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Secure distance based multi-objective artificial rabbits algorithm for clustering and routing in cognitive radio network

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Abstract

Cognitive radio networks (CRNs) are presently undergoing extensive research and are gaining popularity in a wide range of applications. The nodes in a cognitive radio sensor network have flexibility according to data packets due to dynamic transmission techniques. In this study, the energy consumption within the clustering/routing is taken into account for determining the ideal transmission distance. The cluster size is adjusted depending on the number of packets in the cluster and how the nodes are grouped in a clustered shape. Additionally, due to the cognitive capabilities of the sensor node, it is possible to determine the remaining duration of licensed channels that are not in use in a CRN. Secure distance multi-objective artificial rabbits' algorithm (SD-MOARA) based clustering and routing is utilized to fulfill the extendable efficiency in CRN. The goal of the suggested routing system is to forward data packets along lines that utilize the least amount of energy. The outcomes of the proposed SD-MOARA are examined using MATLAB in terms of the following performances: remaining energy (851.4 J), packet delivery ratio (99.9%), packet loss rate (PLR) (0.2%), energy consumption (23.9 J), throughput (0.99 Mbps), average delay (0.42 s) and routing overhead (0.40). The above-stated results demonstrate that the proposed SD-MOARA outperforms the conventional methods.

Keywords

Cognitive radio networks, Clustering, Distance, Multi-objective artificial rabbits algorithm, Routing.

1.Introduction

Recent developments have been made in the field of cognitive radio that involve radio equipment due to its spectrum access capacity [1]. The concept of cognitive radio was first introduced by Joseph Mitola III in 1999 [2]. Cognitive radio networks (CRN) represent a revolutionary approach to wireless communication systems. CRNs find applications in scenarios where spectrum is underutilized, such as rural areas, and in dynamic environments where spectrum conditions change rapidly. Potential applications include wireless broadband access, smart grids [3], emergency communication systems, etc. CRN contain two users, namely, the primary users (PUs) and the secondary users (SUs) [4].

Spectrum scarcity is a major problem caused by an excessive demand for wireless connections [5]. SUs are exploited to utilize vacant licensed bands to get dynamic spectrum access (DSA) which offers a viable solution to the congestion issue [6, 7], while PUs are used to eliminate instantaneous interference [8, 9]. At the initial stage, a CRN network employs either a single licensed channel or multiple licensed channels to control the wireless connections [10]. In contrast, distributed ones have an open structure with no central authority to control the secondary transmission [11].

One of the most investigated methods for scaling down energy usage is node clustering [12]. Nodes are logically grouped to avoid signalling overhead and ensure network connectivity [13]. In addition, sensor nodes are grouped into clusters, and there is a cluster head (CH) in control of cluster operations and

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connectivity between clusters [14]. Different network features and application needs, typically impact the precise goal of such groupings [15]. Clusters divide a network into a manageable and stable form in a dynamic environment to prevent changes in the entire network. Additionally, it lowers the expense of updating routing information in a dynamic context [16]. In CRN, limiting communication to a single hop allows efficient utilization of the spectrum and other resources like node power [17]. Likewise, clustering reduces the necessity of a network-wide upgrade because of the possibility of node mobility or the sudden entrance of a PU. However, there main limitations which exist in prior literatures like some of the traditional routing methods did not examine route fitness before shifting data, which led to several route errors, data communication issues and increased packet loss ratio. In, prior researches the developed method offered less spectrum sharing, so it needed to focus mainly on increasing the spectrum sharing with multiple applications. Similarly, traditional methods ignore hop distance as well as dependability routes, and only depends on energy-available nodes. Whereas, the overhead existence in base station's (BS) communication with the cognitive radios, led to a maximum energy usage. By reducing the number of nodes in the main system, clustering also increases effectiveness of multicasting and routing [18]. This characteristic of CRNs makes it difficult to utilize a spectrum hole effectively, while using the current clustering techniques, that are suitable for traditional networks. The main objective of this work is to minimize the energy consumption within the clustering/routing for determining spectrum sharing. So, a secure distance multi-objective artificial rabbits' algorithm (SD-MOARA) is a recently introduced approach for choosing CHs. It simultaneously considers spectrum dynamics and energy consumption. Additionally, clustering in CRN must be implemented with considerable maintenance [19, 20].

The following are some main contributions of this research work:

- SD-MOARA is a recently introduced approach for choosing CHs. It simultaneously considers spectrum dynamics and energy consumption.
- While transmitting the packets using SD-MOARA, all the CHs manage the access of spectrum within a cluster, that supports handling of energy utilization.
- SD-MOARA offers a straightforward, yet efficient and adaptive forwarding solution for inter-cluster routing that enables radio networks to avoid significant overhead and improve the packet delivery ratio (PDR).

