10.48047/jocaaa.2024.33.06.155

# HARONET – Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc Networks

[1] Majid Shaikh, Research Scholar, Sai Vidya Institute of technology, Bengaluru
[2] Dr. Priti Mishra, Professor, Sai Vidya Institute of technology, Bengaluru

## ABSTRACT

*Cognitive Radio Networks (CRNs) play a pivotal role in addressing spectrum scarcity by enabling dynamic spectrum access and efficient utilization of underused licensed bands. In this context, Cognitive Radio Ad Hoc Networks (CRAHNs) are envisioned to enhance multi-hop wireless communication by leveraging spectrum awareness and opportunistic routing mechanisms. However, the inherent challenges of CRAHNs, such as unpredictable primary user (PU) activity, intermittent spectrum availability, and high node mobility, necessitate the design of specialized routing protocols that can adapt to these dynamic conditions. To address these issues, we propose a novel* ***Hybrid Adaptive Routing for Opportunistic CRAHNs (HARONET)*** *scheme, which integrates cooperation Simulation results demonstrate that HAROCRAHNs significantly outperforms existing spectrum-aware protocols in terms of Quality of Service (QoS) metrics. Specifically, the proposed protocol achieved an* ***average throughput of 5164.55 Kbps****, compared to* ***4585.56 Kbps for SARP*** *and* ***4194.66 Kbps for SSR****. Furthermore, the* ***Packet Delivery Ratio (PDR)*** *attained by HAROCRAHNs was* ***98.77%****, indicating enhanced reliability in end-to-end communication. In contrast, SARP and SSR achieved PDRs of 95.60% and 90.15%, respectively. These results validate that HAROCRAHNs not only improves spectrum efficiency but also ensures robust packet delivery under varying traffic loads and spectrum conditions, making it a promising candidate for next-generation CRAHN deployments spectrum sensing with adaptive routing decisions. The proposed framework synergistically combines the advantages of* ***Spectrum-Aware Semi-Structured Routing (SSR)*** *and* ***Spectrum-Aware Routing Protocol (SARP)****, thereby enabling an intelligent balance between proactive and reactive routing strategies. HAROCRAHNs dynamically evaluates channel availability, interference probability, and link stability to optimize the next-hop selection process. This cross-layer design allows secondary users (SUs) to efficiently utilize available spectrum bands while minimizing disruptions caused by PU activity.*

## 1. INTRODUCTION

Recently, the wireless communications industry has experienced tremendous growth in the spectrum of real-time applications, including health applications, online games, and social networking platforms [1]. Currently, individuals are widely adopting various industries and systems based on wireless services to meet daily life requirements, leading to an increased demand for radio in wireless communications [2]. The frequency spectrum and its availability play crucial roles in wireless communications, affecting both the quality of service and the quality of experience for secondary users. The Federal Communications Commission has highlighted the scarcity of available to support high-bandwidth communications. Furthermore, a study submitted by the Commission concluded that various licenced bands are not being utilized effectively in communications [3].

The optimal use of the available spectrum enhances communication performance within the network. On this basis, the Federal Communications Commission proposed a new methodology that improves network performance through dynamic spectrum allocation. Consequently, a new technology was developed to facilitate this concept: cognitive radio, which supports cognitive radio networks. This innovative approach efficiently senses the available spectrum and promotes effective spectrum utilization [4]. The network comprises two main components: licenced users and unlicensed users. Unlicensed or secondary users utilize the available spectrum while ensuring that they do not interfere with the connections of primary or licenced users, allowing them to sense the spectrum without intercepting or disrupting primary user channels [5].

The problem of developing an efficient routing protocol to calculate the best path in cognitive radio networks is difficult to address because the search space is evolving very quickly because of the increase in the total number of applicable channels and the size of the network [6]. Therefore, the basic concept of cognitive radio is simple and can greatly improve communication performance, which contributes to the construction and development of an efficient routing protocol.

10.48047/jocaaa.2024.33.06.155

However, owing to the increasing complexities and design differences in traditional cognitive radio devices, several challenges exist, including analysing the applicability of the time-varying channel and determining the channel for transmission and reception without causing interference between the primary user and the secondary user, which increases complexity in the design of the media access control layer of the cognitive radio network [7].

Therefore, cognitive radio networks are expected to increase spectrum usage, alleviating the spectrum scarcity problem caused by IIoT applications that occupy part of the spectrum during their operation. However, there is a need for synchronous design between the accurate transmission of processing units and control units across deployment, especially in IIoT environments [8][22]. It is anticipated that the control units will prevent interference and interruptions in transmission with the processing units by adaptively switching to another unused channel, as the processing units have a higher priority in utilizing the licenced frequency spectrum. This is achieved through dynamic access technology, which enables control units to switch between different spectrum holes when the primary user is not present during a specific period or location [9].

There has been great interest in routing cognitive radio networks in recent years, as it relies on a licenced transmission spectrum to send and receive data packets between network control units, as well as an unlicensed spectrum for the routing process, as it is based on managing frequency channels according to the user's needs for many applications used, in which channel allocation must be taken into account, such as the industrial Internet of Things, military applications, smart city applications, healthcare applications, etc. The protocol provides more spectrum for sending and receiving according to data and enhancing smart application communications and reducing the economic cost used. Therefore, interest in cognitive man networks is widespread for various applications, and the development of routing protocols has recently increased. Many studies have specifically proposed routing protocols by discovering free channels and improving routing performance, as they face a set of challenges, including preparing and selecting a strong and stable channel path across multiple channels and the state of different routing paths between source nodes and target nodes, as well as providing high channel stability and a lower probability of interference [10].

The routing protocol must be able to access the inactive or unused spectrum to avoid interference with the central processing unit during the data transmission and reception process. Therefore, channel selection estimation is a challenge that greatly affects the performance of packet routing in the network, which may cause an increase in transmission cost due to interference with the central processing unit. Therefore, it is important to consider the effect of time variability on the selection of channel estimation to ensure the accuracy of information in selecting idle channels for cognitive radio networks [11].

Many routing techniques in cognitive radio networks face several routing problems, especially the increased computation time allocated to find the path and determine the longest path and the increased complexity in analysing the appropriate nodes used to transmit data in the network. To reduce these problems, the routing protocol must have better decision-making capability during its implementation using different users and different cognitive network application environments. One of these techniques is the intelligent optimization of dynamic resource routing for primary and secondary radio and cognitive network users, where an optimal decision is made on the basis of the implementation environment to optimize the use of spectrum resources in the network. In practice, once a channel with a full frequency and a long waiting time is chosen, it affects the activity of the central processing unit. It affects the quality of communication with neighboring nodes. Therefore, the routing protocol needs to consider several factors during the processing of incoming packets, such as choosing the path with the least delay to improve network throughput [12][32].

The processes on which routing techniques in the network are based include sharing routing information with neighboring nodes, managing routing failures, and repairing the failed path. To perform an adequate routing process in the network, routing techniques must meet the mentioned needs, which are considered challenges in the routing process; other challenges in the packet routing process are as follows [13]:

- Minimal Route Discovery Time: The duration required to identify a route to a given destination should be minimized.
- Interference avoidance: In a cognitive radio network, interference between secondary users and primary users must be avoided to ensure the quality of service between secondary users, and sophisticated detection mechanisms must be used when routing packets due to false alarms and missed channel detections [14].
- Reduced Control Overhead: The routing mechanism should minimize the number of packets exchanged during route discovery maintenance to conserve network bandwidth and lower the risk of packet collisions [14].
- Cross-layer design routing decisions: Cognitive networks are closely related to spectrum management and the flexibility of sensing activities, so it is important to take a cross-layer approach to effectively integrate functions into a single model that balances sensing accuracy, throughput, cost-effectiveness, and resource management impact for devices [15].
- Loop-Free Routes: The routing protocol must be ensure that selected paths are free from loops, as loop formation can lead to unnecessary bandwidth usage, packet loss, and repeated circulation of data within the network [15].
- Route Reconfiguration: The protocol should be efficiently adapt to dynamic topologies by reconfiguring routes whenever they become unstable, frequently change, or break due to no mobility [15].

10.48047/jocaaa.2024.33.06.155

## 2. RELATED WORKS

Several researchers has introduced routing protocols tailored for Cognitive Radio Networks(CRNs) to enable adaptive and efficient routing in highly dynamic CRAHN environment.

In [15], they proposed a knowledge-harvesting network by developing a multihop routing protocol, MCSAR, on the basis of the connection quality, energy consumption, and trust values to determine the next hop in the radio frequency. An improved Bellman–Ford algorithm was incorporated to further improve the overall connectivity. Owing to the problem of choosing the best path between two optimal paths, a priority weight calculation was proposed on the basis of the distance from the current node to the destination node and the trust factors for selecting the routing node. The results showed better efficiency in terms of the packet delivery ratio, communication overhead, delay, and increased throughput.

In [16], the authors proposed a Heterogeneous Cognitive Radio routing protocol (HCR) designed to operate across both licensed and unlicensed spectrum bands, enabling efficient packet routing from the source to the destination in a heterogeneous environment. As a result, the protocol effectively addressed the spectrum dynamics of the network by introducing a mechanism that estimates the available spectrum based on the expected channel idle time, sensing range, and the historical connectivity characteristics of each channel. The proposed routing protocol derives its utility from making a trade-off between the channel diversity of the routing path and channel throughput in cognitive radio networks. The results compared the proposed routing protocol with the AODV routing protocol via a separate simulation based on the Java language. The results demonstrated the superiority of the proposed routing protocol. In [17], a routing protocol for multichannel and multihop radio sensor networks was proposed on the basis of spectrum sensing, analysis, and measurement of the delay of each hop of the spectrum channel. As a result, the protocol effectively accounted for the dynamic nature of the spectrum and introduced a mechanism to estimate the available spectrum based on the expected idle duration of each channel. Thus, this methodology allows secondary users to mitigate the communication interruptions resulting from the arrival of primary users and exploit the channel. Thus, the proposed system contributes to improving the transmission performance of each hop. The results showed that the proposed routing algorithm improved the network performance in terms of throughput, delay, and energy consumption while ensuring reliable communication along the specified routes.

