A New Approach for Wireless Sensor Networks based on Tree-based Routing using Hybrid Fuzzy C-Means with Genetic Algorithm

Neetu Sikarwar
Department of Electronic and Communication, ITM University, Gwalior, India
neetusik1@gmail.com

Ranjeet Singh Tomar
Department of Electronic and Communication, ITM University, Gwalior, India
er.ranjeetsingh@gmail.com

Received: 15 February 2024 | Revised: 10 March 2024 | Accepted: 12 March 2024

 DOI: https://doi.org/10.48084/etasr.7078

ABSTRACT

The rapid development of wireless technology has led to the availability of a wide range of networked devices that support numerous applications. Small wireless devices that are powered by batteries create a Wireless Sensor Network (WSN), which collaborates to communicate data through wireless channels to a Base Station (BS). However, a WSN system faces a number of difficulties, with energy efficiency being the most critical one. In order to provide energy efficiency and increase network lifespan, it is crucial to lessen the energy required for data transmission. This research suggests an energy-efficient optimal cluster-based routing strategy to extend the lifespan of a network. Energy conservation is of paramount importance in WSNs featuring mobile nodes. Numerous routing techniques have been proposed to reduce packet loss and boost energy efficiency in such networks. These protocols are not particularly energy-efficient though, because they cannot build the right clusters. In this paper, the tree-based Hybrid Fuzzy C-Means Genetic Algorithm (HFCM-GA) is presented in an attempt to reduce energy loss and increase the packet delivery ratio. Using node mobility and the node energy attribute, this protocol proposes a centralized cluster creation mechanism that produces optimal clusters. Node mobility, node energy, and node distance are additional criteria that a detached node considers while choosing its ideal cluster head. Simulation outcomes demonstrate that the recommended HFCM-GA is superior to the conventional routing protocols regarding the residual energy and coverage ratio.

Keywords-energy efficiency; wireless sensor networks; sensor nodes; routing; clustering; FCM; GA

I. INTRODUCTION

All Wireless Sensor Networks (WSNs) have several reliable data gathering Base Stations (BSs) and a wide network of small, wireless Sensor Nodes (SNs), which often capture the environmental or physical changes [1, 2]. Data are routed across a network from its origin to its final destination [3]. Since network architecture and applications have been developed, routing protocols cannot be improved [4, 5]. Establishing an energy-aware routing system is crucial for the balance of data packet routing and node energy usage [6, 7]. One key indicator of WSN performance is a network's lifespan [8, 9]. HFCM-GA reduces costs, increases efficiency, and extends system life. A Cluster Head (CH) is chosen using HFCM-GA, which deploys residual power, fuzzy c-means, and node position. Energy thresholds and proximity rules help HFCM-GA reduce transmission overhead and avoid CH variations during transmission cycles. Extensive simulations utilizing a broad variety of evaluation performance metrics have proved that FCMDE works. The considered variables include throughput, network durability, and average energy usage. A comparison of approaches revealed the HFCM-GA's efficacy.

Several recent studies on WSN based routing on the use of optimization algorithm. Authors in [10] ameliorated network uptime and energy efficiency with cluster-based optimal routing. Simulations indicate that the proposed routing strategy outperforms the current methods in energy efficiency, network lifespan, and packet delivery ratio. In [11], the proposed E-CDBR reduces latency and energy use for UWSNs. The EEACRA for WSNs was suggested to address the problems of CHs in LEACH [12], like non-optimal proportions, over-accumulated energy consumption, irrational distribution, etc. EEACRA was proven able to maintain an ideal energy balance throughout the network and greatly extend its service life. In [13], EACBM minimizes SN power utilization with heterogeneous network routing. Hierarchical heterogeneous WSNs are benefited the most from energy efficiency improvements over LEFCA, LEACH, SEP, and CEEC. LEACH does not account for source-to-sink data flow since CHs spend energy unevenly and have routing gaps [14]. The simulations support ELEC's efficiency over LEACH. Simulations demonstrate that ELEC-LEACH outperforms MR-LEACH regarding node failure, packet loss, residual energy, and lifespan. Results disclose that the ELEC-LEACH routing method doubles network lifespan while sacrificing 9% energy. The WSNs' biggest problem is the precise environmental data gathering and their transmission to a BS or sink. Real-world and dynamic applications for WSNs provide research support for increased performance. Many academics are creating energy-efficient tree-based routing systems. Therefore, the development of a standardized technique that improves network quality and has a long-term outlook requires active participation [15]. Some important caveats to the work that has been brought up so far are:

