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Research Article

Using a Fuzzy Approach as an Assessment Method to Extend the Lifespan of Wireless Sensor Networks using the LEACH Protocol

Janan Farag Yonan [1,*], Ayser Hadi Oleiwi [1]

[1] *University of Information Technology and Communications (UOITC), Baghdad, Iraq.*

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ABSTRACT

Wireless sensor network is the term used to describe a network where network nodes are wirelessly configured to collect data from the real world. Node sensors depend on finite energy sources, such as batteries, because of the wireless configuration they have. If the battery-operated sensor of the node is not charged, it will be unable to carry out its intended function. If a specific amount of nodes fail, the network will cease to function. Several energy-efficient protocols were developed for Wireless Sensor Networks (WSN), including the LEACH Protocol. The LEACH protocol demonstrates a single cluster-based protocol by dividing available sensor nodes into sets and interacting with each set individually. The shape of an energy can be altered by compressing or expanding it, based on the cluster's configuration. We are comparing the network lifespans of three distinct versions of the LEACH protocol that utilize fuzzy techniques for cluster selection with the lifespan of WSNs generated by a previous version of the protocol.

1. INTRODUCTION

Each Wireless Sensor Network (WSN) consists of multiple sensor nodes and a base station. Limitations exist for the three primary elements of sensors: the communication unit, the processing unit, and the sensing unit [1].

In these networks, sensors communicate processed data collected from the workplace to the base station using a transmitter antenna, considering their individual circumstances and skills. In some Wireless Sensor Networks (WSNs), nodes deteriorate rapidly because of the excessive energy consumption from constantly sending data to the central station. Employing routing protocols, including cluster routing protocols, is a common method to delay this process. These protocols utilize clustering, assigning a node as CH (Cluster Head) for every cluster in the network. Typically, the task of transmitting data to the BS lies with the CHs as stated by [2-4].

Fuzzy logic is increasingly utilized in various fields, including Wireless Sensor Networks (WSN). Lotfi A. Zadeh suggested a method that reaches the correct solution without needing complete problem information (uncertainty) and by depending on human intuition and expertise rather than precise data obtained from fuzzy sets. Each variable in fuzzy logic is assigned a value between zero and one to represent its accuracy, as opposed to the traditional method [5-7].

Wireless sensor networks (WSNs) can be classified based on their intended purpose and environmental conditions. In heterogeneous networks, nodes are dynamic and may move, whereas in homogeneous networks, they are static. Fuzzy logic-based clustering is effective in uniform networks.

Some popular routing strategies are Flooding such as in [6-9]. These networks work effectively in restricted locations but struggle to spread as the number of users grow. Hierarchical routing protocols will serve as the only topic of discussion

*Corresponding author. Email: jananfarag@gmail.com

throughout this study on LEACH and its offshoots. Hierarchical routing wastes less power and extends networks better due to its architecture. This protocol classifies nodes as "special nodes," as well as clusters the network. Cluster heads (CHs) take data from nearby nodes, aggregate it, and then compress it before delivering it to the base station. The CH requires more energy as the other cluster nodes since it provides more services. Rotating a cluster to balance energy loss is usual. Heinzelman as well as colleagues [10] proposed LEACH, the initial hierarchical routing protocol. LEACH clusters based on sensor node signal strength.

2. RELATED WORKS

The studies investigates the use of Wireless Sensor Networks (WSNs) in industries like logistics, healthcare, smart environments, and smart cities, emphasizing their importance in sensing and processing environmental data. WSNs use common transmission protocols such as Nb-IoT, Lorawan, IEEE 802.11.x, and IEEE 802.15.x to send sensor data in practical IoT scenarios. Sensor networks' reliability is greatly dependent on Medium Access Control (MAC) protocols, namely Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and Time-Division Multiple Access (TDMA). Markov chain models have been created to assess the efficiency of various access methods on standard MAC layers such as IEEE 802.11 and 802.15.4. Optimizing transmission protocols is essential for sustaining the efficiency of sensor networks. Improving the effectiveness of clustering algorithms, such as Bayesian and optimal clustering algorithms, can be accomplished by utilizing creative strategies such applying fuzzy logic to the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. Current methods frequently neglect the practical issues of sensor node operation and do not offer a functional MAC layer. IEEE standards like as IEEE 802.11 analyze MAC layer modeling using analytic models that rely on Markov chains. These models provide information on node behavior and estimate system throughput by considering packet arrival probability and collision rates. Examining the relationship between retransmission rates and factors such as node density and neighboring node transmission probability is essential for assessing transmission conditions.

Table 1 compares various technologies used in Wireless Sensor Networks (WSNs), including IEEE standards, Bayesian algorithms, fuzzy logic, and Markov chain models. These technologies offer advantages like improved efficiency and predictive analysis, but also have limitations like lack of practical sensor node operation considerations and implementation complexity. This helps in selecting suitable solutions for WSN deployments.

TABLE I. COMPARATIVE ANALYSIS OF TECHNOLOGIES FOR WIRELESS SENSOR NETWORKS.

