Performance Analysis of Typical Routing Protocols for Cognitive Radio Ad Hoc Networks

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Abstract—Cognitive Radio Ad Hoc Networks (CRAHNs) have powerful growth potential, a solution to solve the scarce spectrum resources problem. Due characteristics can change configuration parameters during transmission, thereby opening up the possibility to use the dynamic spectrum. This leads to the complexity of the design of routing protocols. In this paper, we present the routing protocol is proposed to apply for Cognitive Radio Ad hoc Networks. After explaining the principle of operation, we analyze and evaluate the performance of the protocol on NS2. Simulation results show that the protocol End-to-End with throughput and latency is best improved. Finally, we discuss the limitations of recently routing protocols and propose some further research directions.

Index Terms—Cognitive Radio, CRAHN, AODV, DSR

I. Introduction

With the development of wireless networks, the newest surveyed results [1]-[3] have shown that the fixed spectrum registration and distribution policy is becoming ineffective and unsuitable for radio information systems today. Spectrum can be used more effectively by allowing unlicensed users (SU) to access and use for some time if the Primary User (PU) is not in use. Cognitive Radio Ad hoc Network (CRAHN) is a set of devices capable of operating and switching on different channels (bands) in a dynamic access environment legal sense of licensed frequency bands. Based on this perception, the SUs will take advantage of the opportunity to use the vacant spectral slots without affecting the PU. In Fig. 1, the Cognitive Radio Ad hoc Network consists of SU devices, communicating with each other based on the PU licensed frequency band during the PU idle period or empty spectral slots (channels).

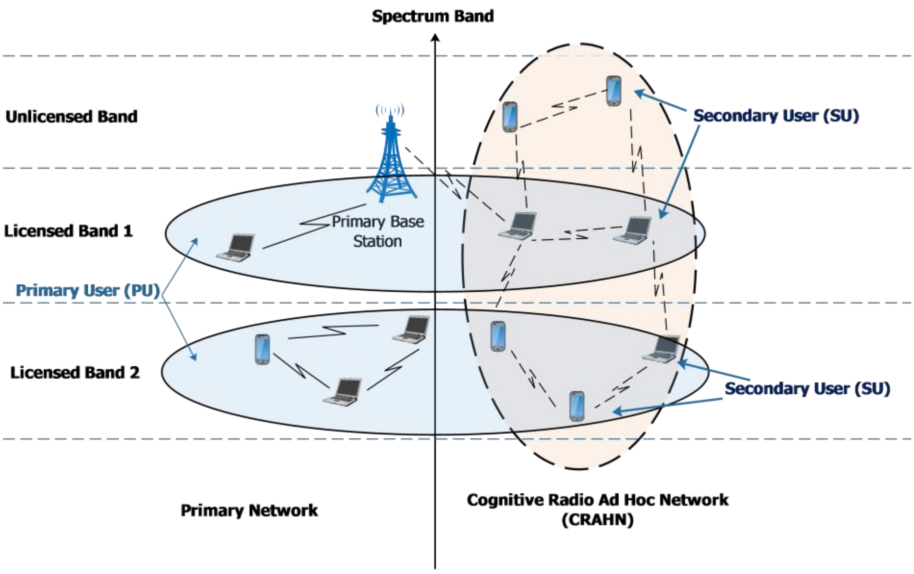

Fig. 1. Cognitive radio ad hoc network architecture.

Although the advantage of reusing spectrum in CRAHN is demonstrated and has a great value both in practice and in theory when spectrum resources are becoming increasingly exhausted. However, the network communications must not affect the PU. This requires devices in the network to continuously monitor and sense the operation of the spectrum. In reality, the CRAHN is established and operated using empty spectral slots based on the registered frequency range of the PUs [4]. Therefore, the task of finding, selecting, and setting the appropriate route (channel, network node) to transmit

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data from the source node to the destination node in a dynamic access environment is a challenge that needs to be addressed.

One of the main challenges of CRAHNs is to ensure the quality of service for SUs. However, this issue goes against the policy of restricting interference with PU. When a PU suddenly appears, the SU must immediately stop the communication and select a new path (node, channel) until the PU completes or stops the transmission [5], [6].

In this paper, we conduct a survey of the proposed routing protocols for CRAHN. The rest of the article is organized as follows. In Section II, we analyze the routing problem in CRAHN. Section III presents the performance evaluation and analysis of some routing protocols. Section IV is to propose the future research direction and Section V is the Conclusion.

