



## **Efficient Energy of Fuzzy based Cluster Routing Protocol in Wireless Sensor Network**

**Puja Deep<sup>1</sup>, Mr. Manoj Singh Tomar<sup>2</sup>**

M. Tech. Scholar, Department of Electronics and Communication Engineering, SORT,  
People's University, Bhopal, India<sup>1</sup>

Associate Professor, Department of Electronics and Communication Engineering, SORT,  
People's University, Bhopal, India<sup>2</sup>

### **Abstract**

Energy efficiency is a critical challenge in Wireless Sensor Networks (WSNs) due to the limited battery capacity of sensor nodes and the high communication cost associated with long-distance data transmission. Traditional clustering protocols such as LEACH often suffer from uneven cluster-head selection, leading to rapid energy depletion and reduced network lifetime. To address these limitations, fuzzy-based cluster routing protocols have emerged as an intelligent and adaptive solution for energy-efficient communication. This study presents an efficient fuzzy-based clustering approach that utilizes multiple decision parameters including residual energy, node density, distance to the base station, and intra-cluster distance to determine optimal cluster-heads. By applying fuzzy inference rules, the proposed method ensures balanced energy consumption, minimizes cluster formation overhead, and enhances routing stability. Simulation analysis demonstrates that the fuzzy-based protocol significantly improves network lifetime, packet delivery ratio, and energy distribution compared to conventional clustering techniques. The results highlight the effectiveness of fuzzy logic in achieving robust, scalable, and energy-aware routing performance in modern WSN applications.

**Keywords:** Routing Protocol, Wireless Sensor Network, Fuzzy System

### **1. INTRODUCTION**

Wireless Sensor Networks (WSNs) have emerged as a powerful technology for real-time monitoring and data collection in various applications such as environmental observation, smart agriculture, healthcare, industrial automation, military surveillance, and smart cities. A WSN typically consists of a large number of small, low-cost, battery-powered sensor nodes deployed randomly or strategically across an environment to sense physical parameters and communicate the collected data to a central Base Station (BS). Despite their wide applicability and flexibility, WSNs face significant challenges primarily due to the limited energy resources of sensor nodes. Since replacing or recharging batteries is often impractical in remote or hazardous environments, energy-efficient communication becomes the most important design goal in WSN routing protocols [1, 2].

Clustering is one of the most efficient mechanisms to reduce communication overhead and balance energy consumption among nodes. In cluster-based routing, sensor nodes are grouped into clusters, and a designated node known as the Cluster Head (CH) is responsible for aggregating data from member nodes and transmitting it to the BS. This hierarchical structure reduces redundant transmissions and improves scalability. Conventional clustering protocols such as LEACH, SEP, and TEEN follow random or probabilistic CH selection strategies, which often lead to suboptimal cluster formation. As a result, nodes with



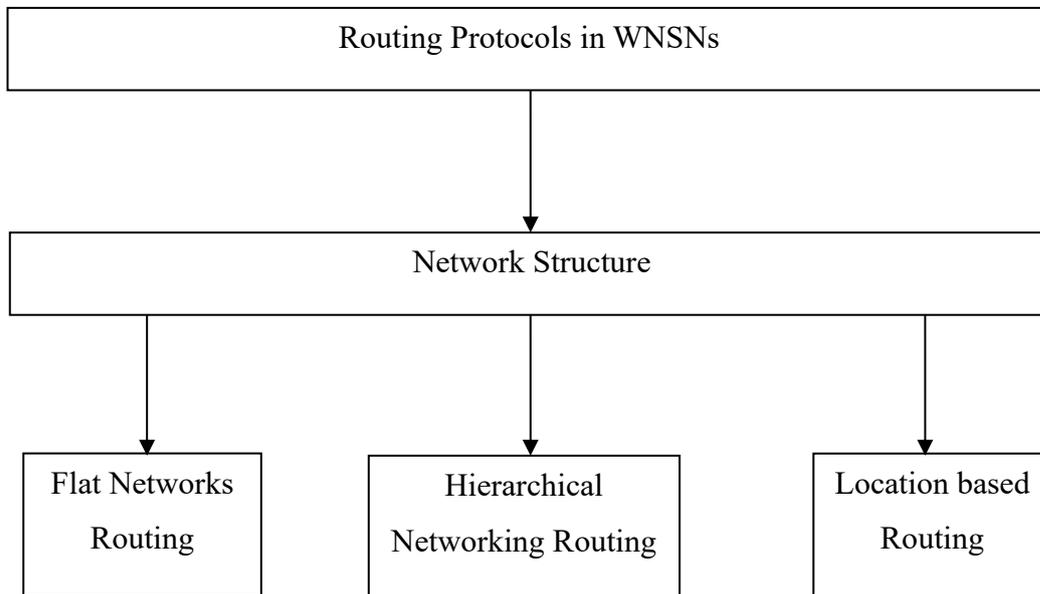


Figure 1: Classification of routing protocols in WSN

In Clustered Architecture, the sensor nodes are logically organized into several clusters depending on the nodes' geographic proximity or other parameters considered by the clustering algorithms [11]. Each cluster is governed by the cluster head node which is yet another sensor node but probably with more energy.

