Reliable and Efficient Cognitive Radio Communication Based on QoS-Driven HCARA Routing Approach

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***Abstract*—Cognitive radio networks are characterized by their ability to adapt to dynamic spectrum variables and network environment conditions. Reliable communication in cognitive radio networks is essential to achieve the most efficient use of spectrum and flexible communication between the different network components. In this paper, a novel Hybrid Cognitive Adaptive Routing Algorithm (HCARA) is proposed for the routing process in cognitive radio networks. HCARA aims to achieve the highest quality of service while minimizing delay during the transmission and reception of data between secondary nodes in the network. The communication path between the nodes is chosen dynamically in a reliable and efficient manner depending on the channel conditions, traffic load, and network topology, as the proposed protocol is based on multiple routing metrics during the decision-making process, including throughput, packet delivery ratio and delay through the round trip of the data transmission. The proposed HCARA was chosen to address limitations in existing routing protocols specifically the Clustering-Based Routing Protocol (CRP) and Multi-metric Routing Protocol with Service Differentiation (MRSED) in terms of throughput and reliability, as evidenced by HCARA's superior performance metrics: an average throughput of 14.64 Mbps, surpassing CRP and MRSED, which recorded 11.86 Mbps and 12.92 Mbps respectively. PDR for HCARA was measured at 98.51%, significantly higher than CRP's 89.24% and MRSED's 94.81%, indicating better reliability in delivering packets to their intended destinations.**

***Index Terms*—Cognitive radio networks, QoS, Clustering-Based Routing Protocol (CRP), Multi-Metric Routing Protocol with Service Differentiation (MRSED), Hybrid Cognitive Adaptive Routing Algorithms (HCARA)**

I. Introduction

Over the past years, many wireless networks have followed a special policy in the process of allocating fixed spectrum in the network. Because of this policy, a large part of the spectrum has not been used, with a percentage of time variation. To make the best use of the wireless spectrum, cognitive radio networks have emerged as a promising solution to deal with the problems of allocating fixed spectrum in wireless networks [1]. Cognitive radio networks are based on two types of users: primary user and secondary users. The primary user has a spectrum range summarized for use while performing his role in the network, the secondary user, the unlicensed user, relies on an unlicensed spectrum range based on the place and time in which the primary user is not present [2]. Use of the licensed spectrum band by secondary users It is important to monitor the presence of the primary user. When the primary user arrives, the secondary user must leave the frequency band he is working on and switch to another band by selecting the spectrum from a group of spectrum frequencies that does not overlap with the primary user's spectrum frequency band [3]. Recently, a new trend has been developed in sensing the frequency spectrum, which plays an important role in wireless sensor networks based on cognitive ratios, which are called cognitive sensor networks [4].

These networks consist of wireless sensors distributed wireless based on the signal in the air frequency bands, relying on cognitive radio devices that communicate with each other through the licensed spectrum bands in a multi-hop manner [5], where the secondary user unit senses the surrounding spectrum bands and selects the most suitable available channel after leaving the idle channel, and the hops are multiple when the main user licensed to obtain the channel arrives [6, 7].

The process of obtaining the path between nodes refers to the routing process, i.e. directing data from the source to the final destination [8]. Many routing techniques in cognitive radio networks face some routing problems, especially the increased computation time allocated to find the path and determine the longest path and the increased complexity in analyzing the appropriate nodes used to transmit data in the network [9, 10]. 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 [11].

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 based on the implementation environment to optimize the use of spectrum resources in the network [12]. The processes on which routing techniques in the network are based are sharing routing information with

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neighboring nodes, how to manage routing failures, and how to repair 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 kept to a minimum.
- Reduced Control Overhead: The number of packets used for route discovery and maintenance should be minimized to conserve bandwidth and prevent collisions [14].
- Loop-Free Routes: Selecting routes that contain loops can lead to unnecessary bandwidth consumption, undelivered packets, and continuous data movement within the network [15].
- Route Reconfiguration: The protocol should be capable of adjusting routes that frequently change or become disconnected [16].

II. Related Works

Many researchers have proposed several routing techniques on the quality of service and cognitive radio network variables to ensure reliable and efficient communication. These protocols aim to achieve dynamic access to the available spectrum in the network. Among these research directions are.

Gudihatti *et al*. [17] developed the cognitive capacity harvesting network as a Multi-Coefficient based Shortest Any-path Routing (MCSAR) routing protocol, which relied on building a link between energy consumption and the amount of weight as a criterion to determine the next hop of the frequency spectrum, by incorporating the improved Bellman-Ford algorithm to ensure an overall improvement in the network connectivity, as it provides two optimal paths based on calculating the weight of each path by measuring the distance from the current node to the directed node. The results showed that the performance of the proposed approach is efficient in terms of packet delivery, end-to-end delay, data transfer throughput, and overall tunneling of communication and computation.

Tran *et al*. [18] proposed an efficient routing protocol based on a dominant connection group (CRD) with dynamic channel selection in cognitive radio networks to ensure the highest throughput and lowest control overhead and energy consumption during node movement in the network. The proposed system is based on clustering and size reduction algorithms for a group of intermediate nodes to provide a search space during the routing phase. The focus area selection algorithm is also adopted to create an efficient path between intermediate nodes. The proposed CRD system, which was implemented in OMNET++, proved to be superior to the traditional AODV protocol in terms of packet delivery ratio, delay, energy consumption, and control overhead.

A new routing approach [19] is proposed to design an efficient routing approach that takes into account the service units in cognitive sensor networks, where it takes a local and global view of the channel availability during routing based on the probability of successful delivery and the average transmission delay during the path establishment phase, where it relies on finding the path on the probability of its successful delivery and the lowest average transmission delay simultaneously for all candidate paths during decision making. The results showed an enhancement in transmission power, performance metric production, and variable packet size compared to previous methods.

An Improved Wolf-Prey-Based (IWPIP) protocol [20] is proposed to find the optimal path in the dynamic 5G environment of cognitive radio networks. It is based on path reliability, shortest distance, and shortest hops which reduce energy consumption and increase network lifetime. The path is evaluated using the fitness function. The results prove the efficiency of the protocol in terms of throughput, energy reduction, energy consumption, and packet delivery in the network.

