Enhancing Cognitive Radio Ad Hoc Networks: Integration of Q-Routing into Clustering Protocols

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Abstract. Cognitive Radio Ad Hoc Networks (CRAHNs) have introduced a myriad of challenges in identifying optimal routing protocols suitable for dynamic and diverse application domains. Traditional routing protocols often overlook the unique challenges posed by CRAHNs, particularly the dynamic topology due to node mobility. This research proposes a revised routing protocol that integrates cluster network topology management with a Q-routing scheme to enhance spectrum utilization, stability, and routing optimization. Clustering is an effective technique for network topology management, addressing issues of scalability and stability by forming large clusters that accommodate more nodes, although large clusters often face instability. The proposed protocol focuses on forming stable and scalable clusters, thereby minimizing communication overhead and improving intra-cluster and inter-cluster routing. Q-routing, based on reinforcement learning, dynamically evaluates the best routing paths by disseminating route packets and enabling each node to make independent routing decisions. Simulation results using OMNeT++ demonstrate the protocol's efficacy in selecting stable routes and shorter paths, leading to improved performance metrics such as packet delivery ratio, throughput, hop count, and routing overhead. The study acknowledges the necessity of real-world implementation to provide accurate insights into the protocol's behavior under varying network conditions. Future work should prioritize real-world scenario testing to validate the simulation results and further enhance the proposed protocol's applicability in practical CRAHN environments.

Keywords: Cognitive Radio Ad Hoc Networks (CRAHNs), Routing Protocol, Ad hoc On-Demand Distance Vector Routing (AODV) and Cognitive Radio Networks.

1 Introduction

Cognitive Radio (CR) technology aims to improve wireless communication by opportunistically using underused licensed spectrum. Cognitive Radio Networks (CRNs) enable unlicensed users (SUs) to dynamically share spectrum with licensed users (PUs) through infrastructure-less networks like Cognitive Radio Ad Hoc Networks (CRAHNs). Challenges in CRAHNs arise from dispersed spectrum bands,

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varying spectrum availability based on PU activity. Clustering is considered an effective solution for managing network topology and addressing scalability and stability in CRAHNS.

Current clustering routing protocols like SMART focus on network stability through dynamic cluster size adjustments but may overlook stability-scalability trade-offs. Integrating Q-routing, a reinforcement learning algorithm, offers potential in determining stable, optimized paths in the network, enhancing stability and scalability in CRAHNs. A proposed cluster-based routing protocol leveraging Q-routing will prioritize selecting stable and efficient routing paths, aiming to enhance network performance in CRAHNs by dynamically evaluating optimal routes. Simulation studies comparing this protocol with the original AODV routing will provide insights into its performance under varying network conditions.

2 Methodology

In our study, we present a new routing protocol that integrates an advanced clustering design with the Q-routing protocol. Q-Routing supports the dissemination of route packets throughout the network, allowing each node to independently make routing decisions based on locally available information. The reward mechanism is based on packet delivery time, highlighting our goal of minimizing the average delivery time for all packets. Furthermore, we enhanced the clustering design through simulation, analyzing and comparing its performance across different nodes and cluster sizes, as illustrated in Fig. 1.

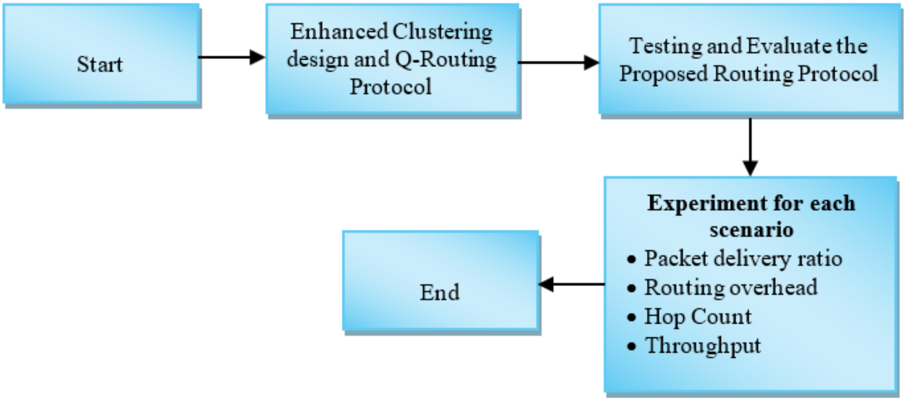

Fig. 1. The Methodology of Cluster-Based Routing Protocol.