The data communication happens in hierarchical fashion, for example, from cluster member node to respective cluster head node and then from a cluster head node to the Base Station either directly or through some other cluster head nodes.

The advantage of such network architecture is that the overall energy expenditure for data communication is minimized. Moreover the network remains stable while it is scaled up in terms of number of nodes. Figure 2 shows a Clustered Architecture of wireless sensor network.

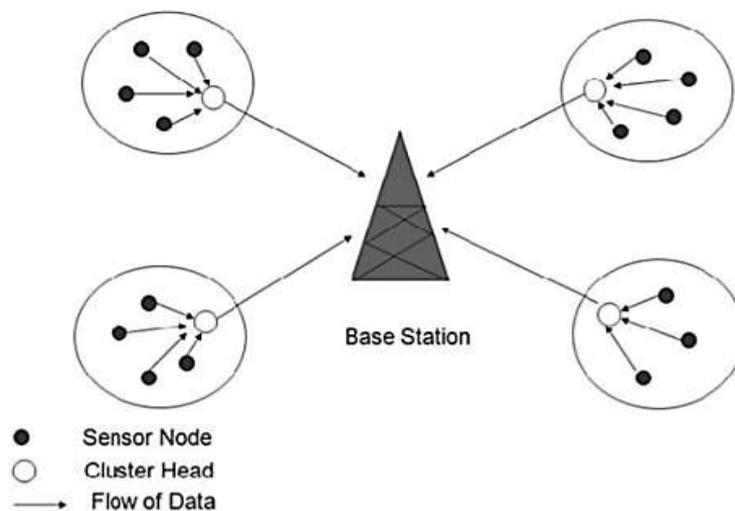


Figure 2: Clustered architecture of wireless sensor network

### 3. PROPOSED METHODOLOGY

The cluster heads are selected from the set of given nodes  $N$  based on probability in the first round and at the end of first round, the residual energy available in the cluster heads are compared with a threshold value. If cluster heads are found to have energy above the threshold, the cluster head selection process is ignored and the existing cluster heads are allowed to continue as cluster head with the same member nodes in the next round. The whole process is repeated until the end of all rounds. This D-LEACH algorithm reduces the number of cluster heads selected and thereby reduced overhead in selection process and minimized energy dissipation in all nodes. The Dynamic cluster head selection algorithm is shown in Figure 3.

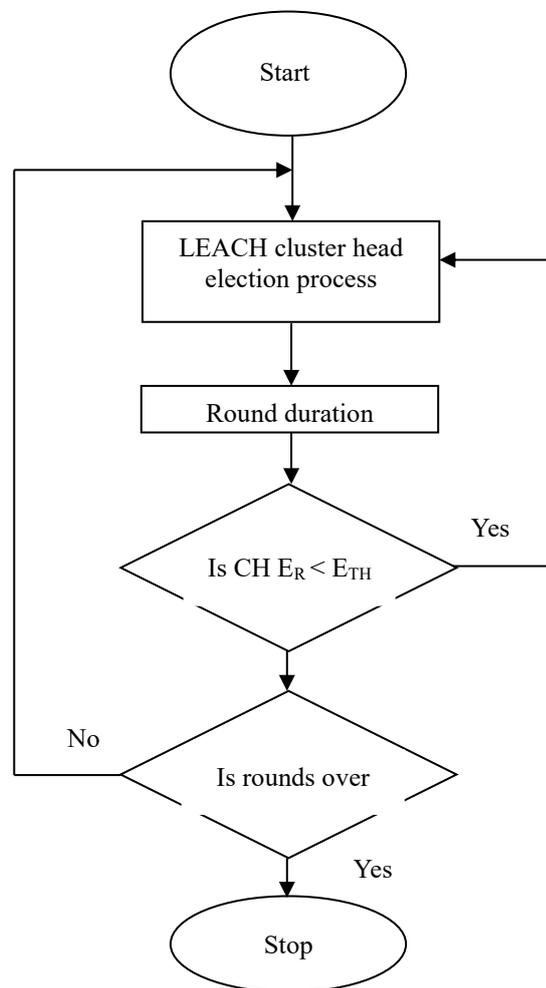


Figure 3: Dynamic Cluster Head Election Algorithm

Assuming the total number of sensor nodes in the network as  $N$  and the probability of cluster heads elected from the set of  $N$  nodes as  $P_{CH}$ , the expected number of Cluster head selected per round  $E(CH)$  in Static LEACH is given by

$$CH_{static} = P_{CH} \times N \quad (1)$$

If the total number of rounds is  $R$ ; then the total number of cluster heads elected in LEACH is given by

$$CH_{LEACH} = P_{CH} \times N \times R \quad (2)$$

Assuming the threshold for residual energy as  $E_{Th}$ , residual energy in nodes as  $E_R$ , and the probability of nodes having energy greater than threshold as  $P(E_R > E_{Th})$ , then the new number of cluster heads selected ( $CH_{New}$ ) in D-LEACH satisfying the condition  $E_R > E_{Th}$  is given by

$$CH_{D-LEACH} = P(E_R > E_{Th}) \times P_{CH} \times N \times R \quad (3)$$

In the set-up phase of D-LEACH protocol, each node decides whether or not become a cluster-head in the first round based on probability, and from second round based on the residual energy of a node. This decision is made by the node  $n$  choosing a random number between 0 and 1. If the number is less than a threshold  $T(n)$  and residual energy greater than pre-set value, the node becomes a cluster-head for the current round. The threshold for the D-LEACH is set as:

$$T(n) = \begin{cases} \frac{p}{1 - p \times (r \times \text{mod}(\frac{1}{p}))} & n \in G \text{ and } E(n) \\ 0 & n \notin G \end{cases} \quad (4)$$