Source	Technology	Advantages	Disadvantages	Year
[11]	IEEE Standards (802.11, 802.15.x)	- Perception and analysis of environmental data - Utilization of standard transmission protocols (e.g., IEEE 802.11.x, IEEE 802.15.x)	- May not address practical aspects of sensor node operation - Lack of practical MAC layer considerations	2022
[12]	Bayesian and optimized clustering algorithms	- Improved efficiency of clustering algorithms - Potential enhancement of network performance	- Limited practical implementation considerations - Complex implementation of fuzzy logic	2021
[13]	Fuzzy logic applied to LEACH protocol	- Enhanced clustering methodology for CH selection - Utilizes various properties for cluster head selection (e.g., energy, node density, distance)	- Lack of consideration for practical sensor node operation aspects - Complexity increases with additional input parameters	2020
[14], [15]	Analytical models based on Markov chain model	- Insight into node behavior - Predictive analysis of system throughput based on packet arrival probabilities and collision rates	- Limited practical implementation considerations - May not fully capture real-world transmission environments	2019

3. METHODOLOGY

3.1 Adaptive Clustering Protocol with Low Energy Consumption (LACH)

LEACH requires the implementation of the "CR" cluster routing principle. There is a single coordinator node that receives reports from all sensor groups in the network. During the initialization phase of the LEACH protocol, a cluster head is chosen, and nodes share their data in the steady-state phase. The cluster head requires significant energy due to its role in integrating and transmitting data from nodes in the cluster. The LEACH Protocol alternates clusters periodically to provide uniform power distribution (Eq. 1).

$$T(n) = \begin{cases} \frac{P}{1-p\,(r \bmod 1/P)} & if\ n \in G \\ 0 & outherwise \end{cases} \quad (1)$$

Round, The current situation is denoted by the variable r in the previously mentioned equation. Group G members are the nodes in the cluster that were not selected as the head in a previous round. If nodes in set G are available to act as cluster heads, set G becomes the cluster head and any residual node energy is directed there. Every node confirms its inclusion in set G at the start of each cycle by comparing its random value, ranging from zero to one, with a probabilistic threshold. Nodes take on leadership of the cluster temporarily when their pseudo-random values fall below a certain threshold, T(n). Once the heads are chosen, the nodes in a cluster will begin relaying data to them. The Cluster Head (CH) is in charge of gathering and sending data to the base station (BS), where it is merged with other data. Figure 1 displays the flow diagram of the LEACH method.

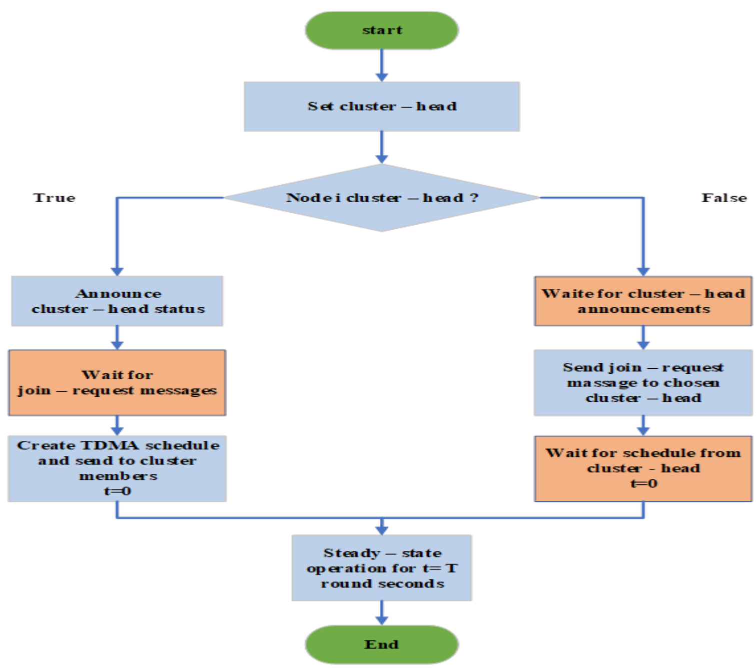

Fig. 1. Flowchart of the LEACH Protocol.

3.2 Fuzzy Logic

Fuzzy logic deviates from traditional binary logic by accommodating ambiguous conditions found in spoken language and other natural contexts. Fuzzy logic uses a Membership Function instead of strict binary logic to indicate that an object belongs to set A based on a single quantity. Lotfi Asker Zadeh introduced the concept of fuzzy sets in 1965. Figures 2 and 3 depict the binary and fuzzy logic representations of the human height range, respectively

