SU 44 which is the destination one. The packets have been delivered from source to destination and its path which is shown in the Fig. 2. After some time, the PU is activated and takes the position of SU 30, and the routing cannot take place across the mentioned path which will cause interference to PUs. This is shown in the Fig. 3. The source node updates the routing table and checks the new path to transmit the packets from source to destination. After the new path has been constructed, routing can occur in that path.

After completing the simulations, the graphs have been plotted. The throughput and packet delivery ratio (PDR) graphs have been plotted. Figure 4 shows the throughput graph in terms of packet size. We have changed the packet size to 256 bytes and 512 bytes. By varying the packet size, the throughput also changes. It can be seen that throughput can be achieved higher when the packet size increases. The throughput can be achieved around 170 kbps in the case of packet size 512 bytes, whereas throughput can be achieved 87 kbps in case of packet size 256 bytes.

Figure 5 shows that throughput plotted against single-hop and multi-hop communication. Single-hop communication can be achieved higher throughput, whereas in case of multi-hop, throughput reduced to a reasonable level. The reason is that throughput can be achieved higher if there is no interference or there must be a direct path. If there are large number of paths between the throughput reduced to a low level.

In Fig. 6, it shows the PDR versus time. PDR is the ratio of packets received in terms of number of packets send. For small packet size of 256 bytes, PDR remains constant after some time, and when packet size increases, PDR value tends to increase.

Fig. 4 Throughput analysis for varying packet size

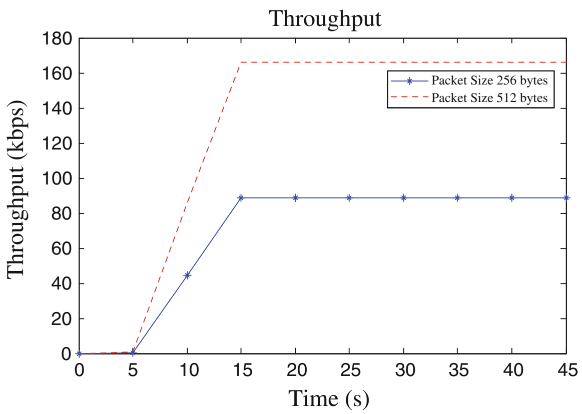


Fig. 5 Throughput analysis for different number of hops

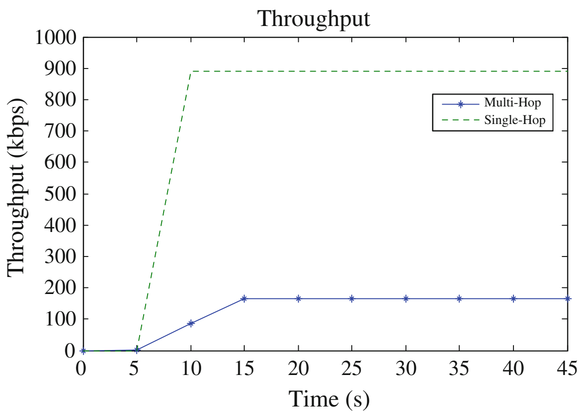
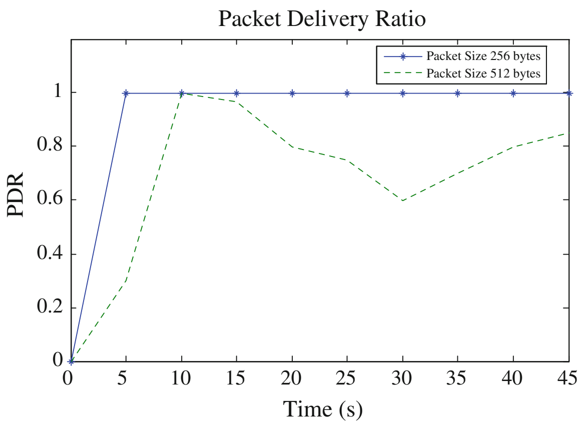


Fig. 6 Packet delivery ratio versus time



5 Conclusion

In this paper, modified AODV routing protocol for cognitive radio ad hoc networks is implemented. The main concept in this protocol is that to establish a optimal route between SUs by taking into account the PUs activity. The protocol provides better adaptivity since the path can be switched if there is any interfering PUs present. Simulation results show that the throughput can be increased if the packet size increases. Also, throughput performance is compared between single-hop and multi-hop. The PDR is also compared with the packet size. The PDR will be constant after 5 s for packet size of 256 bytes, and it varies in case of 512 bytes. The proposed algorithm focuses on PUs' activity and provides better path for SUs to forward packets. It reduces the routing overhead by dynamically changing the route based upon interfering nodes, and overall, it provides better performance.

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