The structure of this study is outlined as follows: Section 2 presents a review of existing clustering and routing-based Cognitive Radio Network (CRN) approaches. Section 3 elaborates on the design of the network architecture and the clustering/routing process using SD-MOARA. The simulation outcomes are presented in section 4, accompanied by an analysis of the proposed approach. Section 5 offers a discussion of the study, and finally, section 6 of this article concludes the research.

2.Literature review

The stability aware cluster-based routing (SACR) for CRN integrates a forwarding method and a clustering system presented by Zhenget et al. [21]. This approach was used in a practical CRN that offered benefits in terms of PDR and delay. With this kind of protocol, a particular common control channel wasn't required. However, the routing method for CRNs has not always been successful in achieving the energy-efficient procedure due to factors such as energy consumption, spectrum sensibility, and optimal packet forwarding during opportunistic spectrum cooperation.

To find the optimal path in an uncertain setting, Ramkumar and Vadivel [22] developed an improved wolf prey inspired protocol (IWPIP). To decrease energy consumption and extend the lifespan, a CRN that utilizes shorter hops, reliable routes, and shorter distances, was developed. In this instance, the data routing analysis was done using the fitness functions. Still, the aforementioned IWPIP ignores hop distance as well as dependability routes, and only relies on energy-available nodes.

The ideal distance-based clustering / routing mechanism for CRN was suggested by Tripathi et al. [23] to enhance the system effectiveness. To determine the ideal transmission distance, the energy consumption of clustered data was taken into account. The routing protocol's goal was to transfer packets along routes that consumed the least amount of energy. After this, a dependable next-hop forwarder was chosen before the packets were forwarded to subsequent nodes. Throughput increased while transferring the data, but along with it, the packet loss too increased.

To extend the network lifetime of CRN, Jyothi et al. [24] suggested an improved routing procedure known as drop factor-based energy efficient routing

(DFBEER). The drop ratio was decreased by using the strategy of excluding nodes that had a greater drop factor. Packet loss is the factor that affects the longevity and data delivery speed. Because of the greater data delivery rate in this study and the lower data-dropping ratio, the network lifetime was increased. Additionally, the strategy minimized the overhead and guaranteed dependable data delivery even under conditions of changeable network features. However, when compared with SACR protocol, the effectiveness of this study was lesser in most of the performances.

Ramkumar and Vadivel [25] demonstrated the whale optimization routing protocol (WORP), that had been developed to improve the lifetime of CRN. To reduce latency and increase the network's effectiveness, the quality of service (QoS) was utilized to choose the optimum path in cognitive radio wireless sensor networks (CR-WSN). Over its rivals, the WORP achieved superior results in the CR-WSN. This routing method did not analyze route fitness before transferring data, which led to numerous route errors and data communication issues.

Vivekanand et al. [26] implemented a new energy-efficient model to create a wireless body area network (WBAN) for telemedicine. The WBAN was connected to the CR controller, which performed compressed sensing to detect an available free spectrum for mitigating interference. The implemented method decreased the energy consumption while the compression ratio increased. And an optimal node that had an increased lifetime and energy in the network, was selected. However, the implemented method had the limitation of minimum sensor size and a minimum battery power.

Srividhya and Shankar [27] implemented a new energy-efficient distance-based spectrum aware optimization (EDSO) algorithm for CRN. In this implemented method, honey bee mating optimization (HBMO) helped in the selection of an optimized cluster, which reduced the energy spent on node re-clustering. However, there were challenges in implementing this model in real-time applications of emergency and public safety.

Gupta and Joshi [28] implemented dueling enhanced Q reinforcement learning (DEQRL) and adaptive transient search differential evaluation routing protocol (ATSDERP). As the implemented method offered less spectrum sharing, it needed to focus on increasing the spectrum sharing with various applications.

Darabkh et al. [29] implemented an adaptive full duplex-CRN (FD-CRNs) routing protocol, which was used a common control channel. But this method had lower efficacy and unreliable performances. Salih et al. [30] implemented a software defined routing protocol (SDRP), which was a cross-layer framework utilized to create a scalable routing decision engine. However, increased PU density affected the throughput rate, that made the SDRP achieve lower throughput values. Wang and Ge [31] implemented a radio frequency energy harvesting-based multihop clustering routing protocol (RFMCRP) that was based on nonlinear energy harvesting (EH) model. To guarantee the stability of cluster construction, an energy control mechanism was implemented for cognitive radio sensor networks (CRSNs) nodes. Additionally, energy level function-based selection criteria were utilized to select high-quality CHs and relays, and to also enhance energy sustainability as well as network security. As the radio frequency energy harvesting (RFEH) relied on ambient RF signals, it was unsuitable for use in shielded or remote areas, wherein the effective powering of nodes would be challenging.

