Energy-Aware Adaptive Fuzzy Clustering Algorithm for Enhanced Wireless Sensor Network Lifetime

S. Prakasam[1] D. Archana[2]
Assoicate Professor[1] Research Scholar[2]
Dept. of Computer Science and Applications
Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya
Kanchipuram, Tamilnadu, India

ABSTRACT

In wireless sensor networks (WSNs), extending the network lifetime while maintaining energy efficiency and stability is a critical challenge, especially in resource-constrained environments. This paper proposes a novel Energy-Aware Adaptive Fuzzy Clustering (EAFC) algorithm designed to dynamically adjust clusters and select Cluster Heads (CHs) based on multiple criteria, including residual energy, node density, and proximity to the base station. The EAFC algorithm employs fuzzy logic to handle uncertainty and ensure that CH selection is optimized, leading to balanced energy consumption and enhanced network stability. Simulation results demonstrate that the EAFC algorithm significantly outperforms traditional clustering methods such as HEED, providing improvements in network lifetime, energy efficiency, and cluster stability. The adaptive nature of the EAFC algorithm allows it to respond effectively to changing network conditions, making it a promising solution for energy-constrained WSNs.

Keywords— Clustering Algorithms, Fuzzy Logic, Energy Harvesting, Network Longevity,Energy consumption

I. INTRODUCTION

Wireless sensor network is a collection of sensor node which is deployed in various locations to analysis, gather data and take necessary action. Various application of wireless sensor network in real life such as industrial automation, home automation, agriculture management, environment monitoring and many other applications. In a Wireless sensor network nodes are wirelessly connected to each other. In the WSN's node consume more energy and immediately the node get depleted much of the time, it can't be re-energized or supplanted by batteries. Node placement in conventional WSN efficiency is lesser because of the power interest and intricacy. The process of synchronization between CH and nodes is constrained by a number of network restrictions that make the group head determination process tedious on account of all current clustering techniques. Consequently, numerous techniques are used to pursue a choice for the CH. By and large, a CH is picked in light of setting up a using energy threshold as the minimum energy criterion to guarantee complete WSN connectivity and dependability depicts the design of a remote sensor organization. Recently, sensor networks have emerged as most of research with potential applications in nearly every industry. For transmission of information, the energy-efficient cluster head is chosen based on the energy and distance parameters. Improved cluster head selection increases system lifetime and network performance overall compared to Leach protocol [1]. The method of dividing nodes into multiple clusters and then choosing a subset of nodes to be the Cluster Heads (CHs) is known as network clustering. Wireless sensor networks based on hierarchical clustering require a clustering routing method due to the unequal node distribution and the limited energy of nodes. The ideal number of cluster heads, chosen based on residual energy, does not need to be precalculated. Depending on the distance, ordinary nodes choose to connect with the sink node or the cluster head of the same original cluster [2].

Tuna Swarm Optimization (TSO) is a network clustering technique that minimizes the communication distance between nodes and their respective cluster centers by taking into account the average and standard deviation of those distances [3]. This reduces the energy consumption of communication within the cluster. Multi-criteria decision-making (MCDM) strategies are utilized to pick energy-efficient CH through intelligent clustering algorithms that execute clustering dynamically in the presence of unpredictable parameters. Using the elbow approach in conjunction with the k-Means clustering methodology to validate the SI score and clustering using the "Density-Based Spatial Clustering of Applications with Noise (DBSCAN)" algorithm [4] clustering model that prioritizes the number of clusters and the cluster head's selection depending on the area and nodes. It measures Packet Delivery Rate (PDR), Lifetime, Energy Consumption, and Throughput [5].

II. LITERATURE REVIEW

In WSN, developing an energy-efficient transfer of data approach is necessary. Data from one sensor node is received by the base station (BS), which then forwards it to another sensor node. The remaining energy, the distance between the sensor node and the base station, and the total number of connected sensor nodes using an energy-efficient routing algorithm [6].By synchronously coding each of the top cluster heads (CHs) into a separate chromosome, a chaotic genetic algorithm is employed to find the best routing patterns. The algorithm converges very rapidly through to new resolution criteria and chaotic genetic algorithms based on a novel fitness function that takes into account load balancing and lowest energy usage. In addition, an adaptive round time that takes load balancing and energy into account is offered to keep the clusters operational and further minimize energy consumption[7][8]. The Harmony Search (HS) Algorithm is used in the clustering protocol based on the meta-heuristic approach (CPMA) to smooth out the energy distribution across the network and lower overall energy dissipation.

