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E-FLEACH: An Improved Fuzzy Based Clustering Protocol for Wireless Sensor Network

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Abstract
Clustering is one of the most energy-efficient techniques for extending the lifetime of wireless sensor networks (WSNs). In a clustered WSN, each sensor node transmits the data acquired from the sensing field to the leader node (cluster head). The cluster head (CH) is in charge of aggregating and routing the collected data to the Base station (BS) of the deployed network. Thereby, the selection of the optimum CH is still a crucial issue to reduce the consumed energy in each node and extend the network lifetime. To determine the optimal number of CHs, this paper proposes an Enhanced Fuzzy-based LEACH (E-FLEACH) protocol based on the Fuzzy Logic Controller (FLC). The FLC system relies on three inputs: the residual energy of each node, the distance of each node from the base station (sink node), as well as the node's centrality. The proposed protocol is implemented using the Castalia simulator in conjunction with OMNET++, and simulation results indicate that the proposed protocol outperforms the traditional LEACH protocol in terms of network lifetime, energy consumption, and stability.

KEYWORDS: Base Station, Cluster Head, Cluster Members, Castalia, FIS, LEACH, OMNET++.

I. Introduction

In today's world, tremendous advancements in sensor equipment technology have resulted in significant implementation capabilities for a variety of applications, including underwater monitoring, health monitoring, smart infrastructure monitoring, tracking, multi-media, and surveillance, opening up new opportunities for integrating them with technologies such as Unmanned Aerial Vehicles (UAVs),5G, and Internet of Things (IoTs)applications [1–3].

Sensors are deployed around the field of interest in WSNs to collect data and monitor global and local environmental conditions. A sensor node is composed of several small, low-cost, and low-power electronic devices, including a battery, sensing unit, storage unit, processing unit, and. communication unit. On the other hand, these nodes have limitations in terms of sensing range, power consumption, and communication range, in addition to storage, processing, and computing resources. Thus, energy-efficient routing protocols are critical for sensor networks.

Numerous cluster-based routing protocols are used to optimize the energy efficiency of WSNs. Thereby this could make a significant contribution to the energy efficiency, stability, and scalability of Wireless Sensor networks. [4].One of the most well-known protocols is the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [5], focuses on adaptive clustering to optimize energy consumption. It can be thought of as a benchmark of a clustering routing protocol in WSNs and MANETs, where nodes in the network field are separated into clusters. Each cluster has one node known as the cluster head (CH), which is chosen randomly. On the contrary, while LEACH retains energy from sensor nodes, its energy efficiency is still somewhat disadvantaged due to random, faster power drain, particularly where smaller nodes per cluster are induced by the unequal distribution of nodes in clusters and time limit due to the use of the TDMA MAC Protocol [5, 6].

Specifically, applying and utilizing fuzzy logic theory in WSN is a powerful and successful way because it supports a more effective combination in evaluating several network parameters. Therefore, this paper proposes an Enhanced Fuzzy based LEACH protocol, namely E-FLEACH, through utilizing a fuzzy logic controller that significantly increases the network lifetime and decreases the number of dead nodes during its rounds. The enhanced LEACH protocol relies on the Type1-Fuzzy Inference Method (T1-FIS) to choose the CHs. The CHs are chosen based on three parameters: (i) residual energy (REN), (ii) the distance between the node and the Base Station (DBS), and (iii) the centrality of the node (CEN).

The rest of this paper will be structured as follows. Firstly, the related works are addressed in Section 2. In Section 3, the network model is discussed. In Section 4, the proposed E-FLEACH protocol is described in detail. Section 5 displays and discusses the simulation results. Finally, in Section 6, the conclusion has been drawn.

II. Related Work

Routing protocol design is a very popular field of research that probably contributed to network lifetime extension. Recently, many research have examined the routing and energy consumption issues associated with WSNs. Numerous intelligent methods, such as Bat Algorithm (BA), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Practical Swarm Optimization (PSO), and Flower Pollination Algorithm (FPA) [7–13] were efficiently utilized as optimization techniques in reducing the energy consumption of WSNs and thus extending the network's lifetime. Meanwhile, others have suggested the use of neuro-fuzzy and deep learning approaches to optimize the performance of the cluster-based routing protocol. Several of these issues include the following: K. Thangaramya [14], proposes to improve the efficiency of LEACH protocol routing efficiency. Additionally, in [15] Y. S. Thakur reveals an efficient method for enhancing the reliability of energy irregularity models through the use of fuzzy deep learning.

On the other hand, since there's no mathematical model defining the relationship between network lifetime and node parameters, the fuzzy logic scheme was found to be the optimal solution to this problem.