In [18], a dynamic behavior protocol was proposed to select a stable transmission path from source to destination. It is based on an edge weight graph based on a parameter called NHDF (next hop factor), which takes into account the node transmission patterns and channel availability to select the optimal path for communication where the node transmission pattern is determined on the basis of the distance, speed and direction of the node and the spectrum awareness measurement in the proposed protocol within the shared communication channels. The results demonstrated improved routing performance through the selection of stable and secure paths, highlighting the superiority of the proposed system compared to existing protocols in the same domain.

In [19], spectrum management was proposed as a new and secure routing algorithm. The proposed system combines the behavior of nodes during the spectrum sensing phase through the belief level, which is the reliability of the node in finding the spectrum channels to use correctly, as well as securing routing messages by distinguishing them via encryption technology. The aim of the proposed system is to make paths available between any two connected nodes in a secure and efficient manner, reduce the negative impacts on authorized users from exploiting the channel and the guest, and reduce the overall cost of choosing the best path to route packets throughout. The results revealed an improvement in the packet delivery rate, a reduction in the loss rate, and the superiority of the proposed protocol in verifying the validity of the algorithm against attacks in the network.

In [20], an efficient interactive routing protocol that considers mobility to calculate node reliability in CR sensor networks was proposed. The proposed protocol accommodates the dynamic behavior that contributes to spectrum availability and determines a stable transmission path relative to the source node as well as its effective role in delivering packets to the receiving nodes, which depends on the distance, speed, direction and reliability of the packet transmission through the node. In addition, the spectrum awareness in the proposed protocol is measured on the basis of several shared channels with similar channel quality, which shows efficient routing performance on the basis of selecting stable paths. The results showed that the proposed protocol outperforms existing protocols in selecting stable and secure paths.

In [21], A routing protocol designed for deployment in ad hoc cognitive radio networks was proposed. They analyzed and evaluated the protocol's performance using a network simulation environment. The results of the proposed system revealed increased throughput and reduced delay. In addition, they discussed the limitations of modern routing protocols, which are based on several additional approaches to improve the network performance in routing packets.

In [23], the authors introduced a spectrum-aware, throughput- and delay-optimized multidistance SAT-MAODV routing protocol that incorporates regional data selection, handshaking, and location-based data sharing. In this approach, nodes maintain local data and utilize it to support routing decisions and track node mobility in military applications. Compared with the MRSA protocol, the proposed protocol was evaluated in a network simulator, and the results revealed its effective role in reducing the routing path and footstep delays by 65% and 13%, respectively, increasing the network

10.48047/jocaaa.2024.33.06.155

throughput by 31%, improving the delivery ratio by 9%, and reducing the latency by 27%.

In [24], they proposed building a robust routing path by reducing interference and routing delay to increase throughput within IIoT nodes by realizing a general routing framework that aims to share information resources and exploit the fullness of channel availability. The time-varying channel estimation technique was used, which is based on physical layer sensing and a data link layer as a channel estimation model. The results showed that the packet delivery rate reached approximately 20% on the basis of the different processing units and users identified in the mobile cognitive radio network, achieving high routing performance in finding a stable path for the channel and reducing the possibility of interference of processing units to maintain reliable communication in the network.

In [25], a hybrid optimization algorithm is used to allocate resources and improve performance in the network via hybrid firefly and gray wolf optimization-based (HFGWOSMOR) algorithms, where the relationship between delay and throughput is analysed to establish a cooperative multipath connection by calculating the energy values of the received signals within the bandwidth and time threshold, thus contributing to solving the performance problems in the SMOR algorithm. The results showed that the proposed system works better than other methods do in the network.

In [26], a multihop routing protocol based on incomplete spectrum sensing (ISSMCRP) is proposed for cognitive radio networks, where a cluster head is selected to call a level function to detect available channels, which contributes to the selection of the high-capacity channel on the basis of the accuracy of passive detection to enhance data delivery within the cluster, for example. In addition, the channel selection and cluster formation are controlled by the cluster head, the channels are selected, and the cluster formation is formed such that the energy consumption between nodes is reduced. The simulation results show that, compared with the existing aggregation routing protocols for cognitive radio networks, the proposed protocol has clear advantages in extending the network lifetime and enhancing its ability to monitor nodes.

In [27], they proposed a routing protocol based on integrating the Q-routing network management in CRAHNs to improve the spectrum usage and stability as well as in transmission routing packets. This protocol considers issues of network expansion and stability by creating large cluster groups that accommodate more nodes despite the challenges faced by these large groups of instability and thus helping to reduce overall communication overhead and improve routing efficiency both within a group and across multiple groups. The proposed Q-routing protocol provides the best routing paths dynamically during the transfer of data between nodes in the network. The simulation results using OMNET++ demonstrated the effectiveness of the protocol in choosing stable and short paths that contributed to improving the performance of packet delivery and increasing productivity, routing expenses and the number of hops during packet transfer from the source to the target.

## 3. PROPOSED METHOD

The proposed routing protocol in cognitive radio networks, Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc Networks (HARONET), represents a major advance in adaptive and efficient routing within the dynamic ad hoc network. It consists of a special methodology based on the strengths of the Spectrum-Aware Semi-Structured Routing (SSR) and Spectrum-Aware Routing Protocol (SARP) protocols in highlighting the ability of the hybrid protocol to adapt dynamically to the requirements of fluctuating spectrum availability and user requirements. The SSR protocol is based on its structured routing capabilities, and the hybrid protocol manages sensitive paths that highlight changes in the radio spectrum. In addition, it leverages the strengths of the SARP protocol to ensure reliable data transmission, even in environments characterized by highly unpredictable spectrum availability. This dual integration of the two protocols in Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc Networks (HARONET) allows for the construction of a more flexible network that contributes to improving resource utilization and reducing latency. Moreover, the hybrid protocol enhances the decision-making process in routing packets by integrating real-time spectrum sensor data, whose decisions are based on current network conditions, which leads to improved throughput, reduced interference, and ensuring more efficient communication in the cognitive radio network. It also addresses the challenges facing dynamic spectrum allocation in the two protocols, thus improving overall performance and communication stability. In cognitive radio networks, the routing protocols used in the proposed system are as follows:

### *3.1* Spectrum-Aware Semi-Structured Routing (SSR)

The SSR routing protocol is based on spectrum awareness while routing packets, allowing nodes to make clear decisions on the basis of real-time spectrum conditions. It first performs spectrum sensing to gather information about available channels that can be shared among neighboring nodes to create a cooperative network environment. Later, when the source node starts transmitting data, it broadcasts a packet requesting a route that includes details about the available spectrum. The intermediate node evaluates this request and updates the route on the basis of its spectrum availability. When the data reach the destination, a response is sent to the source to confirm the selected route and the effective spectrum bands for communication. This contributes to improving the overall routing path in the network. The SSR protocol includes continuous spectrum monitoring

10.48047/jocaaa.2024.33.06.155

mechanisms, thus allowing nodes to switch between channels adaptively in response to primary and secondary user activity, which contributes to uninterrupted data transmission by combining routing and power control strategies by reducing latency and maximizing throughput, thus effectively optimizing scarce spectrum resources and improving routing performance in the entire network.

### *3.2* Spectrum-Aware Routing Protocol (SARP)

The SARP protocol operates in two core stages: channel selection and path discovery. In the channel selection stage, nodes analyze the surrounding spectrum environment to identify usable channels, considering channel quality indicators and primary user

activity, to make an informed decision about which channels to use for data transmission. Once the appropriate channels are determined, the SARP protocol begins path discovery, where nodes exchange path request packets that include details about the available channel. Intermediary nodes can evaluate these requests and respond to them with reply packets, which leads to the establishment of an efficient multihop communication path that makes optimal use of the frequency spectrum by integrating channel selection with routing decisions to increase the efficiency and reliability of data transmission, improve the adaptability of routing in response to changing network conditions, and efficiently use limited spectrum resources in a cognitive radio environment.