2.1 Network Design

In this study, the clustering network design approach is employed to aid in selecting stable routes by configuring both the nodes and the network. Secondary Users (SU) gather information about neighboring nodes and their spectrum accessibility, initiating the process by broadcasting control packets for neighbor discovery. Clusters form with SUs having the highest Q-value and coordinate sharing available channels. The effort focuses on cluster formation and maintenance in Cognitive Radio Networks (CRNs) due to the dynamic nature of channel availability from Primary Users' (PUs) activities. Reinforcement Learning (RL) helps manage dynamic channel availabilities by observing, learning, and executing optimal actions to minimize cluster maintenance. Cluster maintenance involves adjusting size through merging and splitting, with a minimum common channel threshold requirement for operations. Cluster merging combines clusters meeting the threshold, while cluster splitting occurs when a cluster can't meet the threshold.

2.2 The Proposed Q-Routing

The study focuses on a clustering network design approach to enhance route selection by configuring nodes and the network. Secondary Users (SUs) exchange control packets to discover neighbors and form clusters based on Q-values. Cluster maintenance in Cognitive Radio Networks (CRNs) involves adjusting size through merging and splitting clusters for efficient channel access. Reinforcement Learning (RL) helps optimize actions for minimal cluster maintenance. Q-Routing is utilized to model network routes, estimating total costs for path discovery and is adaptable to heavy network loads. In the cluster-based Q-Routing protocol, SUs is equipped with Q-Routing capabilities for neighbor and cluster discovery, route request exchange, and pathway selection based on Q-values.

3 Simulation and Testing

In this research, we simulated different cluster routing performances by evaluating packet delivery ratio, hop count, routing overhead and throughput, using the parameters shown in Table 1.

Table 1. The List of Parameters.

Simulation Parameter	Value
Node Number	2-10
Network Playground Size	20 x 20 km^2
Simulation Time	5 min
Start of Data Transmission	10 sec
End of Data Transmission	300 sec
Node Speed	5 m/s
Radio Propagation Model	Two Ray Ground Model
Traffic Model	Random Traffic Pattern
Channel Type	Wireless Channel
Antenna Type	Omni Antenna

Network Interface Type	802_11/802_11 Cognitive
Node Density	0.5 – 5.0 m/s
Routing Protocol	Clustering Routing Protocol

Packet delivery ratio is the ratio of data packets received by the destinations to those generated by the sources. If a network becomes congested and there is good discipline, packets may queue up at the source and never enter the network [8].

$$\text{Packet Delivery Ratio} = \text{sum of data packets received} / \text{sum of data packets generated} \tag{1}$$

The hop count specifies the number of hops on the path between the source node and the destination node. The study of the hop count of multi-hop path in wireless ad hoc networks is very important because it can provide an evaluation of the network performance such as packet delivery ratio and end-to-end-delay.

$$\text{Hop Count} = \text{total hop count} / \text{total packet received} \tag{2}$$

Routing overhead is the number of routing packets needed for network communication. It is computed using an AWK script, which processes the trace file to produce the result. When nodes exchange routing information using the same bandwidth as data packets, it incurs overhead to the network, known as routing overhead, as these information packets are exchanged periodically at certain intervals [9].

$$\text{Routing overhead} = \text{packets routing} * 100 / \text{total packet received} \tag{3}$$

Throughput efficiency holds great importance in the present scenario of the cogni tive radio system [10]. Throughput refers to the average time a data packet takes to reach its destination. This includes all possible delays caused by buffering during route discovery latency and queuing at the interface queue.

$$\text{Throughput} = \text{total packet size} * (8.0/1000) / (\text{stopTime}-\text{startTime}) \tag{4}$$

Simulations provided a platform for modeling real-world events, aiding our understanding and resolution of cluster routing in Cognitive Radio Ad Hoc Networks (CRAHNs) architecture. This allowed us to visualize models and assess the performance of our research under diverse conditions. In this research, we simulated different cluster routing performances by evaluating packet delivery ratio, hop count, routing overhead and throughput, using the parameters shown in Table 1.