Rai et al. [32] implemented a node clustering protocol for CR-WSN, which was based on evolutionary game theory (EGT). The implemented node clustering algorithm selected the uniformly distributed CH nodes. As a consequence, the consumption was less during the CH selection process, and the proportionally improved as the number of nodes increased.

Arat and Demirci [33] implemented a cognitive radio enabled greedy routing protocol for low-power and lossy networks (CR-GreedyRPL). The technique was used to select routing paths by considering energy efficiency. The practically executed solution was a modified version of RPL's IPv6 routing protocol. The greedy algorithm's implementation produced high link capacity, minimal power consumption, and excellent energy efficiency. Yet, the approach that was used had attained a lower accuracy in its evaluated results.

A previously unknown set of fuzzy input variables were used by Safdar et al. [34] to construct an energy-efficient fuzzy logic-based clustering (EEFC) algorithm that selected the best nodes as CH. The applied EEFC technique took into account four input variables and one output variable to determine whether a node might be chosen as a viable CH. The time it took for the first node dead (FND) in the network was improved using the developed EEFC approach, which showed a noticeably better longevity of the network. But, the overhead presence in BS communication with the CRs, led to an elevated energy usage.

An energy-efficient fuzzy clustering and congestion control algorithm (EFCCA) management method, developed by Jyothi and Subramanyam [35], was used to improve energy efficiency. The multi-objective CH selection technique chose durable and dependable CHs. Increased PDR between individual and CH nodes were made possible by the adopted methodology. Yet, the presumption of constrained energy nodes hindered the data reception and transfer.

From the literature analysis, it is inferred that, to accomplish a dynamic and reliable spectrum access, a significant amount of energy needs to be expended on frequency behaviour and spectrum sensing. As a result, preserving energy for CRNs calls for an energy-efficient architecture. Additionally, due to spectrum instability, centralized routing systems produce substantial signalling overhead while analyzing the structural modification of the CRN. Conventional network protocols, on the other hand, are inapplicable for CRN analysis as these are unable to address the issue of excessive energy usage. Therefore to mitigate the aforementioned clustering and routing challenges and difficulties, a highly reliable approach that is capable of finding a quicker and more acceptable solution, is very necessary. In order to increase the lifespan of the network, this research provides an SD-MOARA-based clustering and routing strategy for the CRNs.

3.Methods

The proposed SD-MOARA model offers resource utilization and adaptability, which are crucial factors for creating an effective CRN routing strategy.

3.1Network model

In this framework, a single CRN with a single gateway and stationary cognitive sensors (CSs) is considered. The CRN's model is depicted in *Figure 1*. This research refers to the production of network packets at CSs and their transmission to targets over one or more nodes.

Here, CS i $(i \in N)$ connects the energy E_{ij} which is superior over permitted channel j in the course of pre-specified threshold ε_{ij} [36], while H_0 and H_1 signifies the absent and present permitted channels. Then, the spectrum complexity i of binary hypothesis problem is stated as Equation (1).

$$Sensing\ Decision = \begin{cases} H_0, if\ E_{ij} < \varepsilon_{ij} \\ H_1, if\ E_{ij} \geq \varepsilon_{ij} \end{cases} \tag{1}$$

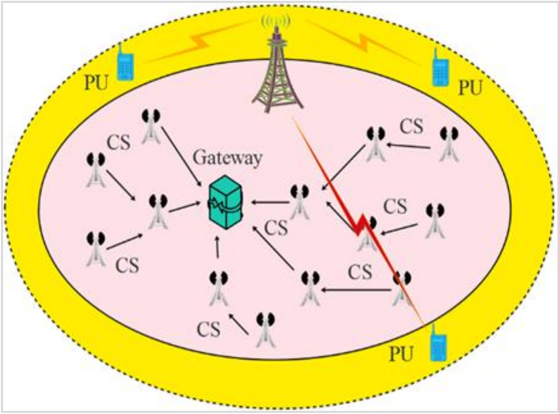

Figure 1 Network Model of CRN

3.2Block diagram

In this paper, SD-MOARA, a routing technique based on clustering processes, that is profitable for all the procedures, is presented as a solution to the congestion problem in a CRN. In cluster-based routing, all nodes are continuously grouped into sectors known as clusters. These clusters are then combined into larger segments to keep the network's architecture usually stable. Cluster leaders possess the critical intelligence needed to coordinate route management and forwarding processes. *Figure 2* displays the flowchart for clustering and routing, executed by SD-MOARA.