- Cluster formation does not take into account residual energy or distance.
- An intermediate node with low energy could die during the round, knocking out the entire network and having a negative effect on data accuracy.

Recent methods display that sink mobility in a regulated channel enhances WSN energy efficiency although path limits complicate routing. The sink with a set speed collects data faster from randomly distributed sensor nodes. Data gathering and energy utilization suffer from this constraint. These research restrictions also influenced WSN's design-efficient GA optimization with FCM clustering.

A. Novelty and Contribution

In this paper, the implementation of a new methodology for routing of WSNs, namely tree-based routing, utilizing HFCM-GA is proposed. The combination of Hybrid Fuzzy C-Means and Genetic Algorithms creates a dynamic hierarchical structure. The methodology covers energy efficiency, network lifespan, and provides a full simulation-based evaluation, representing a substantial step forward in WSN routing algorithms. This study's main contributions are:

- This project intends to develop an energy-efficient WSN multi-hop routing protocol adopting hybrid optimization approaches.
- The novel tree-based routing using Hybrid Fuzzy C-Means with Genetic technique is proposed for WSNs that can survive longer.
- To determine the optimum path from each CH and BS, an energy-efficient routing technique based on the GA is suggested.
- Simulation findings manifest that the proposed technique can successfully reduce network residual energy and coverage ratio.

B. Significance of the Paper

The integration of HFCM and GA is a significant component of the current work since it combines the benefits of fuzzy clustering for node optimization and GA for evolutionary selection of optimal CHs. The flowchart in Figure 1 depicts the important procedures involved, from random node distribution to Data Cluster Head (DCH) establishment and Fuzzy Cluster Head (FCH) determination. The iterative process of using GA settings and FCM cluster centers demonstrates the adaptability and dynamic nature of the proposed HFCM-GA technique.

II. METHODOLOGY

This section provides the problem statement, the proposed methodology, and the utilized algorithms.

A. Problem Statement

Due to strict limits on network expansion and enhancement, confining SNs' energy reserves is considered a WSN initiative. The field's most prominent performance indicator is SN energy dissipation, which is growing more essential as networks age. Energy restrictions cause some SN and network activities to be prioritized over others, affecting system performance and dependability. Maintaining the network's quality over time relies on this matter. Many routing algorithms have been proposed for WSNs to decrease energy consumption and enhance lifetime assessment, but clustering works best.

B. The Proposed Methodology

A tree-based routing approach using HFCM-GA is introduced to overcome the problem of standard energy-efficient protocols. The proposed approach aims to reduce SN's power supply loads, extending the network's lifespan. Hierarchical procedures may need collaboration between CHs, Data Cluster Heads (DCHs), and BSs. The CH in an NC cluster sends data to a DCH, whereas other CHs provide data to a Central Cluster Head (CCH). This flowchart in Figure 1 illustrates the HFCM-GA cluster-based network optimization method's essential steps. The proposed HFCM-GA technique addresses WSN energy efficiency issues by combining HFCM clustering with GA. HFCM is employed to cluster the SNs and optimize their allocation based on membership functions. This streamlines data aggregation and reduces cluster energy use. GA then selects the optimum CHs for each cluster based on HFCM output to maximize network energy efficiency. Therefore, GA leverages HFCM's clusters and its evolutionary search process to find optimum CHs on the basis of fitness functions that include direct distances to a BS, CH distances, transfer energy, and transmissions. The HFCM-GA approach combines these two methods to increase WSN energy efficiency and lifespan, and contribute to sustainable network operation. To manage and maximize node placement in a cluster-based network, the proposed HFCM-GA approach follows a structured flowchart. Nodes are randomly distributed in the network. These nodes are classified into two groups: NCs and FCS according to their proximity to cluster centers. The algorithm moves forward by choosing certain nodes as DCHs through a process known as FDCH. A cluster starts a sequence of operations if it is determined to be the closest cluster (NC). The NC's DCH is primarily in charge of sending data to a BS. In addition, while the specifics of this alteration are not given, there is a stage that involves changing the FCH in this context. The system then determines whether network nodes are still alive or active. In the absence of any discovered active nodes, the algorithm ends.