The majority of clustering protocols are unable to adapt their relevant protocol settings automatically to the variety of various WSNs. Under practically all network conditions, CPMA optimizes its key parameters using the Artificial Bee Colony (ABC) algorithm to better extend the network lifetime and increase network throughput [9]. The traffic load placed on Cluster Heads (CHs) -supported WSNs is greater than that of the other CHs. The clustering technique is used to balance the traffic strain placed on the CHs in clustered IOT-supported WSNs. A routing technique that considers energy consumption when sending data packets from the CHs to their final location. By properly segmenting the area, this will spread the data packets' communication strain among more nodes close to the destination [10].

Both homogeneous and heterogeneous sensors are used to gather desire data. Because their application choice is essential to geography, WSNs are built to run on self-powered sensor nodes. In a WSN architecture that primarily focuses on minimizing network energy consumption, cluster head selection is an important step. In addition to using less power, it organizes sensor nodes into sophisticated network clusters that have longer lifespan. The electrostatic discharge technique is used by the fully connected energy efficient clustering (FCEEC) mechanism to create a fully connected network with shortest path routing from sensor nodes (SNs) to cluster head (CH) in a multihop environment.

By achieving energy-efficient complete connection between sensor nodes, the electrostatic discharge algorithm (ESDA) prolongs the life of the network. More effective than several traditional CH selection approaches in terms of performance parameters like energy efficiency, dead node count, packet transmission, and network delay[11].Due to rising node counts and complexity, wireless sensor networks (WSN) are handling ever-increasing volumes of data. In networks with growing node and sensor values, routing—which is employed for the data aggregation step—plays a significant part in energy efficiency once a query is executed. The energy required for data aggregation can be significantly reduced with the use of an ad-hoc routing approach for queriable routing, extending the life of the network [12]. PFCRE is a clustering routing protocol that uses fuzzy logic and particle swarm optimization to increase network longevity, reduce energy holes, and improve energy efficiency. PFCRE uses an enhanced particle swarm optimization algorithm that takes into account factors like residual energy, distance to base station, and number of relays chosen in order to balance traffic load and minimize energy consumption while forming clusters. Furthermore, the particle swarm optimization approach refines the fuzzy inference system's rules.

To further save processing, clusters are arranged using an adaptive maintenance technique rather than periodic clustering [13].In a clustered WSN, the regular nodes sense their surroundings and send the observed data to a designated head node (CH), which compiles the data before transferring it to the base station. In WSNs, high call ability, decreased routing latency, and enhanced energy efficiency are benefits of clustering nodes. Based on the network architecture and used clustering management techniques, the current clustering approaches are divided into three categories: hybrid, fuzzy logic, and meta-heuristic [14] [15]. WSN research, with an emphasis on AI integration to overcome WSNs' various obstacles in our increasing global environment [16] WSNs are networks with limited energy resources that implement in large-scale WSNs, hierarchical approaches improve network longevity and performance [17].

Wireless sensor network clustering based on three distinct areas, including machine learning, optimization, and conventional strategies. clustering as an effective method to cut down on energy use [18].The innovative application of cluster-based routing and lightweight watermarking techniques, which allows for proactive detection of data tampering and improves the network's [19]. The dependability of supervised machine learning classification techniques for clustering algorithms in WSNs Using the obtained dataset, ML algorithms decision tree and K-nearest neighbor classifications, in particular are applied to forecast the dependability of clustering in WSNs based on high residual energy, low latency, and high packet delivery ratios. Binary values are accepted for the reliability parameter, where zero signifies no reliability and one represents an availability of reliability metrics [20]. To make an efficient energy consumption and to increase network lifetime in WSN with Clustering Approaches.

