SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 22, No. 1, February 2025, 35-55

UDC: 004.7:621.317.38 **DOI: https://doi.org/10.2298/SJEE2501035A**

Original scientific paper

Enhanced SEP Protocol Based on Fuzzy Logic with Dynamic Threshold to Improve the Lifetime of WSNs

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Abstract: Stability and energy efficiency are the key factors that determine how well a Wireless Sensor Networks (WSNs) can perform and last. A Static Election Protocol (SEP) was developed to tackle this problem by selecting stable nodes as cluster heads; however, this protocol depends on random selection, which may cause an uneven energy distribution in the network. To address this problem, a new and improved version of SEP called SEP-FLDT is proposed. In order to optimize the cluster head decision and allow for cluster head switching over time, SEP-FLDT uses fuzzy logic coupled with a dynamic threshold mechanism. Comparison experiments are carried out with existing protocols like LEACH and SEP to prove the efficacy of SEP-FLDT. It is shown that the use of fuzzy logic combined with a dynamic threshold mechanism will lead to better evaluations for optimal clusters, therefore ensuring periodic changes in their selection as well as identifying a set of optimal cluster heads that maximize stability in terms of connectivity. Experimental results from performance evaluations demonstrate improvements in all aspects, such as energy efficiency, connectivity, stability and overall network performance, compared to other methods such as the LEACH and SEP protocols.

Keywords: Energy consumption, SEP, Dynamic threshold, Fuzzy logic, Wireless sensor networks.

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1 Introduction

Wireless Sensor Networks (WSNs) consist of several randomly distributed sensor nodes interconnected via wireless communication channels, and are used to observe and capture environmental data [1]. WSNs have an extensive range of uses across diverse fields such as agriculture, healthcare, defense, smart buildings, emergency rescue, smart cities, and vehicular applications [2–6]. Their nodes are commonly powered by batteries, and are characterized by their limitations in terms of radio capabilities, storage, and onboard processing [7–9]. Energy consumption by nodes plays a pivotal role in determining the native constraints on a WSN, and can therefore be said to determine the network's life [10].

It has been shown that clustering can reduce the energy consumed by nodes, and can help to extend the network lifetime and to achieve robustness and scalability [11, 12]. As can be seen in Fig. 1, clustering is the process of organizing sensor nodes into groups and selecting Cluster Heads (CHs) for each group. The CHs collect all of the information transmitted from the participants and transfer it to the Base Station (BS) [13]; they therefore expend more energy than the participant nodes, and the rapid depletion of CH energy levels may therefore result in early death and disconnection, affecting the connectivity of the network. The method used to elect CHs and the rotation of this role among sensor nodes are therefore considered crucial factors in terms of network lifetime [14–16].

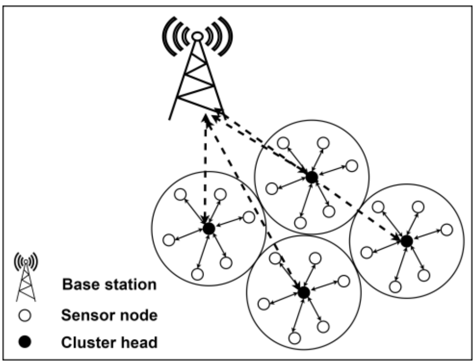

Fig. 1 – *Cluster formation of WSNs.*

Various clustering techniques have been developed to make networks more energy-efficient, and hence to prolong the network lifetime. Low-energy adaptive clustering hierarchy (LEACH) [17] is the most common such protocol, and was proposed for homogeneous networks. In LEACH, the probability of any node becoming a CH is equally distributed. A stable election protocol (SEP) [18] has been proposed as a means of enhancing the efficiency of WSNs. SEP utilizes a two-tier heterogeneous protocol based on two different types of sensor nodes (normal and advanced nodes); these are assigned weighted probabilities with respect to taking on the CH role, offering improved and more reliable performance. However, SEP does not use the extra energy of the higher-level nodes efficiently [19].

In this paper, we present SEP-FLDT, an enhanced version of SEP that leverages fuzzy logic and a dynamic threshold to optimize the performance of SEP. The fuzzy logic component takes into consideration both the level of energy and the distance to the BS to intelligently determine the most suitable CH; by employing fuzzy logic principles, the system can effectively evaluate and compare these two aspects to identify the optimal CH for each cluster. The use of a dynamic threshold mechanism further enhances the efficiency of CH selection within the clusters, enabling timely and adaptive CH changes based on the evolving network conditions, and ensuring optimal performance and resource allocation throughout the network.

The major contributions of this work included integration of fuzzy logic system with a dynamic threshold mechanism as the optimized approach for enhancing the SEP protocol for WSNs. However, unlike traditional SEP, which relies on random CH selection, the proposed SEP-FLDT select CHs by considering both residual energy and distance to the BS. It achieves load balance in using the energy distributed throughout the network to decrease energy death at nodes and increase network lifespan. Moreover, the dynamic CH threshold method enables the CHs selection according to the network condition, making energy efficiency and network stability much better. These enhancements make SEP-FLDT different from other protocols like SEP and LEACH based on clustering and causes it to be a greater advancement in WSNs protocols as it has a better energy utilization and is more resilient.