II. The Routing Problem in CRAHN

Due to CRAHNs without prefixed infrastructure or the center entities [7], SUs must cooperate in an ad hoc manner to exchange and acquire essential information such as the network architecture and the presence of PUs for the routing problem. Thus, the routing protocols must satisfy both cognitive Radio Network (CRN) [8], [9] and Ad Hoc Network [10], [11] requirements, in Fig. 2.

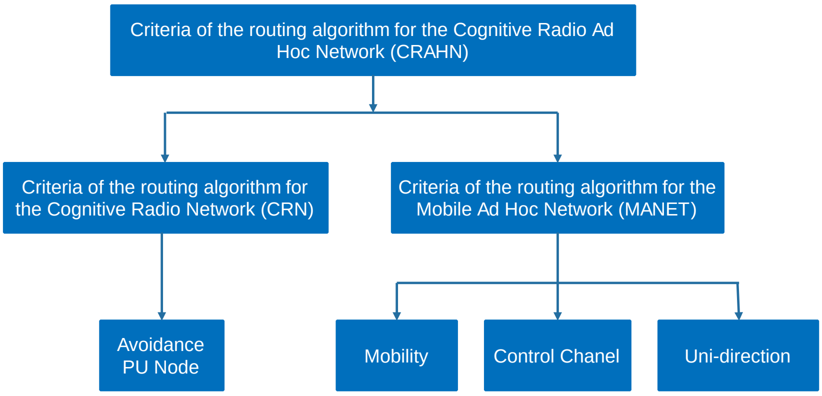

Fig. 2. Cognitive radio ad hoc network architecture.

A significant challenge in the communication of CRAHNs is that SUs must avoid interfering with the transmission process of PUs. Therefore, it is necessary to select the route that satisfies both problems, avoid PU, and establish the terminal communication between SUs. In [12], a PU avoidance scheme is incorporated into the route dis-covery procedure. There are two critical moments when the SU selects the channel: at the start of data transmission and when the route is repaired. In common, the channel information obtained from the sensing mechanism taking place in the physical layer or in the spectrum database is stored at each SU node. The vital information aims to determine a fit route. Some methods of intelligent sensing in the physical layer have been proposed in [13], [14].

The mobile nodes in the CRAHNs use a spectral resource (channel/frequency) that varies in both domains: time and space led to the real-time sensor information can be challenging. Therefore, effective dynamic spectral discovery procedures should be studied when designing a routing protocol for CRAHN.

In the CRAHN environment, the support bands of nodes are constantly changed, so the routing protocols have to face some challenges such as the common control channel determination problem, the channel management problem. Besides, the routing protocol design for CRAHN should not assume bidirectional linkage. Links can be unidirectional [15].

In addition to the above problems, a routing protocol for CRAHN still requires the same criteria as the traditional network routing protocol. These requirements include energy efficiency [16], [17], quality of service (QoS) [18], [19], and information security [20], [21]. Saving energy is particularly important issue of mobile nodes. An attempt to reduce the energy consumption uses the on-demand routing mechanism in [22].

A. The On-demand Routing in CRAHN

In Mobile Ad hoc Networks, the two typical routing protocols are AODV [23] and DSR [24]. Protocols operate based on principle; when a mobile node needs transmission data, it invokes the route discovery procedure to find a route to the destination network node by broadcast the router request packets (RREQ) through intermediate network nodes, in Fig. 3.

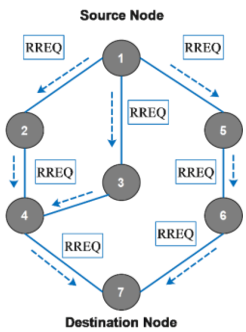

Fig. 3. The route discovery process

The destination network node or the intermediate node (the node has the route to the destination network node) will send a unicast packet, called RREP (Router Reply), to the source network node, in Fig. 4. Besides, protocols also use RRER packets to notify the intermediate network nodes about an error route status.

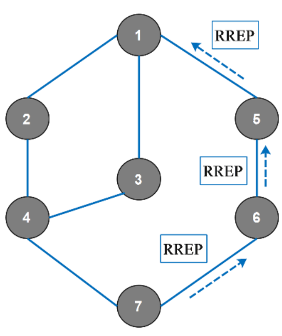

Fig. 4. The route reply process.