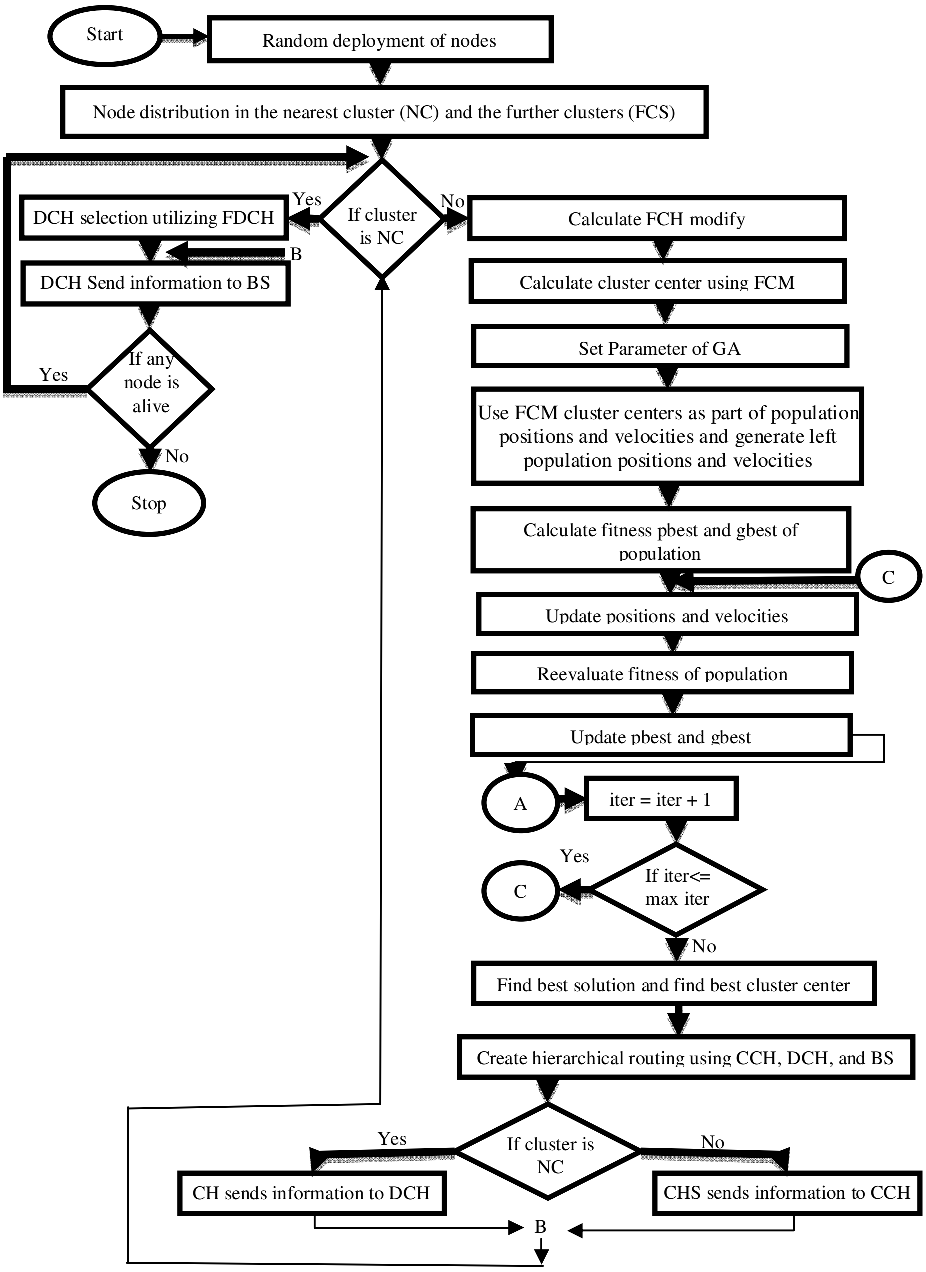

Fig. 1. Flowchart of the proposed HFCM-GA.

If there are still active nodes, the application utilizes FCM clustering to find the cluster center. In the next step, GA settings are established. FCM cluster centers produce the initial population of locations and velocities deploying these characteristics. The system calculates population fitness and updates personal best (pbest) and global best (gbest) results.

The method checks to see whether the maximum number of iterations (max iter) has been achieved after incrementing an iteration counter (iter). Otherwise, the procedure is repeated. The method determines the ideal cluster center and optimum solution after the maximum number of iterations has been reached.

III. EXPERIMENTS AND DISCUSSION

The fuzzy C-means and GA model evaluates the tree-based routing technique. The simulation results of the proposed approach and a few contemporary models were compared regarding dead nodes, live nodes, residual energy, and throughput. The simulation results of two scenarios, with sensing areas of 100 m ×100 m and 200 m ×200 m are presented. Table I portrays the simulation parameters. Performance, energy consumption, and other essential metrics of a WSN can be evaluated by adjusting the values of these parameters, which establish the characteristics and settings for the simulation of a WSN.

TABLE I. SIMULATION PARAMETERS

Parameter	Value	Description
E_{elec}	50 nJ/bit	Energy required for data transmission/reception per bit.
No. of nodes (N)	100	The total number of sensor nodes in a network.
d_{th}	88 m	Threshold distance for transmission.
P_n	0.20	Probability of node being in the 'on' state.
ε_{mp}	0.0013 pJ/bit/m^4	Energy dissipation for multipath fading.