Ali *et al*. [21] proposed a scheme that contributes to the cross-layer packet routing (ABM) which supports the multi-mediation transmission process over cognitive radio networks, where the path is selected based on the arrival delay from source to destination with the other, taking into account the quality of service. The stability of the path and the activity of the central processing unit were measured by the nodes in the network, which ensures avoiding the interference of the central processing unit, continuity in transmission, ensuring efficient use of the channel, and supporting fault resistance during the time. The results show that the proposed scheme is more robust and suitable for supporting cognitive radio networks.

Sheelavant and Sumathi [22] proposed an advanced model of Dynamic Pattern Clustering (DCP) method with a Lexical Subset (LS) system to know and estimate the similarity between the transmitted data in the whole network where the data is clustered to form a page-like format within the network structure which reduces the computation time during the search period based on prediction according to the previously observed data using Volumetric Probabilistic Mining (VPM). The results of the proposed DCP-VPM system, when compared with modern methods, proved its superiority in calculating the average energy consumption and reducing the packet delivery rate by 10% and 18%, thus outperforming all other routing techniques that were compared to the work.

A routing-based protocol [23] was proposed to determine the best path, reduce delay, and increase network efficiency, namely Whale Optimization Routing Protocol (WORP). Its work is based on the concept of whale behaviors while searching for food and dealing with something by giving priority to the remaining energy and the total energy of the nodes, i.e. choosing the path that takes into account the energy. The work was simulated using a Network Simulator (NS), and the results proved that the standard performance measures are superior compared to current routing protocols within cognitive radio networks.

Half-duplex routing protocols without a shared control channel are proposed by adopting multicast and unicast operations in the handover of the data [24]. The first protocol is divided into two parts with the data being transmitted in half-duplex mode and the second protocol tests the proposed channel assignment in the literature. In addition, authors presented a routing protocol based on IBFD that senses the Quality of Service (QoS) units. The performance of the three protocols is studied and compared with the latest protocol called Probabilistic and Deterministic Path Selection (PDPS) using an exclusive simulator based on the Jabber Muscle language. The results are significant improvements to the protocol and increased throughput.

A multi-hop routing protocol based on incomplete spectrum sensing (ISSMCRP) is proposed for cognitive radio networks [25], 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 based-on 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, and the channels are selected and the cluster formation is formed in a way that ensures reducing the energy consumption between nodes. The simulation results show that compared with the existing aggregation routing protocols for cognitive radio networks, the proposed protocol gains clear advantages in extending the network lifetime and enhancing its ability to monitor nodes.

Phaswana and Velempini [26] proposed the on-demand multicast distance vector as (SAT-MAODV) routing protocol in cognitive radio networks which is improved in throughput and delay where nodes are selected based on regional and mobility data and this is done through handshaking and sharing location data where nodes store the location data and use it for routing and movement determination in military application and the proposed system was implemented in a network simulator NS2 and the results showed that the proposed system reduced the routing path and delay by 65% and increased the throughput by 31% which led to improving the delivery rate by 9% and reducing the latency by 27%.

Tran *et al*. [27] proposed an efficient routing protocol based on a connected dominant group with dynamic channel selection (CRD) in a multi-channel cognitive network to obtain the highest packet delivery rate, low control overhead, low delay, and low energy consumption during high-speed node movement in the CRNs. The proposed protocol was applied in Ad-hoc network to formulate a group of nodes used as a path search space for the routing phase. The focus region selection (CFS) was adopted dynamically to create an efficient path from intermediate nodes to avoid interference with the primary user. The proposed system was applied in the OMNET++ simulator. The results showed the superiority of the proposed protocol over the traditional AODV protocol in terms of PDR, delay, control overhead and energy consumption.

Khasawneh *et al*. [28] proposed spectrum management as a new and secure routing algorithm. The proposed system combined measuring the behavior of nodes during the spectrum sensing phase through 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 using encryption technology. The goal of the proposed system is to make the available path between any two connected nodes secure reduce the negative impacts on the authorized users through the spectrum channels and adjust the total cost of the channels used to choose the best path. The results showed 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.

Salih *et al.* [29] proposed 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, based on physical layer sensing and data link layer as a channel estimation model. The results showed that the PDR reached approximately 20% based on 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.

Through the research directions, the proposed system based on Hybrid Cognitive Adaptive Routing Algorithms (HCARA) contributes to enhancing the routing process by improving data transfer and production capacity, reducing delay, increasing the data delivery rate between nodes, reducing computational operations in the nodes, and improve the quality of service in the entire network. In addition, it motivated to develop solutions for dynamic multi-hop routing as dynamic path selection in CRNs, which are essential for efficient spectrum utilization and flexible communication among network components.

III. Proposed Method

The proposed method is based on the adaptive routing algorithm known in cognitive radio networks, which plays an important role in determining and configuring communication paths dynamically according to the network needs of spectrum availability, channel quality, amount of transmitted and received data, and network topology changes. The algorithm aims to improve the routing decision according to the network performance, reliability, and efficiency. The proposed system consists of a hybrid adaptive technique (HCARA) based on the aggregation-based clustering-based routing protocol (CRP) and multi-metric routing protocol with service differentiation for CRNs (MRSED) for cognitive radio networks. The main factor in the proposed system is the quality of service such as latency, throughput, and reliability in cognitive man networks. It takes into consideration the spectrum availability and channel conditions when selecting the methods through which data is routed. It is considered suitable for smart building applications with strict performance requirements related to instantaneous multimedia broadcasting. The routing protocols used are as follows:

A. Clustering-Based Routing Protocol (CRP)

It is a type of cluster-based routing protocol commonly used in wireless sensor networks, where nodes in the network are organized into groups, and each group has a group head or coordinating node responsible for managing all communications within this group or with other groups. Its main goal is to enhance the efficiency and reliability of data transmitted between nodes, improve resource utilization in the network, and enhance energy consumption, as the node organizes 100 groups, which allows these groups to be managed more effectively and facilitates communications between multi-hop nodes.