4 Performance Evaluation

Experiments were conducted to evaluate the performance of two routing protocols using the network simulator OMNeT++. The performance metrics were tested with increasing numbers of hosts, from 2 to 10. The revised cluster-based routing protocol was compared to the non-clustered AODV protocol.

4.1 Performance of Packet Delivery Ratio

Fig. 2 illustrates the packet delivery ratio data for both routing protocols as the number of hosts increases. The revised cluster-based routing protocol achieved its highest packet delivery ratio of 5.19 with 10 hosts, whereas the non-clustered AODV protocol's highest ratio was 1.67 with 2 hosts. The cluster-based protocol performs better with 10 hosts, offering near-optimal routes and enhancing the packet delivery ratio.

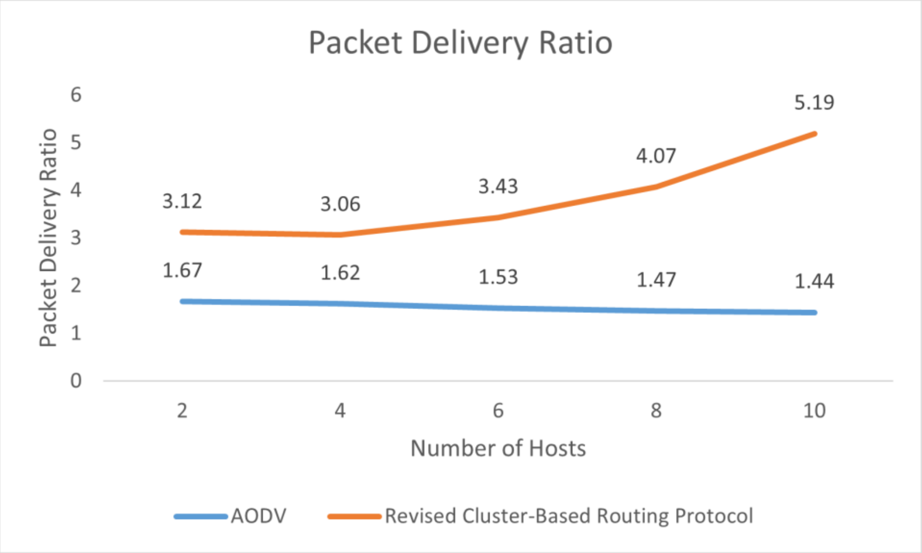

Fig. 2. The Packet Delivery Ratio.

A higher packet delivery ratio is favored in network performance as it indicates a greater proportion of packets reaching their destinations successfully, enhancing network reliability and quality. Achieving a higher ratio leads to better quality of service by reducing packet loss and ensuring consistent network performance, especially crucial for low-latency applications like voice and video conferencing. Q-Routing, integrated into routing protocols, effectively adapts to changing network conditions and scale, helping source nodes determine optimal destinations to manage traffic flow and prevent congestion. Strategies such as clustering and Q-Routing aid in maintaining a high packet delivery ratio, even in large-scale networks, ensuring satisfactory performance.

4.2 Performance of Hop Count

In Fig. 3, the non-clustered AODV protocol shows the lowest hop count at 0.37 with 10 hosts and 0.44 with 2 hosts. In contrast, the revised cluster-based routing protocol exhibits a range from 1.60 (lowest) to 3.47 (highest) for 10 and 2 hosts, respectively. The revised protocol's clustering arrangement and addressing scheme help decrease hop counts and offer alternative paths for node failures. Furthermore, the impact of increasing host numbers on hop count is more notable in the revised cluster-based protocol than in non-clustered AODV.