d_{DCH}	90 m	Distance for direct communication.
ε_{fs}	10 pJ/bit/m^2	Energy dissipation for free space path loss.
E_{DA}	5 nJ/bit/signal	Energy needed to aggregate data..
Simulation rounds	2000	Number of iterations.
Initial energy of the node (E_i)	0.5 J	Initial energy level of each sensor node..
Data packet size (l)	4000 bits	Size of data packets.
Control packet size (l*)	200 bits	Size of control packets.

A. *Simulation Results of the Proposed Hybrid Model*

This section provides the simulation outcome of the proposed model.

1) Results of Scenario-1

The results of Scenario-1 for the proposed hybrid model with 100 nodes consider lifetime evaluation, "FND," "HND," "final node dead," alive nodes, residual energy graph, and coverage ratio graphs.

The x-axis in Figure 2(a) shows node count and the y-axis dispersion. The blue dots indicate distance from the main BS, while the red dots are closer. Figure 2(b) exhibits how HFCM-GA placed sensor nodes. Data administration is simplified when all sensor nodes become CHs. Magenta squares represent data-transmitting Parent Cluster Heads (PCHs), whereas purple stars indicate adjacent nodes.

Figure 3(a) graphs Scenario-1 dead nodes. The amount of dead nodes rises with rounds (0–2000 on the x-axis). Around the 1600th cycle, most network nodes are "dead." The graph demonstrates that more nodes fail as round number increases. Figure 3(b) illustrates Scenario-1 live nodes over time. The number of active nodes with 100 initially alive nodes drops as rounds move from 0 to 1650. All network nodes die at the end of the 1650th round. Working nodes decrease with time. Hybrid FCM-GA model got FND round 63, HND round 901 and final node dead round 1620, respectively.