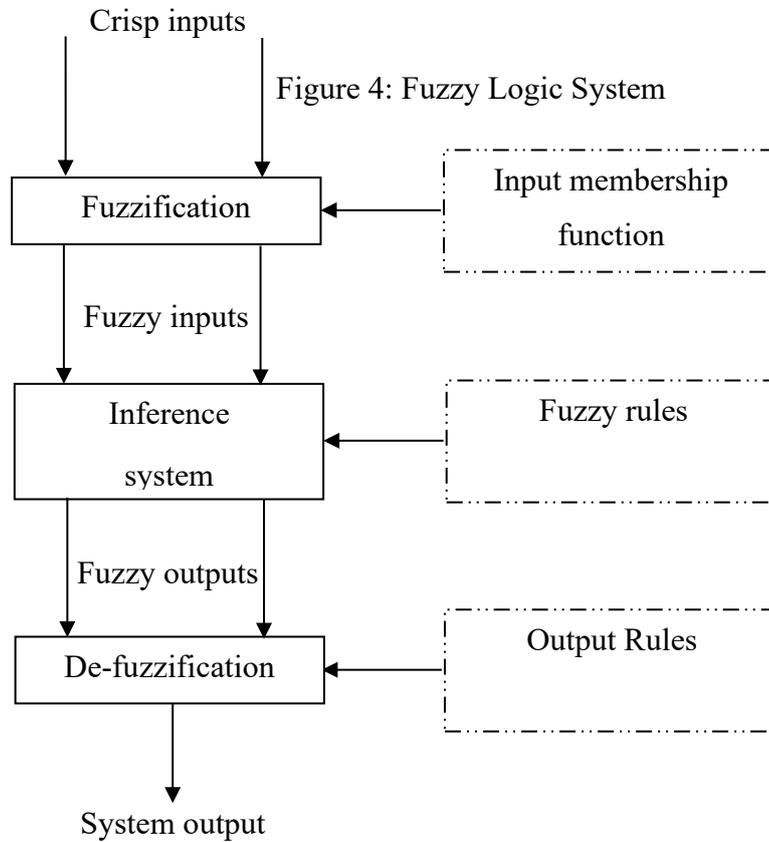
### Fuzzy System

A fuzzy engine, as per figure 4, is typified by the inference system that includes the system rule base, input membership functions that fuzzify the input variables and the output variable de-fuzzification process. Fuzzification is a procedure where crisp input values are represented in terms of the membership function, of the fuzzy sets. The fuzzy logic controller triangular membership functions are defined over the range of the fuzzy input values and linguistically describe the variable's universe of discourse as shown in figure 5.

Following the fuzzification process the inference engine determines the fuzzy output using fuzzy rules that are in the form of if then rules. De-fuzzification is then used to translate the fuzzy output to a crisp value [15].

It is proposed here that the metrics link strength, energy available at a link vertex, and number of hops in a path will be combined into a single decision thereby optimizing a routing protocol over a number of metrics and making it more robust.

Sensor nodes which have high power, memory and processing speed can be used for continuous monitoring.



Sensor nodes with medium power, high memory and high processing speed can be used for event monitoring.

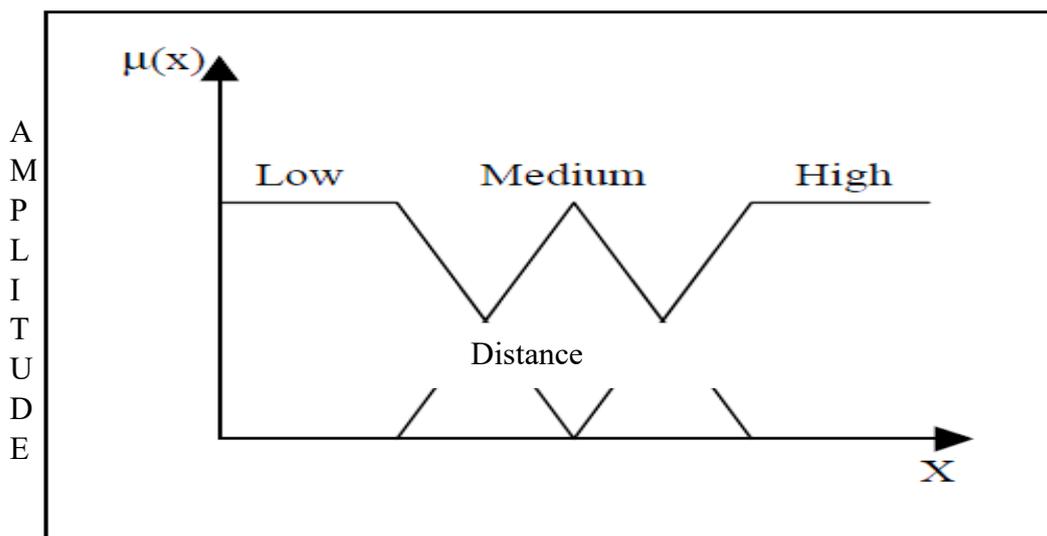


Figure 5: Fuzzy Logic membership Function

Sensor nodes with medium power and low memory and processing speed can be used for critical monitoring. Sensor nodes with low power and low memory and low processing speed cannot be used for monitoring.