Numerous researchers have emphasized the importance of Fuzzy Logic (FL) in the decision-making of the CH selection in WSNs. Among these, recent research are introduced by the authors in [16]; they develop a fuzzy-based clustering algorithm for determining the cluster head (CH) based on the residual energy and the Received Signal Strength Indicator (RSSI) of each node. The proposed methodology operates on rounds, corresponding to the LEACH. Also, Lata et al. [17] proposed the LEACH-Fuzzy Clustering (LEACH-FC) protocol and implemented it to optimize the network's lifetime through cluster head selection and cluster formation. The suggested protocol has been demonstrated to be effective at balancing the energy load on each node, hence increasing the reliability of WSN. Additionally, the authors in [18, 19] introduced several cluster head (CH) selection algorithms based on Type 1 fuzzy logic, each of which uses effective parameters such as residual energy, distance to the Base Station (BS), and others as an input parameter to the fuzzy inference system in order to determine the optimal solution for selecting suitable CHs and cluster formation.

In contrast to the previous works, which used MATLAB to simulate the proposed Fuzzy-LEACH protocol, this research uses a realistic event-driven simulator called Castalia, which is built on the OMNET++ [20]. The purpose of this research is to offer an energy-efficient protocol based on a FIS for extending the network's lifetime and increasing data transmission efficiency. The Enhanced Fuzzy-LEACH methodology determines the cluster head by integrating the residual energy and distance of each node from the Base Station (BS), as well as the node's centrality. Which act as fuzzy logic descriptors to generate a "chance" value for that node during the CH election process.

III. Network Model

In general, the network model required to implement the traditional LEACH and Enhanced-FLEACH is depicted in Fig. 1.

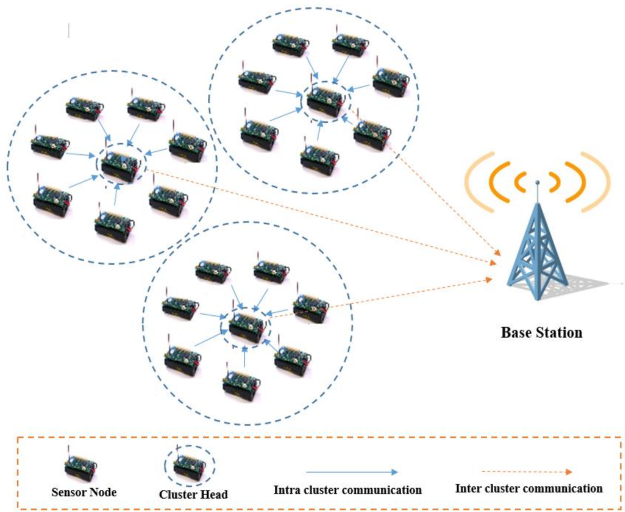


Fig. 1: A General Structure of The Network Model.

Thus the criteria for the network model based on the proposed protocol are considered as follows:

1. N Sensor Nodes are dispersed uniformly over a M X M interesting area and that all nodes and BS are stationary (non-mobile).
2. All sensor nodes are capable of sensing, aggregating, and transmitting data to the BS (i.e., acts as a sink node).
3. The nodes in the network are not chargeable and are homogeneous in terms of initial energy.
4. The Sink Node (BS) is positioned in the network field's center. The communication links between the nodes are frequently believed to be symmetrical. Thus, in terms of packet transmission, the data rate and energy consumption of any two nodes are symmetrical.
5. The nodes are operated in power control mode, with the receiving distance from the node controlling the power output.
6. During each round of the Set-Up phase, cluster heads are still randomly picked but with the addition of fuzzy logic criteria to improve the LEACH protocol's CHs selection process.

IV. The Proposed E-FLEACH Protocol

In general, the CH and its members consume energy while sensing, processing, and communicating. The disadvantage of clustering procedures is that they are probabilistic. Occasionally, they choose two cluster heads for two distinct clusters that are quite close to one another, resulting in a head located at the cluster's edge in some situations. This approach of selecting cluster heads caused a reduction in overall energy efficiency [17]. Therefore, Fuzzy Inference Systems (FIS) and fuzzy decision rules for intelligent CH selection have been introduced to avoid random selection of CHs and to determine the optimal number of selected CHs, as well as to resolve the complexities associated with describing the precise mathematical model of the relationship between network lifetime and node parameters.

a fuzzy logic cluster head selection method is proposed based on three effective parameters: residual energy of each node, distance to BS, and the node's centrality. Indeed, the node with the highest energy, the shortest distance to the BS, and the lowest centrality has the best chance of being chosen as the cluster head. The fuzzy inference system is described in detail below, along with the suggested protocol's operation.

A. *Type 1 FIS*

In our proposal, the Mamdani approach is utilized as a FIS due to its simplicity. The Fuzzy Logic Controller's (FLC) rule is to calculate the probability of selecting a CH given three input descriptors, as illustrated in Fig. 2. This controller has three specified inputs: (i) Residual Energy (REN) and (ii) the distance between each node and the Base Station (DBS), and (iii) the node's centrality. The output of the FIS represents the chance (Fuzzy cost) of each node to be selected as a CH.

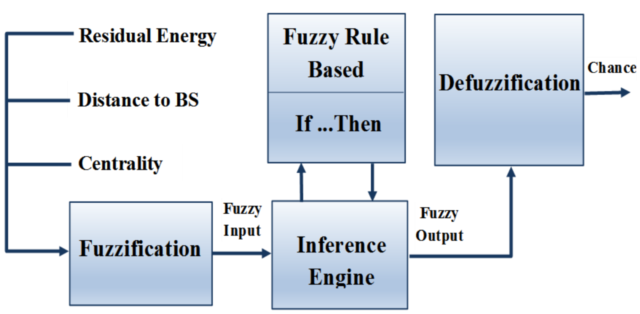


Fig. 2: Fuzzy Inference System.