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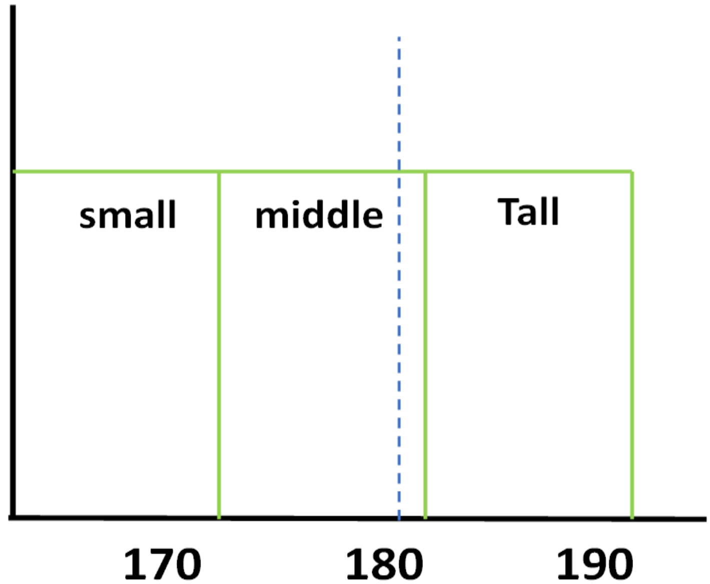

Fig.2. Distances between points in fuzzy and binary logic

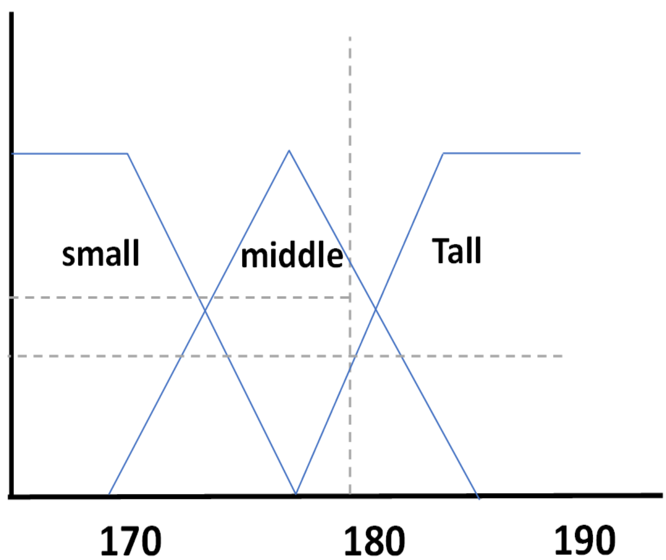

Fig.3. Height intervals in binary and fuzzy logic

A person's height of 179.9 cm falls into the "Middle" category in binary logic because it is below 180 cm and does not qualify as "Tall." As per the measurement rules of fuzzy logic, an individual measuring 179.9 cm can be categorized as belonging to the "Middle" and "Tall" groups.

3.3 Gupta's Fuzzy Logic

Gupta [23] applied fuzzy logic to alter the CH selection criterion of the LEACH Protocol. The fuzzy operation selects the cluster head based on the node's residual energy, density, and centrality, rather than using a random threshold. Below are characteristics of a traditional Mamdani inference-driven fuzzy process.

1. Fuzzify the input variables: by incorporating residual energy, density, and node centrality. Develop a member function that evaluates the compatibility of inputs' fuzzy sets.
2. Evaluating fuzzy rules: involves assigning fuzzy input variables using the rules and deriving the outcome.
3. Aggregated deduced results and rules are produced.
4. normalizing or defuzzifying the generated fuzzy values.

This computation requires the center-of-gravity defuzzification algorithm. Equation 2 displays a comparable equation.

$$COG = \left(\sum \mu_A(X) * X\right) / \sum \mu_A(X) \tag{2}$$

Table 1 displays the input variables (energy, concentration measures, centralized, possibility), while Figures 4, 5, 6, and 7 illustrate the fuzzy set utilized in Gupta's Fuzzy Logic. To determine node density, a square box of 10 meters by 10 meters is drawn with a total span of 20 meters from the central node. The number of vertices within this box is then counted. Gupta's fuzzy logic iteration starts by calculating the probability value of each node. Subsequently, the possibility value is utilized as a criterion for selecting the leaders of each cluster.

TABLE II. VARIABLE INPUT, GUPTA'S FL

Input Variable quantity	**Set Possibility Value**		
E of N	Modest	Moderate	Ascent
concentration gradient of N	Modest	Moderate	Ascent
centralized of N	Modest	Moderate	Ascent