The residual energy per round graph for Scenario-1 is presented in Figure 4. The area is 100×100 m^2. The x-axis represents rounds 0–2000, and the y-axis the residual network energy 0–50J. Cycles reduce network residual energy from the initial 50 J. The number of nodes, their distribution, and their sensing and communication ranges determine the coverage ratio in the sensing zone.

(a)

(b)

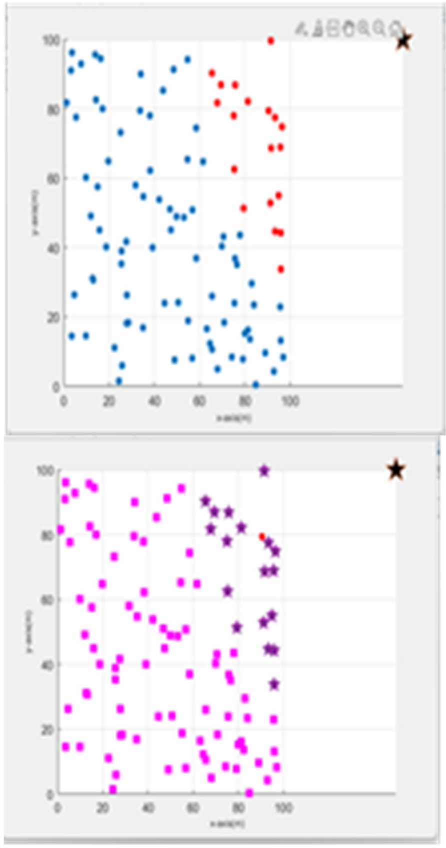

Fig. 2. (a) Hybrid model nodes and (b) final node deployment graph for Scenario-1.

(a)

(b)

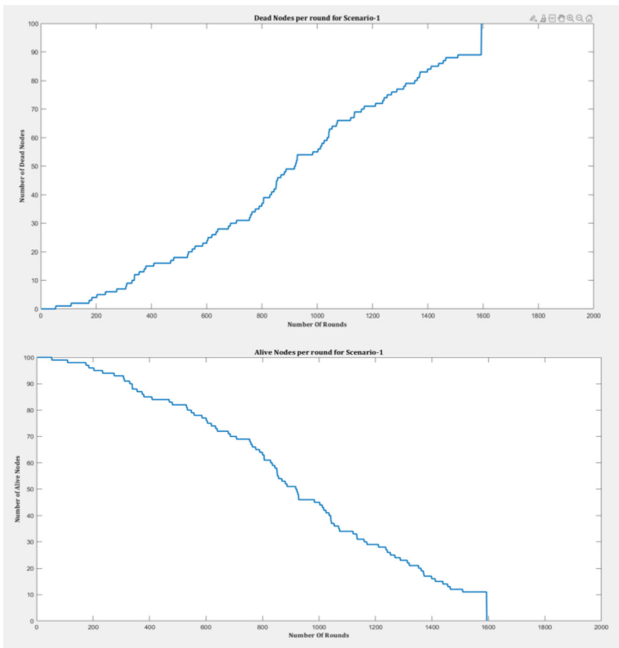

Fig. 3. Hybrid model (a) dead nodes and (b) alive nodes per round for Scenario-1.

(a)

(b)