Our suggested technique utilizes three fuzzy inputs and if-then fuzzy rules to determine the probability of a node being CH. The following definitions apply to the fuzzy inputs:

1- **Residual Energy (REN):** Nodes with a high REN have a good chance of being selected as CHs.

2- The distance between the node and the Base Station (DBS): Nodes that are near to the BS have a more chance of being selected as CHs.
Each node's Euclidian distance from the BS is computed as in Eq. (1):

$$DBS = \sqrt{(x_{Node} - x_{BS})^2 + (y_{Node} - y_{BS})^2} \quad (1)$$

3-Centrality (CEN): The centrality of the node can be defined as the total of distances between nodes within a certain range R of the node, thus, the range R is given by Eq. (2):

$$R = \sqrt{\frac{M}{\pi N\ P}} \quad (2)$$

Where M is the sensor space's size, *P* is the Probability of CHs selection, and N is the total number of nodes. The centrality of any node can be calculated simply by Eq. (3):

$$CEN = d1 + d2 + d3 + \cdots . + dm \quad (3)$$

Fig.3 explains the concept of node centrality. The node with less centrality has a higher chance to be selected as CH.

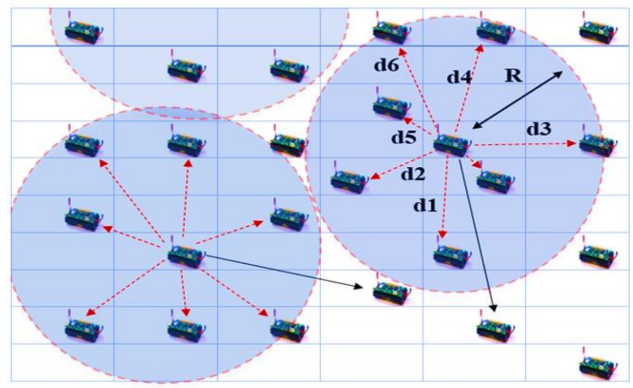
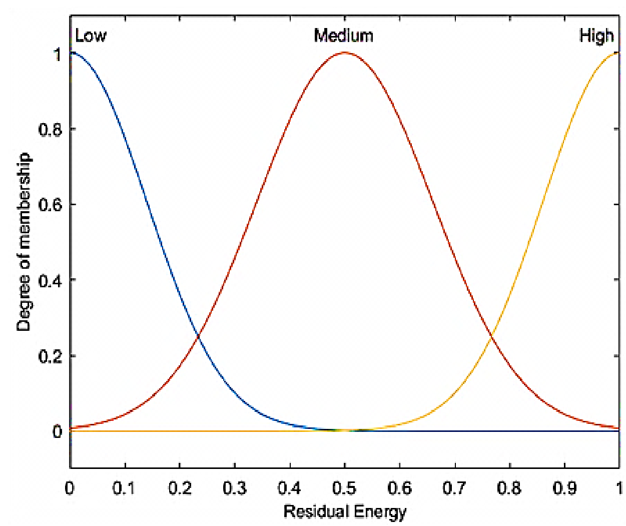


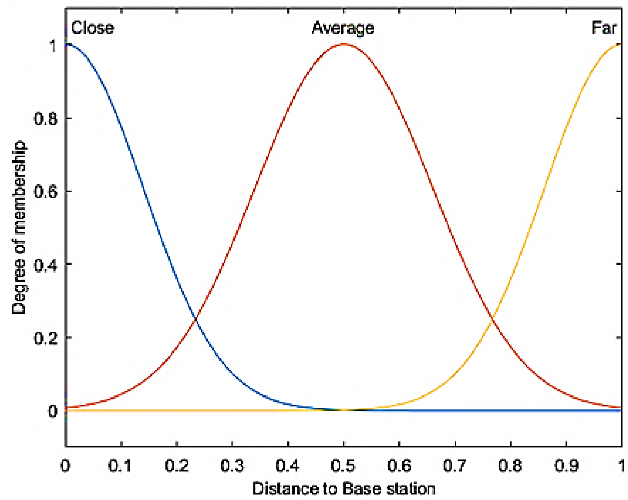
Fig. 3: Node Centrality.

The three distinct parameters REN, DBS, and CEN are normalized with the universe set to [0, 1], and Gaussian membership functions are employed for the input linguistic variables, as illustrated in Fig. 4. Additionally, Table I illustrates the linguistic variables for the Input/ Output MFs. Meanwhile, each of the input parameters is divided into three MFs, necessitating the use of 3^3 = 27 of the rules, which are listed in Table II.