### *3.3* The proposed Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc Networks (HARONET)

The hybrid HARONET routing protocol uses dynamically updated spectral sensor data to contribute to routing decisions, allowing the network to choose paths that maximize spectrum utilization while minimizing interference. This dynamic adaptation ensures that routing is not only efficient but also resilient to fluctuations in radio spectrum availability. By combining the routing capabilities of the SSR protocol with the robust and secure routing mechanisms of the SARP protocol, the hybrid protocol evaluates multiple routing paths on the basis of current network conditions, providing more efficient and accurate path selection for the target, resulting in reduced latency and improved throughput. The most appropriate paths are selected on the basis of real-time data. The hybrid HARONET protocol is designed to address the scalability challenges of cognitive radio networks and accommodate an increasing number of users and devices without compromising routing efficiency. It relies on an adaptive routing mechanism that is flexible to different network sizes and conditions. It is designed to enhance routing efficiency, reliability, and adaptability within cognitive radio ad hoc networks. The main steps of the proposed hybrid routing protocol are illustrated in the following algorithm.

| The proposed Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc Networks ( (hybrid HARONET) algorithm |
|---|
| 1. Initialize the network with nodes and their spectrum sensing capabilities<br>2. While the network is operational do<br>- Spectrum sensing at each node<br>- Share spectrum sensing results with neighboring nodes<br>- Construct a collaborative spectrum awareness map<br>3. Initiate route discovery when a source wants to send data:<br>    - Broadcast a Route Request (RREQ) that includes the source and destination addresses along with information about the usable spectrum.<br>4. Intermediate nodes process RREQ<br>    - Check spectrum availability using collaborative spectrum map<br>    - Update the RREQ with an improved path whenever more favorable spectrum conditions are detected.<br>    - Maintain routing table with best spectrum for each destination<br>5. When RREQ reaches destination:<br>    - Select optimal route based on spectrum availability<br>    - Send route reply (RREP) back to source with selected route and spectrum bands<br>6. Source node begins data transmission using RREP specified route and spectrum<br>7. Monitor spectrum continuously:<br>    - Detect primary user activity<br>    - Adapt by switching to alternative spectrum band if needed<br>    - Initiate new route discovery if connectivity is lost<br>8. Evaluate performance metrics like PDR, delay, throughput to optimize future decisions |
| End of algorithm |

The hybrid HARONET routing protocol is implemented in the fusion center and secondary users in the cognitive radio

10.48047/jocaaa.2024.33.06.155

network as follows:

A. Implementation in the Fusion Center

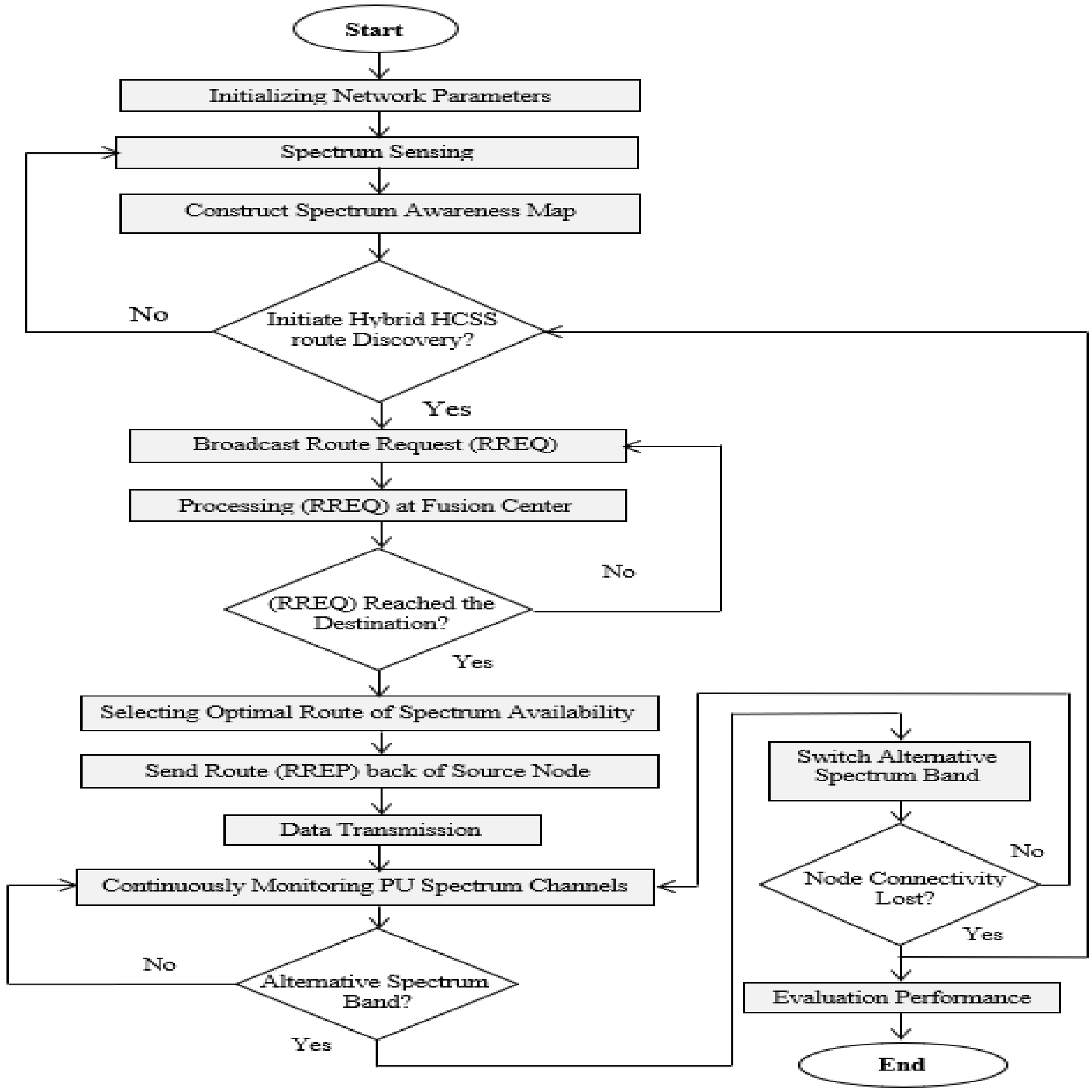
- The collected spectrum sensing data are obtained on the basis of the updated sensing information from secondary users in the network.
- A spectrum availability log file is maintained where the fusion center maintains a log file of current spectrum availability for the different spectrum sensing channels.
- Dynamic spectrum allocation is based on collected spectrum sensing data where the fusion center dynamically allocates available spectrum channels to secondary users while taking into account interference factors, channel quality and user requirements during the allocation process.
- Providing routing information where the fusion center calculates optimal routing paths for data transfer on the basis of current spectrum availability and network conditions, this information is shared with secondary users to ensure optimal reliable routing decisions.

B. Implementation in Secondary Users

- Receive routing information from the fusion center and select optimal paths for data transfer by secondary users.
- SUs maintain a routing table that stores available routes and their corresponding spectrum availability information during the routing process.
- SUs nodes continuously perform spectrum sensing to detect available channels and monitor spectrum usage within their coverage area.
- The routing table is updated by secondary users on the basis of routing information received from the fusion center and spectrum sensor data of secondary users.
- Determine the optimal path from the secondary users' routing table on the basis of spectrum availability, interference, and path length factors when secondary users need to send data.
- Secondary Users (SUs) transmit routing information and data packets through the optimally selected route composed of currently idle channels.
- SUs provide performance feedback of the selected routes and any dynamic changes in spectrum radio availability to the fusion center.

The fusion center and secondary users collaborate to implement the proposed HARONET hybrid routing protocol. The fusion center manages overall spectrum allocation and routing decisions, whereas the secondary user nodes sense the spectrum, maintain the routing table, and select optimal paths for data transmission on the basis of the information provided by the fusion center. This collaboration enables adaptation to dynamic changes in spectrum availability and network conditions, ensuring efficient and reliable data transmission in cognitive radio ad hoc networks. The main steps of the proposed hybrid HARONET routing protocol are shown in Figure 1.

10.48047/jocaaa.2024.33.06.155



10.48047/jocaaa.2024.33.06.155

## 4. EVALUATION METRICS

The proposed system is evaluated with different evaluation metrics, which are explained as follows:

1- Packet delivery ratio (PDR): This ratio measures the ratio of successfully delivered data packets to the total number of packets sent. A higher PDR indicates better reliability [28].
2- End-to-End Delay: Measures the average time taken for a packet to reach the destination from the source. Lower delays are desirable for reliable communication [29].
3- Throughput: Measures the average rate of successful data delivery over the network. Higher throughput is an indicator of reliable communication [30].
4- Goodput (pkts/sec): This is the application-level throughput, excluding protocol overhead and retransmitted packets. Higher values are better, as they reflect the actual successful packet transmission rate, excluding retransmissions and overhead [31].
5- Probability of Channel Collision: This is the likelihood of two cognitive radios attempting to access the same channel simultaneously. Lower values are preferable, as they indicate fewer instances of two radios attempting to use the same channel simultaneously, which can disrupt communication [32].
6- Total network usage (KB): This refers to the total amount of data that has been successfully transferred over the network. Higher values are preferable, as they indicate a more efficient use of the network's capacity to transfer data without packet loss [33].
7- Total resource utilization (%): This represents the percentage of available network resources that can be utilized by the routing protocol. Higher values for this parameter are preferable, as they indicate a more efficient use of the available resources by the routing protocol [35]

## 5. THE PROPOSED SYSTEM IMPLEMENTATION

The proposed system is implemented via the OMNET++ simulator and a dedicated cognitive radio network topology that includes the following primary components: secondary users, the fusion center, primary users, and the base stations of the primary users. The secondary users are responsible for sending and receiving data within the cognitive network, utilizing their radio and wireless cognitive capabilities to dynamically access and use available spectrum channels. In addition, they sense the spectrum to maintain routing tables and choose the optimal paths for data transmission on the basis of the information provided by the fusion center. The fusion center acts as a central unit for managing the total spectrum allocation and making routing decisions. It collects real-time spectrum sensing data provided by secondary users, maintains a database of spectrum availability, and dynamically allocates the spectrum to calculate the optimal routing paths. It then shares this information with secondary users to make routing decisions for them. The primary users are the users who are summarized in the spectrum, and their communications have the highest priority over the rest of the network components. The secondary users must not interfere with the communication and transmission of data with the primary users. The main role of primary users and their base stations is to serve as access channel nodes and provide infrastructure for the network. The proposed network supports wireless communication and dynamic mobility of nodes, allowing them to move freely within the network and supporting different types of mobility, such as linear, circular and random mobility. The dynamic spectrum access feature in the proposed system enables users to adapt.