3.3Overview of artificial rabbits algorithm (ARA)

3.3.1Basic process

The below steps reveal the search processes of ARA approach [37]:

- **Detour foraging (Exploration)**

Detour foraging (exploration) process [38, 39] is explained using Equations (2 to 6) which is enumerated below in detail,

$$X_i(t+1) = X_j(t) + A \times (X_i(t) - X_j(t) + round(0.5 \times R_1)) \times n_1 \tag{2}$$

$$A = L \times c \tag{3}$$

$$L = \left(e - e^{(\frac{t-1}{T})^2}\right) \times sin\ sin\ (2\pi R_2) \tag{4}$$

$$g = ransperm\ (D) \tag{5}$$

$$n_1 \sim N(0,1) \tag{6}$$

Where,

$X_i(t+1)$ → candidate position of the i^{th} rabbit in iteration

$X_j(t)$ → position of the i^{th} rabbit

N → Denotes the population size

t → Maximum number of iterations

D → Dimension Size

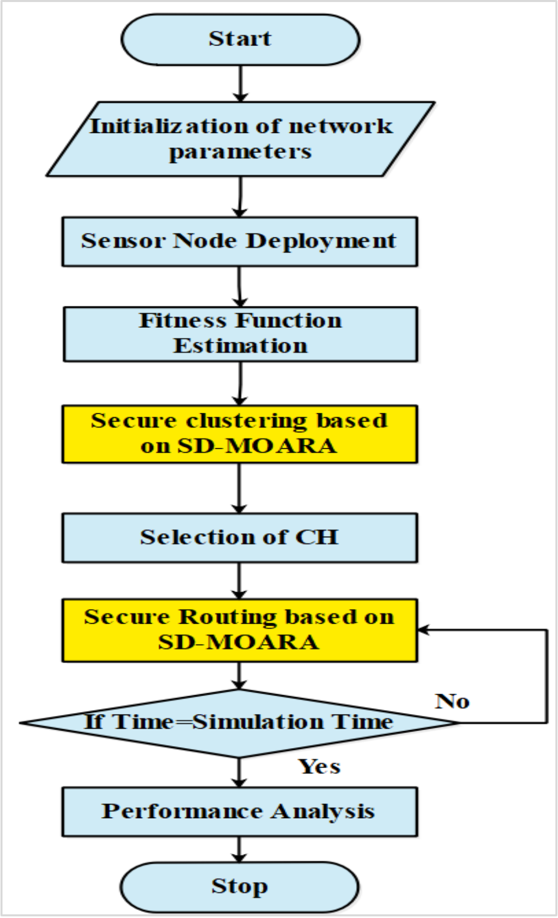

Figure 2 Flowchart of Clustering and Routing by SD-MOARA

The transition from Exploration to Exploitation

The power element E is represented by the following Equation 7. In artificial rabbits' optimization (ARO), the rabbits commonly engage in random concealment in the later stages of the hunt, whereas they are more likely to engage in continuous detour foraging in the initial phases of the iteration / hunt [40, 41]. Equation 7 illustrates the concept of rabbit energy E which is used to create a balanced ratio of exploitation to exploration.

$$E(t) = 4\left(1-\frac{t}{T}\right) In\ \frac{1}{R_4} \qquad (7)$$

Random hiding (Exploitation)

Predators commonly pursue and attack rabbits [42, 43]. For their survival, the rabbits would dig a range of shelter-filled burrows all around the nest. In ARO, a rabbit always builds tunnels along with D dimensions of the search space, before selecting randomly, to reduce the likelihood. Equations (8 to 12) illustrate the mathematical description of this behaviour:

$$X_i(t+1) = X_i(t) + A \times (R_5 \times b_{i,r}(t) - X_i(t)) \qquad (8)$$

$$b_{i,r}(t) = X_i(t) + H \times g_r(k) \times X_i(t) \qquad (9)$$

$$g_r(k) = \{1, if\ k == [R_6 \times D]\ 0,\ otherwise \qquad (10)$$

$$H = \frac{T-t+1}{T} \times n_2 \qquad (11)$$

$$n_2 \sim N(0,1) \qquad (12)$$

Where, R_5 and R_6 refers to two random numbers [0 1]; n_2 is normal distribution;

$b_{i,r}(t)$ states the i^{th} rabbit's burrow at time t.