III. METHODOLOGY

A novel algorithm called as Energy-Aware Adaptive Fuzzy Clustering (EAFC). The main objective of this algorithm is to choose Cluster Heads (CHs) and dynamically modify clusters according to many factors, including as energy levels, node density, and base station proximity, while implementing fuzzy logic to handle uncertainty. This approach is designed to improve the longevity and stability of the network without depending on conventional clustering methods such as LEACH and DBSCAN. The proposed EAFC Block diagram is shown in Figure 1, with an emphasis on the key elements and how they relate to the different phases of data transfer, clustering, and network management.

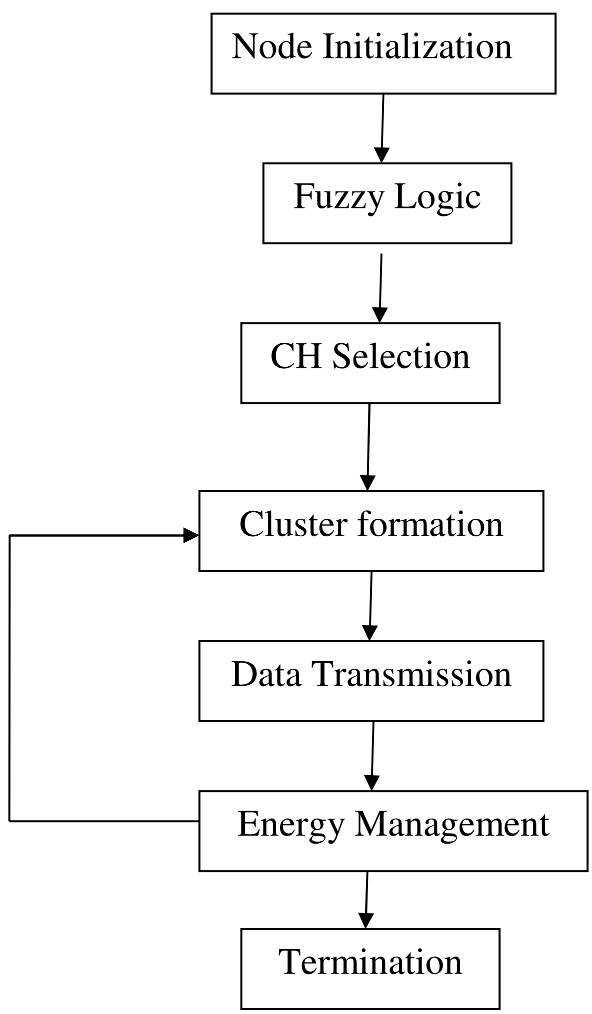

Figure 1 Block diagram of the proposed Energy-Aware Adaptive Fuzzy Clustering (EAFC) algorithm for Wireless Sensor Networks (WSNs)

Energy-Aware Adaptive Fuzzy Clustering (EAFC) Algorithm

Step1: Initialization

- Deployment of Nodes
  - Deploy sensor node haphazardly inside the network region. Set the initial energy levels, positions, and communication capabilities of each node.
- Setting Up the Base Station
  - Set the base station in a predetermined area, typically outside the network's coverage area.

Step 2: Cluster Formation Using Fuzzy Logic

- Fuzzy Factors Definition
  - Define fuzzy factors for the clustering system, for example, energy level (low, medium, high), node density (scanty, moderate, thick), and distance to the base station (close, far)
- Set of fuzzy rules
  - Create a fuzzy rule set that decides the probability of a node turning into a CH in view of its energy level, density, and distance to the base station.
- o Fuzzification
  - Convert crisp inputs into fuzzy ones like energy levels and distances.
- Interference Engine
  - Apply the fuzzy rule set to decide the fuzzy result for every node, addressing its CH criterion.
- Fragmentation
  - Revert the fuzzy output to a clear value and rank nodes according to their suitability as CHs.

Stage 3: Cluster Head (CH) Determination

- CH selection
  - Select the highest nodes in each region to serve as CHs based on the defuzzified values. Guarantee that CHs are equally disseminated across the network to try not to over-burden any single CH.

- CH Pivot
  - o Rotate CHs intermittently founded on leftover energy and node density to adjust the load and prevent early consumption of CHs.