Primary users are those who hold priority in spectrum usage, and their communications take precedence over other network components. The secondary users must not interfere with the communication and data transmission of the primary users. The primary users and their base stations function as access nodes, providing essential infrastructure for the network.

The proposed network supports wireless communication and dynamic mobility of nodes, allowing them to move freely within the network. It accommodates various types of mobility, including linear, circular, and random movement. The dynamic spectrum access feature in the proposed system enables users to adapt to changing spectrum availability and network conditions, ensuring efficient and reliable data transmission, high throughput, and accurate routing decisions.

The network accommodates various node characteristics and channel characteristics, ensuring flexibility and adaptability. By leveraging the capabilities of cognitive radio technology and the HARONET routing protocol, the proposed system aims to enhance the overall performance, reliability, and scalability of the cognitive radio ad hoc network. In addition, the data type used for academic applications as a file data type is represented as a statistics file with an Excel file uploaded and shared among nodes in the network. The file size is 1024 KB.

The proposed architecture is a key component in ensuring reliable connectivity and efficient resource management within the network. It emphasizes the sensing capabilities and data transmission by secondary users, whereas the reliability center manages essential services related to data collection and routing. Together, these components create a robust framework for dedicated cognitive radio network applications, as shown in Figure 2.

10.48047/jocaaa.2024.33.06.155

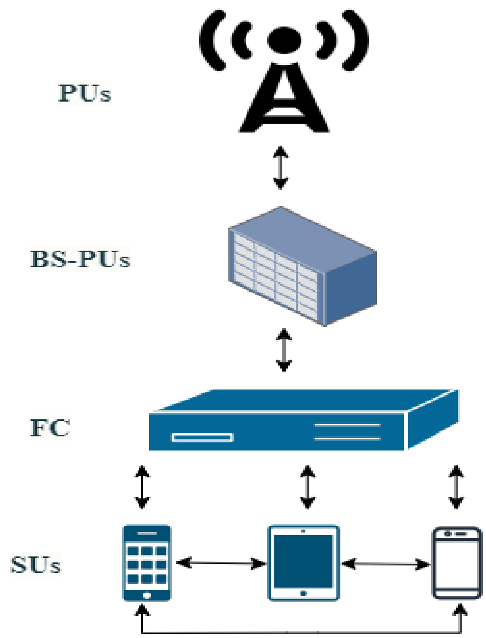



Fig. 2. The proposed network topology.

## 6. RESULTS

The results of the efficient routing protocol Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc Networks (HARONET) within the cognitive radio ad hoc networks, achieved by integrating the cooperative sensing capabilities of secondary users into the SSR and SERP routing protocols, demonstrate that the comparative analyses of four case studies—namely, the hybrid protocol case, SARP protocol, SSR protocol, and the case without a routing protocol—consistently show superior performance in terms of adaptive routing capacity, network flexibility, and evaluated parameters across all scenarios.

The findings indicate that the hybrid HARONET protocol effectively utilizes dynamic spectrum sensing data to inform routing decisions, enabling the network to identify paths that maximize spectrum utilization while minimizing contention. This effectiveness is maintained even under fluctuations and channel migrations, allowing for the discovery of abundant spectrum resources. In contrast, while the SARP and SSR protocols are effective, they do not achieve the same level of performance as the hybrid HARONET protocol because of the more stable and reliable routing mechanisms employed in making routing decisions. The absence of a routing protocol resulted in a significant decrease in efficiency, highlighting the critical role of the hybrid adaptive routing protocol in maintaining network efficiency across various scenarios. Overall, the HARONET approach not only reduced latency and improved throughput but also demonstrated robust scalability, accommodating a growing number of users and devices without compromising routing efficiency. The simulation specifications are shown in TABLE I.

TABLE I. SIMULATION PARAMETERS AND CONSIDERED VALUES OF THE PROPOSED SYSTEM

| Simulation Parameters | | Considered Value |
|---|---|---|
| Network Area | | 1500 m x 1500 m |
| Number of PU | | 5 |
| Transmission Range of PU | | 300 meters |
| Transmission Range of FC and CRs | | 500 meters |
| Number of SU nodes | | 10 |
| Total number of unique link routes of SUs | | 95 |
| Channel availability probability | | 0.95 |
| Data Type | File Data signal size | 1024 KB |
| Simulation Time | | 1800 seconds |

10.48047/jocaaa.2024.33.06.155

| | |
|---|---|
| Type of Channel | Wireless |
| Simulator Name | OMNET ++ 6.0 |
| | |

10.48047/jocaaa.2024.33.06.155

The proposed system is implemented in OMNET ++, and Figure 3 shows the network topology.

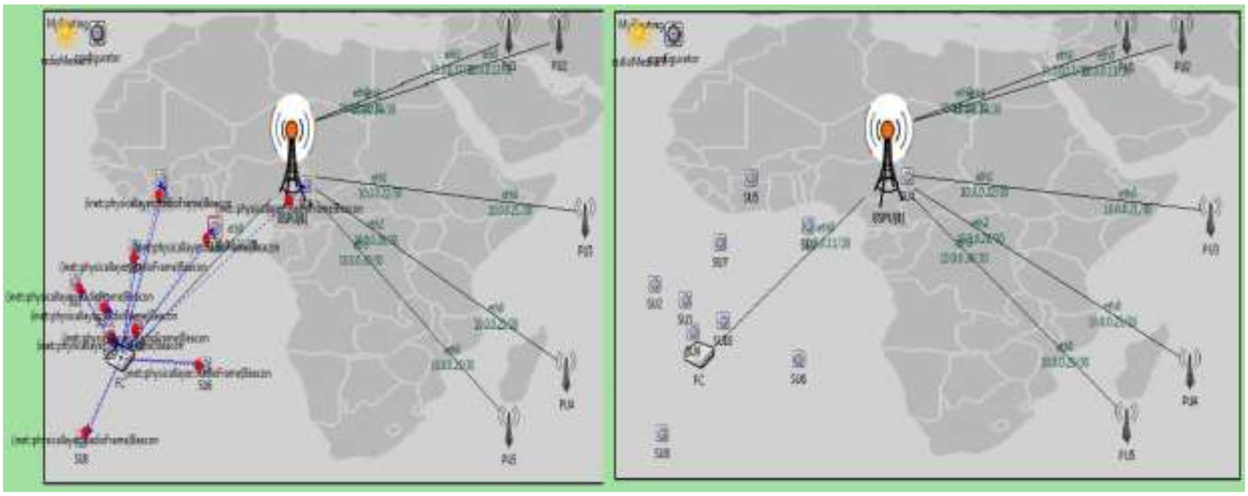


Fig. 3. The proposed network topology.

Figure 4 shows the route building of the fusion center among the cognitive radio network to send and receive data packets. Each node creates its own routing table, which is used to increase network connectivity.

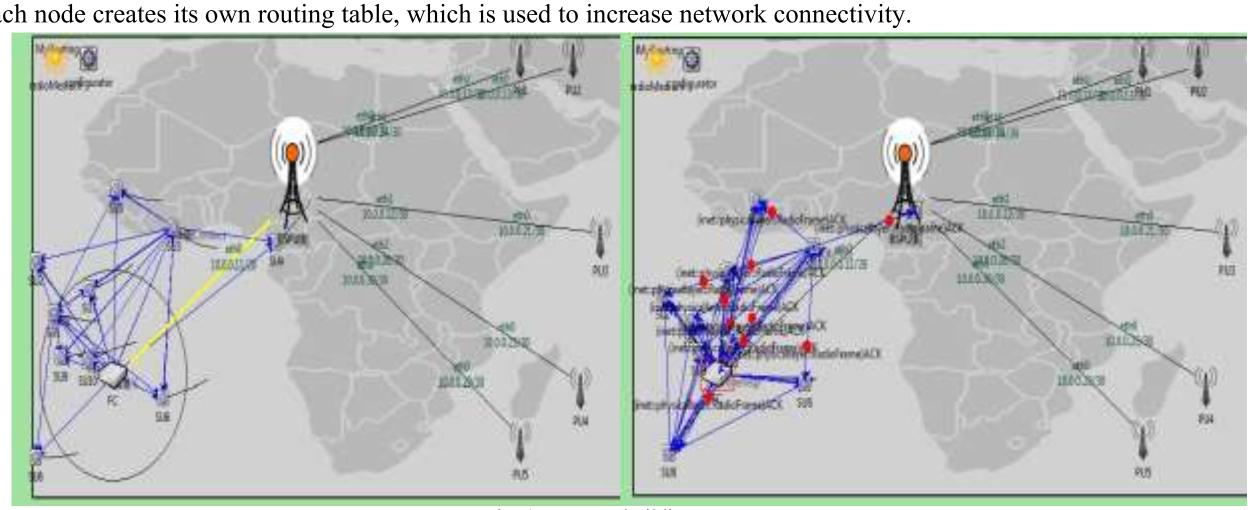


Fig. 4. FC route building process.

Figure 5 shows that the BSPU sends a notification about idle PU-free channels and redirects the result into the FC to add a new channel into the top priority channels to select by secondary users in the case of network overload and spectrum scarcity.

