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Congestion-aware Weighted Sum Routing for Enhanced Network Lifetime in Cognitive Radio Sensor Networks

L.V.R. Chaitanya Prasad[1*], Dr. Yedukondalu Kamatham[2], and Dr. Dhiraj Sunehra[3]

[1*]Department of Electronics and Communication Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, Telangana, India; Research Scholar, Department of Electronics and Communication Engineering, JNTUH, Hyderabad, Telangana, India. lokamchaitanya@gmail.com, https://orcid.org/0009-0006-0862-2615

[2]Department of Electronics and Communication Engineering, CVR College of Engineering, Hyderabad, Telangana, India. kyedukondalu@gmail.com, https://orcid.org/0000-0002-9044-6553

[3]Department of Electronics and Communication Engineering, JNTUH University College of Engineering, Rajanna Sircilla, Telangana, India. dhirajsunehra@yahoo.co.in, https://orcid.org/0000-0002-3696-8860

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Abstract

Conventional Energy-Efficient routing in Cognitive Radio Sensor Networks (CRSNs) often compromises network lifespan. This research proposes a congestion-aware routing scheme that improves both energy efficiency and longevity. Unlike existing protocols, our approach uses a weighted sum of five parameters: distance, energy load, link quality, data flow rate, and neighbor density to guide packets along less congested, energy-efficient paths. The reduced Energy Consumption by 5.67 J, lowering End-to-End delay by 0.05-0.35 ms, decreased network overhead by 0.25-0.65% are attained and this will result in extending the operational Network Lifetime as demonstrated by Network Simulator 2 simulations.

Keywords: Cognitive Wireless Sensor Network, Energy Efficiency, Congestion, Network Lifetime, Weighted Sum Approach.

1 Introduction

Cognitive Radio Sensor Networks (CRSNs) are being widely used for a variety of uses, including industrial process control and environmental monitoring (Chatei et al., 2022; Prasad et al., 2022). But Network Lifetime and Data Transmission are severely hampered by their constrained energy resources and innate susceptibility to congestion (Surenther et al., 2023; Prasad et al., 2022). The main goal of conventional Energy Efficient Routing Protocols for Wireless Sensor Networks is to reduce Energy Consumption (Roshini & Kiran, 2023). This method frequently ignores how congestion affects network performance and it also conserves battery resources (Shafiei et al., 2023).

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*Corresponding author: Department of Electronics and Communication Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, Telangana, India; Research Scholar, Department of Electronics and Communication Engineering, JNTUH, Hyderabad, Telangana, India.

A flexible Routing Protocol was crucial for adapting to various conditions, because of varying traffic patterns and node capabilities of the dynamic nature of Cognitive Radio Sensor Networks (Dansana et al., 2023; Prasad et al., 2023; Malathi, 2024).

Then, addressing of dynamic demands becomes difficult to static Routing Protocol. This will result in inefficient resource utilization, and suboptimal performance (Okine et al., 2024; Prasad et al., 2023).

To address those serious risks, for Cognitive Radio Sensor Networks, a novel Congestion-Aware Routing Scheme (CARS) was presented in this study. By the congestion control, the suggested method balances Energy Efficient. By reducing packet loss and effectively managing traffic flows, the Network lifetime can be optimized (Subhashree & Tharini, 2016).

The following lists the main contributions of the study:

- Energy Efficient and congestion control can be balanced by a novel method called Congestion-Aware Wireless Sensor Routing, as it assigns weights depends upon the specific applications and network conditions.
- The congestion and packet loss can be mitigated by the suggested method. This will also result in extending the Network Lifetime and enhancing the accuracy of Data Transmission.
- Based on traffic patterns and ensuring efficient load balancing as well as preventing bottlenecks in diverse scenarios, the Wireless Sensor approach in Cognitive Radio Sensor Networks allows real-time adjustment of weights.

2 Related Work

For clustering, the Energy-efficient Distance-based Spectrum-aware Optimization (EDSO) technique uses Honey Bee Mating Optimization (HBMO) in (Srividhya & Shankar, 2023). For routing, Donkey and Smuggler Optimization (DSO) method is suggested for enhancing the Bandwidth utilization. This suggested method will ensure effective, collision-free Data Transmission.