In a performance comparison, AODV delivers more than 90% of the packets, the packet delivery ratio of the DSR reaches its highest value in a small node number scenario and decreases with increasing network size [25]. AODV and DSR protocols work very well and have been standardized into protocol routing protocols for mobile ad hoc networks.

However, these protocols have low efficiency when applied in a CRAHN. Because the network environment is more dynamic, stemming from the operation/stop situations of PUs. Therefore, it is necessary to study and propose protocols suitable for routing in the robust dynamic spectrum environment of CRAHN. Some research results in [9], [26], [27] show that the on-demand routing method is ideal than the active routing method, and AODV is more suitable than DSR in the CRAHN environment. The typical approach proposes inserting spectrum-related information into the routing control packets of SUs (RREQ, RREP, RERR) [6]-[8] without evaluating the system overload. Several protocols offer solutions to specific problems such as selfish behavior, traffic balancing, and avoidance of interference to PU. We have summarized some protocols for CRAHN in Table I.

TABLE I. TYPICAL PROPOSED PROTOCOLS FOR CRAHN

Protocol	Contributions
SOP [12], DORP [28]	Improved cumulative delay. However, low efficiency due to no mechanism to reduce the interference effect on PU.
WHAT [29]	Use multi-metrics to select the optimal route. Improved system throughput.
SEARCH [30]	- One of the first proposed routing protocols for CRAHN. - Use the *Kalman* filter method to find channels with affect interference on PUs.
CRP [31]	Integrate information of PUs into the cost function to decision-making selects the minimum interference route. Ensure the communication of the SUs will have the most negligible impact on the PUs.
End-To-End (E2E) Protocol [32]	Modeling and building extension libraries to be able to simulate CRAHN operations on NS2.
Local Coordination Routing [33]	Provide load balancing solutions; Improved latency.

B. AODV-Based Improvement

A simple change to apply AODV to a CRAHN environment is by defining a new routing metric with spectral attributes like in the protocols SOP [12], DORP [28], WHAT [29]. DORP is an improvement of SOP. Both protocols define the cumulative delay metric while WHAT considers the hops and channel metrics. Since the SOP and DORP protocols focus on latency, in Fig. 5. As a result, they have low cumulative latency, while WHAT requires complete information of the quality of routes with multiple aspects considered to improve network performance. However, ensuring the quality of service will also lead to a decrease in network customization.

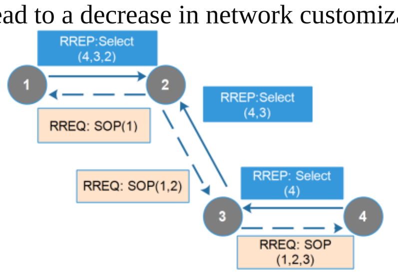

Fig. 5. Adding the spectral metrics to the RREQ packet header

In [30], the authors proposed the SEARCH routing protocol, one of the first to approach the way to solve the routing problem in CRAHN. SEARCH uses the Kalman predictive filtering method to find routes to limit the interference effect on the PU operation. In [31], the CRP routing protocol is proposed. The main contribution of the CRP takes PU noise information into account in the routing cost function of the CRAHN network. This is to ensure that the communication of the SUs will have minimal impact on the PUs. In [32], the authors propose a routing protocol that operates at the network layer for the CRAHN. The main contribution of this work is to model and build the extended libraries that can simulate CRAHN activities on NS2.

Routing is based on local cooperation to solve the load balancing problem [33]. In this protocol, a node becomes an intersection, where many data streams pass through, the local coordination scheme is invoked. The scheme will help intersections decide the direction of the flows based on the assessment of workload. In Fig. 6, node 1 is serving thread 2, node 2 is serving thread 3. When thread 1 appears, it first links to node 1 and node 2 as the intermediate node. The two intersecting nodes perform a local cooperation program to find the appropriate adjacent node to redirect the flow 1. The results are as follows: Node 1 directs flow 1 to node 3, and node 2 directs flow 3 to node 4. However, it aims to load balancing between nodes, which encourages thread redirection to neighbor nodes, creating many new intersections.