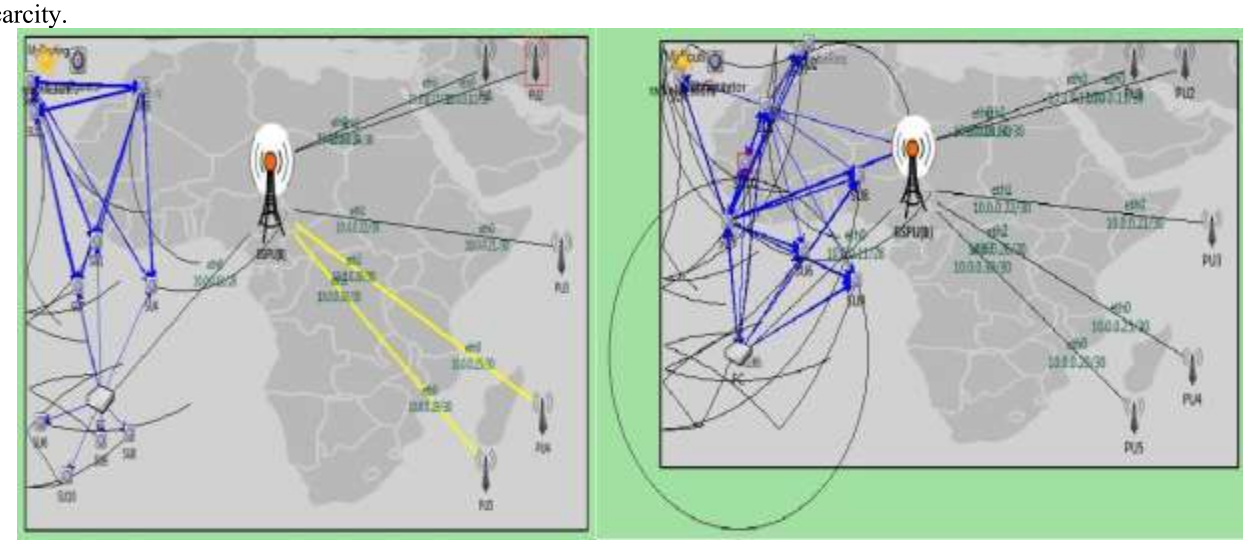


Fig. 5. Channel availability notification alarm messages.

10.48047/jocaaa.2024.33.06.155

Figure 6 shows the data messages exchanged among SUs nodes on the basis of the routing table created in the SU and FC in the case of nodes that require multihop connections.

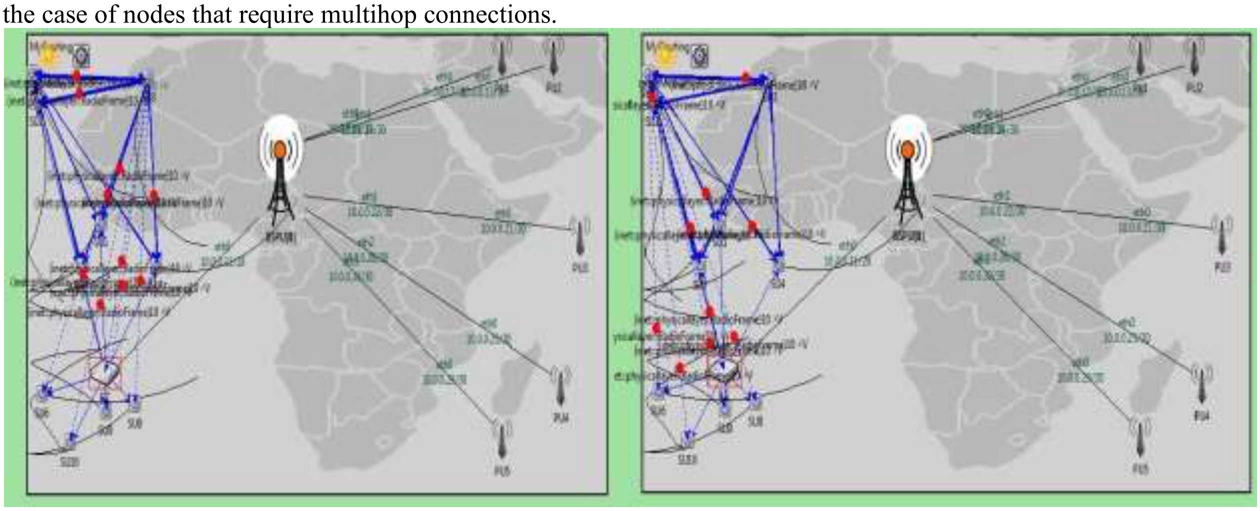


Fig. 6. Data messages redirected among secondary users of the cognitive radio network.

The results of the proposed system are based on four case studies, which are sorted as follows:

### A. Results of Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc Networks (HARONET)

The evaluation of the hybrid HARONET compared with the SARP and SSR reveals that the hybrid HARONET maximizes the average throughput of the secondary users (SUs) by efficiently utilizing the available spectrum holes. The HARONET improves the packet delivery ratio, which indicates better network performance, minimizes the end-to-end delay experienced by packets in cognitive radio networks by optimizing the utilization of available spectrum holes by secondary users (SUs), reducing the time packets spend waiting to be transmitted.

The hybrid HARONET protocol reduces the probability of collisions between the transmissions of the licenced primary user and the cognitive secondary user on the licenced channels. The reduction in collisions leads to fewer retransmissions, lower latency, and a decrease in network congestion. The hybrid HARONET protocol makes effective use of available resources, such as bandwidth, to achieve improved overall network performance, resulting in higher overall network utilization. In addition, it measures the useful data transfer rate (goodput) as the data transfer rate in packets per second increases by reducing collisions and improving the chances of successful delivery of the packet, thus increasing the data transfer rate in the cognitive radio network.

### B. Results of the Spectrum-Aware Routing Protocol (SARP)

Compared with the SSR routing protocol, the SARP protocol increases the useful data transfer rate, excluding retransmission cases, as it selects paths with higher available bandwidths and less interference, which contributes to increasing the successful packet delivery rate and higher data transfer rate in packets per second. In addition, it improves the packet delivery ratio by selecting a path with less spectrum availability and collision, which avoids transmission in congested channels and interference with primary users, as it enhances the overall packet delivery rate and improves the use of available spectrum resources through dynamic adaptation to changing channel states and conditions while allocating traffic to ideal channels that are sufficiently empty, which contributes to reducing congestion and improving overall channel utilization.

### C. Results of Spectrum-Aware Semi-Structured Routing (SSR)

The SSR routing protocol aims to reduce the packet delay from source to destination compared with the SARP routing protocol by relying on intelligent routing decisions that choose the paths with the least congestion by avoiding paths that are likely to experience high delays due to interference or congestion, which contributes to achieving lower transmission times in the network in general and improves channel utilization by actively monitoring spectrum availability and adapting routing decisions accordingly. This protocol ensures that secondary users use the available spectrum slots effectively and thus make the best use of network resources, as it actively monitors the availability of paths. It monitors the spectrum for congested or heavily utilized channels and redirects packets away from high-traffic regions, thereby minimizing collisions and reducing the need for repeated transmissions. This protocol reduces the overall collision rates because the channel is not occupied with excessive transmissions and places an undue routing process.

10.48047/jocaaa.2024.33.06.155

### D. Results without routing protocols

It refers to a situation in which there is no specific protocol or organized path to direct data within the network. This lack of routing structure leads to inefficient use of the available frequency band and low productivity, as packets may be dropped or lost owing to the absence of appropriate routing paths for delivering packets from the source to the destination. The packet delivery ratio would decline substantially in the absence of effective routing protocols. In the absence of defined paths, packets may not reach their intended destinations, resulting in a greater number of lost packets and a reduced PDR. The lack of mechanisms to handle dynamic channel conditions further exacerbates this issue.

Figure 7 shows the average throughput of the proposed hybrid routing protocol case compared with other cases.