The decision to continue with a network broadcast will be determined via a fuzzy logic system with the caching parameters being applied to a fuzzifier that translates them into fuzzy sets.

#### 4. SIMULATION RESULTS

While often referred to as wireless sensor network, they can also control actuators that extend control from cyberspace into the physical world. Recent technological advances in hardware have enabled the deployment of tiny, low power sensors with limited on-board signal processing and wireless communication capacities. Wireless sensor network (WSN) become increasingly useful in variety critical applications, such as environmental monitoring, smart offices, battlefield surveillance, and transportation traffic monitoring.

Round = 1000

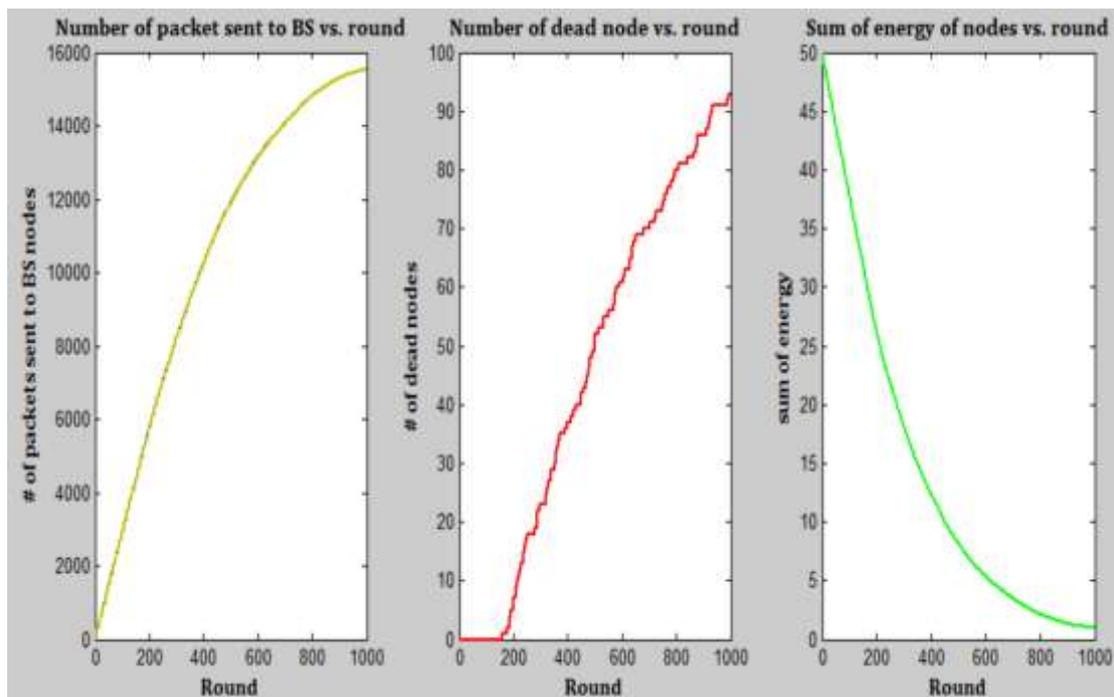


Figure 6: Number of packet sent in 1000 round

1000 rounds vs packets sent to base station (BS) is represented by figure 6 (a). It is clearly that the increase round than increase packet sent to BS station but decrease the sum of energy of nodes is shown in figure 6 (c). 1000 round vs number of dead node is represented by figure 6 (b). Number of dead node is depending on the number of packet send. Usage scenarios for these devices range from real time tracking, to monitoring of environmental conditions, to ubiquitous computing environments, to monitoring of the health of structures or equipment.

1200 rounds vs packets sent to base station (BS) is represented by figure 7 (a). It is clearly that the increase round than increase packet sent to BS station but decrease the sum of energy of nodes is shown in figure 7 (c). 1200 round vs number of dead node is represented by figure

7 (b). Number of dead node is depending on the number of packet send. Usage scenarios for these devices range from real time tracking, to monitoring of environmental conditions, to ubiquitous computing environments, to monitoring of the health of structures or equipment.