This paper is divided into several sections, Section 2 present the related work, Section 3 offers comprehensive definition of the network model, while Section 4 introduces the proposed SEP-FLDT protocol. The performance of the protocol is then evaluated in Section 5, and Section 6 concludes the paper.

2 Related Work

Various clustering techniques have been proposed to achieve energy preservation and improve the longevity of WSNs. LEACH [17] is considered the primary protocol for clustering WSNs, in which the network is divided into several clusters with each node having an equal probability P of becoming a CH in a given round. Over time, every node is expected to serve as a CH approximately once every 1/P round. Each node generates a default number, bounded by zero and one, randomly. When this value is lower than a predetermined threshold, that node becomes CH. SEP [18] is a heterogeneous WSNs protocol that has two types of nodes: normal and advanced, where the initial energy level of the advanced nodes is greater than the normal nodes. The selection of the CH in the SEP is determined by the weighted election probability of each node, which is dependent on the remaining energy of the nodes.

Hybrid, Energy-Efficient, Distributed (HEED) [20] is a well-known distributed clustering protocol based on two clustering parameters: the node degree and the node residual energy. The node degree helps in balancing the load among the CHs. Through the use of this parametric combination for CH selection, HEED is able to incorporate load balancing functionality and achieve relatively high energy efficiency. HEED produces clusters that are balanced in size, and the size of a given cluster is not influenced by its distance from the BS; however, due to the need for inter-cluster communication, sensor nodes close to the BS are quickly drained of energy. The Distributed Energy-Efficient Clustering (DEEC) protocol [21] was proposed for two-level and multi-level heterogeneous WSNs. In this approach, a sensor node is selected as a CH based on the remaining energy of each node and the average energy of the network, and nodes with higher initial and remaining energies have a better probability of becoming CH. However, nodes that are closer to the BS expend more energy compared to those that are further away, due to the additional load on nodes within the neighborhood of the BS. The Threshold-sensitive Energy Efficient sensor Network (TEEN) protocol [22] can be considered an improvement on LEACH. TEEN employed two types of thresholds: a Hard Threshold (HT) and a Soft Threshold (ST) for controlling the number of data transmission. An HT it is an absolute value for sensing attribute, when the node detects this value, it activates its transmitter and sends the data to the CH. An ST it is a small variation in the value of the sensed attribute which causes the node to turn on its transmitter and transmits its data to the CH.

The most important factor of a routing protocol for WSNs is the energy consumption and lifetime of a network. Alomari et. al. [23] presents a systematic literature review on the energy efficiency of dynamic clustering in a heterogeneous environment of WSNs. Different cluster-based methods were analyzed to determine which technology should be deployed by analyzing specific criteria to support the selection process. Jain and Goel [24] present an energy efficient fuzzy routing protocol for WSNs to enhance network lifetime, which employed a fuzzy logic tools, fuzzy sets, and fuzzy decision rules for selection the CHs and establishing multi-hop routes to the BS. Alomari et. al. [25] present a new protocol named E-LEACH to enhance the longevity of WSNs used in autonomous cars. E-LEACH employed k-means clustering to categorize nodes, decreases node density by deactivating superfluous sensors, and implements a sleep/awake protocol to enhance energy conservation. The simulation findings indicate that E-LEACH outperforms established protocols such as LEACH and TTDFP regarding throughput and network longevity. In order to improve the energy efficiency and Quality of Service (QoS) of Vehicular Ad-hoc Networks (VANETs), Al-Hchaimi [26] proposed a new algorithm called

DOEQ-VANET, which conserves energy without sacrificing the accuracy of crucial data by employed the heterogeneity of Multiprocessor System-on-Chip (MPSoC) and approximation computing to dynamically modify computational accuracy for non-critical applications. Sen et. al. [27] introduced a new method for prolonging the lifespan of WSNs in uncertain environment, using a mix of K-medoids clustering and a Multi-Criteria Decision Making (MCDM) mechanism for the selection of CHs. The proposed method employed the K-medoids method to organize the sensor nodes into clusters, while the MCDM approach assesses prospective CH based on many parameters, including proximity to the BS, average distance of cluster nodes, reliability, and residual energy. Sahoo et. al. [28] proposes a method to find the maximum time connectivity of sensor nodes in a WSNs considering uncertain voltage and distances, which utilize triangular fuzzy numbers to represent these uncertainties and then employ a defuzzification technique to convert the fuzzy problem into a crisp one. A modified Floyd-Warshall algorithm was employed to determine the optimal path with the longest connectivity duration. Sen et. al. [27] proposed a method for selecting CHs in WSNs that takes network parameter uncertainty into account. The entropy-weighted Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method was used to select CHs, which depended on a variety of factors, such as residual energy, number of neighbors, distance from the BS, average distance of cluster nodes, distance ratio, and reliability. Sahoo et. al. [29] proposed a method by combining MCDM approaches with intelligent clustering algorithms to increase the lifespan of WSNs in uncertain environments. Their strategy achieves energy savings over current techniques like LEACH-FC and REAC-IN by using DBSCAN for clustering and MCDM for CH selection.