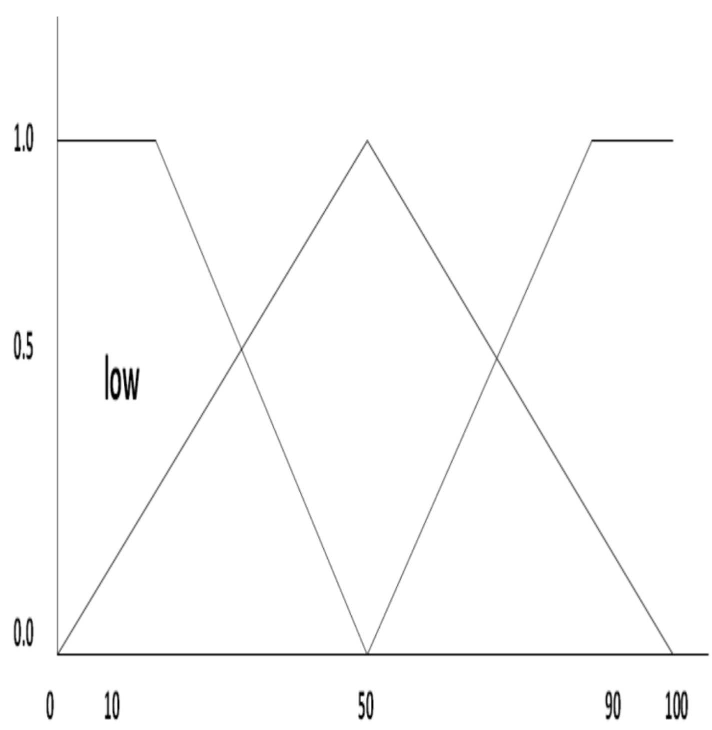

Fig.4. Energy of Gupta's Fuzzy Logic

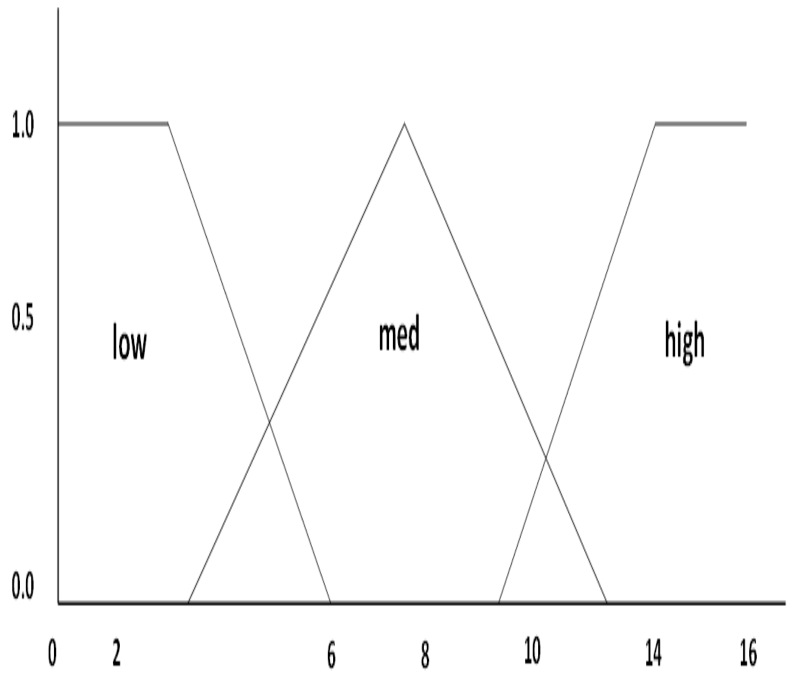

Fig.5. Gupta's Fuzzy Logic concentration metrics

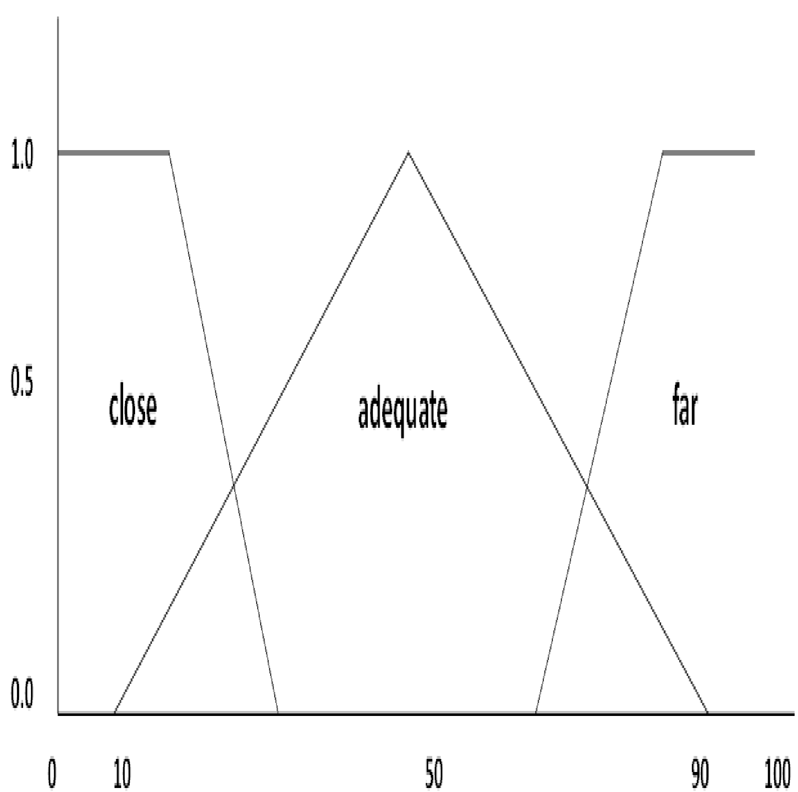

Fig.6. Gupta's Fuzzy Logic Centralization

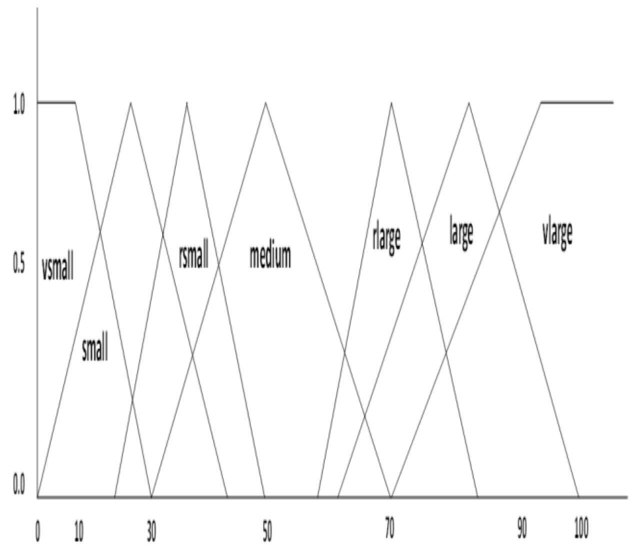

Fig.7. potential application of Gupta's Fuzzy Logic

3.4 CHEF Fuzzy Logic

The CHEF Fuzzy Logic system utilizes the quantity variables and fuzzy groups as presented in Table 2 and Figure 8. A node's centrality is determined by the distances to all other nodes within a specified radius r. Below is an equation that lists the potential values.: (Eq. 3).

$$r = \sqrt{\frac{M}{\pi\, n\, P}} \tag{3}$$

P represents the probability of selecting the cluster head, n is the total number of nodes, and M denotes the sensor space's area.

TABLE III. CHEF'S INPUT VARIABLE

Variable quantity of Input	Possibility Value of Set		
Energy of Node	little	lock	rise
Centrality of Node	lock	adequate	afar

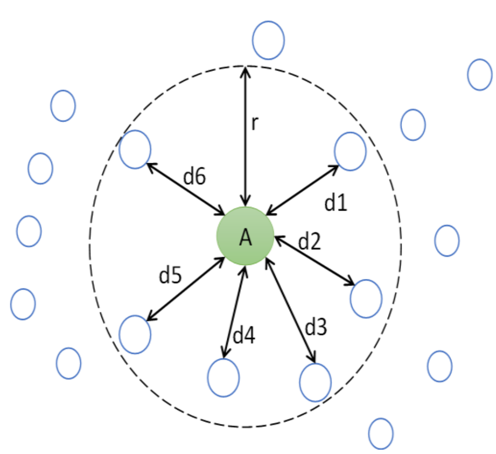

Fig.8. The distances between node A and its neighbors as a function of r.

The CH in CHEF is selected in a manner similar to how it is done in the LEACH Protocol. After selecting a leader, the CH is compared to the probability value of each partner node. The node with the highest value in a cluster gets relocated to the top of the cluster.The LEACH-FL protocol operates similarly to the LEACH protocol. The LEACH Protocol selects the cluster head node by comparing its random number to a random threshold denoted by the symbol T. (n). LEACH-FL selects a cluster head by evaluating a fuzzy probability against T. (n).

3.5 Fuzzy logic with LEACH

Table 3 and Figures 9, 10, 11, and 12 display the LEACH-fuzzy FL logic input variables, such as (distance, node density, battery level, and probability). Utilize the provided fuzzy set and equation that are provided below to determine the fuzzy probability value.

$$Prob.value = (N.Energy) * 2 + (N.\ density) + (2 - N.\ Centr)$$

TABLE IV. ONE INPUT PARAMETER OF LEACH-FL

Variable quantity of Input	Possibility Value of Set		
Energy of Node	little (zero)	medium (one)	rise (two)
Concentration of Node	little (zero)	medium (one)	rise (two)
Centrality of Node	lock (zero)	adequate (one)	afar (two)

