International Journal of Science, Strategic Management and Technology
Volume **02** Issue **04** April-**2026** | ISSN: **3108-1762 (Online)** | Impact Factor: 3.8
An International, Peer-Reviewed, Open Access Scholarly Journal Indexed in recognized academic databases

Fuzzy Logic Driven Cluster Head and Vice Cluster Head Selection in Improved LEACH Protocol

Dipika Sharma
Sharma.dipika02@gmail.com
Department of Computer Science & Engineering, SBSSU, Gurdaspur

https://doi.org/10.55041/ijsmt.v2i4.570

Cite this Article: Sharma, D. (2026). Fuzzy Logic Driven Cluster Head and Vice Cluster Head Selection in Improved LEACH Protocol. International Journal of Science, Strategic Management and Technology, *02*(04). https://doi.org/10.55041/ijsmt.v2i4.570

Abstract

Wireless Sensor Networks (WSNs) play a vital role in monitoring environmental and physical conditions, but their performance is highly constrained by limited energy resources. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is widely used for energy-efficient routing; however, it suffers from issues such as early cluster head (CH) failure and reduced network lifetime. To address these limitations, this work proposes an improved VLEACH protocol incorporating fuzzy logic for intelligent selection of cluster heads and vice cluster heads. The proposed approach utilizes fuzzy if-then rules based on parameters such as residual energy and node centrality to optimize the selection process. Additionally, a threshold-based mechanism is introduced to limit unnecessary vice cluster head assignments, thereby reducing energy consumption. The protocol is evaluated through MATLAB simulations using performance metrics such as network lifetime, packet transmission, and node death rate. Experimental results demonstrate that the proposed fuzzy-based VLEACH significantly enhances network lifetime and energy efficiency compared to traditional LEACH and VLEACH protocols. The first and last node death rounds are substantially improved, validating the effectiveness of the approach.

Keywords

Wireless Sensor Networks (WSN), LEACH, VLEACH, Fuzzy Logic, Cluster Head Selection, Energy Efficiency, Network Lifetime, Routing Protocol, MATLAB Simulation, Node Energy Optimization

1.1Wireless Sensor Network

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes.

International Journal of Science, Strategic Management and Technology
Volume 02 Issue 04 April-2026 | ISSN: 3108-1762 (Online) | Impact Factor: 3.8
An International, Peer-Reviewed, Open Access Scholarly Journal Indexed in recognized academic databases

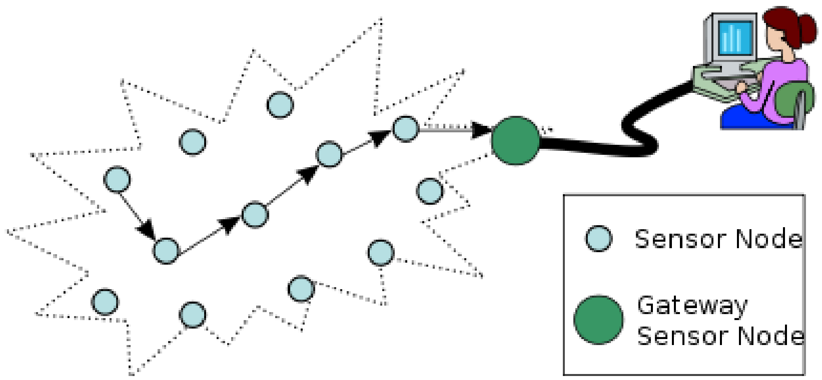

Figure1.1: Multi-hop wireless sensor network architecture

1.1.1 Sensor Node

The main task of a sensor node in a sensor network is to monitor events, i.e., collect data, perform quick local data aggregation, and then transmit the data. Sensor nodes which have limited battery power. Sensor nodes of WSN have the capability of self-organizing the network. The transmission between the sensor's nodes is done through wireless medium.

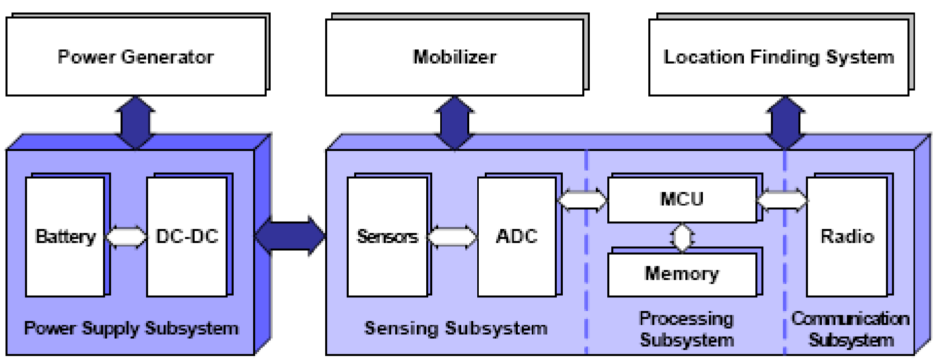

Figure1.2: Internal structure of sensor node

This figure1.2 redrawn from shows the architecture of a typical wireless sensor node, as usually assumed in the literature. It consists of four main components:

(i) a sensing subsystem including one or more sensors (with associated analog-to-digital converters) for data acquisition; (ii) a processing subsystem including a micro-controller and memory for local data processing; (iii) a radio subsystem for wireless data communication; and (iv) a power supply unit.