Round = 1200

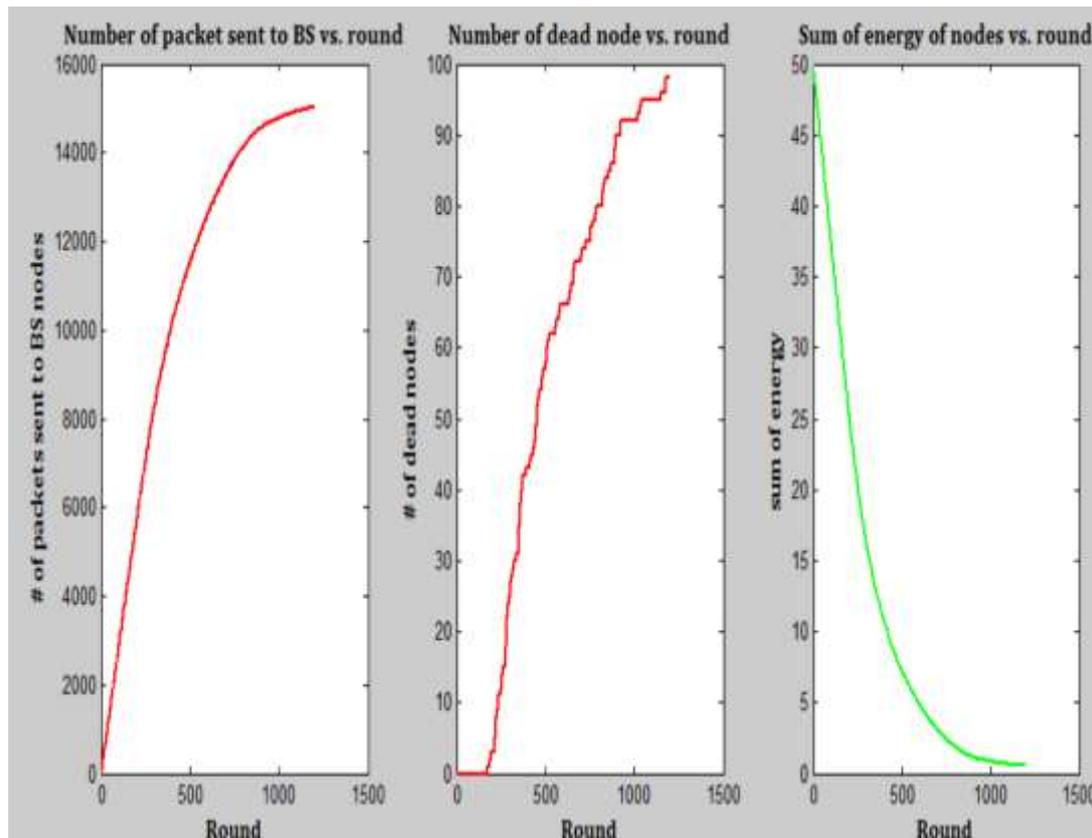


Figure 7: Number of packet sent in 1200 round

We applied our suggested model to measure the concentration of Radon and found that our model gives satisfactory simulation results. Table 1 shows the maximum concentration of Radon measured by the sensors situated at different locations.

Table 1: Packet Sent to Base Station Node

Round	250	500	700	1000	1200
Packet sent	7100	11300	14000	15500	15800

As shown in table 1 the packet sent to base station node are obtained from the proposed dynamic cluster head using fuzzy interference system. From the analysis of the results, it is found that the proposed dynamic cluster head using fuzzy interference system gives a higher packet sent to base station 15800 in 1200 rounds and lower packet sent to base station 7100 in 250 rounds. Sensors facilitate the instrumenting and controlling of factories, offices,

homes, vehicles, cities and the ambiance, especially as commercial off-the-shelf technology becomes available. With sensor network technology ships, aircraft and buildings can “self-detect” structural faults.