In (Clement et al., 2024), the author predicted channel usability for secondary users to reduce sensing time, using a deep deterministic policy gradient technique to select optimal channels and sensing times, thereby potentially decreasing energy consumption and enhancing cognitive radio efficiency (Prakash & Prakash, 2023).

In (Wang & Liu, 2023), the Imperfect Spectrum Sensing-based Multi-Hop Clustering Routing Protocol (ISSMCRP) for Cognitive Radio Sensor Networks improves data transmission by selecting cluster heads and relays based on spectrum sensing capabilities and optimizes cluster radii to reduce energy consumption (Balamurugan et al., 2018).

In (Ram, 2023), the Energy-Efficient Adaptive Sensing (EEAS) method for Cognitive Radio Sensor Networks addresses spectrum access issues by distinguishing between Primary Users and Primary User Emulation Attacks (PUEA), enhancing throughput and energy efficiency.

3 Proposed Methodology

For addressing the conventional energy-centric Routing Protocol, a congestion-aware Wireless Sensor approach is presented in Cognitive Radio Sensor Networks. This suggested method addresses the conventional energy-centric Routing Protocol limitations. The factors like degree of distance, average energy load, link quality, data flow rate, and neighbor density can be considered for balancing Energy Efficient with Network Lifetime by this method. Shorter paths are given priority to save energy, paths with dependable communication channels are selected, nodes with plenty of buffer space are taken into account, and traffic load is distributed evenly throughout the network to prevent areas of congestion. The Energy Efficient path were selected by the method, as it optimizing these factors. This will result in robust congestion, ensuring Data Transmission, as well as extending the Network Lifetime.

A. Weighted Sum Approach

Based on the significance level, numerical weights were assigned to factors by a Decision-Making (DM) method named Wireless Sensor approach. By multiplying each factor's value by its weight, the Wireless Sensor is computed. Later, summing these weights for the assessment purpose.

B. Parameter Selection and Weight Assignment

The proposed weighted sum approach considers five key parameters:

Degree of Distance (DoD): A node's Energy Consumption during communication is managed by the distance factor. When the distance between the node and the Base Station is reduced, the node consumes less energy. Selection methods are therefore developed with this parameter in mind in order to reduce the average distance among Sensor Nodes and Base Station. This may be expressed in Eq. (1).

$$D_{toBS} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \quad (1)$$

Where, x_i and y_i are the $xandy$ positions of $nodei$ and x_j and y_j are the x and y positions of BS.

Average Energy Load (AEL): AEL, a key indicator of average energy load across a routing line, helps in selecting relays. A node's Energy Consumption rate is calculated by subtracting the remaining energy after the first round from its initial energy, with conserved energy used as the starting energy in subsequent rounds. The Average Energy load of the chosen routing plan is computed by considering the total Energy Consumption rate of sensor nodes involved in transmitting data. The Energy Consumption rate of the sensors is computed and then compared to the Average Energy load. If the computed value is less than the Average Energy load, then the node satisfies the criteria to function as a relay node. The determination of Average Energy load is carried out as Eq. (2).

$$AEL = \frac{\sum_{i=1}^{N} \frac{E_{pre} - E_{rc}}{E_{pre}}}{Num_{relays}} \quad (2)$$

Here, the variable E_{rc} reflects the amount of energy spent by the sensor node in the current round, while E_{pre} represents the energy value of the node in the previous round. Num_{relays} represents the total number of relay nodes in the route.

In this context, E_{rc} represents the energy consumption of the sensor node in the current round, whereas E_{pre} represents the energy consumption of the node in the prior round. Num_{relays} represents the overall count of relay nodes in the route.