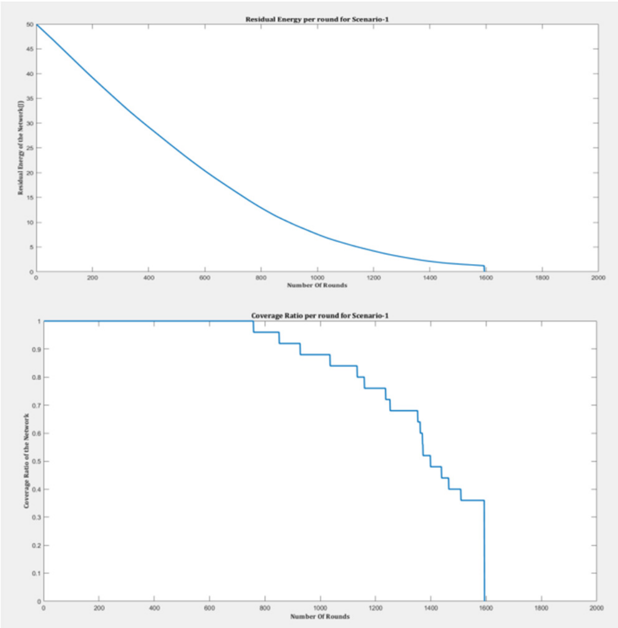

Fig. 4. Hybrid model (a) residual energy and (b) coverage ratio (CR) per round for Scenario-1.

2) Results of Scenario-2

The results of Scenario-2 for the proposed hybrid model with 200 nodes are provided in this section using the lifetime evaluation, including FND, HND, final node dead, alive nodes, residual energy, and coverage ratio.

(a)

(b)

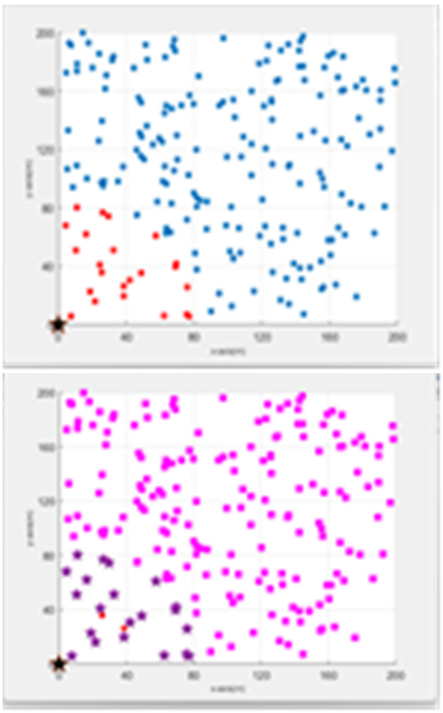

Fig. 5. (a) Hybrid model nodes and (b) final node deployment graph for Scenario-2.

The deployment graph is observed in Figure 5(a). This sensor network entails 200 random nodes. Blue sensor nodes are further from the hub or sink than the red ones. Figure 5(b) shows BS and SN deployment. The pink nodes represent cycle CHs. The nearest purple nodes die as CH many rounds later. Red PCHs are needed for a reliable information flow.

(a)

(b)

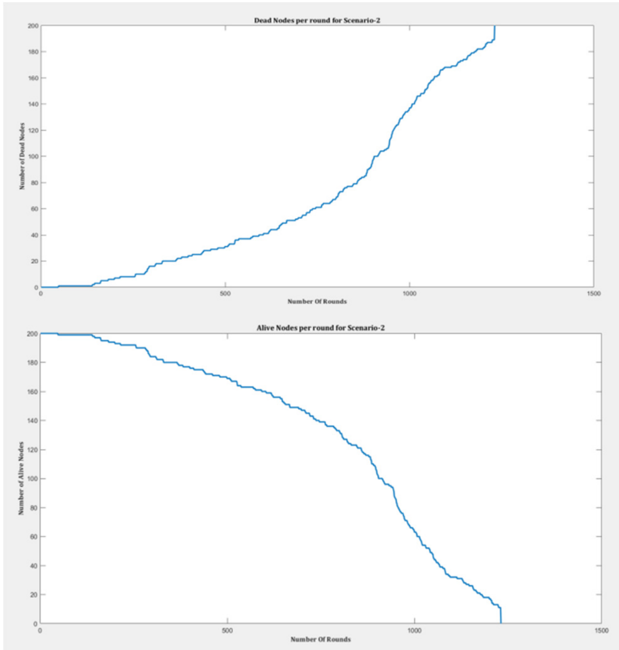

Fig. 6. Hybrid model (a) dead nodes and (b) alive nodes per round for Scenario-2.

