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A Survey: On Routing Protocols in Cognitive Radio Ad Hoc Networks

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Abstract **- Ad-hoc routing protocols with cognitive capabilities have been proposed which solves the problem of spectrum scarcity. It does it by intelligently allowing the unlicensed devices to opportunistically communicate in the available licensed spectrum, while ensuring that the performance of the licensed users is not affected. New emerging routing protocols is a taxing job due to variation in channel usage and channel accessibility by nodes in the network. In this paper, we discussed about adaption of On-Demand routing protocols for cognitive scenario by addressing their merits and demerits.**

Keywords — Mobile Ad hoc Network (MANET), Ad hoc on demand distance vector (AODV), Cognitive Radio Ad-Hoc Network (CRAHNs), Primary users (PUs).

I. INTRODUCTION

Cognitive Radio Ad-Hoc Networks (CRAHNs) have been proposed as Mobile Ad hoc Networks (MANETs) for cognitive wireless scenarios where in nodes are equipped with cognitive radios to meet future demands of spectrum efficiency. In CRAHNs, most of research work is carried on Medium Access Control (MAC) and physical (PHY) layer. In MAC and PHY layers as well research are focused on single-hop scenarios that incorporate spectrum sensing, spectrum decision and spectrum sharing techniques. Very few routing protocols have been designed for CRAHNs. So there is a need of integrated work at the lower layers with network layer routing protocols for better and effective solutions so that these protocols work well in cognitive environment as well. Ad hoc on demand distance vector (AODV) routing protocol has been proposed as an efficient routing protocol for MANETS. In CRAHNs, research has also been initiated to modify AODV protocol for cognitive scenario. Many routing protocols have been proposed, which modify AODV for cognitive scenario. The organization of this paper is as follows. In Section II the routing in CRAHNs is discussed. Section III explores the various routing protocols in CRNs. Section IV highlights the various research issues and future work. Section V concludes the paper.

II. ROUTING IN CRAHNS

A number of works propose routing protocols for cognitive radio networks, ranging from making an adaptation of existing routing protocols to constructing completely new routing protocols to fulfil the characteristics of cognitive radio networks (CRNs). In CRNs, nodes can work on different and unlicensed frequency bands whenever available. They have route maintenance procedures that can be used to solve frequent connectivity changes in cognitive wireless networks.

The routing protocols in CRAHNs should satisfy requirements for both CRNs and MANETs. AODV is an on-demand routing protocol used in MANETs and support the properties of dynamic topology, self-organizing, self-configuring, and mobility [1]. Applying this routing protocol directly to cognitive radio networks is not viable, due to its poor performance in the dynamic spectrum utilization environment. Therefore, suitable modifications are necessary in AODV [2] for its adaptation to CRN scenario.

III. CRN ROUTING PROTOCOLS

Many protocols have been proposed by numerous authors [references] that can be best suited for cognitive scenario by adding new metrics with spectrum properties. We will discuss few of them in the subsequent section.

Spectrum-aware on-demand routing protocol (SORP) [3] extends AODV protocol to match needs of CRAHNs. SORP considers switching among available channels while establishing the path which incorporate delays. Another consideration is back off delay that is caused by multi-flow interference within a frequency band. Therefore, it takes into account the cumulative delay which is the combination of both switching and back off delay. These delays are caused due to switching among bands and multi-flow interference within frequency band. The switching among active bands and interference within bands are the shortcomings of SORP which needs to be resolved. In order to resolve these limitations which are causing delays, authors have proposed to transform AODV protocol by incorporating spectrum opportunity (SOP) information in the request packet. On obtaining this SOP information, receiving node assign RF band to its CR transceiver accordingly. Reply packet helps in sending back this RF band information to the source node as well to the midway nodes. According to their results, this modification in AODV leads to substantial drop in cumulative delays.

In addition to cumulative delay like in SORP, DORP [4] also takes in account the queuing delay caused by the transmission of other flows on the node. Such protocols like SORP and DORP are suitable for delay sensitive application since they focus on delays. They result in fairly lower cumulative delay and smoother cumulative delay change in handling intersecting flows.

Multi-hop Single-transceiver Cognitive Radio Networks Routing Protocol (MSCRP) [5] is another on demand protocol based AODV. MSCRP is proposed assuming only one transceiver for each node working on single frequency at a time. Author assumed that there is no common channel for control information exchange. This will be taken care by exchanging control messages amongst each other on available channels over the network. The basic aim of this protocol is to mitigate the deafness problem which is occurring due to switching of channels at nodes in the network. Due to frequent switching of channels delay becomes apparent which is mathematically evaluated and analysed. Simulation results show the comparison of AODV and MSCRP; variation in the results is seen depending upon the traffic load in the network. MSCRP improves the network throughput considerably.CR transceiver functions on only one channel at a particular time. Results of modification shrink data transmission time and shows significant improvement in the network throughput.