Step 4: Formation of a Cluster

- Association of Nodes
  - o Based on distance and signal strength, nodes associate with the closest CH. Guarantee that the cluster size is adjusted to try not to over-burden any CH.
- DynamicAdaptation
  - o periodically reconsider the cluster utilizing the fuzzy validation framework to adjust to changes in network conditions, like node energy consumption or new node sending.

Stage 5: Information Transmission

- Intra Communication
  - o Sensor node send information to their particular CHs. Use energy-effective transmission procedures to limit energy utilization.
- Communication among Clusters
  - o CHs collect data from their cluster members and, if necessary, use multi-hop communication to send it to the base station.

Stage 6: Energy Update and Re-Clustering

- Energy Update
  - o Update the energy levels of all nodes following each communication round
- Re-Clustering
  - o Initiate re-clustering when CHs' energy levels fall below a certain threshold or when the topology of the network significantly changes. Re-run the CH selection process based on fuzzy logic.

Step 7: Termination

- Lifetime of Network
  - o Continue the procedure until a predetermined number of CHs or nodes run out of energy, which ends the network's lifespan.

The EAFC algorithm's sequential process, from initialization to termination, is depicted in the proposed flow diagram in Figure 2, highlighting the feedback loop for re-clustering based on energy updates.

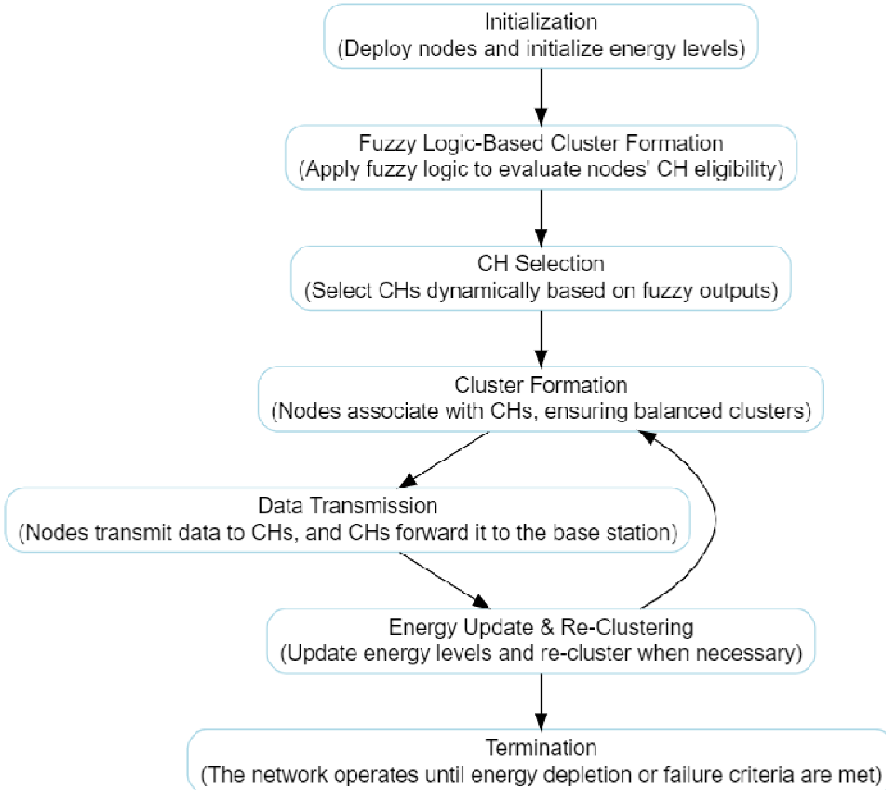

Figure 2. Flow diagram of the Energy-Aware Adaptive Fuzzy Clustering (EAFC) algorithm for Wireless Sensor Networks (WSNs)

IV. RESULTS AND DISCUSSIONS

Through a series of simulations, the proposed Energy-Aware Adaptive Fuzzy Clustering (EAFC) algorithm for Wireless Sensor Networks (WSNs) was evaluated in terms of network lifetime, energy consumption, and cluster stability. When contrasted with conventional clustering algorithms like HEED and random Cluster Head (CH) selection methods, the outcomes demonstrate that the EAFC algorithm is capable of optimizing WSN performance. Other clustering algorithms, such as HEED and a fundamental random CH selection method are contrasted with the EAFC algorithm. Network lifetime, energy consumption, and cluster stability are the performance metrics. The most important simulation parameters used to evaluate the EAFC algorithm's performance are listed in Table 1.