1.2Factors Influencing Sensor Network

A sensor network design is influenced by many factors, which include fault tolerance; scalability; production costs; operating environment; sensor network topology; hardware constraints; transmission media; and power consumption. These factors are addressed by many researchers. However, none of these studies has a full integrated view of all factors that are driving the design of sensor networks and sensor nodes. These factors are important because they serve as a guideline to design a protocol or an algorithm for sensor networks. In addition, these influencing factors can be used to compare different schemes.

1.2.1 Fault tolerance

Some sensor nodes may fail or be blocked due to lack of power, have physical damage or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. This is the reliability or fault tolerance issue. Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures. For example, if sensor nodes are being deployed in a house to keep track of humidity and temperature levels, the fault tolerance requirement may be low since this kind of sensor networks is not easily damaged or interfered by environmental noise.

On the other hand, if sensor nodes are being deployed in a battlefield for surveillance and detection, then the fault tolerance has to be high because the sensed data are critical and sensor nodes can be destroyed by hostile actions. As a result, the fault tolerance level depends on the application of the sensor networks, and the schemes must be developed with this in mind.

1.2.2 Scalability

The number of sensor nodes deployed in studying a phenomenon may be in the order of hundred or thousand. Depending on the application, the number may reach an extreme value of millions. The new schemes must be able to work with this number of nodes. They must also utilize the high-density nature of the sensor networks. The density can range from few sensor nodes to few hundred sensor nodes in a region, which can be less than 10 m in diameter.

In addition, the number of nodes in a region can be used to indicate the node density. The node density depends on the application in which the sensor nodes are deployed. For machine diagnosis application, the density for the vehicle tracking application is around 10 sensor nodes per region.

1.2.3 Production costs

Since the sensor networks consist of a large number of sensor nodes, the cost of a single node is very important to justify the overall cost of the networks. If the cost of the network is more expensive than deploying traditional sensors, then the sensor network is not cost-justified. As a result, the cost of each sensor node has to be kept low. The cost of a sensor node should be much less than 1$ in order for the sensor network to be feasible.

1.2.4. Hardware constraints

A sensor node is made up of four basic components a sensing unit, a processing unit, a transceiver unit and a power unit. They may also have application dependent additional components such as a location finding system, a power generator and a mobilize. Sensing units are usually composed of two subunits: sensors and analog to digital converters (ADCs). The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit. The processing unit, which is generally associated with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks.

1.2.5. Sensor Network Topology

Numbers of inaccessible and unattended sensor nodes, which are prone to frequent failures, make topology maintenance a challenging task. Hundreds to several thousands of nodes are deployed throughout the sensor field. They are deployed within tens of feet of each other. The node densities may be as high as 20 nodes/m3. Deploying high number of nodes densely requires careful handling of topology maintenance. We examine issues related to topology maintenance and change in three phases:

1.2.6. Environment

Sensor nodes are densely deployed either very close or directly inside the phenomenon to be observed. Therefore, they usually work unattended in remote geographic areas.

1.2.7. Transmission media

In a multihop sensor network, communicating nodes are linked by a wireless medium. These links can be formed by radio, infrared or optical media. To enable global operation of these networks, the chosen transmission medium must be available worldwide. One option for radio links is the use of industrial, scientific and medical (ISM) bands, which offer license-free communication in most countries.

1.2.8. Power consumption

The wireless sensor node, being a micro-electronic device, can only be equipped with a limited power source (<0.5 Ah, 1.2 V). In some application scenarios, replenishment of power resources might be impossible. Sensor node lifetime, therefore, shows a strong dependence on battery lifetime. In a multihop ad hoc sensor network, each node plays the dual role of data originator and data router. The disfunctioning of few nodes can cause significant topological changes and might require re-routing of packets and re-organization of the network.

1.3LEACH (Low Energy Adaptive Clustering Hierarchy):

LEACH is one of the first hierarchical routing approaches for sensors networks. LEACH is a self-organizing, adaptive clustering protocol. It uses randomization for distributing the energy load among the sensors in the network. The following are the assumptions made in the LEACH protocol:

i. All nodes can transmit with enough power to reach the base station.
ii. Each node has enough computational power to support different MAC protocols.
iii. Nodes located close to each other have correlated data.

According to this protocol, the base station is fixed and located far from the sensor nodes and the nodes are homogeneous and energy constrained. Here, one node called cluster-head (CH) acts as the local base station. LEACH randomly rotates the high-energy cluster-head so that the activities are equally shared among the sensors and the sensors consume battery power equally. LEACH also performs data fusion, i.e. compression of data when data is sent from the clusters to the base station thus reducing energy dissipation and enhancing system lifetime. LEACH divides the total operation into rounds each round consisting of two phases:

a) Set-up phase and b) Steady Phase

1.4 VLEACH

VLEACH is the new version of LEACH protocol, the cluster contains; CH (responsible only for sending data that is received from the cluster members to the BS), vice-CH (the node that will become a CH of the cluster in case of CH dies), cluster nodes (gathering data from environment and send it to the CH).

In the original LEACH, the CH is always on receiving data from cluster members, aggregate these data and then send it to the BS that might be located far away from it. The CH will die earlier than the other nodes in the cluster because of its operation of receiving, sending and overhearing. When the CH die, the cluster will become useless because the data gathered by cluster nodes will never reach the base station.

In V-LEACH protocol, besides having a CH in the cluster, there is a vice-CH that takes the role of the CH when the CH dies because the reasons we mentioned above by doing this, cluster nodes data will always reach the BS; no need to elect a new CH each time the CH dies. This will extend the overall network life time.