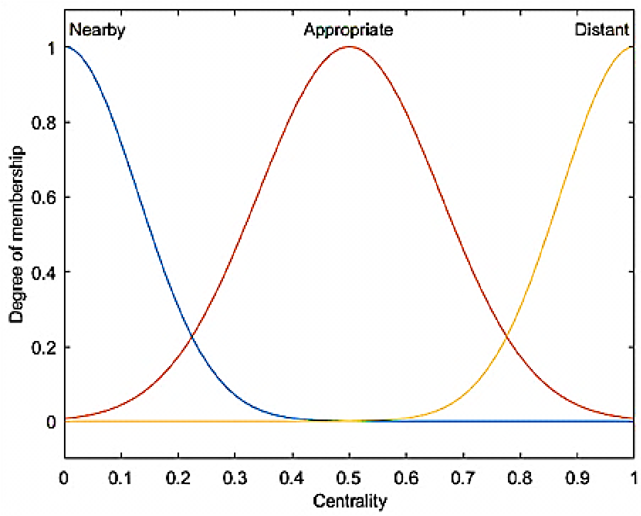


(a) MFs of Input Variable REN.

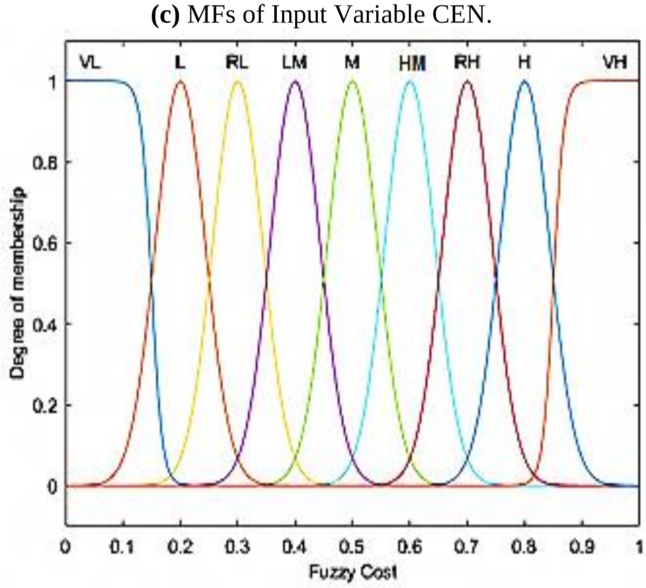
Fig. 4**:** Fuzzy Inference System of Proposed Algorithm with MFs of Input Variables REN, DBS, CEN, and output.



(b) MFs of Input Variable DBS.



(c) MFs of Input Variable CEN.



(d) MFs of the output variable.

Fig. 4**:** Continued.

TABLE I
TS /OUTPUT LINGUISTIC VARIABLES.

Parameter	**Linguistic Variable**
Residual Energy (RE)	Low (LW), Medium (MD), High (HG)
Distance to BS (DB)	Close (CL), Average (AV), Far (FA)
Centrality (CEN)	Nearby (NE), appropriate (AP), Distant (DS)
Chance	Very Low (VL), Low (L), Rather Low (RL), Low Medium (LM), Medium (M), High Medium (HM), Rather High(RH), High(H), Very High(VH).

TABLE II
FUZZY RULES

Rule No.	**REN**	**DBS**	**CEN**	**Chance**
1	LW	CL	NE	RL
2	LW	CL	AP	L
3	LW	CL	DS	VL
4	LW	AV	NE	RL
5	LW	AV	AP	L
6	LW	AV	DS	VL
7	LW	FA	NE	RL
8	LW	FA	AP	L
9	LW	FA	DS	VL
10	MD	CL	NE	HM
11	MD	CL	AP	M
12	MD	CL	DS	LM
13	MD	AV	NE	HM
14	MD	AV	AP	M
15	MD	AV	DS	LM
16	MD	FA	NE	HM
17	MD	FA	AP	M
18	MD	FA	DS	LM
19	HG	CL	NE	VH
20	HG	CL	AP	H
21	HG	CL	DS	RH
22	HG	AV	NE	VH
23	HG	AV	AP	H
24	HG	AV	DS	RH
25	HG	FA	NE	VH
26	HG	FA	AP	H
27	HG	FA	DS	RH

B. The Proposed Protocol

In this subsection, we describe a cluster head selection technique based on residual energy, distance to BS, and the centrality of each node utilizing a fuzzy logic system along with a modified threshold equation. The suggested protocol operates on a round basis, similar to the LEACH protocol. Each round consists of a setup phase and a steady-state phase, during the setup phase, CHs are selected, established, and each CH assigns a TDMA schedule to the members of its cluster.

i. SET-UP Phase

1- Cluster Head Selection: Due to the random selection of CHs in traditional LEACH and the probability of a being a CH remaining equal for each node, resulting in an energy imbalance in the network after several rounds. We develop a new modified threshold for the (E-FLEACH) protocol that takes into account the sensor node's energy score and the probability of becoming the cluster head. The new threshold, T_{new}(node) can be expressed as follows:

$$T_{new}(node) = \frac{K}{N}\left(\frac{1}{1-\frac{K}{N}\left(r \bmod \frac{N}{K}\right)} + \frac{E_{node}}{E_{max}}\right) \quad (4)$$

where K and N represent the total number of CHs and the total number of nodes, respectively. The ratio $\frac{K}{N}$ represents the percentage of nodes to be selected as CHs (P). Also, r is the current round, and E_s is the remaining energy of the sensor nodes. Finally, E_{max} indicates the maximum energy.