Spectrum-aware routing protocol (SPEAR) [6] focuses on path availability that is retained by either channel reservation algorithm or backup path. In this routing protocol route is established between nodes with varied or heterogeneous spectrum availability. A Route Request (RREQ) message is broadcasted on common control channel during route discovery process. The superlative path is chosen by the destination node on the basis of aforementioned metrics. It next inserts the channel assignment in RREP. It then makes route setup and channel reservation by spreading a channel reservation message to the neighbours within their interference domain. The message contains timeout and time-to-live parameter broadcasts channel reservation message. This transmission happens at regular intervals. Nodes stops sending reservation messages at the end of the communication. SPEAR intends to increase the network performance. Various routing metrics like highest throughput, least hop count and channel quality are evaluated.

The backup channel and cooperative channel switching (BCCCS) routing algorithm provides a backup channel focusing on the issue of route maintenance in CRAHNs [7]. In BCCCS routing algorithm, each node periodically updates a list of available channels and their priorities. This uses a number of control packets like channel requests (CREQ), channel reply (CREP), and channel information (CINFO) packets. CREQ contains CR user ID (CRID) of the source node and channel counters along with AODV RREQ packet components. CREP have CRID of both the source and destination nodes, link metric, and prioritized channel list in addition to normal RREP packet and CINFO messages are periodically exchanged with neighbouring nodes to refresh available channels list and priorities list. While selecting the channel for communication, the destination node chooses the least used channel by referring to the channel counters. The nodes simply switch to a second priority channel on the available channels list when the main route is broken, and straight away learn the next backup channels.

In the cognitive radio environment where the available spectrum bands are dynamically varied over time and space, the link reliability is relatively low, thus broken links might occur frequently, and in those cases, the provision of backup channel would result in immediate route recovery and avoids the repetition of the time and resource consuming route discovery scheme. Hence, providing backup channel might be a good solution.

Another advanced approach of AODV modification is traffic-aware routing protocol (TACR) that combines the traffic-aware routing and Q-learning algorithm on on-demand routing protocol [8]. In route discovery, the intermediate node triggers the prediction model when RREQ is received. The prediction model formula includes the prediction time interval, standard normal random variable, and two constant controlling parameters. TACR is able to perceive current traffic information by implementing a packet called cognitive packet (CP). Traffic prediction and traffic perception are used as an input to a route decision making process. The Q-Learning technique is employed in the route maintenance process. Q-learning enables a network to self-configure, self-manage and self-adapt. When the Q-value reaches a certain threshold, it means that the quality of the path is better and routing will increase the route lifetime of this path. On the contrary, routing will reduce the route lifetime of this path. So, the source node should resend RREQ soon to find a better path. The results of TACR are end-to-end delay, packet loss rate reduction, and throughput increase when traffic arrival rate is high.

The frequent activity of PUs in CRAHNS enforces the secondary users to vacate the respective frequency band and leads to increased channel switching delay and rerouting probability.

Authors in [9] have tried to improve the two new metrics namely rerouting probability and channel usage ratio for the cognitive radio scenarios. The protocol is based on the following key assumptions: 1) Use of common control channel along with the CR transceiver in each node. 2) PUs are static with each one on each channel. 3) Channel occupancy by PUs is exponentially distributed. 4) Perfect channel sensing by PUs. Author modified the existing AODV protocol in the following way to produce the desired results: a) Added a Path Availability Time (PAT) field in RREQ packet to calculate the total time at a node for which a path can be used. b) Added a Channel field in the routing table of each node to know which channel to use. c) Added an assigned Channel field in RREP Packet. d) Added a new type of message i.e. channel switching message in network for the purpose of route maintenance to handle PUs activity. Using above assumptions and modifications authors tried to find a path with maximum stability time which depends upon the number of hops in the path (or length of the path) and available time of each link on the path. They have achieved 20%-50% better rerouting probability as compared to AODV.

Author [10] has proposed a multi path routing approach for finding multipath routes and to generate shortest path between source and destination which will reduce intra flow interference and interflow interference respectively. It will reduce cost as well. Paper is based on pro-active link state routing algorithm and finds the shortest path among the multiple routing paths in CRAHNs. Every node in the network is capable of handling multiple transceivers and has multiple channels. The objective is to keep the cost and interference minimal while computing the paths thereby enhancing the bandwidth of the network. Metrics used by this protocol are cost and interference using modified Dijkstra algorithm.

IV. Research Challenges and future work

The future research for routing protocols in CR networks includes cross-layer design [11]. The cross-design needs the cooperation between routing and spectrum management functions in order to resourcefully become accustomed to modifications network properties. Also, there is strong need of a routing protocol for CR scenario which would be able to offer a better route selection. One of the open issues for routing protocols for CRAHNs is the security aspect [12] as the basic nature of CR networks makes them more vulnerable to attacks. An attacker node may deliberately block the available space in the spectrum resulting in degrading the performance of the system and also adversely affect the quality of service [13]. We consider that critics on the existing routing protocols for CRAHNs is open up new emergent issues. In order to extend these already existing routing protocols or developing new routing scheme, their performance assessment needs to be done in real world scenario.

V. Conclusion

The routing protocol of CRAHNs satisfies both CR networks and ad hoc networks requirements. The routing protocols for CRAHNs are an exigent task as there is lot of assortment in channel usage by nodes and channel availability for nodes. In this paper, we discussed about few editions over AODV routing protocol. We highlighted several routing technique and its impact performance, benefits and limitations of this adaption over AODV. Finally, we have concluded the paper by giving few upcoming research challenges and future implications.

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