B. Multi-Metric Routing Protocol with SErvice Differentiation for CRNs (MRSED)

It is a multi-metric routing protocol designed for cognitive man networks to differentiate between network services according to their capabilities such as modulation segment frequency and power. It is based on the available spectrum and network conditions to determine the optimal path to route packets through and improves routing decisions in a network by considering multiple metrics according to different data traffic.

C. The proposed Hybrid Cognitive Adaptive Routing Algorithms (HCARA)

The proposed novel HCARA routing protocol is particularly suitable for both secondary user base stations and secondary users in cognitive radio networks. In the case of secondary users, the spectrum not used by the primary user is utilized and it provides efficient routing to maintain the connection while taking into account the adaptation when the dynamic spectrum is available by the primary user. It ensures efficient network management and rapid adaptation to network variables, especially different quality of service. When the proposed system is implemented in secondary user base stations, the hybrid algorithm is adaptive to spectrum variables, which facilitates efficient communication between user units and their seats and provides efficient data transfer without interfering with secondary users.

The proposed HCARA routing protocol is designed based on the benefits of both routing protocols CRP and MRSED with service differentiation for cognitive radio networks with the aim of improving performance, reliability and data transferability in an optimal manner. The system organizes nodes in the form of groups, which enhances the scalability of the network and how it is managed. Each group has a group head who manages communication within the group, organizes data transfer, and improves routing efficiency. It also provides multiple measures such as node connection stability in the network and task distribution during path discovery. It also allows the possibility of distinguishing between different services for data that are transferred between users, which is very important for applications that require varying quality of service. The proposed HCARA protocol benefits from the strengths of both protocols in terms of aggregation and multi-scale routing, thus providing more efficient data transfer than the separate protocol. It provides the scalability of CR nodes as the clustering approach allows HCARA to manage larger networks effectively, reducing overhead and improving route discovery times. In addition, it allows high Quality of Service requirements as the service differentiation aspect of MRSED ensures that critical data packets receive the necessary priority, enhancing the overall performance of the network. The pseudocode of the Hybrid Clustering and Adaptive Routing Algorithm (HCARA) is shown as follows.