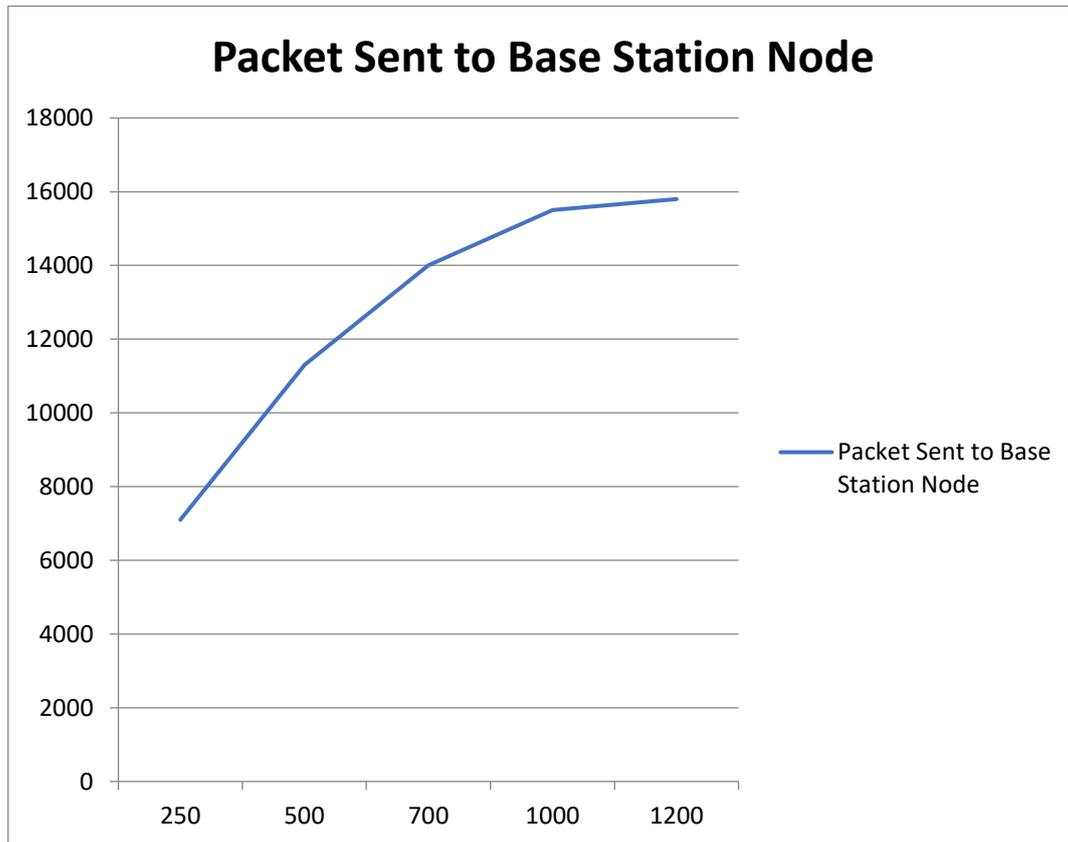


Figure 8: Packet sent to base station node

Figure 8 shows the graphical illustration of the performance of different rounds discussed in this research work in term of packet sent to base station. From the above graphical representation it can be inferred that the proposed dynamic cluster head using fuzzy interference system gives the best performance for rounds 1200.

Table 2: Dead Node vs Round

Round	250	500	700	1000	1200
Dead node	11	58	65	91	93

As shown in table 2 the dead nodes are obtained from the proposed dynamic cluster head using fuzzy interference system. From the analysis of the results, it is found that the proposed dynamic cluster head using fuzzy interference system gives higher dead nodes 93 in 1200 rounds and lower dead nodes 11 in 250 rounds.

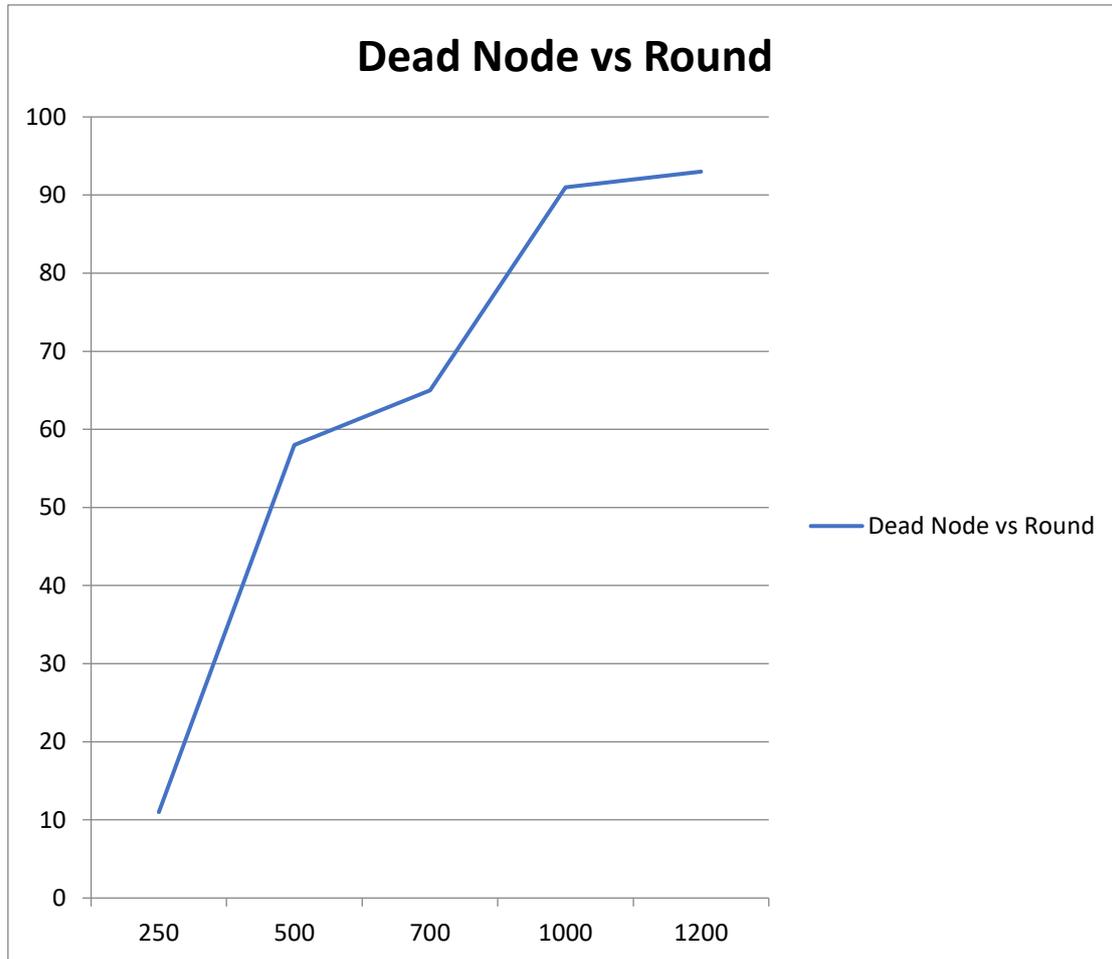


Figure 9: Dead node vs round

Figure 9 shows the graphical illustration of the performance of different rounds discussed in this research work in term of dead nodes. From the above graphical representation it can be inferred that the proposed dynamic cluster head using fuzzy interference system gives the best performance for rounds 250.