(a)

(b)

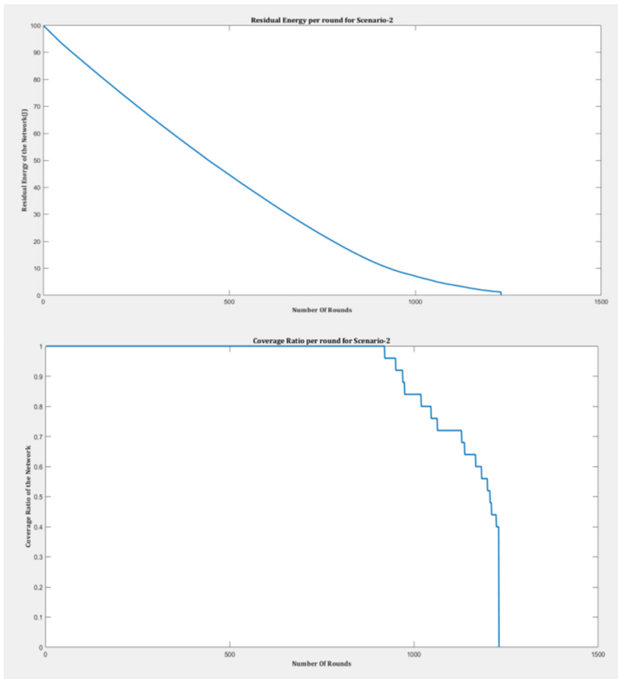

Fig. 7. Hybrid model (a) residual energy and (b) coverage ratio (CR) per round for Scenario-2.

Figure 6 displays the line graph of dead and alive nodes in each iteration for Scenario-2, with the BS placed at (0, 0) and the Sensing Region being 200×200 m^2. The x-axis demonstrates the total rounds between 0 and 1500 and the y-axis the dead nodes between 0 and 200. No nodes survived after a large number of rounds. The HFCM-GA model gave FND round 51, HND round 946, and final node dead round 0, respectively.

Figure 7 depicts Scenario-2's sensing area's residual energy after one cycle. Data transfer in the sensing zone with two BSs 150 and 100 m apart. The CR for each round in both scenarios is displayed in Figure 9.

B. Comparative Analysis between the Proposed and Existing Models

The results are compared in this section, which also includes tables and graphs disclosing the results.

Table II and Figure 8 portray the comparison of the network lifespan assessment results. Table III and Figure 9 compare the results of the proposed method and existing EEHCHR methods. It can be seen that the proposed HFCM-GA outperforms the existing EEHCHR.

TABLE II. COMPARISON RESULTS OF THE PROPOSED MODEL FOR BOTH SCENARIOS

Network lifetime evaluation	Scenario-1, 100 nodes	Scenario-2, 200 nodes
FND (First Node Dead)	63	51
HND (Half Nodes Dead)	901	946
LND (Last Node Dead)	1620	0

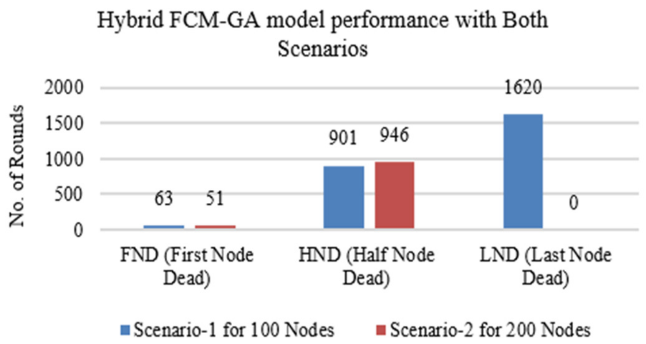

Fig. 8. Bar graph for both scenario comparison.