The pseudocode of hybrid clustering and adaptive routing algorithm (HCARA)

```
Step 1: Initialize Network Parameters
        For each node in the network do
            If node is not yet part of a cluster then
               Form a new cluster with this node as the cluster head
            end if
           Assign neighboring nodes to this cluster based on proximity and signal strength
        end for
Step 2: Route Discovery
        Send data to a destination:
              If route exists in routing table, then use existing route else
                  Broadcast RREQ (Route Request) within the cluster
                  Wait for RREP (Route Reply) from cluster members
              end if
Step 3: Broadcast CH Announcement with RREQ Handling
         When a cluster member receives RREQ:
                If RREQ already processed then
                     Discard RREQ
                   else
                     Update RREQ with local metrics (back-off delay, link stability)
                     Forward RREQ to the next hop or cluster head
                end if
Step 4: Inter-Cluster head Routing
        When RREQ reaches a cluster head:
          If destination is within the same cluster, then
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            Generate RREP with accumulated metrics
        else
            Forward RREQ to neighboring clusters
      end if
Step 5: RREP Generation
    When destination node receives RREQ:
            Generate RREP with cumulative metrics (back-off delay, link stability, energy)
            Unicast RREP back to the source along the reverse path
Step 6: Data Transmission
    Once route is established: Send data packets along the selected path, respecting service differentiation
Step 7: Route Maintenance
    When link breakage is detected:
     Initiate local repair within the cluster
     If repair fails then
            Send RERR (Route Error) to source
            Source initiates new route discovery
     end if
Step 8: Periodic Cluster Maintenance
    Periodically check cluster membership and reassign cluster heads if necessary
Step 9: Evaluating the HCARA routing protocol
Step 10: End
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However, Fig. 1 shows the proposed Hybrid approach's main steps of the combined routing approaches to building an adaptive route in the network, in the first step of the initialization process, the initialize network parameters, refer to setting up various parameters that will guide the functioning of the network such as Node Parameters, Network Configuration Parameters, Routing Metrics and Service Requirements and so on. Deploying nodes randomly refers to placing nodes in a network area without a specific pattern or predetermined arrangement to ensure coverage and connectivity. The Cluster Formation (CRP) decision is built with the condition "Is CH Selection Time?", if it is "Yes" the processes applied with Cluster Head (CH) selection process, broadcast CH announcement and nodes join clusters, and if the condition is "No", it is waiting for next selection time. The mathematical model for cluster head (CH) selection using a weighted sum approach that incorporates Residual Energy (RE) and Distance to Base Station (DBS), it defines the model as follows:

- Residual Energy (RE): The remaining energy of node *i*.

To ensure that the metrics are on a comparable scale, we can normalize them. Eq. (1) is showed the normalization of residual energy can be done as follows:

$$RE_{norm} = \frac{RE_i}{RE_{max}} \tag{1}$$

where RE_{max} is the maximum residual energy among all secondary user nodes.

- Distance to Base Station (DBS): The Euclidean distance from node *i* to the base station. Eq. (2) shows the distance to base station normalization.

$$DBSnorm = \frac{DBSi}{DBS_{max}} \tag{2}$$

The DBS_{max} is the maximum distance to the base station among all nodes. Eq. (3) shows the score for each node *i* to be selected as a cluster head can be calculated using the following weighted sum formula:

$$CH\_Scorei = w_1 RE_{norm} - w_2 DBS_{norm} \tag{3}$$

where w_1 is the weight assigned to the normalized residual energy (higher weight indicates more importance). w_2 is the weight assigned to the normalized distance to the base station (higher weight indicates more importance). Eq. (4) shows the weights w_1 and w_2 should satisfy the condition as follows:

$$w_1 + w_2 = 1 \tag{4}$$

This ensures that the contributions of both metrics are balanced in the score calculation. So, the selection process of cluster head is calculated as follows: calculate CH_Score *i* for each node in the network. The node with the highest CH_Score is selected as the cluster head.