Table 3: Sum of Energy vs Round

Round	250	500	700	1000	1200
Sum of energy	22	8	4	2	1

As shown in table 3 the sums of energy are obtained from the proposed dynamic cluster head using fuzzy interference system. From the analysis of the results, it is found that the proposed dynamic cluster head using fuzzy interference system gives higher sum of energy 22 in 250 rounds and lower sum of energy 1 in 1200 rounds.

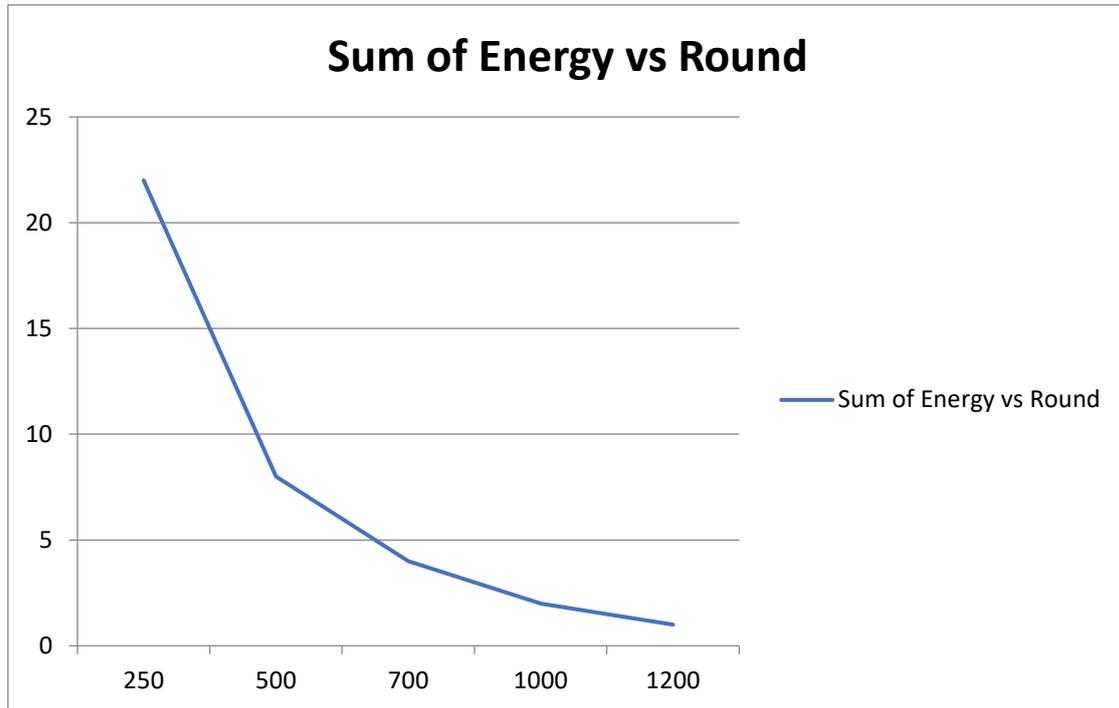


Figure 10: Sum of energy vs round

Figure 10 shows the graphical illustration of the performance of different rounds discussed in this research work in term of energy. From the above graphical representation it can be inferred that the proposed dynamic cluster head using fuzzy interference system gives the best performance for rounds 1200.

## 5. CONCLUSIONS

The study of fuzzy-based cluster routing protocols demonstrates that intelligent decision-making significantly improves energy efficiency and overall performance in Wireless Sensor Networks (WSNs). Traditional clustering approaches such as LEACH, which rely on probabilistic or random cluster-head selection, often lead to unbalanced energy consumption and premature node failure. In contrast, fuzzy logic provides a more adaptive and accurate method by incorporating multiple decision factors—such as residual energy, distance to the base station, node density, and intra-cluster distance—into the cluster-head selection process. By applying a fuzzy inference system, the routing protocol can effectively handle uncertainty and dynamic changes within the network, resulting in more stable clusters and uniform energy distribution.

The findings highlight that fuzzy-based clustering significantly enhances key performance metrics, including network lifetime, packet delivery ratio, and energy utilization. The ability to select the most appropriate cluster heads reduces long-distance transmissions, minimizes communication overhead, and prevents hotspot formation around the base station. Compared to conventional routing protocols, fuzzy-based methods demonstrate superior adaptability in heterogeneous and real-time WSN environments.