Link Quality (LQ): The connection quality between nodes might appear in different states, and the evaluation of link quality uses current coordinates. The link quality is given as Eq. (3).

$$L_{quality} = \frac{1}{(1 - {R_n}/{Tx_n + 1})} \quad (3)$$

Here, LQ denotes link quality of Node 'n', R_n denotes radius of node 'n', and Tx_n denotes the node's maximum transmission range. This link quality may be denoted as Eq. (4).

$$LQ = \frac{1}{M} * \sum_{i=1}^{N} L_{quality}(N) \quad (4)$$

Data Flow Rate (DFR): Congestion occurs when a node's incoming packets exceed its transmission capacity, leading to a packet arrival rate that surpasses the service rate, resulting in increased delays and packet losses. The time interval between consecutive packet arrivals at a given node is known as the packet arrival time (T_{pa}), which is inversely correlated with the packet arrival rate (P_{ar}). The time a packet takes from arriving at the node to being forwarded is called the packet service time (T_{ps}), which is inversely correlated with the packet service rate (P_{sr}). T_{ps} includes the time spent in the queue awaiting the transmission of more packets as well as packet retransmissions.

The breakdown of the packet arrival and service rates are given as Eq. (5).

$$P_{ar} = {}^{1}/_{T_{pa}}\, ;\; P_{sr} = {}^{1}/_{T_{ps}} \quad (5)$$

Where, T_{pa}: Packet arrival time, T_{ps}: Packet service time.

The Data flow rate (DFR), calculated by dividing the packet arrival rate by the packet service rate, is crucial for identifying congestion and given by Eq. (6):

$$DFR = \frac{P_{ar}}{P_{sr}} \quad (6)$$

When $P_{ar} > P_{sr}$, DFR goes up, indicating that the node is experiencing overload traffic. An elevated DFR indicates more traffic jams at the node. One way to identify congestion is to use the packet service rate.

A node experiences less congestion when the Data flow rate value is decreased. The route cost is determined by the data flow rate from the node to the Base Station, and it is computed as Eq. (7).

$$DFR_{cost} = \sum_{i=1}^{n} TI_n \quad (7)$$

Neighbor Density (ND): The Neighbor Density refers to the number of nodes located within a specific spatial proximity to a given node. It essentially captures the level of occupancy around a node in the network.

Every node measures the values of the above five parameters and weights are assigned to these parameters based on their relative importance and network conditions. The sum of weights must equal 1 and represented below Eq. (8).

$$WS_{node} = \omega_1 * DoD + \omega_2 * AEL + \omega_3 * LQ + \omega_4 * DFR + \omega_5 * ND \quad (8)$$
$$where, \omega_1 + \omega_2 + \omega_3 + \omega_4 + \omega_5 = 1$$

A node broadcasts a Route Request (RREQ) message to nearby nodes to start the route discovery process when it needs to transmit a packet. The formula is used by each neighbor to calculate its unique weighted sum. After that, the computed WS value is added to the RREQ and sent, starting the multi-hop route discovery process.

The destination node selects the route with the lowest weighted total and sends a Route Reply (RREP) along it. Intermediate nodes update their routing tables to guide data packets along this chosen path.

C. Algorithm

Algorithm 1 Weighted Sum approach with Relay Selection

For all nodes 'n'
Calculate $DoD_n, AEL_n, LQ_n, DFR_n, ND_n$
End for
Data transmission
Broadcast route discovery to neighbours
For all neighbours 'n'
Compute $\boldsymbol{WS_n} = \omega_1 * DoD + \omega_2 * AEL + \omega_3 * LQ + \omega_4 * DFR + \omega_5 * ND$
Add $WS_n \rightarrow RREQ_n$
End for
While (! terminate) do
For all nodes 'n'
Compare WS
if $WS_n > WS_m$ then
$\boldsymbol{relay} \leftarrow n$End if
End for
End while
Determination of $Relaynode(n_i), \forall i, 1 \leq i \leq n$, (i.e. route R) using WS.
End

4 Simulation Results and Discussion

Under various conditions, the simulation is conducted and outcomes are obtained, that are presented in this section. The nodes are randomly distributed in the selected network area of 1000 m x 1000 m. The size of every unit of data is 1024 bytes, and an initial energy of 100 J is allocated to every node. By altering the network size within the range of 50 to 250, the robustness of the suggested method is assessed. Table 1 shows the simulation parameters.