However, after the cluster head selection process, the metric collection is applied based on (MRSED). The collected metrics are Energy, Link Quality, and Delay to identify different service requirements as Latency-Sensitive, and Throughput-Sensitive. Routing Decision is evaluated routes based on collected metrics. Then the data transmission happens based on the best route and the Data Aggregation at CH based on CRP, the transmission schedule setup is applied based on CRP with the processes as Nodes Send Data to CH and CH to CH Communication, CH to Base Station (BS) Communication. The transmitted data is based on chosen routes based on (MRSED) to provide route and cluster maintenance and check the decision condition as "Is Route Quality Degraded or Service Requirement Not Met? (MRSED)" If "Yes" the process of Update Routes occurred, otherwise if the condition "No" Continue Normal Operation Processed. Besides, check the decision condition of "Is CH Node Failure Detected? (CRP)", if yes, the re-clustering process is applied otherwise continue normal operation and the operation is finished. The proposed weighted sum model effectively balances the importance of residual energy and distance to the base station in the cluster head selection process.

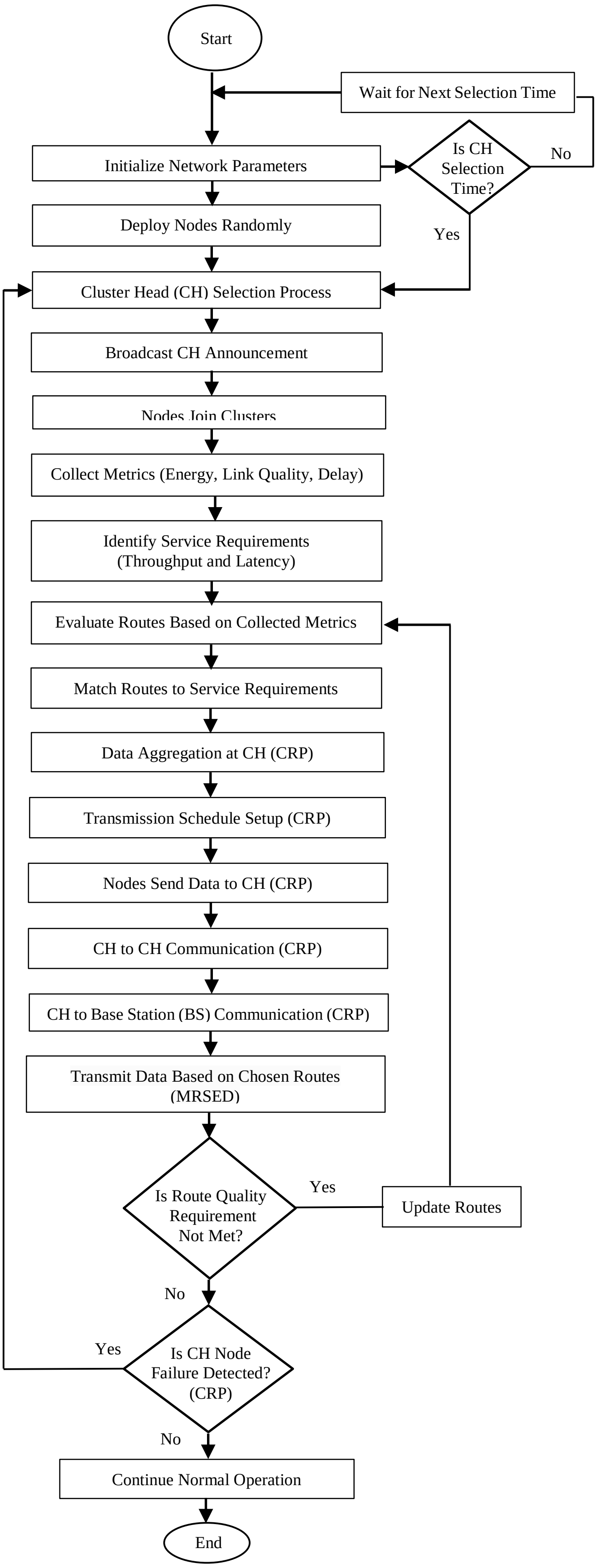

Fig. 1. Flowchart of the proposed hybrid HCARA routing approach.

IV. PROPOSED SYSTEM IMPLEMENTATION

The proposed system is implemented with the network topology components are Secondary Users (SUs), Base Stations for Secondary Users (BS-SUs), Primary Users (PUs), Base Station for Primary Users (BS-PUs), cluster head and network elements (Access Point, Router). The proposed cognitive network supports wireless communication and mobility with different mobility types as linear and random mobility with dynamic spectrum access for data type, node characteristics, and channel characteristics.

Data type used for environmental applications such as Text, Image, and Files:

- Text data type: It is represented as temperature reads, earthquake, and wind ratio. The text reading size is (80 B).
- Image data type: It is represented as images of earthquakes or changes in desert areas. In some cases, they are pictures from camera sensors, and they record pictures and snapshots of rain and wind of different sizes. The image size is (60 KB)
- File data type: It is represented as a statistics file with an Excel file uploaded and shared among nodes in the network. The file size is (850 KB).

In addition, the proposed system has been implemented in OMNET++ based on the following components:

- Secondary Users (SUs): It is wireless cognitive radio nodes used to send and receive data over the identified channels while adhering to the Quality of Service (QoS) requirements. The task of the used SUs is to monitor the spectrum to identify available channels that are access not being used by primary users (PUs), they join clusters formed by Cluster Heads for efficient communication and resource management, and it collaborate with other SUs to share spectrum information and optimize network performance.
- Base station-secondary users (BS-SUs): It is used in the proposed system to manage spectrum radio sensing, suggest optimal PU channel (channel allocation), and decrease the computation process (enhance network performance) on secondary users. It collects data from multiple SUs within its coverage area to reduce transmission overhead, it facilitates communication between SUs and the core network or the internet by acting as a relay node. Ensure that the data transmitted from SUs meets the required QoS standards, such as latency and throughput and it manages signaling for resource allocation and channel assignment among SUs.
- Primary Users: It is a licensed node that uses the licensed spectrum for communication, ensuring minimal interference with SUs. It maintains high-priority communication needs and ensures that their data transmission is not disrupted by SUs.
- Base Station-Primary Users (BS-PUs): It handles data from PUs and ensures efficient transmission to the appropriate destinations. Also, it coordinates with other base stations and network components to manage resources effectively. In addition, it ensures that PUs receive the necessary bandwidth and service quality, especially during peak usage times.

- Cluster Heads (CHs): It provides cluster formation by organizing SUs into clusters based on proximity and communication needs, optimizing resource usage. It provides data aggregation and forwarding by collecting data from member SUs and forwarding it to the BS-SUs or other CHs, reducing redundancy and improving efficiency. Besides, it provides routing decisions by making routing decisions based on QoS metrics (latency, throughput, reliability) to optimize communication paths. In addition, it ensures resource management by monitoring the energy levels and performance of SUs within the cluster to maintain network reliability and efficiency.

In the proposed architecture, each component plays a crucial role in ensuring reliable communication and efficient resource management in cognitive radio networks. SUs focusses on spectrum sensing and data transmission, while BS-SUs and BS-PUs manage data aggregation and routing. Cluster Heads facilitate organization and optimize routing decisions based on QoS requirements. Together, these components create a robust framework for cognitive radio network operations in intelligent building applications, as it is shown in Fig. 2.

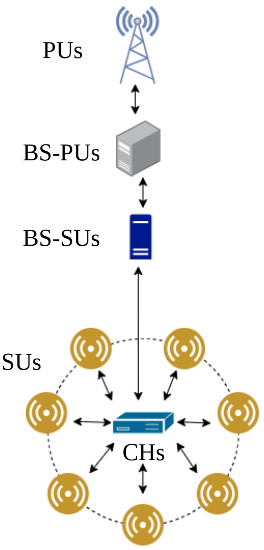

Fig. 2. The proposed cognitive radio network topology components.