The proposed methodology demonstrates that optimized SVM models can significantly improve soil moisture prediction accuracy compared to conventional approaches, reducing water wastage and operational costs. Moreover, the deployment of such models within IoT-based smart farming systems allows continuous monitoring and automated irrigation scheduling, contributing to resource-efficient and sustainable agriculture. Despite these advancements, challenges remain, including model transferability across diverse soil types, data sparsity, and integration of heterogeneous datasets. Future research should focus on hybrid machine learning models, multimodal data fusion, and adaptive algorithms capable of handling dynamic environmental conditions to further enhance prediction reliability. Overall, optimized SVM-based soil moisture estimation provides a promising solution for intelligent irrigation, precision farming, and long-term agricultural sustainability.

## REFERENCES

- [1] M. Umapiya, M. Thanulatha, H. N. Chandana and R. Shashikiran, "Efficient Clustering Algorithm for Wireless Sensor Networks to Optimize the Network Lifetime and Energy," *2025 International Conference on Knowledge Engineering and Communication Systems (ICKECS)*, Chickballapur, India, 2025, pp. 1-7.
- [2] Wenfen Zhang, Yulin Lan Anping Lin, Min Xiao "An Adaptive Clustering Routing Protocol for Wireless Sensor Networks Based on a Novel Memetic Algorithm " *IEEE Sensors Journal*, VOL. 25, No. 5, 01 March 2025.
- [3] Walid Osamy, Bader Alwase, Ahmed Salim, Ahmed M. Khedr and Ahmed Aziz, "LBAS: Load-Balancing Aware Clustering Scheme for IoT-Based Heterogeneous Wireless Sensor Networks.," *IEEE Sensors Journal*, Vol. 24, No. 9, 01 May 2024.
- [4] Laxminarayan Sahoo, J. Shri Supriyan Sen, Kalishankar Tiwary, Sarbast Moslem and Tapan Senapati "Improvement of Wireless Sensor Network Lifetime via Intelligent Clustering Under Uncertainty." *IEEE ACCESS*. 2024. 3365490.
- [5] Duoliang Han, Xiujuan Du and Xiaojing Tian "Fuzzy C-Means Clustering and Improved Arithmetic Optimization AlgorithmBased Layering Cooperative Routing Protocol for UASNs " *IEEE Sensors Journal*, Vol. 24, No. 15, 01 August 2024.
- [6] J. Jayachandran, K. Vimala Dev "ESWC: EER-CGHHOA: A Hybrid Genetic Algorithm Driven Dynamic Clustering for Energy Efficient Routing in Border Surveillance WSNs." *IEEE ACCESS*. 2024. 3438191.
- [7] Muhammad Yeasir Arafat., Sungbum Pan. Eunsang Bak, "Distributed Energy-Efficient Clustering and Routing for Wearable IoT Enabled Wireless Body Area Networks." *IEEE ACCESS*. 2023. 3236403.
- [8] Rachna Sharma, Bhargavi Deshpande "An Efficient Hybrid Routing Scheme with LEACH Protocol for the Enhancement of Lifetime of the Network in WSN " *2023 IEEE 4th Annual Flagship India Council International Subsections Conference (INDISCON)*.
- [9] Rohit Pachlor and Deepti Shrimankar, "LAR-CH: A Cluster-Head Rotation Approach for Sensor networks", *IEEE Sensors Journal*, Volume 18, Issue 23, PP. No. 01-08, Dec.1, 2018.
- [10] M. Bheemalingaiah and M. M. Naidu, "Performance Analysis of Power -aware Node-disjoint Multipath Source Routing in Mobile Ad Hoc Networks", *IEEE 7th International Advance Computing Conference*, PP. No. 361-371, IEEE 2017.



## **International Journal of Research and Technology (IJRT)**

**International Open-Access, Peer-Reviewed, Refereed, Online Journal**

**ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529**

**| An ISO 9001:2015 Certified Journal |**

- [11] Dogan Yildiz, SerapKaragol and Okan Ozgonenel, “A Hyperbolic Location Algorithm for Various Distributions of a Wireless Sensor Networks”, Smart Grid and Cities Congress and Fair (ICSG), 5th International Istanbul, PP. No. 451-459, IEEE 2016.
- [12] Alexandros Ladas, Nikolaos Pavlatos, Nuwan Weerasinghe and Christos Politis, “Multipath Routing Approach to Enhance Resiliency and Scalability in Ad-hoc Networks”, Ad-hoc and Sensor Networking Symposium, PP. No. 01-06, IEEE 2016.
- [13] Pengwu Wan, BenjianHao, Zan Li, Licun Zhou, Mian Zhang, "Time differences of arrival estimation of mixed interference signals using blind source separation based on wireless sensor networks", IET Signal Processing, vol.10, issue 8, pp.924-929, 2016.
- [14] Mohammadi K., Alavi O., Mostafaeipour A., Goudarzi N. And Jalilv and M., "Assessing different parameters estimation methods of Weibull distribution to compute wind power density", ELSE VIER Energy Conversion and Management Journal, Vol.108, pp. 322-335, 2016.
- [15] Miriam Carlos-Mancilla, Ernesto López-Mellado, and Mario Siller, “Wireless Sensor Networks Formation: Approaches and Techniques,” Journal of Sensors, vol. 2016, Article ID 2081902, 18pages, 2016.