3.4CH Selection using SD-MOARA

The SD-MOARA is utilized for CH routing and selection. This SD-MOARA is much more effective for creating routing protocols in emergencies because it has a collision avoidance feature by origin.

3.4.1Fitness function

The proposed SD-MOARA chooses the CH from the clusters for secure data transmission. To obtain a proper fitness, the calculations are made. The clustering optimization is done using the requirements as listed below:

(a) Residual Energy (RE)

RE [44] is depicted in Equation 13.

$$Minimize\ RE = \sum_{i=1}^{m} \frac{1}{E_{CHi}} \qquad (13)$$

(b) Inter and intra cluster distance (D)

Each CH's distance from the BS is thoroughly explained. The transmission distance controls the energy consumption which is used by the sensor network. As the access point gets further away from the mobile node, it takes greater amounts of energy to complete the process. D1 and D2 are inter- and intra-cluster which are expressed using Equations 14 and 15.

$$MinimizeD1 = \sum_{i=1}^{m} (dis\ (CH_j, BS)) \qquad (14)$$

$$MinimizeD2 = \sum_{j=1}^{q} \left(\sum_{i=1}^{cm_j} dis\left(s_i, CH_j\right)/cm_j\right) \qquad (15)$$

The count of nodes is referred as cm_j; Distance between i^{th} and j^{th} CH refers to $dis\left(s_i, CH_j\right)$. Thus,

$(F(x))$ is subjugated to each objective $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$, and it is revealed in Equation 16.

$$F(x) = \frac{f_i - f_{min}}{f_{max} - f_{min}} \qquad (16)$$

The function value is indicated as f_i; f_{min} and f_{max} are shown as minimum and maximum functions which is stated in Equation 17.

$$Minimumfitness = \alpha_1 CM + \alpha_2 L_j + \alpha_3 \mathrm{RE} + \alpha_4 D1 + \alpha_5 D2 \qquad (17)$$

Where, $\sum_{i=1}^{5} \alpha_i = 1$; and $\alpha_i \in (0,1)$
Each fitness function is given a weighted parameter, designated as α_i. After considering RE, $D1$, and $D2$, the node with the highest remaining energy is chosen to minimize the transmit power across the network. As a consequence, these fitness functions are exploited to identify the ideal data transmission path. According to the function of RE and distance, Clustering Head is selected.

3.5Routing using SD-MOARA

The major aim is to identify a suitable neighbouring route from each CH to the BS. Once the routing is established, the network starts to transmit the data. The subsequent portions explain the fitness function:

(a)Link Lifetime (LLT)
A data packet must be present for the system link to connect with various network devices [45]. A network link failure could lead to routing failure in the network. To lessen the impact of failure, the routing procedure calculates the lifespan. Additionally, the mobility position, node coordination, and movement characteristics are used to determine the communication link's lifetime. 2 nodes G_1 and G_2 are positioned at U_{G1}, V_{G1} and U_{G2}, V_{G2}. The LLT is calculated as shown in Equations 18 to 20,

$$LLT = \frac{-(fk+xz)+\sqrt{(f^2+z^2)w^2-(fz-xk)^2}}{(f^2+z^2)} \qquad (18)$$

$$\begin{cases} f = J_{G1}\cos\theta_{G1} - J_{G2}\cos\theta_{G2} \\ k = U_{G1} - U_{G2} \\ x = J_{G1}\sin\theta_{G1} - J_{G2}\sin\theta_{G2} \end{cases} \qquad (19)$$

$$z = V_{G1} - V_{G2} \qquad (20)$$

w is the transmission limit, J_{G1} refers mobility speed of G_1; J_{G2} is the speed mobility of G_2; U_{G2} represents the node coordination of G_2 and U_{G1}; V_{G1} declares the node at G_1; θ_{G1} indicates the direction at G_1; θ_{G2} characterizes the direction at G_2.

Ultimately, a single objective function, represented by Equation 21, is created by combining all of the numerous objective fitness values.

$$Routingfitness = \delta_1 \times LLT + \delta_2 \times CM + \delta_3 \times D1 + \delta_4 \times D2 + \delta_5 \times RE \qquad (21)$$

The weighted parameters are denoted as $\delta_1, \delta_2, \delta_3, \delta_4$ and δ_5, which are equivalent to 0.25, 0.3, 0.20, 0.15 and 0.25 respectively. Once the routing is determined by SD-MOARA, the transfer of data packets is started from one node to another. Therefore, LLT is employed in routing to determine the efficiency.