V. RESULTS

The simulation of the hybrid routing algorithm, Clustering-Based Routing Protocol (CRP), and Multi-metric Routing Protocol with Service Differentiation for CRNs (MRSED) were conducted in OMNET++ using a defined set of parameters to ensure a comprehensive evaluation of their performance. The proposed system was implemented with the characteristics of a network with dimensions within the simulator of 1000 meters × 1000 meters and accommodates a group of primary and secondary nodes, where 10 channels as PUs channels and 20 secondary user nodes as CR nodes as the cognitive radio transmission nodes, and the coverage area of the primary users reaches 300 meters, while the secondary stations and cognitive radio devices operate within a range of 400 meters. The movement of nodes in the network is dynamic based on wireless communication, and the multimedia data is transferred between the nodes in the network at a flow rate of 512 Kbps and the packet size is 1024 bytes. The probability of the channel being available by the primary nodes reaches 85%, which is a high probability of the spectrum being available by the primary users for secondary users, as shown in Table I.

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

Simulation parameters		Considered value
Network Area		1000m × 1000m
Number of PU		10
Transmission Range of PU		200 meters
BSs and CRs		300 meters
Total No of BSs		1
Number of SU nodes		20
Total number of unique link routes of SUs		190
Channel availability probability		0.85
Data Type	Text Data signal	80 B
	Image Data signal	60 KB
	File Data signal size	850 KB
Simulation Time		1800 seconds
Type of Channel		Wireless
Simulator Name		OMNET ++

The proposed system implemented in OMNET ++ and Fig. 3 shows the network topology which consists of 10 primary users as available channels, and 20 secondary users, as cognitive radio nodes that send and receive data types (Text, Image, and Files).

Fig. 4 shows the Primary user assigns an idle channel and redirects the information to Base Station-Primary Users (BS-PUs) which pass into the Secondary User Base Station (SUBS) to select the idle channel and add the channel to the active free list channels.

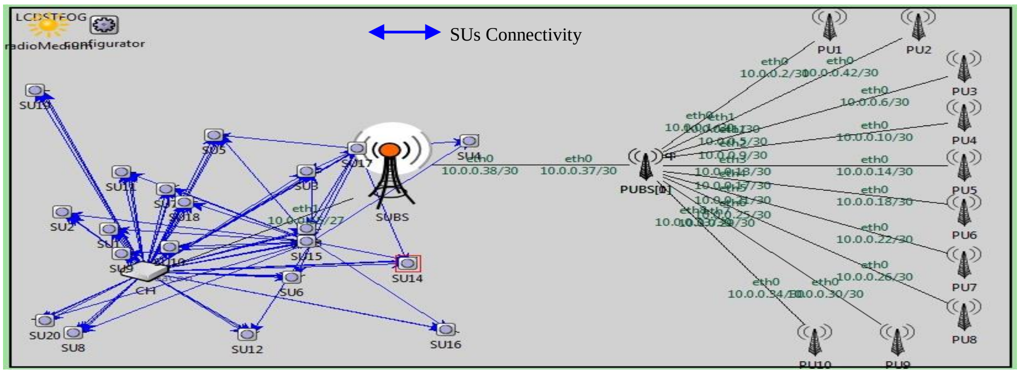

Fig. 3. The proposed network topology.

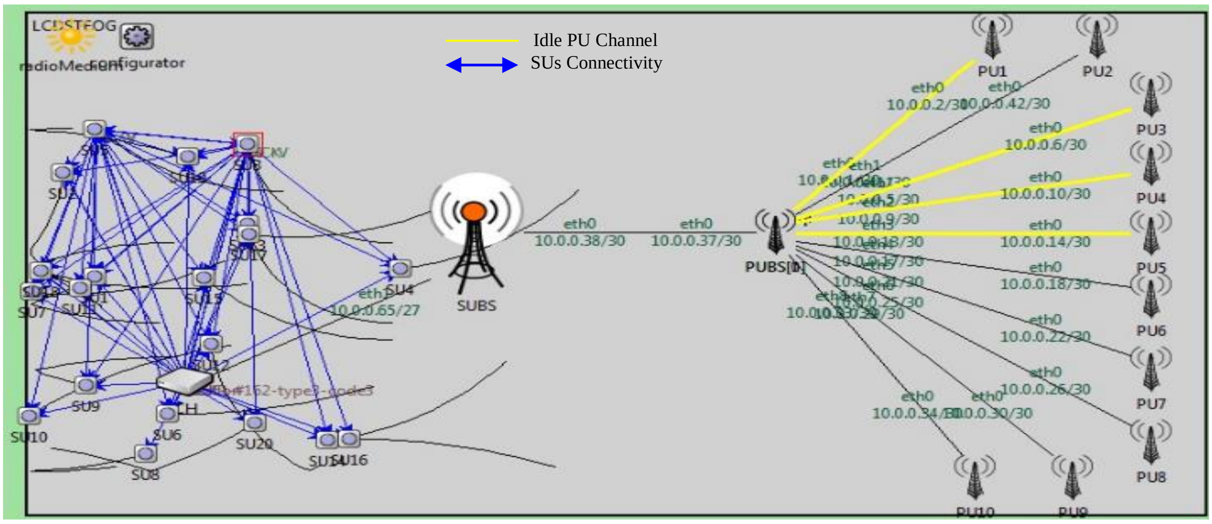

Fig. 4. Idle channel primary user (PU) availability.

The results obtained from the implementation of the Hybrid HCARA proposed protocol showed an improvement in performance metrics including throughput, average packet delivery ratio, packet delay from start to target, and data transfer throughput in the network. The results of the hybrid protocol outperformed the other used protocols as MRSED and CRP routing protocols in all metrics, which indicates the effectiveness of the proposed protocol in improving the optimal use of network and node resources and enhancing the overall performance of nodes for the cognitive man environment. It has proven its worthiness to improve communication efficiency in the dynamic spectrum. The results of the proposed system are based on 4 case studies, which are classified as follows.

A. Results of Hybrid Cognitive Adaptive Routing Algorithms (HCARA)

The evaluation of the hybrid routing protocol in cognitive radio networks highlighted the strengths of dynamic spectrum access processing. The results showed its effective role in reducing latency and increasing throughput, making it suitable for an environment that is highly time-based in data delivery and maintains paths in the face of changing spectrum conditions for different media. Therefore, this protocol is considered adaptive in reliable communication between secondary users.

B. Results of Multi-Metric Routing Protocol with Service Differentiation (MRSED)

The evaluation results of this protocol showed its effective role during the path discovery process, as it addressed the dynamic challenges of the cognitive radio network resulting from node mobility and movement in the network, as this protocol was based on backoff delay and link stability. It also collectively contributed to the selection of the path with a view to quality-of-service considerations, as it effectively balances between different performance metrics, making them suitable for environments where spectrum characteristics are unpredictable, as it enhances the reliability of communication due to the intermittent communication that often occurs in dynamic cognitive radio networks. The results also highlighted the ability of the protocol to distinguish between service levels to prioritize data traffic, ensuring critical data transmission that is less susceptible to spectrum variables that cause disconnections.

C. Clustering-Based Routing Protocol (CRP)

The evaluation results of this protocol showed its effectiveness in improving path selection while ensuring that there is no interference with primary users, as it integrates metrics related to spectrum availability and interference into the routing decision-making process. It also significantly reduces path transition time, which simplifies the path formation process in the network. In addition, the results showed its ability to distinguish between services by allowing multiple classes of paths with different quality of service in line with the channel availability available from primary users, which occurs in a dynamic environment with rapidly changing spectrum availability.