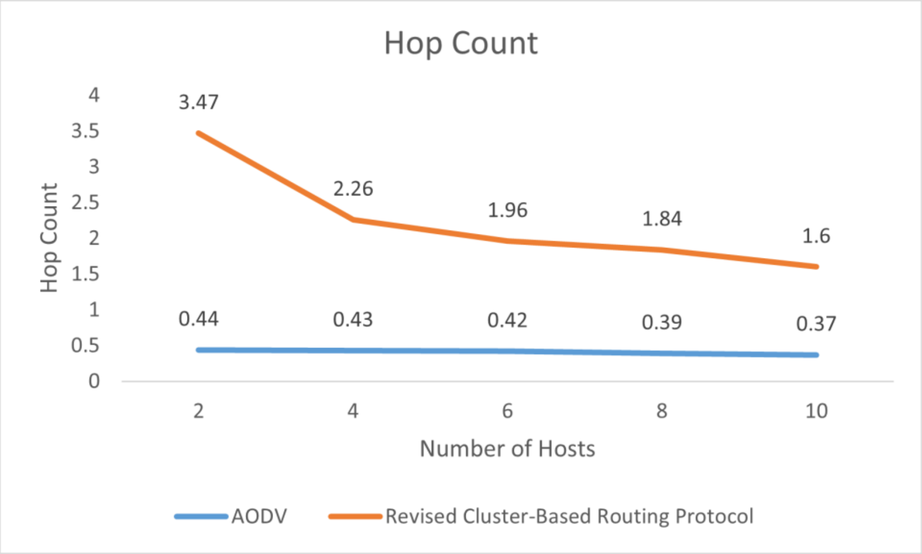

Fig. 3. The Hop Count.

In network performance, the optimal hop count is not solely determined by being higher or lower; it hinges on factors like latency, reliability, scalability, and resource use to meet network demands. Lower hop counts offer efficiency and easier management with direct routes, while higher hop counts enhance scalability and reliability by providing redundancy. The revised cluster-based routing protocol and Q-Routing technology work together to optimize routing paths dynamically and select the next hop for improved efficiency, striking a balance between these considerations.

4.3 Performance of Routing Overhead

According to Fig. 4, the revised cluster-based routing protocol shows the highest routing overhead at 0.03% with 2 hosts, reducing to 0.02% with 10 hosts. In contrast, non-clustered AODV maintains a steady routing overhead of 0.01% with increasing hosts. The fixed size of routing update packets limits control overhead, making these protocols less suitable for highly dynamic ad hoc networks due to scalability constraints.

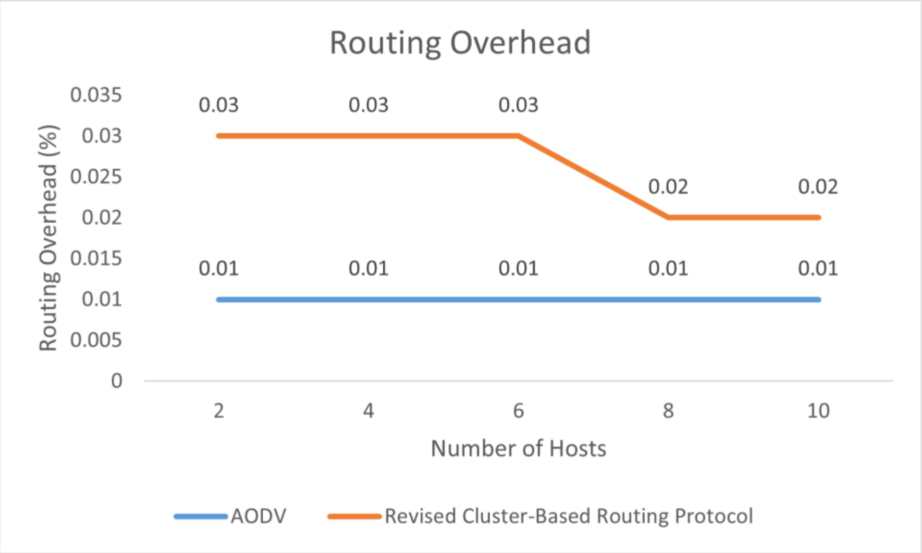

Fig. 4. The Routing Overhead.

Lower routing overhead is favored in network performance as it indicates more efficient resource utilization and improved overall performance. Routing overhead refers to the additional resources consumed by routing protocols for network information management. Finding a balance between low routing overhead, robustness, and stability is essential for network connectivity and fault recovery. The Revised Cluster-Based Routing Protocol initially has higher overhead than non-clustered AODV but reduces significantly after optimizing the path. Routing overhead typically increases with the number of hosts due to complex topologies and computational demands, but Q-routing, a reinforcement learning algorithm, helps hosts dynamically find optimal paths for efficient and scalable routing in large networks.