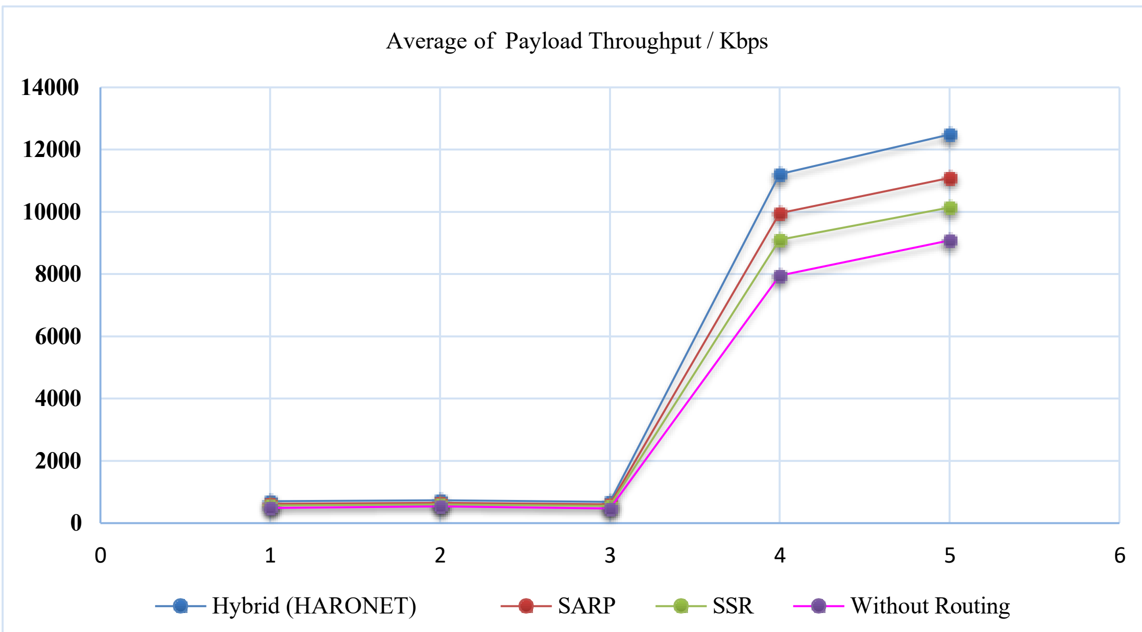
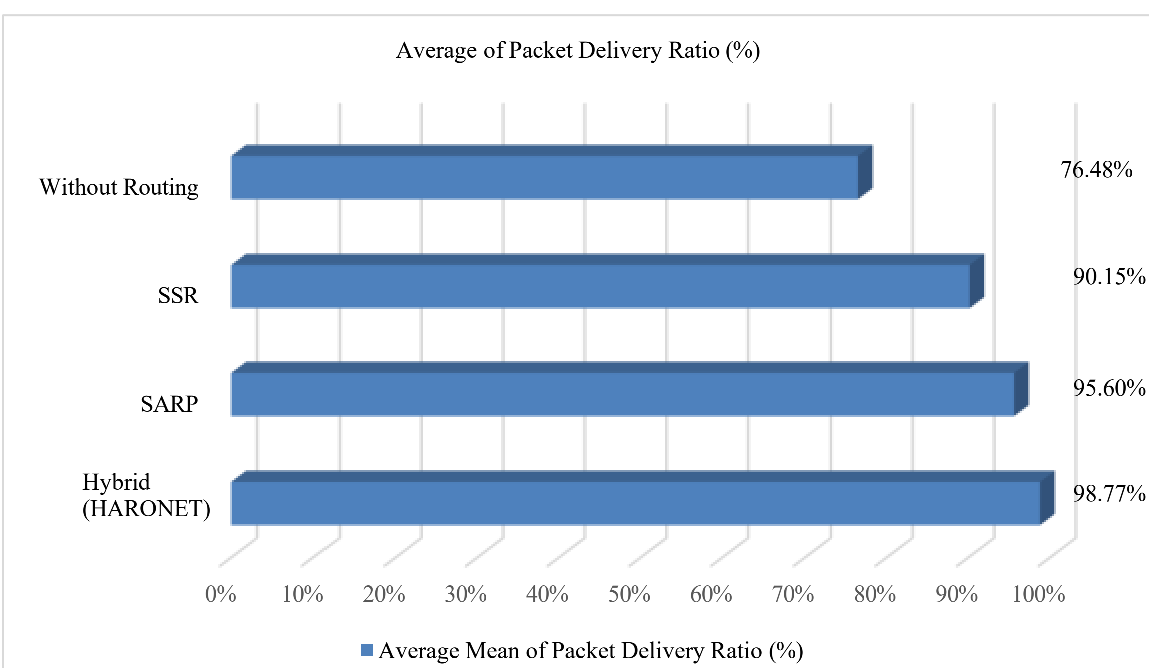



Fig. 7. Average throughput of the proposed cases.

Figure 8 shows that the average packet delivery ratio of the hybrid approach is better than that of the other methods because of an increase in successfully arrived and acknowledged packets among nodes on the basis of the required path suggested by the HARONET protocol.



10.48047/jocaaa.2024.33.06.155

Fig. 8. Average packet delivery ratios of the proposed cases.

Figure 9 shows the end-to-end delay of arriving packets from the source to the destination as secondary user nodes and FC elements, which show that HARONET decreases delay due to the strategy used for routing and rerouting packets during network traffic.

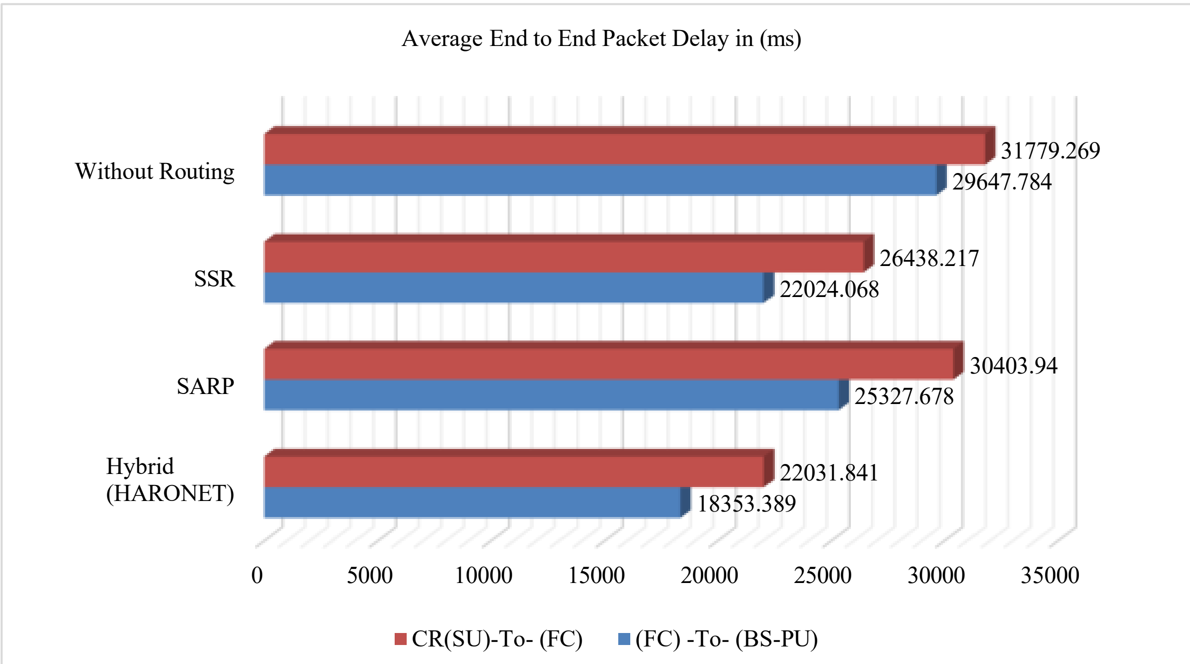



Fig. 8. Average delay of the proposed cases.

Figure 9 shows that the average probability of channel collision decreases because of the channel management strategy used by the HARONET routing protocol, which controls idle and busy PU channels.

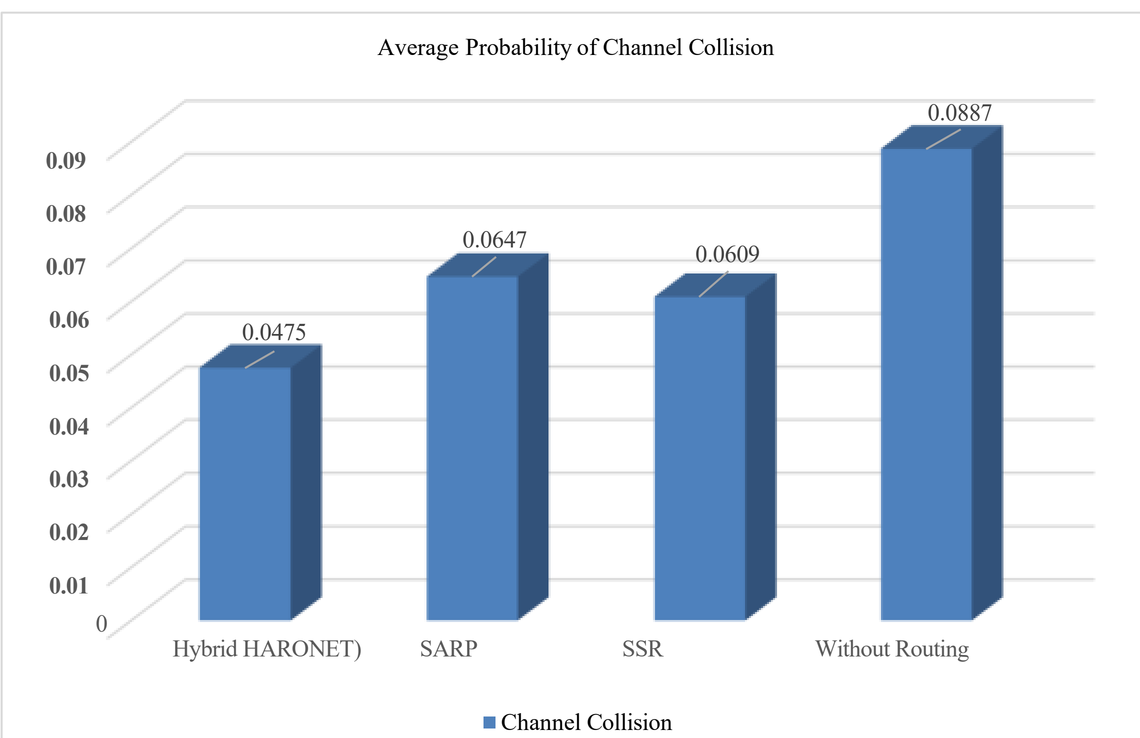



Fig. 9. Average number of channel collisions in the proposed system.

10.48047/jocaaa.2024.33.06.155

Figure 10 shows the total average network and resource utilization of the proposed system, which increases because the resource allocation features ensured by the HARONET routing protocol, which manages network resources such as bandwidth and computing power, can help improve overall network performance and utilization. It balances the network load, minimizes redundant transmissions, and optimizes paths such that they tend to use resources more effectively.