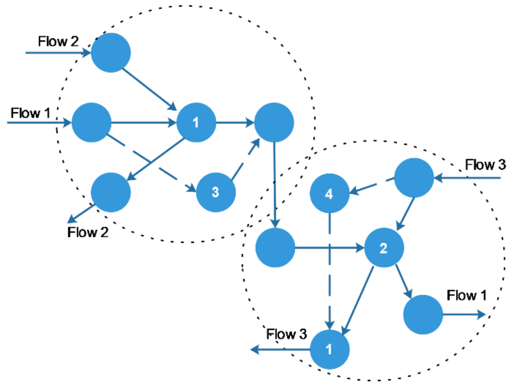

Fig. 6. Load balancing routing based on the local cooperative scheme

III. Performance Evaluation

In this section, we conduct performance evaluation and analyze some typical proposed routing protocols for CRAHN networks, namely SOP [12], CRP [31], and End-to-End (E2E) [33] on NS2 simulation software.

A. Simulation Scenario

We use the network architecture shown in Fig. 7. The system is arranged in the square area [1000m x 1000m], the diameter of each cell is 250m; transmission range of PU is 250m; transmission range of SU from 250m. The simulation system has 100 SUs randomly arranged in the region, and 10 PU nodes were placed at the center of each cell. We use the 802.11b protocol to transmit data. The packet size is 1000 bytes.

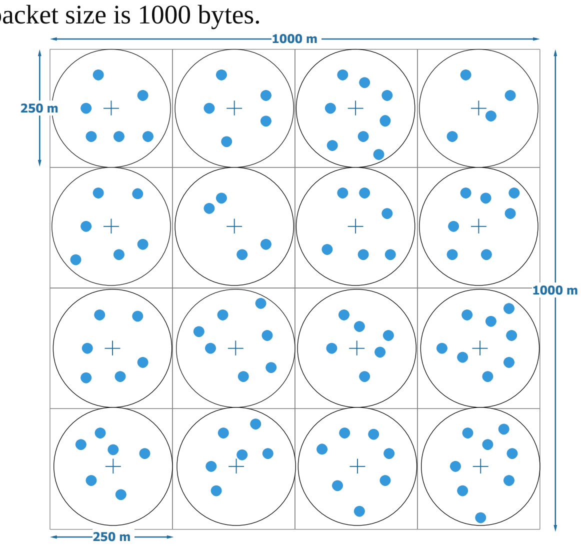

Fig. 7. The network topology used for performance evaluation

We evaluate the network performance with protocols are installed based on the average delay, throughput, and hops number. The system simulation parameters are summarized in Table II.

TABLE II. Simulation Parameters

Parameters	Value
Protocols	SOP [12], CRP [31], E2E [33]
Simulation Time	300s
Number of PUs	10
Number of SUs	100
Topology Size	1000 m x 1000 m
Mobility of Nodes	2 m/s
Distances	50, 100, 150, 200, 250, 300
Mobility Model	Random Waypoint

Fig. 8 has shown that the E2E protocol delay time is low when the distance between the source and destination node is short. When this distance increases up to 200 (m), the delay of the CRP is the lowest compared to other protocols.