Table 1: Network Parameters

S. No	Network Parameter	Value
1.	Area of Network	1000 m x 1000 m
2.	Packet Size	1024 bytes
3.	Size of Network	50, 100, 150, 200, 250
4.	Type of Traffic	CBR
5.	Transmission agent	UDP
6.	Energy of Node	100 Joules

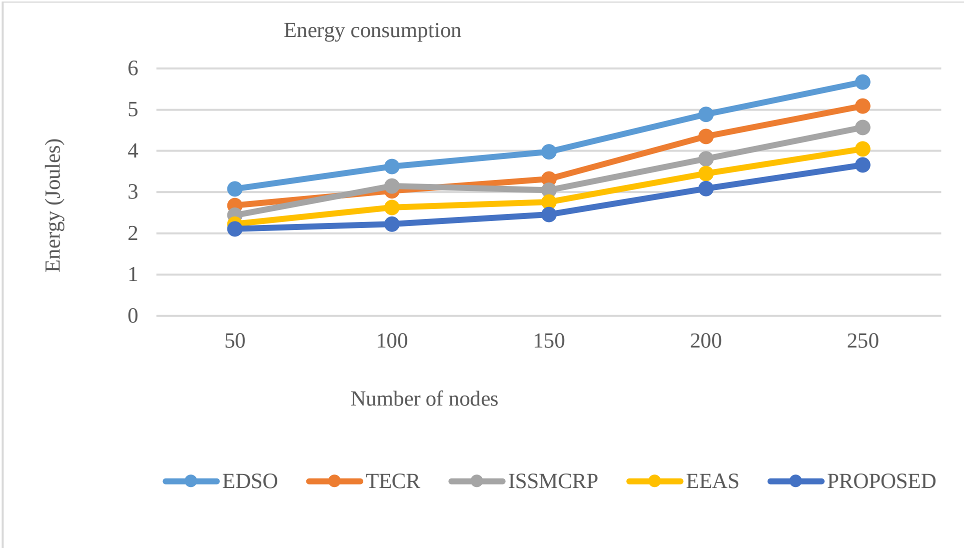

Figure 1: Energy Consumption

NODES	EDSO	TECR	ISSMCRP	EEAS	PROPOSED
50	3.08	2.68	2.44	2.23	2.11
100	3.62	3.03	3.15	2.63	2.23
150	3.98	3.32	3.05	2.76	2.46
200	4.89	4.35	3.81	3.45	3.09
250	5.67	5.09	4.57	4.05	3.66

The Congestion-Aware Routing Scheme was implemented in the suggested method, as it enhances the Energy Consumption. Packets that are delivered through less congested paths with ample energy resources was ensured by this method. The energy load over the network was effectively distributed by this method. Comparing this method to conventional protocols, the Energy Consumption is much lower and more efficient because it reduces needless retransmissions. The Energy Consumption of the current approaches was 5.67 Joules higher than the average energy consumption of the suggested method in the tests, which was 3.6 Joules. Figure 1 shows the Energy Consumption for different number of nodes.

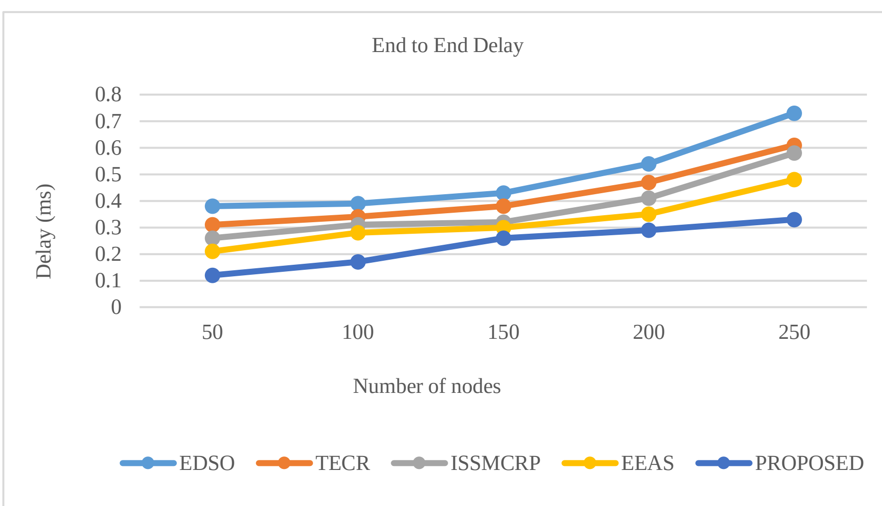

Figure 2: End to End Delay

NODES	EDSO	TECR	ISSMCRP	EEAS	PROPOSED
50	0.38	0.31	0.26	0.21	0.12
100	0.39	0.34	0.31	0.28	0.17
150	0.43	0.38	0.32	0.3	0.26
200	0.54	0.47	0.41	0.35	0.29
250	0.73	0.61	0.58	0.48	0.33