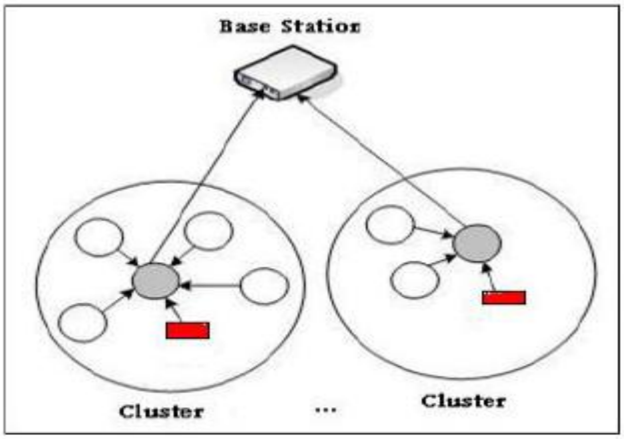

Figure1.6: V-LEACH

1.5Fuzzy If Then Rules

Fuzzy systems are built to replace the human expert with a machine using the logic a human would use to perform the tasks. Suppose we ask someone how hot it is today. He may tell us that it is hot, moderately hot or cold. He cannot tell us the exact temperature. Unlike classical logic which can only interpret the crisp set such as hot or cold, fuzzy logic has the capability to interpret the natural language. Thus, fuzzy logic can make human-like interpretations and is a very useful tool in artificial intelligence, machine earning and automation. Fuzzy logic operates on the basis of rules which are expressed in the form of If-Then constructs, also know as horn clauses.
Fuzzy logic can be used for real-time decisions in WSN. Different parameters can be merged according to the predefined fuzzy rules and making decision based on the output result is a vital application of fuzzy control.

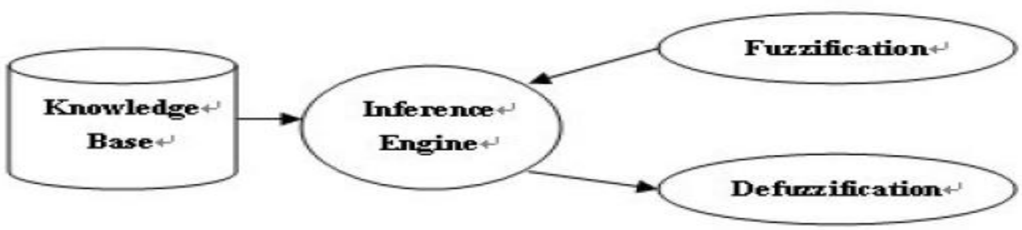

Figure1.7: FIS Architecture

Chapter 2
LITERATURE SURVEY

M.J. Handy et al. [3] has focused on reducing the power consumption of wireless microsensor networks. Therefore, a communication protocol named LEACH (Low-Energy Adaptive Clustering Hierarchy) is modified. They extend LEACH'S stochastic clusterhead selection algorithm by a deterministic component. Depending on the network configuration an increase of network lifetime by about 30 % can he accomplished. Furthermore, an important quality of a LEACH network is sustained despite the modifications: For the deterministic selection of cluster-heads only local and no global information is necessary. The nodes themselves determine whether they become cluster-heads. A communication with the base station or an arbiter-node is not necessary. Additionally, the metrics FNA (First Node Dies), HNA (Half of the Nodes Alive), and LND (Last Node Dies) which describe the lifetime of a microsensor network have been presented.

Piyakul Tillapart et al. [5] have been proposed many cluster-based routings, to reduce energy usage in wireless sensor networks. Among those proposed, LEACH (Low Energy Adaptive Clustering Hierarchy) is a well-known cluster-based sensor network architecture which aims to distribute energy consumption evenly to every node in a given network. This clustering technique requires a predefined number of clusters and has been developed with an assumption that the sensor nodes are uniformly distributed through out the network. In this paper, they propose a hybrid clustering and routing architecture for wireless sensor networks. There are three main parts in their proposed architecture which are a modified subtractive clustering technique, an energy-aware cluster head selection method and a cost-based routing algorithm. These are all centralized techniques and are expected to be executed at the base station.

D.Brinza et al. [6] explored the problem of maximizing sensor network lifetime, i.e., time during which the set of targets is covered. They propose centralized algorithms for lifetime maximization with provable approximation ratio for the realistic model studied. In this paper they introduce reliability requirement for distributed target-monitoring protocols and prove that previously considered protocols are reliable. A new Deterministic Energy-Efficient Protocol for Sensor networks (DEEPS) aimed at prolonging lifetime is proposed. They prove that DEEPS is reliable and compare DEEPS with several known target-monitoring protocols and showing almost 2 times increase in the lifetime for DEEPS over known protocols.

V.Loscri et al. [4] proposed a modification to a well-known protocol for sensor networks called Low Energy Adaptive Clustering Hierarchy (LEACH). This last was designed for sensor networks where end user needs to remotely monitor the environment. In such situation, the data from the individual nodes must be sent to a central base station, often located far from the sensor network, through which the end-user can access the data. They build a two-level hierarchy to realize a protocol that saves better the energy consumption. Our TL-LEACH uses random rotation of local cluster base stations (primary cluster-heads and secondary cluster-heads). It allows to better distribute the energy load among the sensors in the network especially when the density of network is higher. TL-LEACH uses localized coordination to enable scalability and robustness. They observed that TL-LEACH has allowed to reach a 20% increase as it regards the delivered packets and an increase of even the 30% of the lifetime of the network.