D. Result of without Routing Protocols

The nature of nodes in cognitive radio networks is dynamic in spectrum usage and the need for efficient and reliable communications between nodes in the network, so the concept of routing without routing may be considered irrelevant in this network, but the results have proven that the absence of routing protocols leads to challenges in the network such as disconnected connectivity and varying link quality between nodes. The node must adapt the ability to modify its communication strategies in real-time and according to the response of each request directed to it from neighboring nodes. Therefore, decision-making mechanisms are required by the routing protocols. When comparing this case with the proposed Hybrid HCARA system, it was found that the superior throughput performance of the hybrid routing algorithm is attributed to the ability of this algorithm to combine the strengths of both MRSED and CRP protocols to be able to route packets while taking into account all metrics, including network resource management, adapting to dynamic spectrum conditions, and giving priority to traffic according to the type of data sent, thus improving the overall throughput compared to individual protocols or the absence of any routing mechanism for packets, as it shown in Fig. 5.

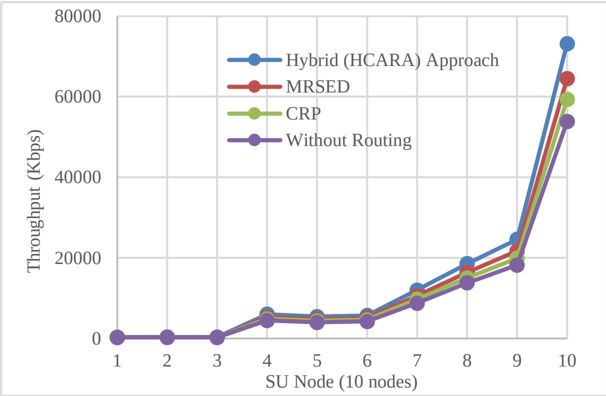

Fig. 5. Average throughput (Kbps) of the proposed case studies.

Fig. 6 shows that the scenario in which no routing protocol is implemented in the network has a significantly higher average processing time, indicating that the nodes are inefficient in routing and transmitting data between them. In contrast, the proposed hybrid system effectively improves the processing, allowing faster path discovery and maintenance of lost paths. This ensures reduced computational costs and faster and more accurate decision-making based on available paths, thus improving the overall performance of the entire network.

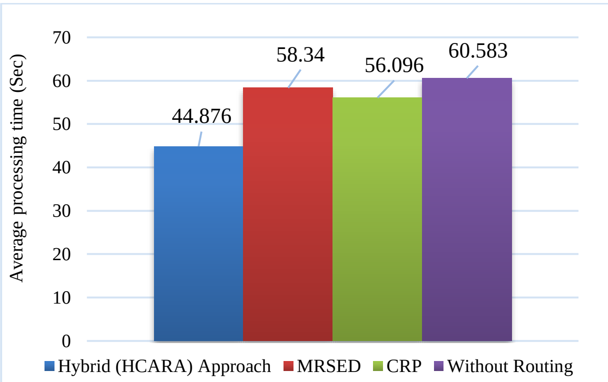

Fig. 6. Average processing time of the used case studies.

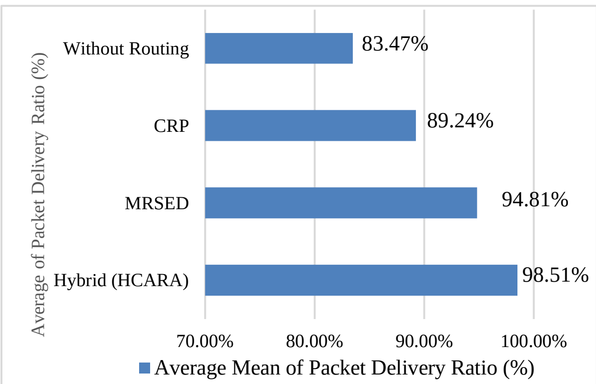

Fig. 7. Average packet delivery ratio of the proposed cases.

In Fig. 7, the results show that the scenario without a routing protocol has a significantly lower packet delivery rate, highlighting the inefficiency of this scenario in data transmission. On the other hand, the hybrid protocol showed great effectiveness in delivering packets to the target, thus indicating that the hybrid protocol is superior in maintaining packet delivery rates in different network conditions.

In Fig. 8, the results showed that the hybrid protocol effectively reduces the time taken for each packet to cross the network by providing the best and shortest path with the lowest request processing costs and thus delivering data faster in the cognitive radio network.

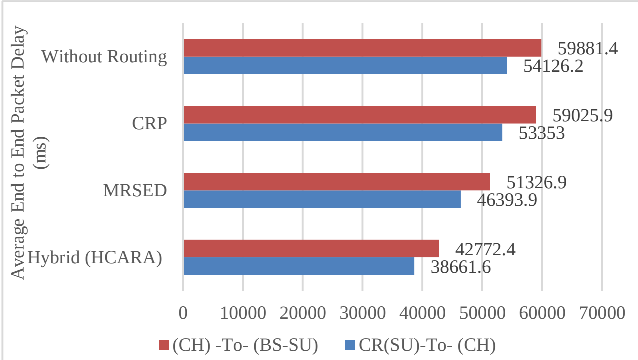

Fig. 8. Average delay of the proposed cases.

Fig. 9 shows that in the scenario where there is no routing protocol in the network, the channel utilization is lower, so it is inefficient use of the available spectrum. In contrast, the Hybrid approach of the routing protocol improves the access to the channel proposed by the cluster head of the node group, which in turn exchanges the channel information with the secondary base station, thus distributing the data traffic across the available channels better and using the channel, in general, is more efficient to meet the requirements of the various data users traffic and reducing the spectrum time to a minimum during the process of searching for the available channels from the primary users of cognitive radio networks.

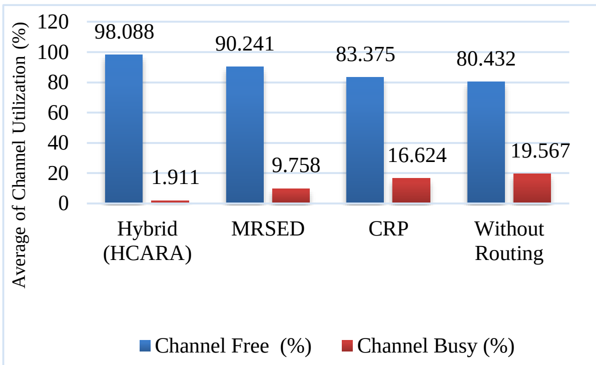

Fig. 9. Average channel utilization.

Fig. 10 shows that the Hybrid routing protocol effectively reduces the probability of false alarms during the decision-making process for routing packets in the network, thus ensuring accurate detection of node activity, reduces the probability of unnecessary spectrum evacuation by secondary users, thus ensuring efficient channel access and lower transmission collisions between devices compared to the scenario without a routing protocol, which has higher false alarms and channel collisions, is inefficient in spectrum sensing and channel access management, thus increasing the chances of packet collisions, increasing the delay in decision-making processes, and reducing the reliability and efficiency of the cognitive radio network.

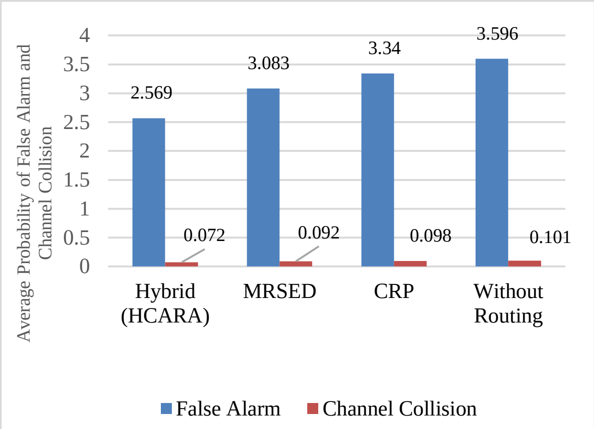

Fig. 10. Average probability of false alarm and channel collision.

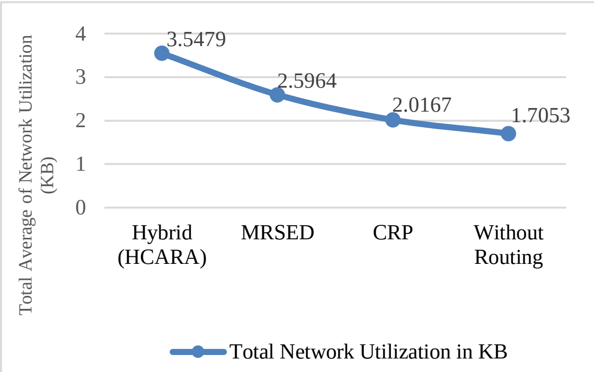

Fig. 11. Total average of network utilization.

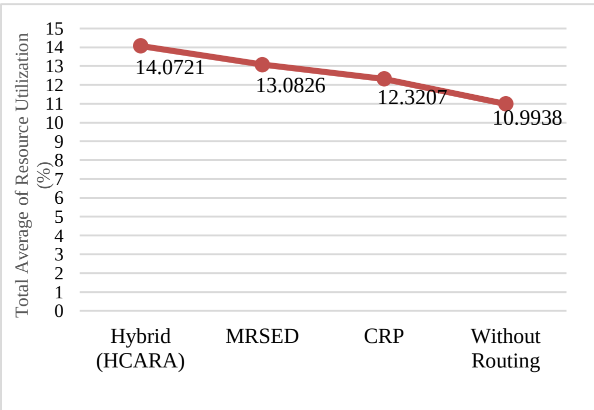

Fig. 12. Total average of resource utilization.