It determines the number of nodes; the area of sending, starting energy levels, the base station's situation, the transmission range, and the total simulation time in rounds.. These boundaries structure the reason for dissecting the adequacy of the proposed calculation with regards to network lifetime, energy efficiency, and stability. The proposed EAFC approach's gradual decrease in active nodes is depicted in Figure 3. until about 3,000 rounds, the network is stable and most nodes are still alive. After however, nodes start using up energy and gradually drop off until the network ends that,around 4000 rounds.

Table 1 Simulation Parameters for the Energy-Aware Adaptive Fuzzy Clustering (EAFC) Algorithm

Simulation parameters	Values
Number of Nodes	100
Network Area	100x100 meters
Initial Energy	1000 units per node
Base Station	Positioned at (50, 100)
Transmission Range	20 meters
Simulation Time	4000 rounds

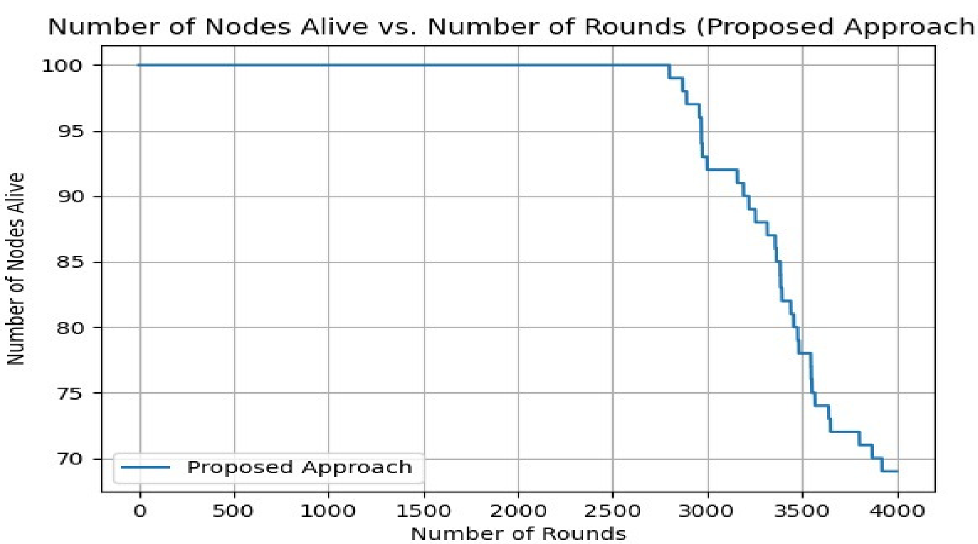

Figure 3 Number of Nodes Alive vs. Number of Rounds using the Proposed Energy-Aware Adaptive Fuzzy Clustering (EAFC) Approach

4.1 Network Lifetime

The EAFC calculation essentially improves the network lifetime. This is accomplished by dynamically selecting CHs in response to a set of fuzzy logic criteria, such as the density of nodes, energy levels, and distance from the base station.

By guaranteeing that CHs are chosen from node with higher energy holds and ideal situations inside the network, the EAFC calculation prevents early energy exhaustion and equitably disperses the energy utilization across the network. The simulation results show that the EAFC algorithm consistently has more alive nodes than the other algorithms in comparison over multiple rounds. This suggests that the EAFC algorithm is better at extending the WSN's operational life, making it ideal for applications where network longevity is crucial.