The pseudo-code description of the E-FLEACH protocol is shown in Algorithm 1. The BS initiates the setup phase by broadcasting an advertisement (ADV) message with a specified power level to all sensor nodes. Based on the received signal strength (RSSI), each sensor node is capable of calculating its distance to the base station (DBS), the residual energy (REN), and centrality (CEN). They are used to calculate the membership functions for a fuzzy inference system (FIS). The "chance" value for each node can be derived from the FIS output. If a node's probability is smaller than the modified threshold and it satisfies the "chance" requirement, node i becomes the CH for the current round.

2- Cluster Formation: Once the CHs are elected, they broadcast ADV messages to the rest of the sensors using Carrier Sense Multiple Access (CSMA) MAC protocol. Non-CHs must maintain their receivers throughout the setup phase to hear all CHs' ADV messages. After this phase is complete, each sensor determines which cluster it belongs based on the RSSI value. Meanwhile, each sensor node (SN) transmits Joint Request (JOIN-REQ) messages to its corresponding CH using CSMA.

3- Schedule Creation: Each CH node generates a Time Division Multiple Access (TDMA) schedule by the number of JOINT-REQ messages received. The schedule is broadcast back to the cluster's nodes to inform them when they can transmit.

ii. Steady-State Phase

During the steady-state phase, each sensor node transmits its data to the CH during its assigned time slot, where it is aggregated and sent to the BS.

Algorithm 1: The Proposed E-FLEACH Protocol

1: Begin
2: Read the network configuration
3: For i=1: N
4: Run The proposed fuzzy system
5: Define the FIS input parameters REN, DBS, CEN
6: Execute FIS based on the rule base
7: Obtain the chance of sensor node i
8: $T_{new}(i) = \frac{K}{N}\left(\frac{1}{1-\frac{K}{N}\left(r \bmod \frac{N}{K}\right)} + \frac{E_i}{E_{max}}\right)$
9: If (rand (0,1) < $T_{new}(i)$ && chance ≥ Q) Then
10: CH_i : Broadcast ADV Message.
11: CH_i : Receive JOIN-REQ Message.
12: CH_i : Broadcast TDMA Schedule.
13: CH_i : Receive data from CM_m.
14: CH_i : Send the aggregated data to the BS.
15: else
16: $NON-CH_i$: Receive ADV Messages from CHs.
17: $NON-CH_i$: Send JOIN-REQ Message to its CH.
18: $NON-CH_i$: Receive TDMA Schedule.
19: $NON-CH_i$: sends data within its time slot.
20: $NON-CH_i$: Sleep.
21: End if
22: End For
23: End

V. Simulation Results

The performance evaluation of the E- FLEACH protocol is discussed in this section using the Castalia simulator and OMNET++. The network of our simulations consists of 100 sensor nodes spread uniformly over an area of 100*100m^2. We consider the base station to be in the (50,50). Initial energy for all nodes is 3Joule. Moreover, Table III describes the environmental network parameters used in the simulation.

TABLE III
SIMULATION PARAMETERS

Parameter	Value
Network Size	100*100 m^2
No. of Nodes	100
Percentage of CHs	0.05
Location of BS	(50,50)
Radio Model	CC2420
Simulation time	300s
Round time	20s
Data Packet Size	2000 Bytes
Packet Header Size	25 Bytes

Experiment Case 1:

Fig. 5 illustrates the First Node Dead (FND), Half Nodes Dead (HND), and Last Node Dead (LND). The results indicate that the E-FLEACH protocol outperforms the LEACH in terms of FND, HND, LND by 60.3774%, 32.5%, and 17.1271%, respectively.

The total number of alive nodes was examined in Fig. 6. As seen, a significant increase in the total number of alive nodes is achieved as compared to the traditional LEACH Protocol. Moreover, the total consumed Energy was examined in Fig. 7. In the LEACH protocol, the energy consumption becomes nearly 83.91% of the sensor energy during the first 140 rounds; while the proposed protocol consumed just 73.88% of the initial sensor energy.

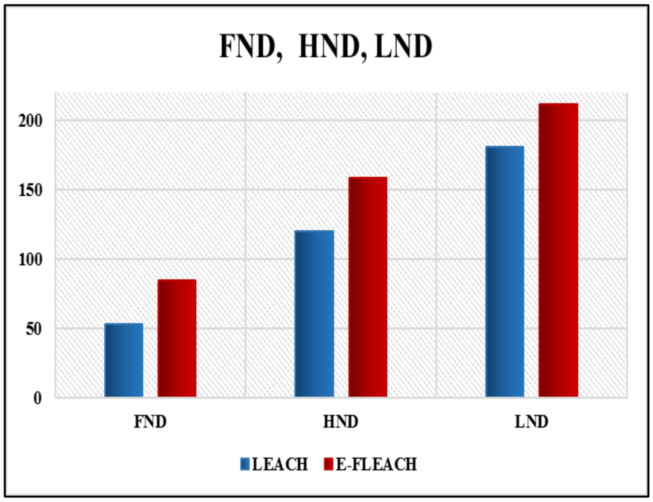


Fig. 5: FND, HND, LND.