The optimal path was selected by a Wireless Sensor of key parameters and preventing congested paths paves way for reduction of End to End delay via the suggested method.

This approach ensures packets take quicker routes, minimizing waiting times and delays. The low delays were consistently maintained and this method dynamically adapts to network conditions. When compared to other methods, the suggested method attains higher, approximately 0.05 to 0.35 ms. This will also result in improving performance. Figure 2 presents these results.

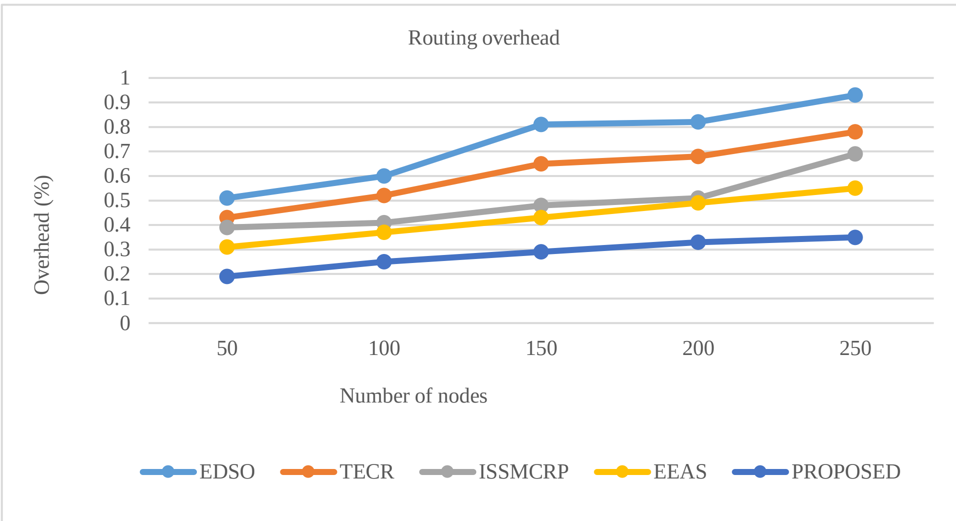

Figure 3: Network Overhead

NODES	EDSO	TECR	ISSMCRP	EEAS	PROPOSED
50	0.51	0.43	0.39	0.31	0.19
100	0.6	0.52	0.41	0.37	0.25
150	0.81	0.65	0.48	0.43	0.29
200	0.82	0.68	0.51	0.49	0.33
250	0.93	0.78	0.69	0.55	0.35

Figure 3 shows the outcomes of the simulation for the network overhead. When compared to alternative protocols, the suggested approach drastically lowers network overhead. It achieves an overhead of roughly 0.25% at higher node counts (250 nodes), whereas competing protocols have overheads between 0.5% and 0.9%. This approach reduces control message exchanges by optimising Route Selection (RS) using a Wireless Sensor of essential factors and dynamically adapting to network conditions. When compared to conventional protocols, this effective routing technique lowers overhead by roughly 0.25% to 0.65%, the efficiency of the network is improved.