Jing Chen and Hong Shen [8] proposed MELEACH-L: More Energy-Efficient LEACH for Large-scale WSNs expanded version of MELEACH. The major functions of MELEACH applicable to large-scale WSNs whose dimension is much larger than the largest transmission radius of the sensor nodes.

Lu Cheng et al. [8] has proposed an energy-efficient, weighted clustering algorithm which improves the cluster formation process of LEACH by taking residual energy, mutual position, workload balance and MAC functioning in to consideration because cluster formation not only dissipates lots of energy but also increases overhead. The algorithm is flexible and coefficients can be adjusted according to different networks. The simulation experiments demonstrate the proposed algorithm in this paper is better in performance than LEACH. The simulation experiments prove EWC achieve energy efficiency by selecting more suitable cluster heads and keep workload and energy balance.

CHAPTER 3
PROBLEM FORMULATION

3.1 Problem Statement

LEACH is a hierarchical protocol in which most nodes transmit to cluster heads, and the cluster heads aggregate and compress the data and forward it to the base station (sink). Each node uses a stochastic algorithm at each round to determine whether it will become a cluster head in this round. LEACH assumes that each node has a radio powerful enough to directly reach the base station or the nearest cluster head, but that using this radio at full power all the time would waste energy. Nodes that have been cluster heads cannot become cluster heads again for P rounds, where P is the desired percentage of cluster heads. Thereafter, each node has a 1/P probability of becoming a cluster head in each round. At the end of each round, each node that is not a cluster head selects the closest cluster head and joins that cluster. The cluster head then creates a schedule for each node in its cluster to transmit its data. All nodes that are not cluster heads only communicate with the cluster head in a TDMA fashion, according to the schedule created by the cluster head. They do so use the minimum energy needed to reach the cluster head, and only need to keep their radios on during their time slot. The main objective of this work is to improve Vice-cluster head-based LEACH protocol i.e. VLEACH by using the fuzzy if then rules. Fuzzy if then rules will decrease the requirement of number of Vice-cluster heads by assigning vice-cluster head to those nodes which are having the lowest energy among all cluster heads. If in case more than one cluster head has lowest energy then more vice cluster heads will be used. And also, a new threshold k will be used which will not allow to become a node to vice cluster head until node(s) remaining energy become less than the threshold k. This will decrease the energy consumption of VLEACH and will result in increase in network lifetime.

3.4 Objectives

The principal objective of this project is to improve the network life time of the proposed fuzzy based VLEACH.

i. The overall objective is to optimize the energy consumption by using the fuzzy rules to decrease the number of vice clusters.
ii. A new threshold k will be used which will not allow to become a node to vice cluster head until node(s) remaining energy become less than the threshold k.
iii. The performance evaluation will be done by taking the result from the fuzzy based VLEACH and will be compared with VLEACH.
iv. Comparison will be drawn between VLEACH and fuzzy based VLEACH by taking following parameters
   a. Packets sent to base station
   b. Packets sent to cluster head
   c. Network life time
   d. When first node dies

CHAPTER 4

EXPERIMETAL SETUP

This dissertation has focused on a three-level hierarchical clustered heterogeneous sensor network with 100 sensor nodes which are randomly distributed over the 100×100 m2 area. The sink or base station is located at point (50×50). The packet size that the nodes send to their cluster heads as well as the aggregated packet size that a cluster head sends to the sink is set to 4000 bits. The initial energy of each normal node is set to 0.5 Joule. The proposed approach has been implemented in MATLAB and the performance has been evaluated by simulation. In this work, we have measured the lifetime of the network in terms of rounds when the first sensor node dies. All the parameter values including the first order radio model characteristic parameters are mentioned in the Table 4.1 below:

Table 4.1: Various parameters and their values

PARAMETERS	VALUES
Sensor field	100×100
Sink position	50×50
Total sensor nodes	100
Maximum cluster heads	10
M	0.3
Packet size	4000
Efs	10pJ/bit/m^2
Emp	0.0013pJ/bit/m^4
E_{DA}	50nJ/bit
E_O	0.5 J
P	0.1
A	3

International Journal of Science, Strategic Management and Technology
Volume **02** Issue **04** April-**2026** | ISSN: **3108-1762 (Online)** | Impact Factor: 3.8
An International, Peer-Reviewed, Open Access Scholarly Journal Indexed in recognized academic databases