TABLE III. COMPARISON OF EXISTING AND PROPOSED MODELS

Network lifetime evaluation	Proposed HFCM-GA method		Existing EEHCHR Method	
	Scenario-1	Scenario-2	Scenario-1	Scenario-2
FND	63	51	45	31
HND	901	946	735	731
LND	1620	0	1359	1024

IV. KNOWLEDGE GAP

To close the knowledge gap, the study highlights the shortcomings of the existing energy-efficient protocols in WSNs and stresses the need for better routing techniques. By fusing the advantages of GA with HFCM clustering, the hybrid character of the suggested approach closes this gap and produces a more thorough and efficient solution. Through a performance comparison with other approaches, the comparative analysis provides additional validation for the suggested model's importance. The study presents key evaluation measures, such as LND, HND, and FND, offering a thorough analysis of the effectiveness of the proposed model.

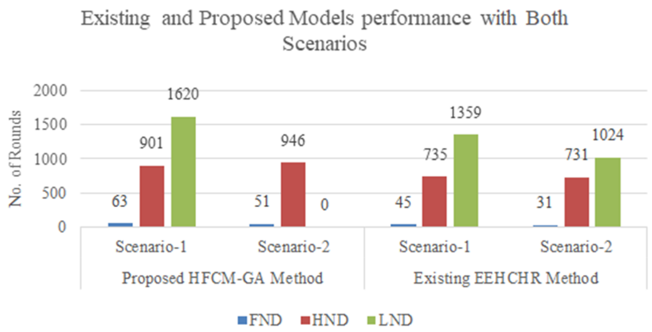

Fig. 9. Comparison graph between existing and proposed methods for both scenarios.

V. CONCLUSION AND FUTURE WORK

This study presents a novel clustered routing system that effectively uses electricity infrastructure. HFCM-GA tree-based routing is introduced to boost network lifespan and improve WSN data collection. Hybrid clustering was employed to maximize each node's power supply. All CHs were selected using energy-efficient fitness algorithms that adjust to nodes' residual energy. HFCM-GA outperforms similar algorithms in network lifespan, residual energy, and coverage. Simulation results demonstrate that the suggested methodology reduces residual energy in the network and improves coverage. The thorough assessment conducted and the emphasis placed on energy efficiency support the long-term viability and operation of WSNs. The main problem with this study is that it does not explain the FCH modification in depth, thus it is hard to monitor how the model works. The suggested HFCM-GA method needs additional validation and sensitivity analysis of the simulation settings to certify that it can handle different networks and real-world scenarios. The proposed wireless sensor network routing protocol can be made more reliable and applicable by improving the clarity on model specifics and conducting comprehensive validation efforts. Future study will enhance the CH selection function employed to categorize multitier heterogeneous sensor networks via metaheuristic optimization. The results of the current research can be useful in multimodal and heterogeneous sensor networks. Further studies should look into how well the suggested method performs in other environmental settings and whether it can be scaled to larger networks. The recommended WSN routing protocol might be made more flexible and effective by integrating it with modern technologies like edge computing and machine learning for adaptive routing decisions.

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AUTHORS PROFILE

Neetu Sikarwar is an assistant Professor at Jiwaji University, Gwalior, India. She has obtained M. Tech. Electronics & Communication Engineering from ITM College, Gwalior and is pursuing her Ph.D. degree in Electronics & Communication Engineering from the Institute of Technology and management university, Gwalior, India. In an academic career spanning over 20 years, she has published and presented research papers in several national and international journals and conferences. Her current research area is wireless sensor networks.

Ranjeet Singh Tomar is a Professor and the Dean of Academics at the ITM University Gwalior, India. He has obtained the M. Tech. Electronics & Communication Engineering from Malviya National Institute of Technology Jaipur, India and the Ph.D. degree in Information Technology from Indian Institute of Information Technology Allahabad, India. In an academic career spanning over 23 years, he has published and presented research papers in several national and international journals and conferences. His current research areas of interest include wireless communication, digital communication, information theory and coding, and vehicular technology. Presently, he is an Editor of the International Journal of Communication, Networks & Computing published by the ITM University Gwalior, India. He is an Executive Committee member and fellow of IETE (India) and a member of the IEEE and IE (India).