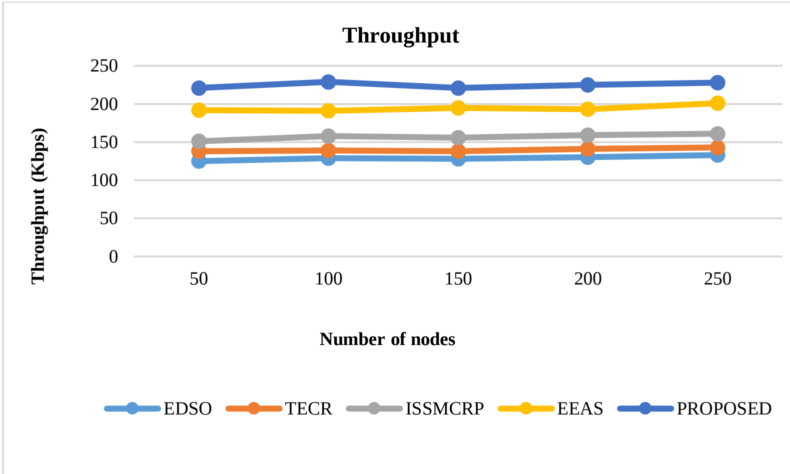

Figure 4: Network Performance

NODES	EDSO	TECR	ISSMCRP	EEAS	PROPOSED
50	125	138	151	192	221
100	129	139	158	191	229
150	128	138	156	195	221
200	130	141	159	193	225
250	133	143	161	201	228

Figure 4 presents the throughput simulation results. By optimising Route Selection using a Wireless Sensor of important factors, the suggested strategy increases throughput by ensuring that packets are transmitted over less crowded channels. Retransmissions and packet collisions are decreased as a result. Data flow is further improved by the method's dynamic adaptation to network conditions, which preserves efficient routing. During the study, the suggested approach consistently maintained an average throughput rate of up to 228 kbps.

5 Conclusion

A Congestion-Aware Routing Scheme for Congestion Radio Sensor Network is suggested in this study that minimises Energy Consumption and increases Network Lifetime is presented. To route packets towards less congested channels with adequate energy resources, the suggested strategy employs a Wireless Sensor technique that combines congestion control and Energy Efficient. In order to direct packets onto less crowded channels with enough energy resources, the Wireless Sensor is given a weight based on network conditions. A longer Network Lifetime is a result of this method's mitigation of network bottlenecks and reduction of packet loss. The suggested method, evaluated through simulations, significantly improves network lifetime while maintaining comparable energy consumption to traditional protocols, making it suitable for high throughput Congestion Radio Sensor Network applications.

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Authors Biography

L.V.R. Chaitanya Prasad, received his B.Tech Degree in Electronics and Communication Engineering from the C.V.S.R College of Engineering, Hyderabad in 2006 and M.Tech degree in Digital Communication from the Kakatiya Institute of Technology and Science (KITS), Warangal in 2008. Presently, he is working as an Assistant Professor in the Department of Electronics and Communication Engineering, Sreenidhi Institute of Science and Technology (SNIST), Hyderabad. He is currently pursuing Ph. D in the Department of Electronics and Communication Engineering at Jawaharlal Nehru Technological University, Hyderabad (JNTUH). His research interests include Cognitive Radio Sensor Networks, Wireless Sensor Networks, Wireless Communication Networks and 5G Communications.

Dr. Yedukondalu Kamatham, is currently working as a Professor and Head of Electronics and Communication Engineering at CVR College of Engineering, Hyderabad, India. His research interests include Adaptive/ biomedical Signal Processing, Wireless Communications including 5G and beyond and Global Navigation Satellite Systems. He has about 70 research publications in various Journals and Conferences. He has delivered 16 invited lectures and has organized various training programmes and symposia for Faculty and Students in the field of ECE. He has been a reviewer for several journals. He is a Senior Member of IEEE, Fellow of IETE, and Life member of Indian Society for Technical Education (ISTE). He has 25 years of teaching experience.

Dr. Dhiraj Sunehra, is currently working as a Professor of Electronics and Communication Engineering at JNTUH University College of Engineering, Rajanna Sircilla. His research interests include Digital and Embedded Systems, Green Wireless Communications and Global Navigation Satellite Systems. He has about 75 research publications in various Journals and Conferences. He has delivered 31 invited lectures and has organized various training programmes and symposia for Faculty and Students in the field of ECE. He has been a reviewer, and has chaired 16 technical sessions in various IEEE Conferences. He is a Senior Member of IEEE, Life Member of IETE, Indian Geophysical Union (IGU), Indian Society for Technical Education (ISTE) and Member of Association for Computing Machinery (ACM).