CHAPTER 5
RESULTS AND PERFORMANCE ANALYSIS

5.1 Results

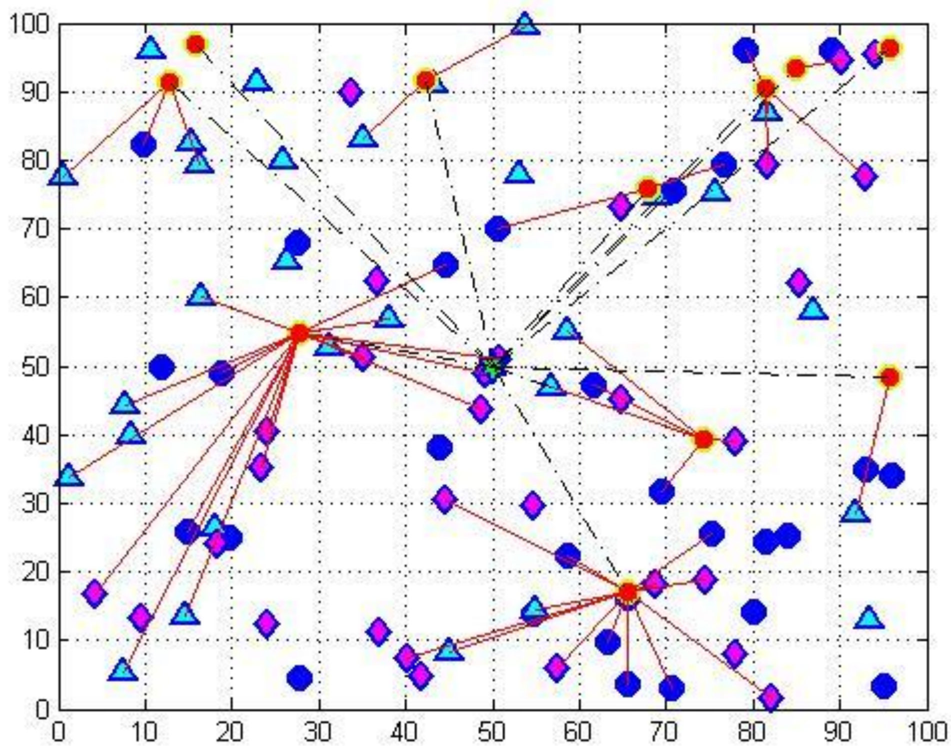

Figure 5.1: Network in active stage

Once the implementation starts, the first view that comes to be perceived is shown in figure 5.1. The screen is divided in to various regions that are called clusters. Each cluster thus formed has a cluster head, normal nodes or advance nodes. The entire network has a base station that is responsible for the collection of data from all other nodes. Figure 5.1 the active environment of fuzzy based VLEACH. Cyan is representing the base station. Blue circle nodes are representing the normal sensor nodes. Cyan triangle nodes are representing the intermediate sensor nodes and magenta diamond nodes are representing the advance sensor nodes. Red circle is representing the cluster heads. Black lines are representing how data communicate to the base station. Red lines are showing the Communication between member nodes to cluster head.

International Journal of Science, Strategic Management and Technology
Volume **02** Issue **04** April-**2026** | ISSN: **3108-1762 (Online)** | Impact Factor: 3.8
An International, Peer-Reviewed, Open Access Scholarly Journal Indexed in recognized academic databases

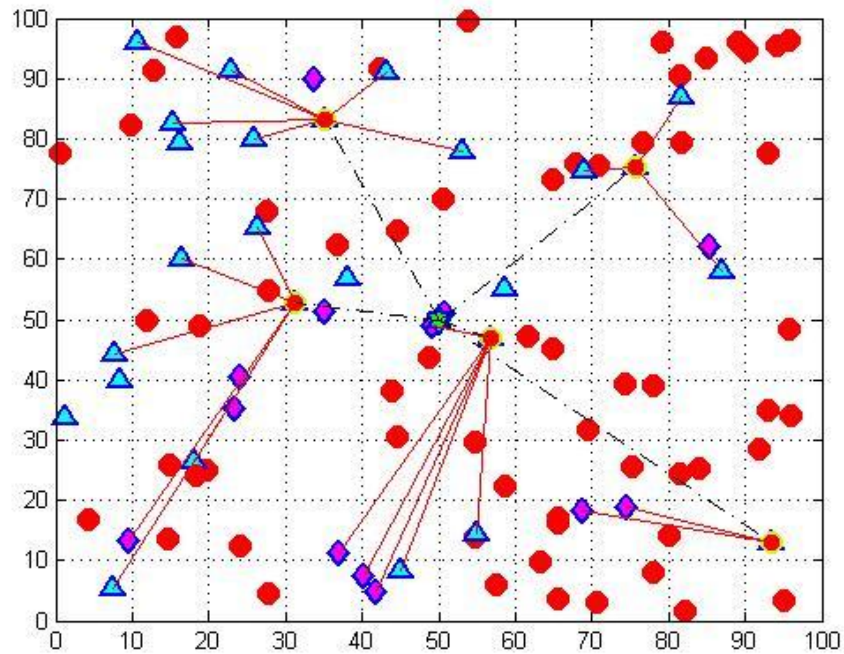

Figure 5.2: WSN with some dead nodes.