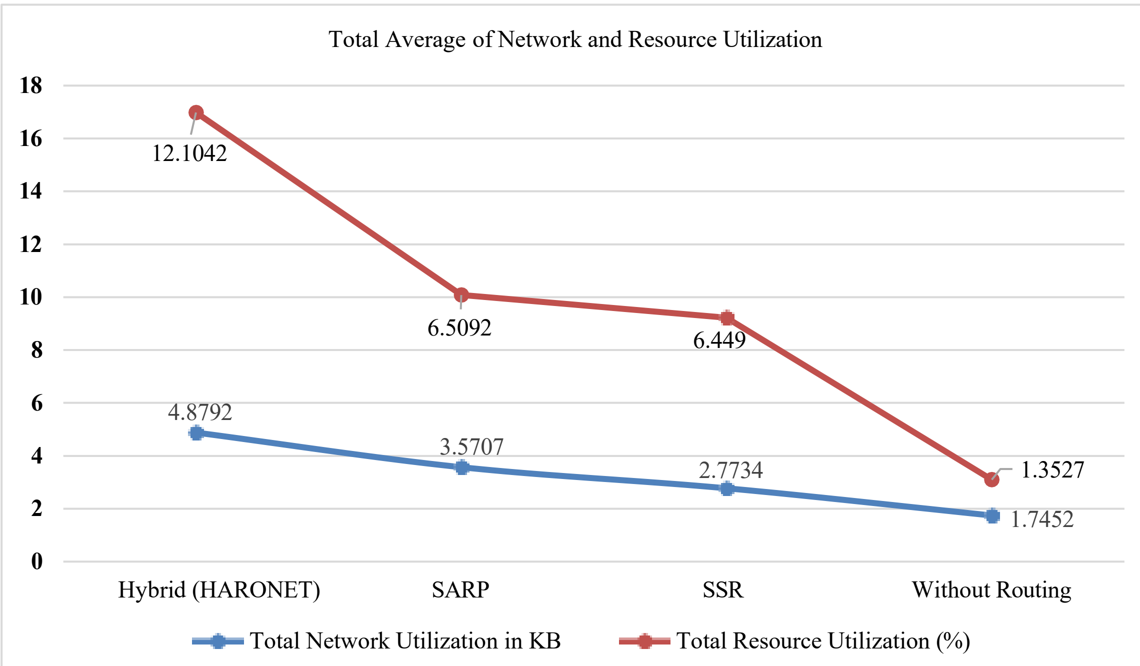



Fig. 10. Total average network and resource utilization.

Figure 11 shows that the hybrid HARONET routing protocol increased goodput due to efficient resource allocation and faster convergence and scalability, which optimized network performance, allowing for more effective transmission of secondary user data in cognitive radio networks.

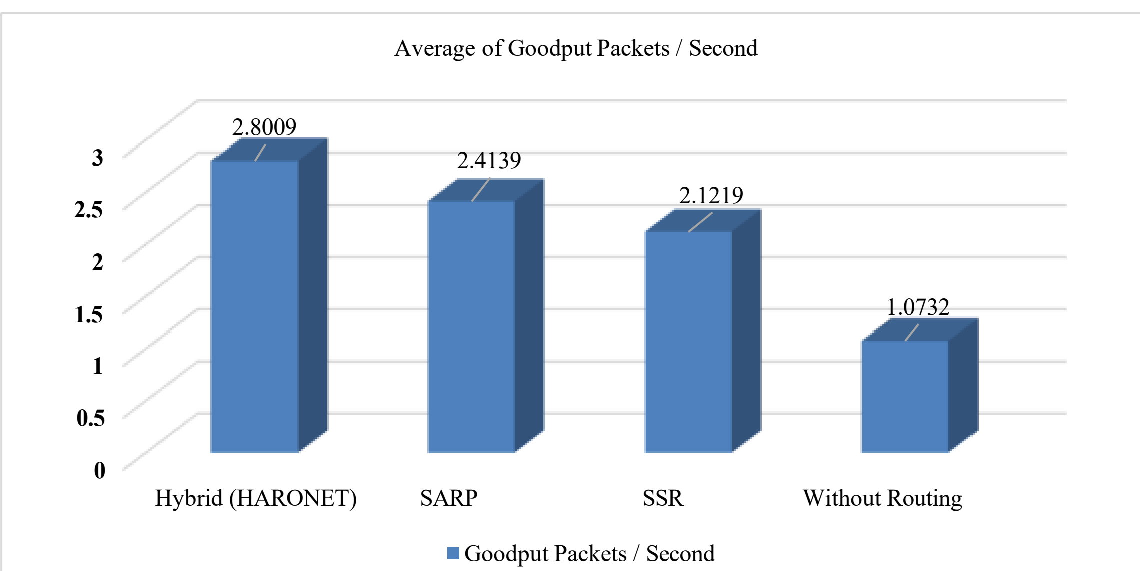



Fig. 11. Average number of Goodput Packets/Second

TABLE II shows the proposed case studies of hybrid HARONET approach comparisons in the cognitive radio network. Compared with the other methods, the proposed hybrid HARONET protocol achieves higher throughput, indicating better data transfer efficiency, and has a high average packet delivery ratio because of its reliability in ensuring that packets

10.48047/jocaaa.2024.33.06.155

reach their final destination. Additionally, the hybrid approach showed a lower delay in applications that require real-time

communications, indicating a low collision probability and the need for few retransmissions, which demonstrates its efficiency in managing resources and handling large amounts of data traffic effectively in the network, making it an ideal choice in network communication scenarios that require high performance and reliability.

TABLE II. COMPARISON OF EVALUATION METRICS FOR THE PROPOSED SYSTEM

| Evaluation Metrics | Hybrid (HARONET) Approach | SARP | SSR | Without Routing |
|---|---|---|---|---|
| Average of Payload Throughput/Kbps | 5164.56 | 4585.56055 | 4194.66209 | 3707.3174 |
| Average of Packet Delivery Ratio (%) | 98.77% | 95.60% | 90.15% | 76.48% |
| Average End to End Packet Delay in (ms) | 20192.615 | 27865.809 | 24231.1425 | 30713.5265 |
| Average Probability of Channel Collision | 0.0475 | 0.0647 | 0.0609 | 0.0887 |
| Total Average of Total Network Utilization in KB | 4.8792 | 3.5707 | 2.7734 | 1.7452 |
| Total Average of Total Resource Utilization (%) | 12.1042 | 6.5092 | 6.449 | 1.3527 |
| Average of Goodput Packets in Second | 2.8009 | 2.4139 | 2.1219 | 1.0732 |

TABLE III and TABLE IV show the proposed hybrid HARONET approach compared with other related works associated with the routing approach in a cognitive radio network.

TABLE III. AVERAGE PDR OF THE PROPOSED SYSTEM COMPARED WITH OTHER-RELATED WORKS

| Ref.No | Year | No. of nodes | Environment | Method | Average PDR % |
|---|---|---|---|---|---|
| [19] | 2020 | 20 | Routing algorithm in QualNet and the results analysed in MATLAB | Cognitive Ad Hoc On-Demand Distance Vector protocol (CAODV) | 65% |
| | | | | Hybrid Routing Algorithm | 65% |
| [23] | 2023 | 40 | NS 2 | SDRP | 82% |
| | | | | D2CARP | 75.1% |
| | | | | CAODV | 76% |
| **The proposed** Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc (HARONET) | | 10 | OMNET ++ | Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc (HARONET) | 98.77% |
| | | | | Spectrum-Aware Routing Protocol (SARP) | 95.60% |
| | | | | Spectrum-Aware Semi-Structured Routing (SSR) | 90.15% |

TABLE IV. AVERAGE END-TO-END DELAY OF THE PROPOSED SYSTEM COMPARED WITH OTHER RELATED WORKS

| Ref.No | Year | No. of nodes | Environment | Method | Average End-To-End Delay |
|---|---|---|---|---|---|
| [20] | 2020 | 10 | NS 2 | OCAS | 62 Sec |
| | | | | PRACB | 55 Sec |
| | | | | DMN | 61 Sec |
| | | | | Reactive routing protocol | 58 Sec |
| **The proposed Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc (HARONET)** | | 10 | OMNET ++ | Hybrid Adaptive Routing for Opportunistic Cognitive Radio Ad-Hoc (HARONET) | 18.353 Sec |
| | | | | Spectrum-Aware Routing Protocol (SARP) | 25.327 Sec |
| | | | | Spectrum-Aware Semi-Structured Routing (SSR) | 22.024 Sec |

## 7. CONCLUSION

Cognitive radio networks offer a promising solution for efficient radio spectrum usage by enabling dynamic spectrum access and enhancing adaptive communication flexibility, significantly improving spectrum efficiency to meet the increasing demands for wireless services. The proposed hybrid HARONET routing approach has made substantial progress in ad hoc cognitive radio networks by integrating the strengths of both the SSR and the SARP of routing protocols, enabling

10.48047/jocaaa.2024.33.06.155

advanced, adaptive, and efficient routing within highly dynamic ad hoc cognitive radio environments. The results demonstrated the superiority of the HARONET hybrid routing protocol in terms of average throughput, packet delivery ratio, reliable connectivity, and the time taken to deliver packets from source to destination. The superiority of the hybrid protocol in average throughput during successful data transfer across the network is due to the protocol allowing for improved data flow and reduced congestion, which enables efficient and adaptive management of multiple paths with changing network conditions, which leads to

throughput compared with traditional protocols. Additionally, by increasing the packet delivery rate on the basis of network conditions, the hybrid protocol reduces the loss of data, which ensures a high delivery rate even in complex and congested environments. The hybrid protocol also has the ability to adapt quickly to changes in the topology of the network. This ability helps maintain the stability of the connection without interruptions. Future directions in this field focus on exploring the integration of the hybrid protocol with advanced SDN technologies, as well as incorporating machine learning and artificial intelligence. These advancements greatly enhance the ability to adapt and make routing decisions, such as increasing the level of central control to manage the spectrum efficiently and predictively sensing the spectrum to facilitate accurate proactive routing decisions.