4.Results

The outcomes of the recommended SD-MOARA approach are described in this section. The software requirements are established with MATLAB 2021b on a Windows OS, running at 2.7 GHz, with an i5-7500U CPU and 16 GB of RAM. The goal is to discover the most effective way to control the network's energy usage according to the routing method's recommendations. The CSs are thought to be spread out in a square region by a relative density. The broadcast range of each PU transmitter is 150 meters. Each CS's initial value is chosen at random. The variables utilized in the simulations are listed in *Table 1*.

Table 1 Hardware and experimental setup

Constraints	**Range**
Routing Protocol	SD-MOARA
Simulation time	50 s
Packet size	1024 byes
Radio Range	250m
Initial Energy	100 J
Nodes count	1000
Bandwidth	200 kHz
Number of PU	16
PU transmission radius	150 m
Interfaces	3
Area	1000 × 500
CS count	300

4.1Remaining energy

Here, SD-MOARA employs the multicast feature of wireless networks, to reduce the routing costs. The CH rotation method is specifically used by SD-MOARA to spread the load within the cluster. SD-MOARA has a smaller routing overhead than DFBEER [24] and Traditional SACR [21]. *Table 2* contains the quantitative analysis of the remaining energy. According to *Table 2*, the proposed SD-MOARA's unutilized energy is 851.4 J, which is significantly higher than those of the earlier methods that contain 773.1 J and 761.7 J of unutilized energy, respectively.

Table 2 Analysis of remaining energy

Operating time (sec)	**RE (Joule)**			
	Parameters	**SACR [21]**	**DFBEER [24]**	**Proposed SD-MOARA**
0	Area = 1000 × 500	773.1	761.7	851.4
500	Initial Energy = 100J	739.3	740.3	842.4
1000		720.7	716.4	826.3
1500		700.9	701.5	811.1
2000		691.7	691.3	800.9
2500		682.8	688.3	789.8
3000		661.2	668.4	777.1

4.2Packet delivery ratio (PDR)

PDR evaluation is the determination of total number of packets that arrive at the BS to the total number of packets provided by CSs. The efficiency evaluation for PDR is displayed in *Table 3* which demonstrates that SD-MOARA obtains a significantly greater PDR of 99.9%, the conventional SACR [21] achieves a PDR of 99.2% and the DFBEER's [24] PDR is measured at 98.7%. This enhancement is due to secure routing, while performing secure routing the data loss is reduced and the packets are delivered successfully.

Table 3 Analysis of PDR

Occurrence Probability (q)	**PDR (%)**		
	SACR [21]	**DFBEER [24]**	**Proposed SD-MOARA**
0.1	99.2	98.7	99.9
0.2	98.4	97.9	98.9
0.3	97.7	97.1	98.1
0.4	96.9	96.3	97.4
0.5	96.1	95.6	97

4.3Delay

The delay outcomes of the proposed SD-MOARA and conventional methods are given in *Table 4*. The increased occurrence probability (q) necessitates longer queue durations and more retransmissions, which adds to the overall routing system's delay. Additionally, by choosing the CH as a router, the proposed SD-MOARA increases the forwarding efficiency as opposed to existing SACR [21] and DFBEER [24]. *Table 4* displays the average delays measured for the aforesaid models. The greatest increment of delay happens at $q = 0: 1$, leading to average delays of 0.42 seconds for SD-MOARA, 0.63 seconds for SACR, and 0.51 seconds for DFBEER.

Table 4 Analysis of delay

Occurrence Probability (q)	**Delay (s)**		
	SACR [21]	**DFBEER [24]**	**Proposed SD-MOARA**
0.1	0.63	0.51	0.42
0.2	0.65	0.54	0.43
0.3	0.69	0.58	0.49
0.4	0.71	0.59	0.51
0.5	0.72	0.61	0.52

4.4Energy consumption

Due to this fact, every CS should assist with the routing in flat structures while using SACR [21] and DFBEER [24] algorithms. The evaluated findings of energy consumption, are presented in *Table 5*. *Table 5*, demonstrates that the proposed SD-MOARA consumes lesser energy of 23.9 Joules, which is better than SACR [21] and DFBEER [24] (i.e.) 25.2 Joule and 26.1 Joule, respectively. This much of energy consumption is achieved by performing clustering and identifying shortest path

4.5Throughput

The successful outcomes after execution of the recommended and conventional methods, are given in *Table 6*. The suggested SD-MOARA provides significantly better output measures, as it offers throughput results that are superior to those of SACR [21] and DFBEER [24]. Due to SD-MOARA's extensive network lifespan, the access point collects extra network packets. According to *Table 6*, the proposed SD-MOARA achieves a throughput of 0.99 Mbps, which is higher than the throughputs of 0.90 Mbps and 0.81 Mbps respectively measured in SACR [21] and DFBEER [24].