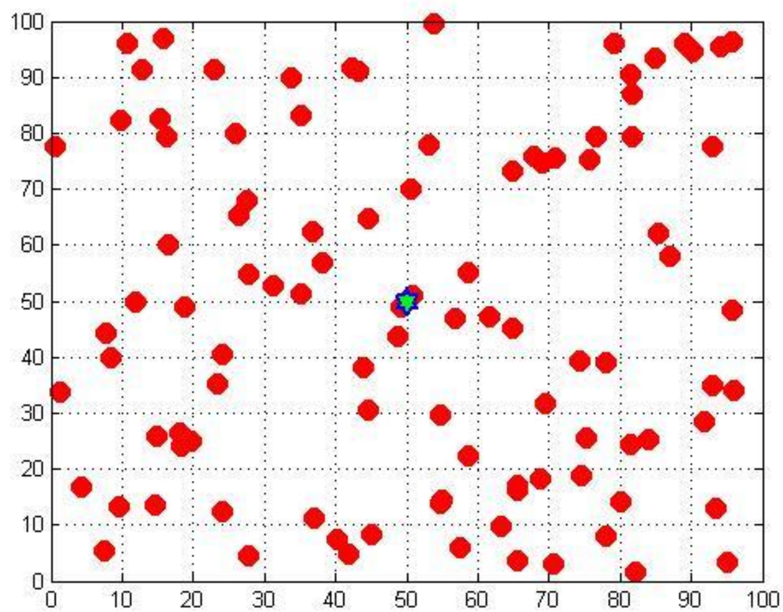

Figure 5.3: Dead nodes analysis

Fig 5.3 is showing the end of the sensor environment of fuzzy based VLEACH where all the nodes are dead. Figure 5.3 has shown the alive node comparison of the VLEACH, Proposed Algorithm of alive nodes when the initial energy is 0.5. It is clearly shown that the LEACH behaves almost equally except when the first node dies. However, the Proposed algorithm has shown that the first and last node dead time behaves better than VLEACH. Therefore, proposed algorithm has shown a significant improvement over the VLEACH. First node may alive upto the 1008th round and last node may alive upto 1380th

International Journal of Science, Strategic Management and Technology
Volume **02** Issue **04** April-**2026** | ISSN: **3108-1762 (Online)** | Impact Factor: 3.8
An International, Peer-Reviewed, Open Access Scholarly Journal Indexed in recognized academic databases

round in VLEACH protocol and First node may alive upto the 1734th round and last node may alive upto 2153th round in VLEACH protocol as shown in figure5.3.

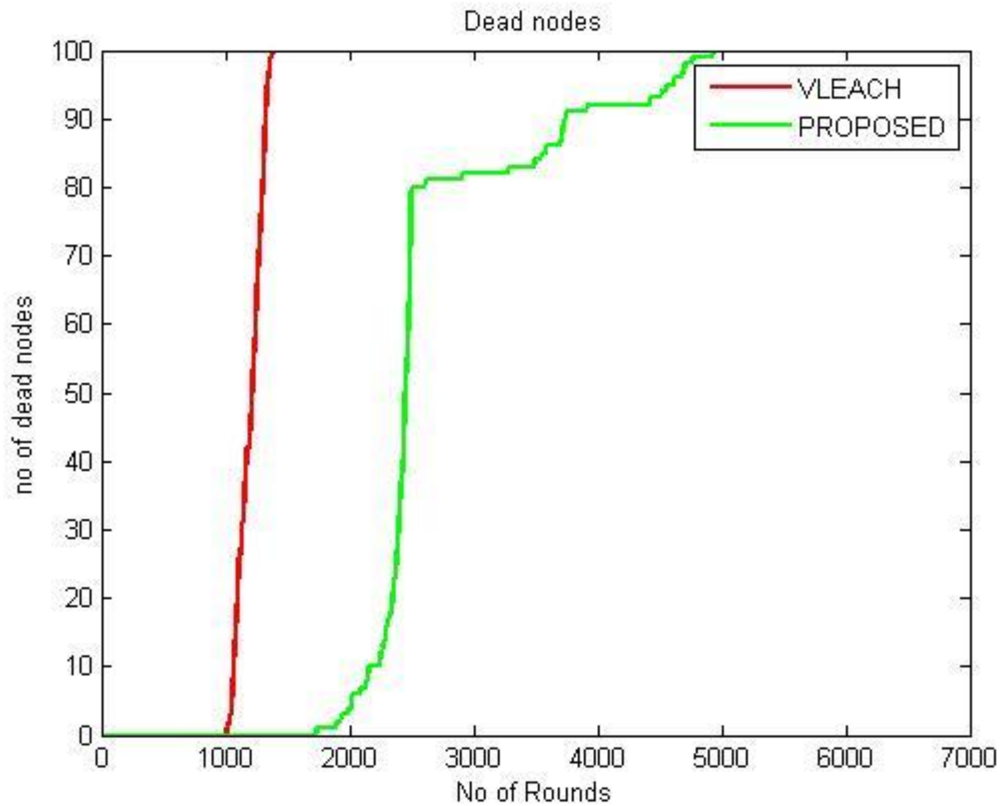

Figure 5.4: Dead nodes analysis with initial energy Eo= 0.5

Figure 5.4 has shown the comparison of the VLEACH and Proposed Algorithm of dead nodes when the initial energy is 0.5. It is evidently publicised that the VLEACH performs practically correspondingly except when the principal node expires.