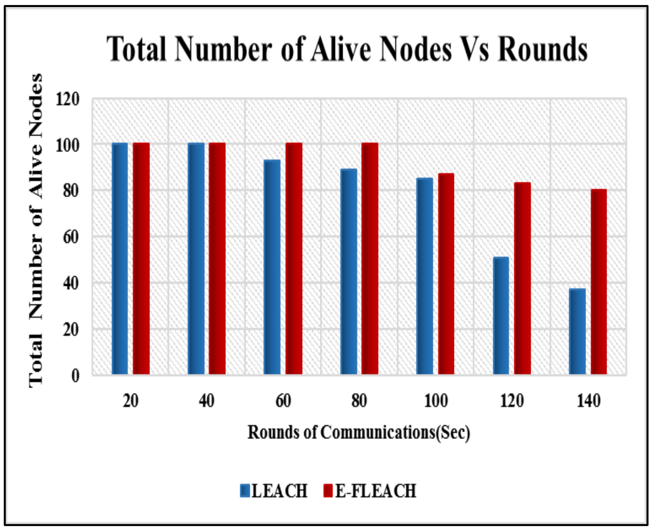


Fig. 6: Total Number of Alive Nodes.

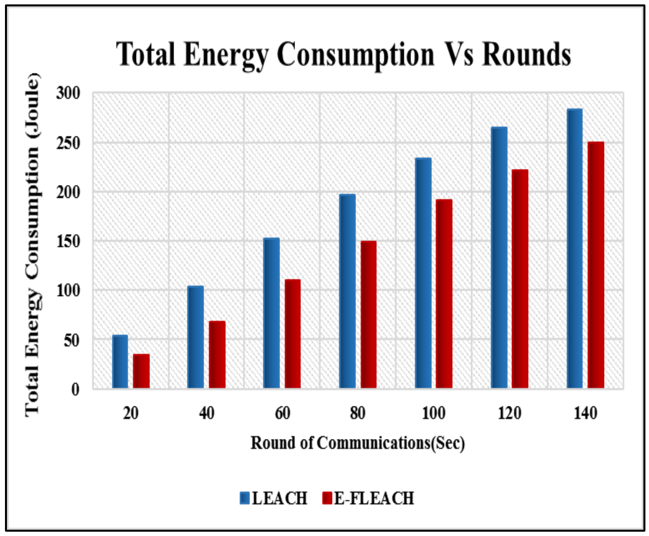


Fig. 7: Total Energy Consumption.

Experiment Case III:

In this experiment, the proposed protocol is evaluated using two area sizes, with different node densities, and the different percentages of CHs as shown in Table IV.

TABLE IV
OVERVEIW OF NETWORK CONFIGURATIONS

Area (m2)	Node density	No. of Nodes	CH Percentage
200 * 200	0.002	80	2%, 5%, 8%
	0.006	240	
	0.01	400	
300 * 300	0.002	180	2%, 5%, 8%
	0.006	540	
	0.01	900	

On the other hand, Figures 8, 9, and 10 present the results of the total energy consumption (Joule) for the proposed E-FLEACH protocol under different conditions of area sizes, node density, and CHs percentage.

Notice that as the percentage of CHs increases, the total energy consumption decreases for the same node density with different area sizes. The reason states that when the percentage is increased, the number of clusters increases, accordingly; and this will decrease the distance between the SNs and CHs; and then the SNs become in less energy consumption. Additionally, once the node density increases with the same area and the same percentage, the energy consumption in SNs will also increase. Meanwhile, the increase in the area size also led an increase in the energy consumption of SNs when both the node density and percentage remain same. It is found that 8% is an optimum CH percentage value when the node density is equal to 0.002 in the area size 200 * 200 m^2, and 300 * 300 m^2. As a result, one can conclude that as the node density is increased, the number of networks nodes increases as well; which consequently shows that an optimum CH percentage of 8%

can be obtained when the node density is either equal to 0.006 or 0.01 in the area size 200 * 200 m^2. Meanwhile, the optimum percentage becomes 5% using 0.01 of node density at area 300 * 300 m^2.

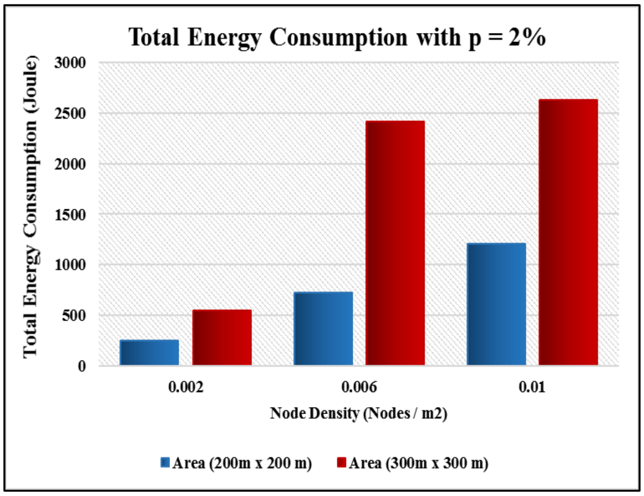


Fig. 8: Total Energy Consumption with p = 2%.