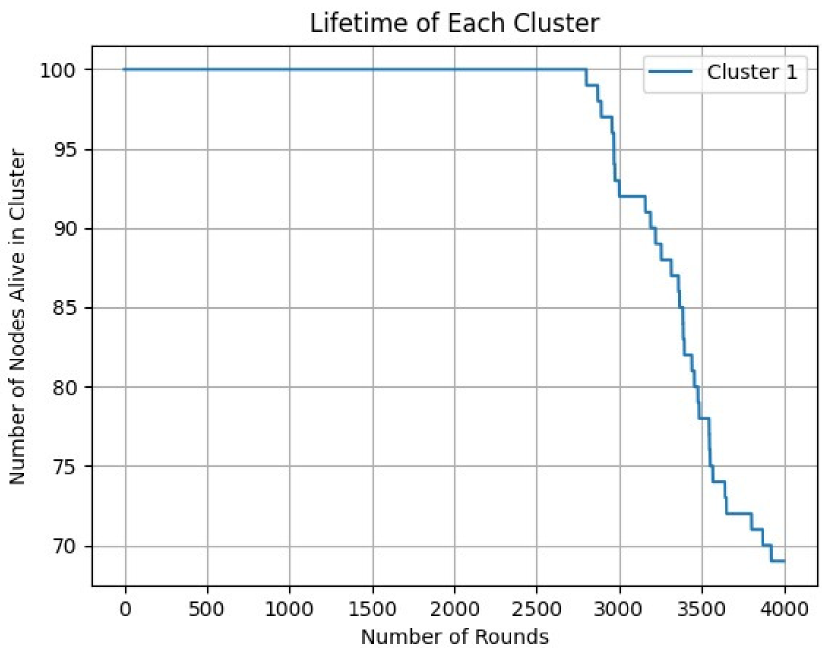

Figure 4 Lifetime of Each Cluster over the Number of Rounds using the Proposed Energy-Aware Adaptive Fuzzy Clustering (EAFC) Approach.

Figure 4 shows the number of nodes alive in a cluster after some time (estimated in adjusts). The cluster stays stable with essentially all nodes alive until around 3000 rounds, after which a continuous downfall happens, demonstrating energy exhaustion and node dropout until the cluster stretches around 70 nodes by 4000 rounds.

V. CONCLUSION

The results demonstrate that the EAFC algorithm effectively increases WSN stability and lifetime. By taking into account a variety of factors like energy, distance, and density, the fuzzy logic-based method enables CH selection that is more informed. By ensuring that clusters remain balanced, this adaptive clustering technique reduces the likelihood of early CH failures and extends the lifetime of the network as a whole.

Contrasted with existing strategies like Regard, which essentially center on lingering energy, EAFC gives a more comprehensive methodology by coordinating numerous variables into the dynamic cycle. This outcome in better energy the board and group security, especially in unique network conditions. In conclusion, the WSN clustering methods are significantly improved by the EAFC algorithm. It outperforms conventional methods in terms of network lifetime, energy efficiency, and cluster stability by incorporating fuzzy logic and adaptive re-clustering.

The Energy-Aware Adaptive Fuzzy Logic Clustering (EAFC) calculation shows predominant execution in broadening the lifetime of remote sensor network. The application of EAFC in various WSN scenarios, such as mobile sensor networks and heterogeneous environments, or the incorporation of additional parameters into the fuzzy logic system could be the subject of future research.

REFERENCES

1) R Priyadarshi, RR Kumar An Energy-Efficient LEACH Routing Protocol for Wireless Sensor Networks, Proceedings of the Fourth International Conference on Microelectronics ,2021•Springer

2) N Chen, R Wen, S Ma, P Wang, Clustering Routing Algorithm for Wireless Sensor Networks- 2023 IEEE 3rd International 2023 - ieeexplore.ieee.org

3) YD Yao, HC Li, ZB Zeng, C Wang,Clustering Routing Protocol Based on Tuna Swarm Optimization and Fuzzy Control Theory in Wireless Sensor Networks - IEEE Sensors, 2024 - ieeexplore.ieee.org

4) Laxminarayan Sahoo , Shri Supriyan Sen , Kalishankar Tiwary,Sarbast Moslem , And Tapan Senapati,Improvement of Wireless Sensor Network Lifetime via Intelligent Clustering Under Uncertainty,IEEE Access Volume 12, 2024 Digital Object Identifier 10.1109/Access.2024.3365490

5) Mohammad Faiz, Ramandeep Sandhu , Mohd Akbar, Anwar Ahmad Shaikh, Chandani Bhasin, Nausheen Fatima, Machine Learning Techniques in Wireless Sensor Networks: Algorithms, Strategies, and Applications, International Journal Of Intelligent Systems And Applications In Engineering ,July-2023issn:2147-67992147-6799 Www.Ijisae.Org