## References


[1] S. Nayak and R. Patgiri, “6G Communication Technology: A Vision on Intelligent Healthcare,” in *Health Informatics: A Computational Perspective in Healthcare*, 2021, pp. 1–18. doi: 10.1007/978-981-15-9735-0_1.

[2] Q. V. Khanh, N. V. Hoai, L. D. Manh, A. N. Le, and G. Jeon, “Wireless Communication Technologies for IoT in 5G: Vision, Applications, and Challenges,” *Wireless Communications and Mobile Computing*, vol. 2022, pp. 1–12, Feb. 2022. doi: 10.1155/2022/3229294.

[3] A. Vidal-Balea, Ó. Blanco-Novoa, P. Fraga-Lamas, and T. M. Fernández-Caramés, “Developing the Next Generation of Augmented Reality Games for Pediatric Healthcare: An Open-Source Collaborative Framework Based on ARCore for Implementing Teaching, Training and Monitoring Applications,” *Sensors*, vol. 21, no. 5, p. 1865, Mar. 2021. doi: 10.3390/s21051865.

[4] A. S. Hamood and S. B. Sadkhan, “Keywords Sensitivity Recognition of Military Applications in Secure CRNs Environments,” in *2017 Second Al-Sadiq International Conference on Multidisciplinary in IT and Communication Science and Applications (AIC-MITCSA)*, Dec. 2017, pp. 96–101. doi: 10.1109/AIC-MITCSA.2017.8722991.

[5] S. B. A. Khaliq et al., “Defence against PUE attacks in ad hoc cognitive radio networks: a mean field game approach,” *Telecommunication Systems*, vol. 70, no. 1, pp. 123–140, May 2018. doi: 10.1007/s11235-018-0472-y.

[6] S. M. Elghamrawy, “Security in Cognitive Radio Network: Defense against Primary User Emulation attacks using Genetic Artificial Bee Colony (GABC) algorithm,” *Future Generation Computer Systems*, Aug. 2018. doi: 10.1016/j.future.2018.08.022.

[7] A. S. Hamood and S. B. Sadkhan, “Cognitive radio network security status and challenges,” in *2017 Annual Conference on New Trends in Information & Communications Technology Applications (NTICT)*, Mar. 2017, pp. 1–6. doi: 10.1109/NTICT.2017.7976105.

[8] A. R. Uppala, C. V. Narasimhulu, and K. S. Prasad, “A Novel MAC Protocol with Fusion Center and Adaptive Full-Duplex Communication for Cognitive Radio Networks,” *IETE Journal of Research*, vol. 69, no. 7, pp. 4230–4242, Jul. 2021. doi: 10.1080/03772063.2021.1951368.

[9] T. S. Malik and M. H. Hasan, “Reinforcement Learning-Based Routing Protocol to Minimize Channel Switching and Interference for Cognitive Radio Networks,” *Complexity*, vol. 2020, pp. 1–24, Aug. 2020. doi: 10.1155/2020/8257169.

[10] H. B. Salameh et al., “Effective peer-to-peer routing in heterogeneous half-duplex and full-duplex multi-hop cognitive radio networks,” *Peer-to-Peer Networking and Applications*, vol. 14, no. 5, pp. 3225–3234, Jun. 2021. doi: 10.1007/s12083-021-01183-6.

[11] Majid Shaikh et al., “MIMODSA:Non-Pre-emptive Scheduling in Cognitive Radio Ad-Hoc Networks (CRAHNs)”, 2nd International Conference on IOT, Social, Mobile, Analytics and Cloud in Computational Vision and Bio-Engineering (ISMAC - CVB 2020), pp. 20, 2020.

[12] R. S. U. Suseela et al., “Cross layer protocol architecture for spectrum-based routing in cognitive radio networks,” *IET Networks*, Aug. 2023. doi: 10.1049/ntw2.12101.

10.48047/jocaaa.2024.33.06.155


[13] M. M. Aslam et al., "Sixth Generation (6G) Cognitive Radio Network (CRN) Application, Requirements, Security Issues, and Key Challenges," *Wireless Communications and Mobile Computing*, vol. 2021, pp. 1–18, Oct. 2021. doi: 10.1155/2021/1331428.

[14] K. A. Darabkh et al., "Efficient Routing Protocol for Optimal Route Selection in Cognitive Radio Networks Over IoT Environment," *Wireless Personal Communications*, vol. 129, no. 1, pp. 209–253, Nov. 2022. doi: 10.1007/s11277-022-10093-6.

[15] S. Gudihatti, S. H. Manjula, and V. K. R, "Samcar: Spectrum Aware Multi-coefficient Based Shortest Anypath Routing In Cognitive Radio Networks," *International Journal of Electronics & Communication Engineering & Technology*, vol. 10, no. 3, Jun. 2019. doi: 10.34218/IJECET.10.3.2019.004.

[16] H. Al-Mahdi and Y. Fouad, "Design and analysis of routing protocol for cognitive radio ad hoc networks in Heterogeneous Environment," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 1, pp. 341–351, Feb. 2019. doi: 10.11591/ijece.v9i1.pp341-351.

[17] H. Tran-Dang and D. Kim, "Link-delay and spectrum-availability aware routing in cognitive sensor networks," *IET Communications*, vol. 14, no. 20, pp. 3639–3651, Nov. 2020. doi: 10.1049/iet-com.2019.0994.

[18] S. Akter and N. Mansoor, "A Spectrum Aware Mobility Pattern Based Routing Protocol for CR-VANETs," in *2020 IEEE Wireless Communications and Networking Conference (WCNC)*, May 2020. doi: 10.1109/WCNC45663.2020.9120760.

[19] M. Khasawneh, A. Azab, and A. Agarwal, "Towards Securing Routing Based on Nodes Behavior During Spectrum Sensing in Cognitive Radio Networks," *IEEE Access*, vol. 8, pp. 171512–171527, 2020. doi: 10.1109/ACCESS.2020.3024662.

[20] S. Akter et al., "An Efficient Routing Protocol for Secured Communication in Cognitive Radio Sensor Networks," in *2020 IEEE Region 10 Symposium (TENSYMP)*, Jan. 2020. doi: 10.1109/TENSYMP50017.2020.9230638.

[21] A. V. Dang et al., "Performance Analysis of Typical Routing Protocols for Cognitive Radio Ad Hoc Networks," *Journal of Communications*, pp. 844–850, 2022. doi: 10.12720/jcm.17.10.844-850.

[22] Majid Shaikh, Padmavathi H G, Dr. Sasi Kumar M , "An Exploration on Routing Protocols in Cognitive Radio Ad Hoc Networks", International Journal of Advanced Research in Science & Technology (IJARST) Volume 7, Issue 4, July 2020.

[23] P. Phaswana and M. Velempini, "Spectrum-Aware Transitive On-Demand Routing Protocol for Military Cognitive Radio Ad Hoc Networks," *South African Computer Journal*, vol. 35, no. 2, Dec. 2023. doi: 10.18489/sacj.v35i2.17389.

[24] Q. M. Salih et al., "Dynamic channel estimation-aware routing protocol in mobile cognitive radio networks for smart IIoT applications," *Digital Communications and Networks*, vol. 9, no. 2, pp. 367–382, Apr. 2023. doi: 10.1016/j.dcan.2023.01.019.

[25] S. M. Kamruzzaman, A. Alghamdi, and M. Rahman, "Spectrum and energy aware multipath routing for cognitive radio ad hoc networks," in *2014 International Conference on Information and Communication Technology Convergence (ICTC)*, Oct. 2014. doi: 10.1109/ICTC.2014.6983150.

[26] J. Wang and C. Liu, "An imperfect spectrum sensing-based multi-hop clustering routing protocol for cognitive radio sensor networks," *Scientific Reports*, vol. 13, no. 1, Mar. 2023. doi: 10.1038/s41598-023-31865-5.

[27] Padmavathi H G, Majid Shaikh, Dr. Sasikumar M, "A Detailed Excursion on Machine Learning Approach, Algorithms and Applications", *IJSRD - International Journal for Scientific Research & Development, Vol. 8, Issue 5, 2020 , ISSN (online): 2321-0613*

[28] H. Mostafaei, "Energy-Efficient Algorithm for Reliable Routing of Wireless Sensor Networks," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 7, pp. 5567–5575, Jul. 2019. doi: 10.1109/TIE.2018.2869345.

[29] T. Chin, M. Rahouti, and K. Xiong, "Applying software-defined networking to minimize the end-to-end delay of network services," *Applied Computing Review*, vol. 18, no. 1, pp. 30–40, Apr. 2018. doi: 10.1145/3212069.3212072.

[30] H. Chen et al., "Ultra-Reliable Low Latency Cellular Networks: Use Cases, Challenges and Approaches," *IEEE Communications Magazine*, vol. 56, no. 12, pp. 119–125, Dec. 2018. doi: 10.1109/MCOM.2018.1701178.

[31] J.-D. M. M. Biomo, "MBA-DRR: A Delay-Reducing Routing Protocol for Multi-Beam Directional Antennas in Multi-Hop Ad Hoc Networks," Nov. 2019. doi: 10.22215/etd/2019-13707.

[32] R. Ghosh et al., "Performance analysis based on probability of false alarm and miss detection in cognitive radio network," *International Journal of Wireless and Mobile Computing*, vol. 20, no. 4, pp. 390–390, Jan. 2021. doi: 10.1504/IJWMC.2021.117530.

[33] S. M. Khaniabadi et al., "An intelligent sustainable efficient transmission internet protocol to switch between User Datagram Protocol and Transmission Control Protocol in IoT computing," *Expert Systems*, Sep. 2022. doi: 10.1111/exsy.13129.