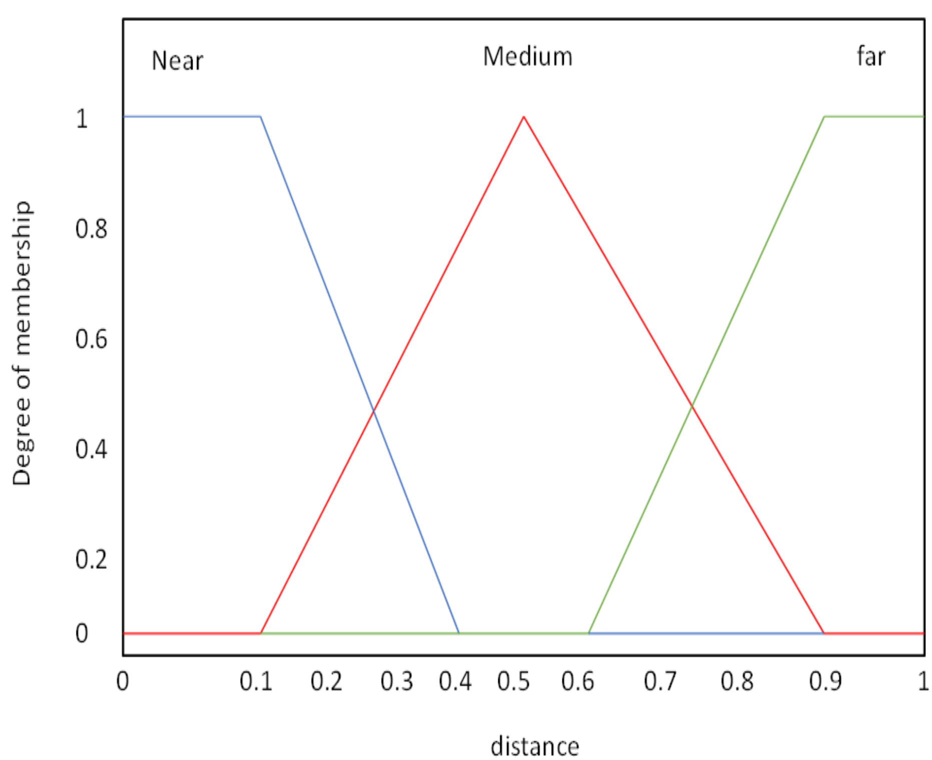

Fig.9. LEACH-FL Distance

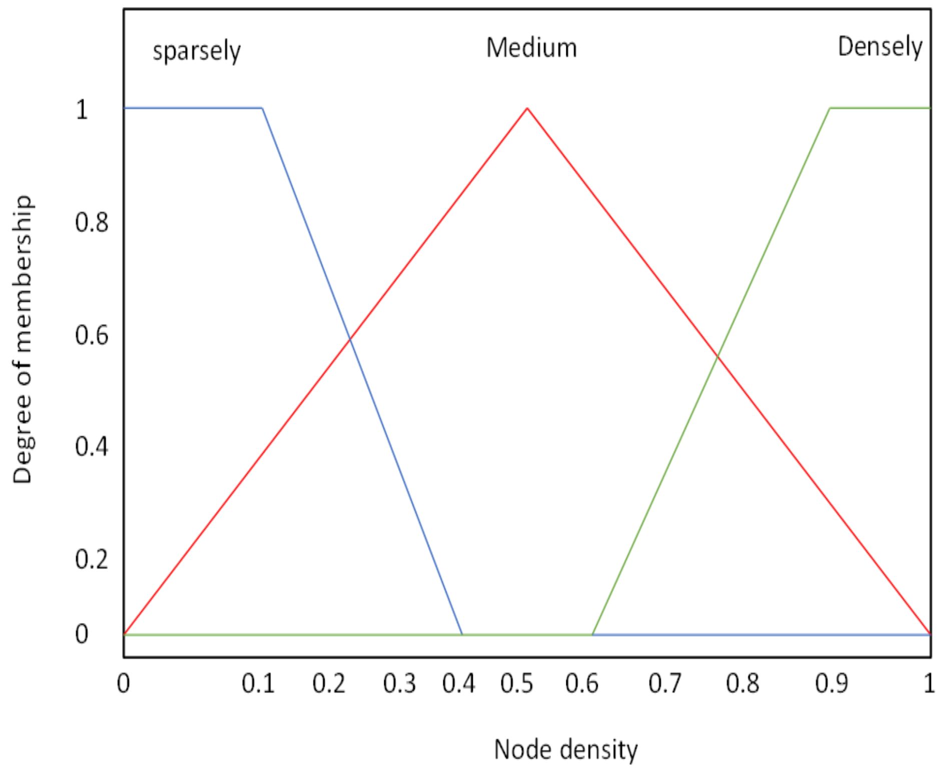

Fig.10. Node density in LEACH-FL

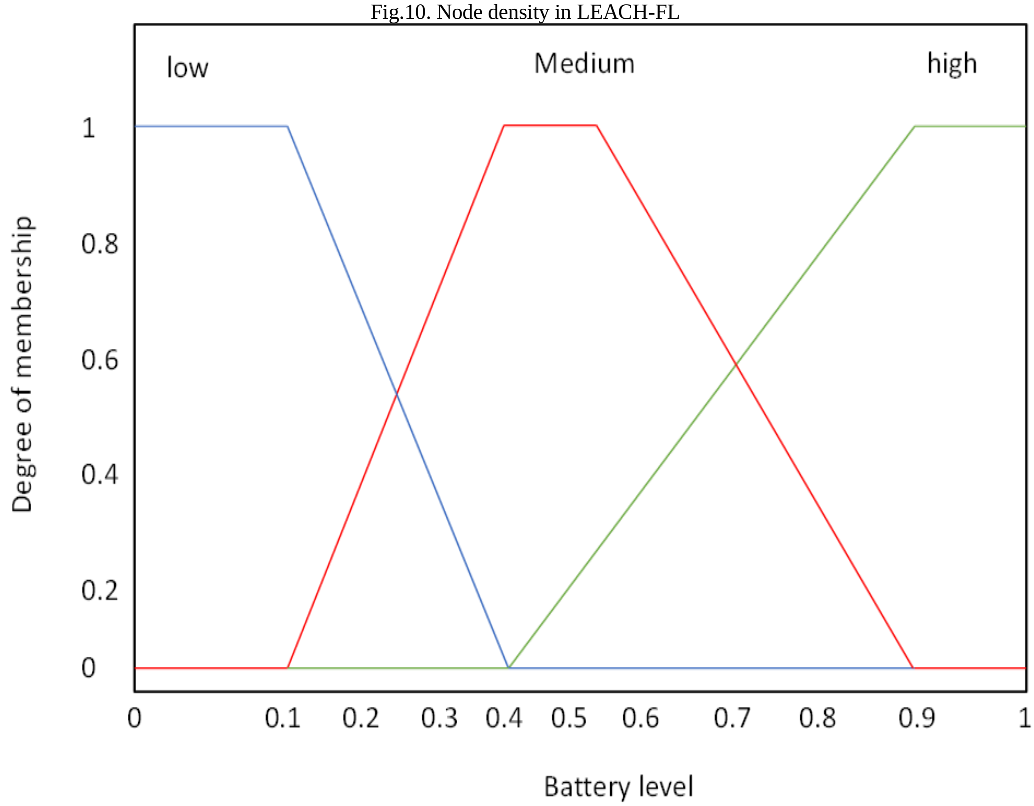

Fig.11. The battery life of LEACH-FL

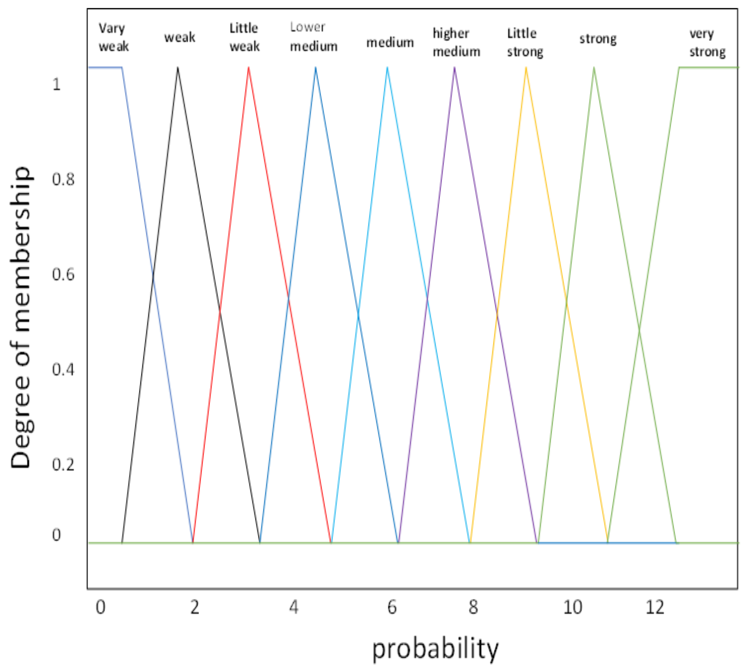

Fig.12 .Likelihood of LEACH-FL

LEACH-FL effectively performs the same functions as the LEACH Protocol. The LEACH Protocol determines the cluster head by comparing a randomly set threshold to the total number of nodes, T(n). LEACH-FL determines the cluster head by comparing the FL probability of the cluster head with T. This is the method it use to choose the leader.

4. SIMULATION AND RESULTS

Table 4 illustrates the impact of the LEACH Protocol, three distinct FL protocols (Fuzzy Logic of Gupta's, CHEF, and LEACH-Fuzzy Logic), and one more protocol on a Wireless Sensor Network (WSN). This simulation was conducted on the assumption that the beam splitter (BS) would be positioned precisely at the geometric center of the sensor area.

TABLE V. PARAMETERS OF THE EMULATION

Parameter	Value
Data Aggregation	5nJ / bit / signal
Radio equipment's loss of energy	50 nJ / bit
Dissipation of energy to operate the radio apparatus	10pJ/bit/m^2
Multiple-path Transmitter Amplifier Model	0.013 pJ /bit /m^2
No. of Sensor N	100
No. of Sens N	100 by 100
No. of Sens N	50 by 50 (base), 50 by 150 (in the road)
Initial E	0.5J

TABLE VI. RESULTS OF EMULATION

	LEACH Protocol	Gupta	CHEF	LEACH-FL
FND	338	258	365	302
80 percent Alive	374	375	404	376
50 percent Alive	407	410	428	406