6) Navpreet kaur,Inderdeep kaur,Aulakh,An Enhanced Clustering Approach For Enhancement Of Lifetime In Wireless Sensor Network,webology ,Vol18 n03 2021

7) Wang chu-Hang,Liu Xiao-Li,Hu Huang shui,Han you-jia,Energy-Efficient and Load-Balanced Clustering Routing Protocol for Wireless Sensor Networks Using a Chaotic Genetic Algorithm,IEEE Access,August 2020

8) 8. Yu Han , Gang Li , Rui Xu , Jian Su , Jian Li And Guangjun Wen , Clustering the Wireless Sensor Networks: A Meta-Heuristic Approach, IEEE Access8 ,December 2020

9) Neha Sharmaa , Dr. Vishal Guptab,Meta-heuristic based optimization of WSNs Localisation Problem- a Survey ,Procedia Computer Science,January 2020

10) Ramin Yarinezhad,Masoud Sabaei ,An optimal cluster-based routing algorithm for lifetime maximization of Internet of Things, Journal of parallel and Distributed Computing,Volume 156,October 2021

11) G. C. Jagan and P. Jesu Jayarin, Wireless Sensor Network Cluster Head Selection and Short Routing Using Energy Efficient ElectroStatic Discharge Algorithm, Journal of Engineering,Volume 2022, Article ID 8429285, 10 pages

12) René Bergelt, An Energy-aware Ad-hoc Routing Strategy for Queriable Wireless Sensor Networks, Embedded Self Organizing Systems (Vol 9. No 2. 2022) (pp. 3-8)

13) Huangshui Hu, Xinji Fan, Chuhang Wang, Tingting Wang,Yuhuan Deng, Particle swarm optimization and fuzzy logic based clustering and routing protocol to enhance lifetime for wireless sensor networks ,Cluster Computing, https://doi.org/10.1007/s10586-024-04453-z

14) Preetha ,R. Rao , Amruta Lipare,Damodar Reddy, Edla and Saidi Reddy Parne, An Energy-Efficient Routing Algorithm for WSNs UsingFuzzy Logic , Sensors 2023, 23, 8074. https://doi.org/10.3390/s23198074

15) Rahul Priyadarshi, Energy-Efficient Routing in Wireless Sensor Networks: A Meta-heuristic and Artificial Intelligence-based Approach: A Comprehensive Review ,Archives of Computational methods in Engineering,January 2024

16) Ahmed Mahdi Jubair , Rosilah Hassan , Azana Hafizah Mohd Aman , Hasimi Sallehudin ,Zeyad Ghaleb Al-Mekhlafi , Badiea Abdulkarem Mohammed ,and Mohammad Salih Alsaffar , Optimization of Clustering in Wireless Sensor Networks: Techniques and Protocol,springer,April-2024

17) Wesal Bassem Nedham and Ali Kadhum M. Al-Qurabat ,A comprehensive review of clustering approaches for energy efficiency in wireless sensor networks ,International Journal of Computer Applications in Technology Vol. 72, No. 2,2023

18) J. Amutha,Sandeep Sharma,Sanjay Kumar Sharma ,Strategies based on various aspects of clustering in wireless sensor networks using classical, optimization and machine learning techniques: Review, taxonomy, research findings, challenges and future directions, Computer Science Review ,Volume 40, May 2021, 100376

19) Pendukeni Phalaagae , Adamu Murtala Zungeru , Boyce Sigweni , Selvaraj ajalakshmi , Herbet Batte c d, Odongo S. Eyobu, An energy efficient authentication scheme for cluster-based wireless IoT sensor networks https://doi.org/10.1016/j.sciaf.2024.e02287 June 2024;Scientific African journal homepage: www.elsevier.com/locate/sciaf

20) Amutha. J, Sharma. S, Reliability of clustering algorithm in wireless sensor networks using supervised machine learning classification approaches, 2021 International Conference on Advancement in Design, Development, Engineering, Processing, and Characterization, ADDEPC 2021; Volume 2853, Issue 1, 7 May 2024, Article number 020263.