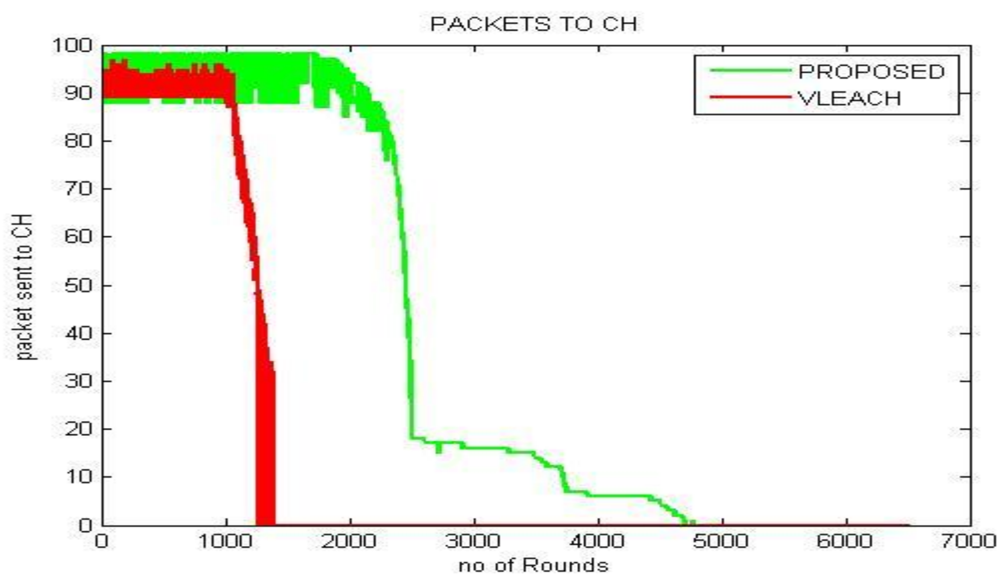

Figure5.5: Packets Transfer to the CH with initial energy Eo= 0.5

International Journal of Science, Strategic Management and Technology
Volume **02** Issue **04** April-**2026** | ISSN: **3108-1762 (Online)** | Impact Factor: 3.8
An International, Peer-Reviewed, Open Access Scholarly Journal Indexed in recognized academic databases

Figure 5.5 has shown the no of packets transfer to the CH in VLEACH and Proposed Algorithm when the initial energy is 0.5. It is evidently publicised that the Vleach performs practically better than the LEACH because of its stable election.

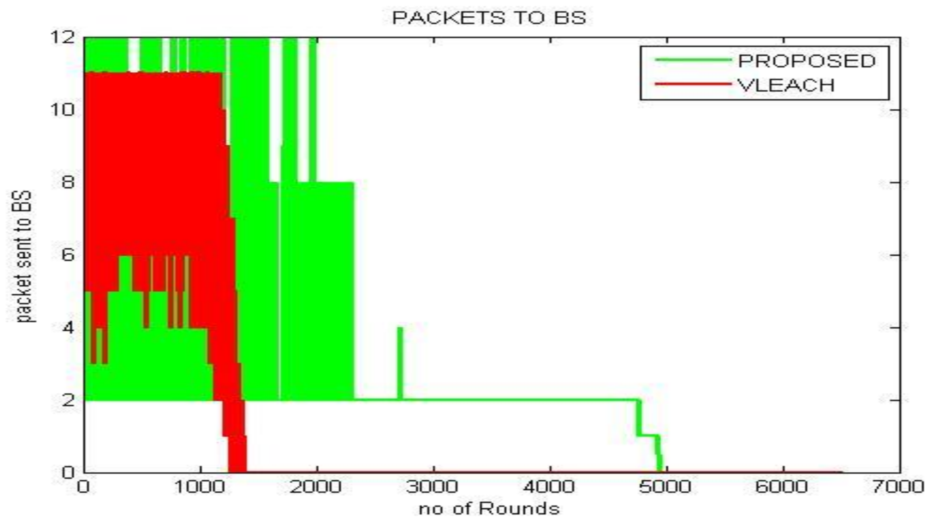

Figure 5.6: Packet transmission to the BS with initial energy Eo=0.5

Figure 5.6 has shown the Packet transmission to the BS in VLEACH and Proposed Algorithm when the initial energy is 0.5. It is clearly shown that the VLEACH behaves almost equally except when the first node dies.

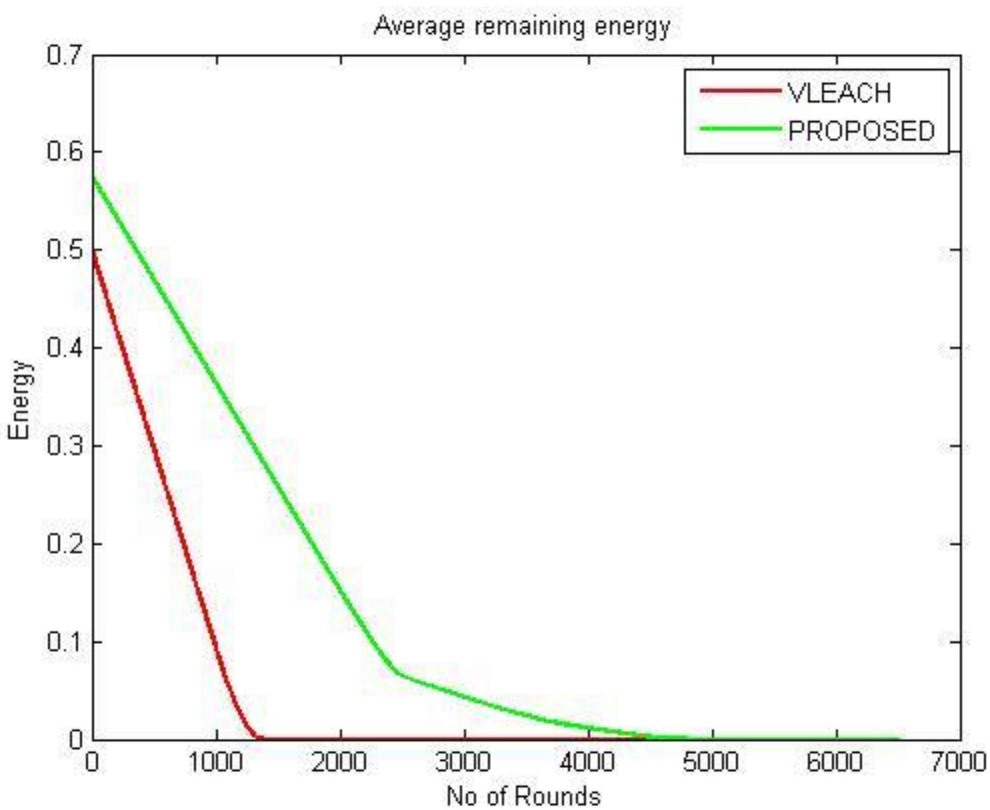

Figure5.7: Average remaining energy analysis

Figure 5.7 has shown the average remaining energy analysis in VLEACH and Proposed Algorithm when the initial energy is 0.5. It is evidently publicised that the VLEACH performs practically correspondingly except when the principal node expires. However, the Proposed algorithm has shown that the first and last node dead time behaves better than VLEACH. Therefore, proposed algorithm has shown a significant improvement over the VLEACH.