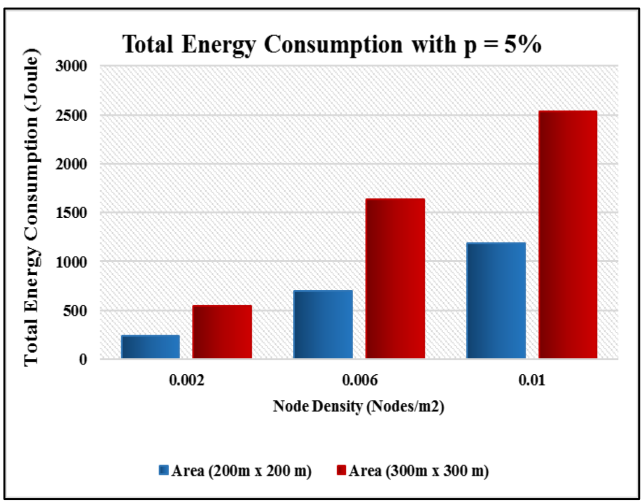


Fig. 9: Total Energy Consumption with p = 5%.

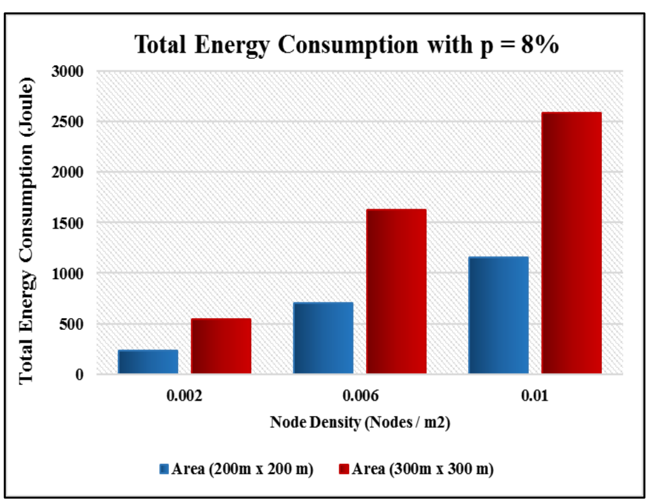


Fig. 10: Total Energy Consumption with p = 8%.

VI. Conclusion

Numerous routing protocols based on clustering algorithms have been proposed to improve the energy efficiency of WSNs. LEACH is one of the first protocols for homogeneous WSNs to be based on a clustering algorithm. The LEACH algorithm does not take energy consumption into account when selecting CHs; instead, it relies on a predefined probability. This paper proposed a new approach for utilizing the Type 1 Mamdani-fuzzy scheme to enhance sensor node performance in WSNs. The simulation results show that the proposal effectively reduces energy consumption, resulting in energy savings at network nodes and consequently increase the network lifetime. Notice that, FND, HND, LND are improved by 60.38%, 32.5%, and 17.13%, respectively with respect to the original LEACH protocol. FND improvement indicates that the proposed protocol is more stable than the LEACH protocol. Also, LND presents a noticeable improvement in the network lifetime.

Furthermore, the E-FLEACH protocol is evaluated for three CH percentage scenarios with varying area sizes and node densities to examine the effectiveness of selecting appropriate CHs percentage and nodes density in the design of the network model. For future work, intelligent algorithms such as FPA, GWO, ACO, and ABC algorithms can be utilized to improve the routing strategy in sensor networks. Additionally, multi-hop routing techniques can be also considered instead of single-hop routing.

Conflict of Interest

The authors have no conflict of relevant interest to this article.

References

[1] K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi, and M. Mustaqim, “Internet of Things (IoT) for Next-Generation Smart Systems: A Review of Current Challenges, Future Trends and Prospects for Emerging 5G-IoT Scenarios,” *IEEE Access*, vol. 8. pp. 23022-23040, 2020, doi: 10.1109/ACCESS.2020.2970118.

[2] N. Islam, M. M. Rashid, F. Pasandideh, B. Ray, S. Moore, and R. Kadel, “A Review of Applications and Communication Technologies for Internet of Things (Iot) and Unmanned Aerial Vehicle (UAV) Based Sustainable Smart Farming,” *Sustain.*, vol. 13, no. 4, 2021, doi: 10.3390/su13041821.

[3] M. A. Mahdi and S. T. Hasson, “A Contribution to the Role of the Wireless Sensors in the IoT Era,” *J. Telecommun. Electron. Comput. Eng.*, vol. 9, no. 2–11, pp.1-6, 2017.

[4] A. A. H. Hassan, W. M. Shah, M. F. Iskandar, and A. A. J. Mohammed, “Clustering Methods for Cluster-based Routing Protocols in Wireless Sensor Networks: Comparative Study,” *Int. J. Appl. Eng. Res.*, vol. 12, no. 21, pp. 11350-11360, 2017.