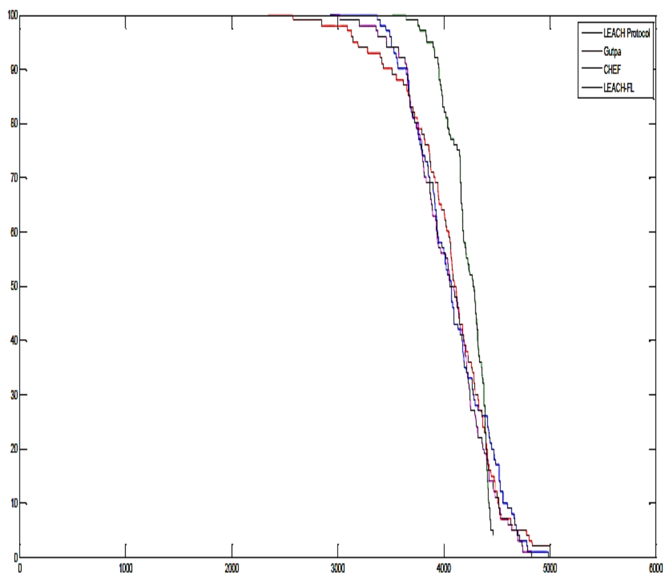

Fig.13. Fuzzy logic was used to find three Results .

The LEACH CHEF algorithm produced the best results when the base station was positioned at the center of a sensor zone, as indicated in Table 5. Our conclusions were based on the outcomes of our comparison.; see Figure 14.

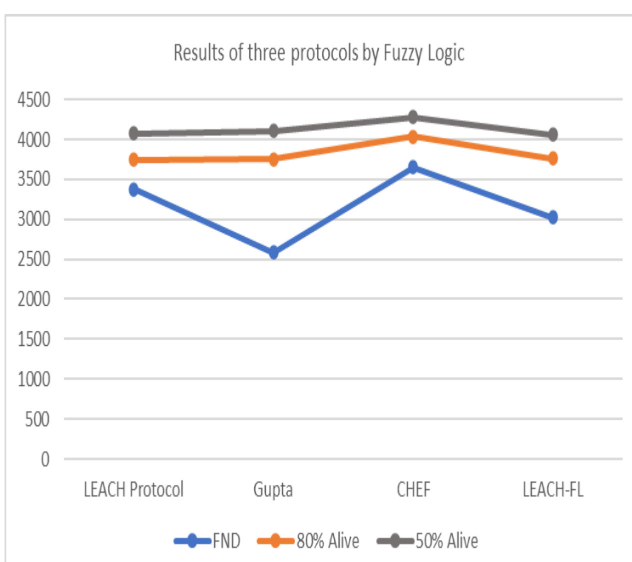

Fig.14. Three protocols via Fuzzy Logic

The defuzzification module determines its values by the centroid methodology, which involves summing up the outcomes of all rules. Our concept is fundamentally rooted in the Mamdani method [24]. Each node in the Wireless Sensor Network (WSN) calculates the probability value (Prob) to be utilized in the Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm instead of a random integer. During each iteration of the process, nodes with Prob values below the threshold are designated as cluster heads. After evaluating the findings of our model and comparing them to other models, we concluded that our model is superior overall. Figure 15 illustrates the comparison between the first dead node of the suggested model and 50% alive with findings from previous studies.

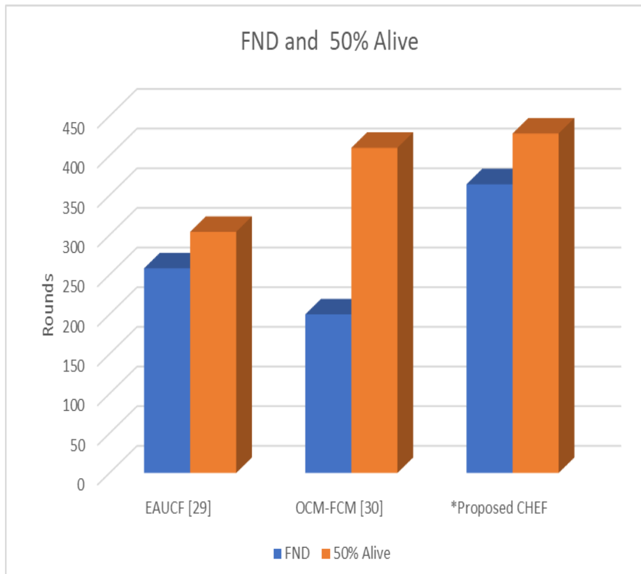

Fig.15. Comparison FND as will as 50% alive for 100 nodes.

5. CONCLUSIONS

Ultimately, a WSN aims to reduce the network's overall energy footprint while increasing its lifetime. This method proposes a new way to cluster WSNs using FL. Based on the simulation results, CHEF shown the greatest potential for extending the lifetime of a network out of the three Fuzzy Logic protocols examined in this study. By utilizing the LEACH protocol's threshold equation T in a unique way, CHEF is able to adjust the cluster according to the position of the base station (n). The fact that clusters persist after the primary node has been moved has been shown in a number of studies. Consequently, if the base station is situated in an open external zone, both LEACH-FL and Gupta's Fuzzy Logic are likely to fail. Methods to expand fuzzy logic systems in terms of both size and number of nodes will be the focus of our future research. We will also explore alternative tactics and compare them to our methodology to find out whether there are better ways to increase the lifetime of WSN.

Conflicts of Interest

The author declares no conflicts of interest with regard to the subject matter or findings of the research.

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