CHAPTER 6
CONCLUSION

This dissertation has focused on understanding the existing research on energy consumption problems in heterogeneous WSNs. Much research has been done in WSNs to increase the network lifetime. Many researchers have found many optimized ways to find the optimal clusters. But it is found that the most of the existing researchers has neglected the problem of the mobile sink in heterogeneous WSNs. Therefore, we have modified VLEACH using fuzzy cost. It has been found from the survey that the most of the existing researchers has worked hard to prolong the network lifetime. This has come up with significant improvement over the existing protocols like LEACH. But it is also found that the most of the researchers has neglected many issues. This research work has proposed an improvement for the heterogeneous WSNs using fuzzy based cluster head selection. The VLEACH has used different probability function for selecting the best cluster head by using the residual energy and average energy of the network. But VLEACH has neglected the use of number of neighbours of sensor nodes during cluster head selection. So, this work has proposed new absolute and fuzzy based heterogeneous protocol. The fuzzy cost will be evaluated on the basis of the residual energy and the node centrality. The fuzzy cost will be dynamic in nature as it is evaluated in each round. Due to the limitation of the real time environment this work has done simulation in the well-known MATLAB tool. The comparative analysis has shown the significant improvement of the proposed protocol over others.

REFERENCES

1. W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-Efficient Communication Protocol for Wireless Microsensor Networks,” *Proc. 33rd Hawaii Int. Conf. System Sciences (HICSS)*, 2000.
2. I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless Sensor Networks: A Survey,” *IEEE Communications Magazine*, vol. 40, no. 8, pp. 102–114, 2002.
3. M. J. Handy, M. Haase, and D. Timmermann, “Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection,” *IEEE MWCN Workshop*, 2002.
4. V. Loscri, G. Morabito, and S. Marano, “A Two-Level Hierarchy for Low-Energy Adaptive Clustering Hierarchy (TL-LEACH),” *IEEE Vehicular Technology Conference*, 2005.
5. P. Tillapart, S. Thajchayapong, and K. Keerativoranan, “Hybrid Clustering and Routing Architecture for Wireless Sensor Networks,” *International Conference on IT*, 2005.
6. D. Brinza, E. Gelenbe, and G. Pujolle,“Energy-Efficient Routing Algorithms for Wireless Sensor Networks,” *IEEE ICC*, 2005.
7. J. Chen and H. Shen, “MELEACH-L: More Energy-Efficient LEACH for Large-Scale WSNs,” *International Conference on Communications*, 2008.
8. L. Cheng, C. Chen, J. Ma, and W. Chen, “An Energy-Efficient Weighted Clustering Algorithm for WSNs,” *IEEE WiCOM*, 2008.
9. S. Lindsey and C. S. Raghavendra, “PEGASIS: Power-Efficient Gathering in Sensor Information Systems,” *IEEE Aerospace Conference*, 2002.
10. O. Younis and S. Fahmy “HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks,” *IEEE Transactions on Mobile Computing*, vol. 3, no. 4, pp. 366–379, 2004.

11. H. Karl and A. Willig, “Protocols and Architectures for Wireless Sensor Networks,” *John Wiley & Sons*, 2005.
12. C. Intanagonwiwat, R. Govindan, and D. Estrin, “Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks,” *Proc. ACM MobiCom*, 2000.
13. K. Akkaya and M. Younis, “A Survey on Routing Protocols for Wireless Sensor Networks,” *Ad Hoc Networks*, vol. 3, no. 3, pp. 325–349, 2005.

14. N. A. Pantazis, S. A. Nikolidakis, and D. D. Vergados, "Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 2, pp. 551–591, 2013.
15. J. Nayak and B. Naik, "Fuzzy Logic-Based Clustering Algorithm for Wireless Sensor Networks," *International Journal of Computer Applications*, vol. 43, no. 15, 2012.
16. S. Gupta and P. K. Jana, "Energy Efficient Clustering and Routing Algorithms for Wireless Sensor Networks: A Survey," *International Journal of Computer Applications*, 2015.
17. A. Manjeshwar and D. P. Agrawal, "TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks," *IEEE IPDPS*, 2001.
18. M. Ye, C. Li, G. Chen, and J. Wu "EECS: An Energy Efficient Clustering Scheme in Wireless Sensor Networks," *IEEE International Conference on Performance Computing and Communications*, 2005.
19. S. Selvakennedy, S. Sinnappan, and Y. Shang, "A Modified LEACH Protocol for Wireless Sensor Networks," *IEEE Conference on Advanced Information Networking and Applications Workshops*, 2007.
20. R. Suganya and R. Shanthi "Fuzzy Logic Based Energy Efficient Clustering in Wireless Sensor Networks," *International Journal of Advanced Research in Computer Engineering & Technology*, 2013.