Table 5 Analysis of energy consumption

Occurrence Probability (q)	Energy Consumption (Joule)		
	Existing SACR [21]	Existing DFBEER [24]	Proposed SD-MOARA
0.1	25.2	26.1	23.9
0.2	25.8	26.4	24.4
0.3	26.3	26.9	24.8
0.4	26.8	27.5	25.1
0.5	27.1	27.9	25.4

Table 6 Analysis of throughput

Occurrence probability (q)	Throughput (Mbps)		
	SACR [21]	DFBEER [24]	Proposed SD-MOARA
0.1	0.81	0.71	0.94
0.2	0.84	0.75	0.95
0.3	0.86	0.77	0.96
0.4	0.89	0.79	0.98
0.5	0.90	0.81	0.99

4.6Overhead

The efficiency of overhead performance was examined by comparing the proposed SD-MOARA and conventional models. The SD-MOARA routing overhead is smaller than that of the previous conventional models. *Table 7* summarizes the quantitative analysis of the routing overhead. *Table 7*, clearly shows that SD-MOARA has achieved a better routing overhead of 0.40 which shows more efficacy than those of SACR [21] and DFBEER [24], evaluated at 0.71 and 0.59 respectively. This is achieved by finding shortest path and performing clustering.

Table 7 Analysis of overhead

Occurrence probability (q)	Overhead		
	SACR [21]	DFBEER [24]	Proposed SD-MOARA
0.1	0.59	0.71	0.40
0.2	0.71	0.81	0.46
0.3	0.83	0.86	0.49
0.4	0.92	0.93	0.54
0.5	0.93	0.96	0.60

4.7Packet loss rate(PLR)

The effectiveness of the present technique SD-MOARA, is tested in this case, in light of the obtained PLR results. In comparison to traditional methods, SD-MOARA produces superior results. The PLR of SD-MOARA is lower than that of conventional SACR [21] and DFBEER [24]. *Table 8* summarizes the statistical evaluation of PLR effectiveness. *Table 8* elucidates that the proposed SD-MOARA has an improved PLR of 0.2% than the 0.8% and 1.3% of standard techniques. The evaluation results show that the SD-MOARA approach outperforms SACR [21] and DFBEER [24], because it has a longer network lifespan than the conventional protocols, which is a result of more data packets being transmitted to destination points by the SD-MOARA.

4.8Alive nodes

Nodes that have sufficient energy to distribute data, are said to be “alive”. The difference among the total number of nodes and the number of alive nodes is the number of dead nodes. In order to lower the energy consumption of the sensors and increase the number of alive nodes, energy-efficient CH and optimal route identification techniques are used. *Table 9* shows the performance analysis of alive nodes with respect to number of rounds.

Table 8 Analysis of PLR

Occurrence Probability (q)	PLR (%)		
	Existing SACR [21]	Existing DFBEER [24]	Proposed SD-MOARA
0.1	0.8	1.3	0.2
0.2	1.6	2.1	1.1
0.3	2.3	2.9	1.9
0.4	3.1	3.7	2.6
0.5	3.9	4.4	3

Table 9 Analysis of alive nodes

Number of rounds	Parameters	Alive Nodes		
		Existing SACR [21]	Existing DFBEER [24]	Proposed SD-MOARA
2000	Area = 1000 × 500	910	903	989
4000	Initial Energy = 100J	823	782	912
6000		657	664	842
8000		531	518	786
10000		468	459	563

5. Discussion

The ideal transmission distance in a CRN is calculated in this study by accounting for the energy usage within the clustering/routing process. To achieve the maximum efficiency in a CRN, SD-MOARA based clustering and routing is developed and compared with SACR [21] and DFBEER [24]. The major aim of this proposed system is to forward data packets via the energy-efficient paths. Resource utilization and adaptability are essential components for a successful CRN routing strategy, which are provided by the SD-MOARA model. The proposed SD-MOARA is evaluated on MATLAB in terms of various performance metrics. Where, the SD-MOARA obtains a significantly greater PDR of 99.9% which is higher than the conventional SACR [21] and the DFBEER [24] because this routing method did not analyze route fitness before transferring data. This enhancement is due to secure routing, while performing secure routing the data loss is reduced and the packets are delivered successfully. Additionally, by choosing the CH as a router, the proposed SD-MOARA increases the packet forwarding efficiency as opposed to existing SACR [21] and DFBEER [24]. Moreover, the proposed SD-MOARA has an improved PLR of 0.2% than the 0.8% and 1.3% of existing SACR [21] and DFBEER [24]. Moreover, due to SD-MOARA's maximum network lifespan, the access point collects more network packets. Furthermore, performing clustering and shortest path identification by utilising the energy-efficient CH and optimal route identification techniques, the minimum energy consumption of the proposed SD-MOARA is achieved whereas the maximum energy of the alive nodes are preserved thus lead to the maximum count of alive nodes. The results above show that the proposed SD-MOARA outperforms conventional techniques namely the DFBEER and SACR models.