4.4 Performance of Throughput

In Fig. 5, non-clustered AODV exhibits inconsistent throughput performance, decreasing from 2407.58 kbps with 2 hosts to 2269.41 kbps with 10 hosts. In contrast, the re vised cluster-based routing protocol shows higher throughput, with values of 2872.84 kbps at 2 hosts and 3074.82 kbps at 10 hosts. The protocol's ability to avoid network loops and maintain stable routes, even in the event of broken links, contributes to its slightly better throughput compared to non-clustered AODV. Additionally, the impact of host numbers on throughput is less pronounced in the revised cluster-based routing protocol than in non-clustered AODV.

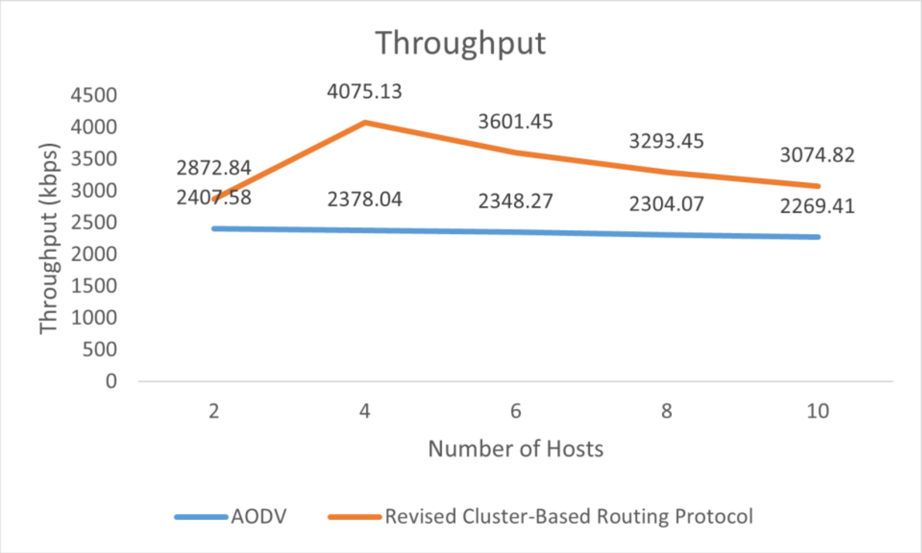

Fig. 5. The Throughput.

With traditional network routing protocols like non-clustered AODV, network throughput typically decreases as the number of hosts increases. This decline is primarily due to an elevated risk of network congestion, especially in shared segments or links, where more hosts contend for limited bandwidth, leading to increased packet collisions and queuing delays that diminish overall throughput. It's important to note that the relationship between network throughput and host numbers is not purely linear, and various factors can affect network performance. Employing efficient routing protocols and network optimization techniques can help mitigate the impact of growing host numbers on network throughput.

5 Conclusions

The study evaluated a revised cluster-based routing protocol with an adaptive Q-Routing scheme in Cognitive Radio Ad Hoc Networks (CRAHNs) using the OMNeT++ simulator. Compared to traditional AODV routing, the revised protocol demonstrated superior performance in Packet Delivery Ratio, especially with 10 hosts, improving packet delivery with near-optimal routes. The protocol's design minimized hops between nodes, particularly noticeable with 10 hosts, enhancing efficiency in route establishment and maintenance. Additionally, the revised protocol showed decreasing routing overhead compared to AODV, indicating scalability and suitability for dynamic ad hoc networks. It consistently outperformed AODV in throughput across scenarios and host numbers, maintaining stable and higher throughput values. The integration of clustering and Q Routing in the protocol significantly enhanced stability, scalability, and overall performance in CRAHNs, promising efficient spectrum utilization and adaptability to diverse applications. While simulation results provide insights, real-world implementation vali dation is necessary. Overall, the study contributes by proposing an improved routing protocol tailored for CRAHNs, offering performance insights under varied conditions to advance wireless networking with more robust communication protocols in CRAHNs.

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