Fig. 11 and Fig. 12 showed that the Hybrid routing protocol allows for effective management of network resources, which ensures efficient distribution of traffic to the network, reduces idle capacity, increases the total utilization of the network and its resources, and thus ensures the absorption of the largest number of users within the single bandwidth to achieve the most efficient use of data transfer for the secondary user and reduces the consumption of resources and processing power by directing the packets in the network after taking intelligent decision processes that prevent repeated transmission and retransmission cycles compared to the case of the without routing protocol that is based on randomness in routing packets, where network resources are exhausted and the misuse of the infrastructure of the supporting network components, delay of packet transmission, and increased randomness in data transfer has been proven.

Fig. 13 shows the improvement achieved by the Hybrid proposed routing protocol in increasing the goodput rate when compared to the scenario that does not contain a routing protocol. This is due to the advantage of the Hybrid protocol in dealing effectively with data transfer by improving the routing decision effectively, preventing collisions, reducing packet loss, and delivering them in the shortest possible time. Thus, the Hybrid protocol ensures reliable and efficient use of network resources, which allows for higher goodput rates and improving the performance of the entire network. On the other hand, the case of not using a routing protocol causes packet collisions, increases the delay in data reaching the target, and drains network resources, which reduces its efficiency.

The Table II showed that the Hybrid (HCARA) routing protocol improves the packet delivery ratio compared to other works that use routing protocols, work environments, and different numbers of primary and secondary users. This is due to its effective role in allocating resources in the network, reducing packet collisions and the time taken to deliver packets to the receiving end, and preventing packet redirection to the same node, based on the benefits of both routing protocols MRSED and CRP.

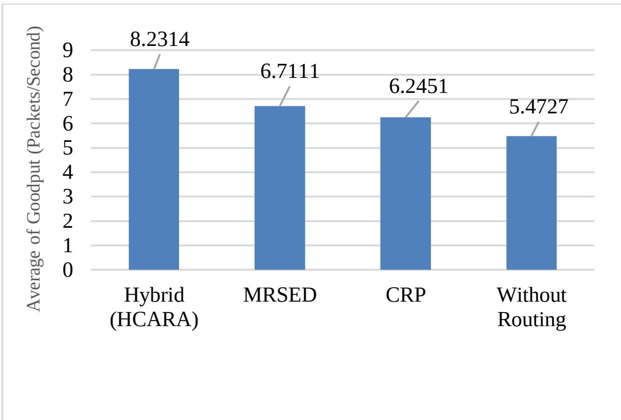

Fig. 13. Average of goodput packets / second.

TABLE II: PDR COMPARISONS OF THE HYBRID HCARA SYSTEM

Ref. No	Year	No. of nodes	Environment	Method	PDR %
[17]	2019	7	MATLAB	Multi-Coefficient based Shortest Anypath Routing (MCSAR)	82.5 %

				spectrum-aware anypath routing (SAAR)	77.5 %
				Unicast Routing (SAR-1)	58.75 %
				Opportunistic Cognitive Routing (OCR)	72.25 %
[27]	2019	50	OMNET++	CR-AODV	85 %
				Connected dominating set (CDS)	95 %
[28]	2020	20	QualNet and MATLAB	Cognitive Ad Hoc On-Demand Distance Vector protocol (CAODV)	65 %
				Hybrid Routing Algorithm	65 %
[29]	2023	40	NS 2	Software-Defined Routing Protocol (SDRP)	82 %
				Dual Diversity Cognitive Ad-hoc Routing Protocol (D2CARP)	75.1 %
				Cognitive Ad-hoc Ondemand Distance Vector (CAODV)	76 %
[30]	2023	20	Network Simulation	Genetic Algorithm Fuzzy Decision System (GA-FDS)	96.5 %
				Hybrid Fuzzy Genetic Decision System Analysis (FGDSA)	97.1 %
The proposed Algorithm (HCARA)		20	OMNET ++	Hybrid (HCARA)	98.51%
				MRSED	94.81%
				CRP	89.24%

VI. CONCLUSION

Packet routing in cognitive radio networks is a topic that requires great attention because it affects the reliable communication flow in the network. Therefore, it has become necessary to propose protocols that contribute to improving the overall network performance. The proposed HCARA routing algorithm has shown significant progress in simulation results in a reliable and effective manner, outperforming current routing protocols such as the aggregation-based routing protocol and the multi-scale routing protocol with service discrimination. The results showed that the hybrid routing protocol improves overall network performance metrics such as average channel utilization of Hybrid (HCARA) is 98.088 %, MRSED is 90.241 % and CRP is 83.375 %. The average Probability of False Alarm is 2.569, 3.083, 3.34 and Channel Collision is 0.072, 0.092 and 0.098 of HCARA, MRSED, and CRP respectively. The Goodput of Hybrid (HCARA) is 8.2314 packets/second, MRSED is 6.7111 packets/second and CRP is 6.2451 packets/second which ensures spectrum utilization of the main user channels in the network by adapting the HCARA protocol to dynamic network conditions and taking into account the quality of service to meet user requirements during packet routing, as well as managing resources efficiently to meet the requirements of strong and effective wireless communication. Future work will focus on implementing the hybrid routing protocol in real-world scenarios based on artificial intelligence techniques.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Author A conceptualized the study, designed the research methodology, supervised the project, and provided critical revisions. Author B conducted the experiments and collected the data, implemented the practical side, analyzed the data interpreted the results, and wrote the manuscript. All authors reviewed and approved the final version of the manuscript.

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