5.1Limitations

It was observed in this research that, while running the model's simulation, execution of the output took more time. And there are more chances for attackers in CRN technology than other wireless networks. The information might be eavesdropped or modified without warning. Moreover, the channel might be congested or misused. Because of their adaptability, CRNs are more susceptible to a wide range of security issues and threats, which will impair the network's functionality. Issues of CRNs such as, attacks at different layers in the network, and adversarial impacts on performance due to security threat level, received little attention.

A complete list of abbreviations is shown in *Appendix I.*

6. Conclusion and future work

This study provides an effective routing system that takes into account a node's mobility and dependability within the CRN. The suggested protocol chooses a reliable transmission channel from a source node to the destination while accommodating the dynamic behaviour of the spectrum availability. The effectiveness of the suggested approach has been assessed in terms of cluster and routing generation. The main concept of this research is to acquire the necessary data effectively from the network by devising an optimal, energy-efficient clustering and routing procedure. When contrasted with the conventional techniques of SACR and DFBEER, the modelled effects of SD-MOARA, provided better performance deliveries.

The suggested SD-MOARA outperforms traditional system structures, as shown by the simulation findings, detailed as follows: delay is 0.42 s, PLR is 0.2 % and energy consumption is 23.9 J. It additionally accomplishes a PDR of 99.9%, a throughput of 0.99 Mbps, a routing overhead of 0.40 and RE of 851.4 J. This study can be extended in the future by focussing on security measures (by avoiding various attacks such as denial of service (DoS), root to local attacks (R2L), user to root attack (U2R) etc) to improve the network quality attributes using the current approach or unique hybrid approaches and variable characteristic limits.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

K.N. Shyleshchandra Gudihatti: Background work, conceptualization, methodology, dataset collection, implementation, result analysis and comparison, preparing and editing draft and visualization. **K. Pradeep Kumar:** Supervision, review of work and project administration.

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Appendix I

S. No.	Abbreviation	Description
1	ARO	Artificial Rabbits' Optimization
2	ATSDERP	Adaptive Transient Search Differential Evaluation Routing Protocol
3	BS	Base Station
4	CH	Cluster Head
5	CR-GeedyRPLR	Cognitive Radio Enabled Greedy Routing Protocol for Low-Power and Lossy Networks
6	CRN	Cognitive Radio Networks
7	CRSN	Cognitive Radio Sensor Networks
8	CR-WSN	Cognitive Radio Wireless Sensor Networks
9	CS	Cognitive Sensors
10	DEQRL	Dueling Enhanced Q Reinforcement Learning
11	DFBEER	Drop Factor-Based Energy Efficient Routing
12	DSA	Dynamic Spectrum Access
13	DoS	Denial of Service
14	EDSO	Energy-Efficient Distance-Based Spectrum Aware Optimization
15	EEFC	Energy-Efficient Fuzzy Logic-Based Clustering
16	EFCCA	Energy-Efficient Fuzzy Clustering and Congestion Control Algorithm
17	EGT	Evolutionary Game Theory
18	EH	Energy Harvesting
19	FD-CRN	Full Duplex-CRN
20	FND	First Node Dead
21	HBMO	Honey Bee Mating Optimization
22	IWPIP	Improved Wolf Prey Inspired Protocol
23	LLT	Link Lifetime
24	PDR	Packet Delivery Ratio
25	PLR	Packet Loss Rate
26	PU	Primary Users
27	QoS	Quality of Service
28	RE	Residual Energy
29	RFEH	Radio Frequency Energy Harvesting
30	RFMCRP	Radio Frequency Energy Harvesting-Based Multihop Clustering Routing Protocol
31	R2L	Root to Local attacks
32	SACR	Stability Aware Cluster-Based Routing
33	SD-MOARA	Secure Distance Multi-Objective Artificial Rabbits' Algorithm
34	SDRP	Software Defined Routing Protocol
35	SU	Secondary Users
36	U2R	User to Root attack
37	WBAN	Wireless Body Area Network
38	WORP	Whale Optimization Routing Protocol