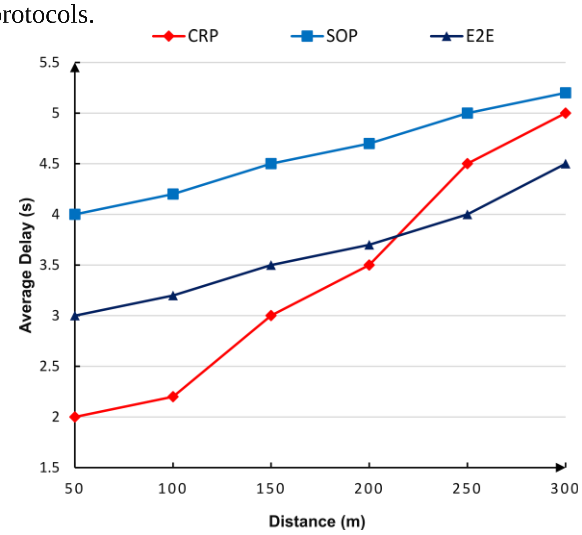

Fig. 8. Delay & Distance

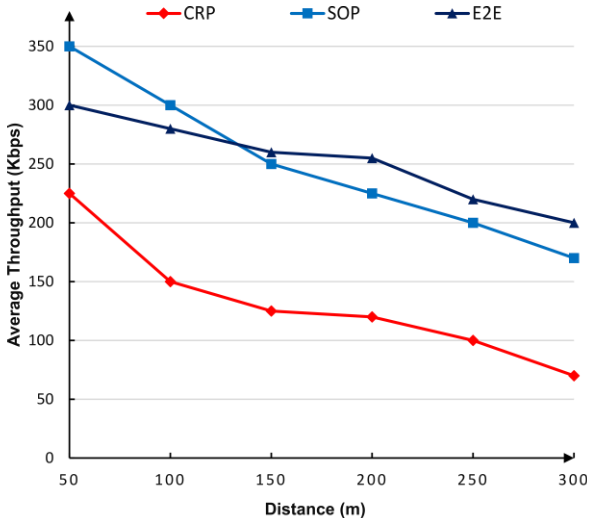

Fig. 9. Throughput & Distance

Fig. 9 shows the relationship between the throughput and the distance between the source and destination nodes in the CRAHN. The simulation results show that

SOP provides the highest throughput when the distance between the source and destination node is less than 150m. As this gap increases, E2E offers better throughput than the other two protocols.

Fig. 10 has shown the relationship between the hops number (the intermediate node numbers the packet must pass through) from the source node to the destination node. Accordingly, as the distance between the source node and the destination node increases, the number of intermediate nodes that the packet must pass through tends to increase. This is consistent with theoretical calculations. In the evaluated protocols, E2E provided the best results with the intermediate node numbers, which a packet must pass is the lowest in all scenarios.

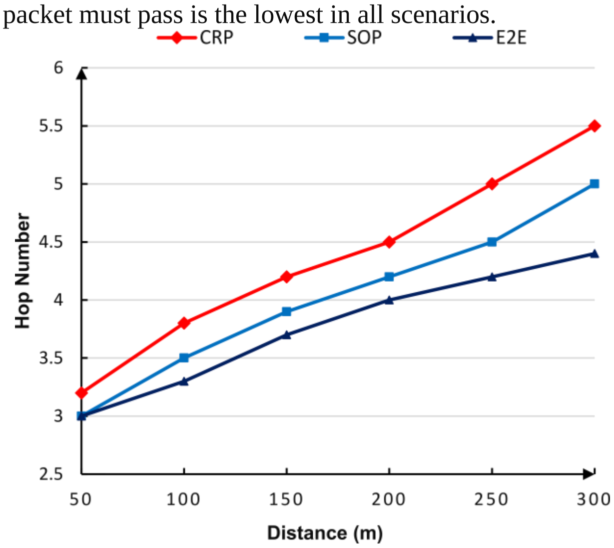

Fig. 10. Hop number & Distance

IV. Further Research Directions

In a CRAHN environment, a routing protocol is responsible for ensuring communication between SUs without interfering with PUs. In order to solve this issue, the routing mechanism must obtain information about the spectrum and channels from the physical layer to choose the paths between the nodes. The most straightforward approach includes relevant routing parameters in control packets such as PU survival probability, spectrum usage cycle of PUs, and interference level. Therefore, intervention routing parameters are considered viable solutions for routing in cognitive radio ad hoc networks.

The routing parameters should reflect the available bands, the quality/stability of the links, the performance of PUs, and the service requirements for SUs [34]. In the next research direction, we propose to use the cumulative expected transmission time parameter to find routes with high end-to-end throughput for CRAHN networks.

V. Conclusion

In this paper, we conduct a survey of the typical routing protocols in a cognitive radio ad hoc network environment. On-demand based routing protocols such as AODV and DSR are suitable for Mobile Ad hoc Networks environments but have low performance in CRAHN. Through analysis, we have found that AODV is more suitable than DSR in the CRAHN environment. Recently, there are many research results have proposed AODV-based improved protocols for CRAHN. Simulation results have indicated that the E2E routing protocol improves in terms of throughput and delay compared to other protocols. Finally, we present the future research direction to propose high-performance routing protocols for the cognitive radio ad hoc network environment.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

D. V. Anh, N. D. Tan, N. T Ban and N. M. Quy conducted the research; D. V. Anh analyzed the data; D. V. Anh, N. D Tan, N. M. Quy wrote the introduction, N. M. Quy and N. T. Ban revised the paper; D. V. Anh simulated and formatted the paper. All authors had approved the final version. The corresponding author is Dr. Nguyen Minh Quy.

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