[5] O. S. Kwon, K. D. Jung, and J. Y. Lee, “WSN Protocol based on LEACH Protocol using Fuzzy,” *Int. J. Appl. Eng. Res.*, vol. 12, no. 20, pp. 10013-10018, 2017.

[6] J. S. Lee and C. L. Teng, "An Enhanced Hierarchical Clustering Approach for Mobile Sensor Networks Using Fuzzy Inference Systems," *IEEE Internet Things J.*, vol. 4, no. 4, pp. 1095-1103, 2017.

[7] Z. Cui, Y. Cao, X. Cai, J. Cai, and J. Chen, "Optimal LEACH protocol with modified bat algorithm for big data sensing systems in Internet of Things," *J. Parallel Distrib. Comput.*, vol. 132, pp. 217-229, 2019, , doi: 10.1016/j.jpdc.2017.12.014.

[8] G. Devika, D. Ramesh, and A. G. Karegowda, "Swarm Intelligence–Based Energy-Efficient Clustering Algorithms for WSN: Overview of Algorithms, Analysis, and Applications," in *Swarm Intelligence Optimization*, pp. 207-261, 2020.

[9] M. A. Tamtalini, A. E. B. El Alaoui, and A. El Fergougui, "ESLC-WSN: A Novel Energy Efficient Security Aware Localization and Clustering in Wireless Sensor Networks," *IEEE*, pp. 1-6, 2020, doi: 10.1109/IRASET48871.2020.9092203.

[10] N. Sharma and V. Gupta, "Meta-heuristic based optimization of WSNs energy and lifetime-A Survey," *IEEE*, pp. 369-374, 2020, doi: 10.1109/Confluence 47617.2020.9058294.

[11] T. Shankar, T. James, R. Mageshvaran, and A. Rajesh, "Lifetime Improvement in WSN using Flower Pollination Meta Heuristic Algorithm Based Localization Approach," *Indian J. Sci. Technol.*, vol. 9, no. 37, 2016, doi: 10.17485/ijst/2016/v9i37/102117.

[12] Deepshikha, P. Arora, and Varsha, "ENHANCED NN BASED RZ LEACH USING HYBRID ACO/PSO BASED ROUTING FOR WSNs," *IEEE*, pp. 1-7, 2017, doi: 10.1109/ICCCNT.2017.8203901.

[13] C. Patra, S. Biswas, and S. Mullick, "Effect of Different Optimization Methods in Determining the Clusterheads in Wireless Sensor Network," *IEEE*, pp. 497-502, 2018, doi: 10.1109/SPIN.2018.8474124.

[14] K. Thangaramya, K. Kulothungan, R. Logambigai, M. Selvi, S. Ganapathy, and A. Kannan, "Energy Aware Cluster and Neuro-Fuzzy Based Routing Algorithm for Wireless Sensor Networks in IoT," *Comput. Networks*, vol. 151, pp. 211-223, 2019, doi: 10.1016/ j.comnet .2019.01.024.

[15] Y. S. Thakur and D. K. Sakravdia, "An improved reliability on wireless sensor network for energy irregularity models using fuzzy deep learning protocol: Fdlp," *Int. J. Sci. Technol. Res.*, vol. 9, no. 1, pp. *4384-4389*, 2020.

[16] H. A. A. Al-Kashoash, Z. A. S. A. Rahman, and E. Alhamdawee, "Energy and RSSI Based Fuzzy Inference System for Cluster Head Selection in Wireless Sensor Networks," pp. 102-105, 2019, doi: 10.1145/ 3321289 .3321319.

[17] S. Lata, S. Mehfuz, S. Urooj, and F. Alrowais, "Fuzzy Clustering Algorithm for Enhancing Reliability and Network Lifetime of Wireless Sensor Networks," *IEEE Access*, vol. 8, pp. 66013-66024, 2020, doi: 10.1109/ ACCESS.2020.2985495.

[18] S. H. Abbas and I. M. Khanjar, "Fuzzy Logic Approach for Cluster-Head Election in Wireless Sensor Network," *Int. J. Eng. Res. Adv. Technol.*, vol. 5, no. 7, pp. 14-25, 2019, doi: 10.31695/ijerat.2019.3460.

[19] R. Logambigai and A. Kannan, "Fuzzy logic based unequal clustering for wireless sensor networks," *Wirel. Networks*, vol. 22, no. 3, pp. 945-957, 2016, doi: 10.1007/s11276-015-1013-1.

[20] K. A. Ngo, T. T. Huynh, and D. T. Huynh, "Simulation Wireless Sensor Networks in Castalia," pp. 39-44, 2018, doi: 10.1145/3193063.3193066.

[21] A. Rajput and V. B. Kumaravelu, "FCM clustering and FLS based CH selection to enhance sustainability of wireless sensor networks for environmental monitoring applications," *J. Ambient Intell. Humaniz. Comput.*, vol. 12, no. 1, PP. 1139-1159, 2021, doi: 10.1007/s12652-020-02159-9.