SEP is a heterogeneous-aware protocol in which two types of sensors are used: normal nodes and advanced nodes. The selection of the CH in SEP is determined by assigning a weighted election probability to each node based on its initial energy. The election probability and rotating epoch are directly correlated with the nodes' initial energy rather than their remaining energy. Moreover, advanced nodes become CHs more frequently, and after several rounds, the energy of these nodes becomes less than that of the normal nodes. To overcome this drawback, this paper presents an enhanced version of SEP in which fuzzy logic and a dynamic threshold are employed to optimize the performance. In this way, the proposed SEP-FLDT scheme increases the stability and lifetime of the network.

3 Network Model

The energy model used in this paper to simulate a WSN with heterogeneous nodes and its environment is as follows:

The radio energy dissipation model (illustrated in Fig. 2) indicates that any attempt to send messages of length L-bits over a distance d with an acceptable Signal-to-Noise Ratio (SNR) must satisfy certain criteria. The energy consumption calculation is shown in (1), and the importance of meeting these requirements to achieve optimal energy efficiency while maintaining effective wireless communication is emphasized.

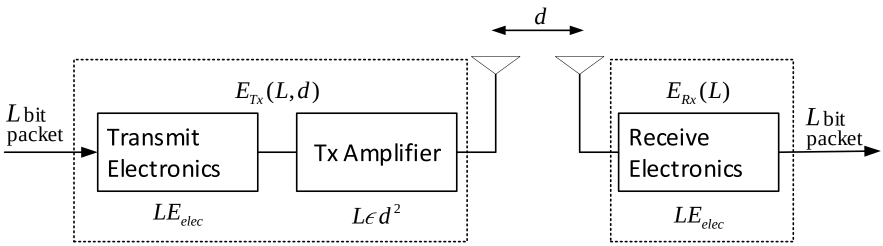

Fig. 2 – *Radio energy dissipation model.*

The amount of energy used per bit during the operation of either the transmitter or the reception circuit [30], denoted as E_{elec}, depends on the amplifier model used for the transmitter.

$$E_{Tx}(L,d) = \begin{cases} LE_{elec} + L\epsilon_{fs} d^2, & \text{if } d \le d_0; \\ LE_{elec} + L\epsilon_{mp} d^4, & \text{if } d > d_0; \end{cases} \tag{1}$$

where E_{elec} represents the energy used per bit to operate either the transmitter or the reception circuit, ϵ_{fs} and ϵ_{mp} depend on the transmitter amplifier, and d is the distance between the sender and the receiver.

The values of ϵ_{fs} and ϵ_{mp} are determined by the transmitter amplifier model. Equating these two expressions for $d = d_0$ gives a value of $d_0 = (\epsilon_{fs}/\epsilon_{mp})^{0.5}$ to transmit or receive an L-bit message, meaning that the radio expends an energy $E_{RX} = LE_{elec}$. Assuming that there are n uniformly distributed nodes across a given area A, A = M×M, and that the BS is situated in the middle of the field, where the distance between any node and the BS or its CH is $\le d_0$, the energy dissipation of the CH in a given round can be expressed using the following formula:

$$E_{CH} = \left(\frac{n}{k} - 1\right) LE_{elec} + \frac{n}{k} LE_{DA} + LE_{elec} + L\epsilon_{fs}\, d_{toBS}^2, \tag{2}$$

where the symbol k denotes the number of clusters, E_{DA}, is the processing cost for transmission to the BS, and d_{toBS} represents the average distance from the CH to the BS. The energy consumption for a non-CH node is determined as follows:

$$E_{nonCH} = LE_{elec} + L\epsilon_{fs} d_{toCH}^2, \tag{3}$$

where d_{toCH} represents the average distance between a sensor node and its associated CH.

4 Methodology

4.1 SEP

In SEP, the election of CHs is solely based on probability assigned to each node type in a similar manner to the LEACH protocol; such election still occurs randomly. A fraction m of total n nodes is provided with an additional energy factor α, which are called advanced nodes. SEP defines the (p_{nrm}) and (p_{adv}) which are the weighted election probability for normal and advanced nodes, respectively. The probabilities for both normal and advanced node to be a CH are given by (4) and (5).

$$p_{nrm} = \frac{p_{opt}}{1 + m\,\alpha}, \tag{4}$$

$$p_{adv} = \frac{p_{opt}(1+\alpha)}{1 + m\,\alpha}, \tag{5}$$

where p_{opt} is the optimal probability of each node becoming a CH.

In SEP, two different thresholds are defined, one for normal nodes and the other for advanced nodes, as given by (6) and (7):

$$T(S_{nrm}) = \begin{cases} \dfrac{p_{nrm}}{1 - p_{nrm}\left(r \bmod \dfrac{1}{p_{nrm}}\right)}, & \text{if } S_{nrm} \in G; \\ 0, & \text{otherwise}; \end{cases} \tag{6}$$

$$T(S_{adv}) = \begin{cases} \dfrac{p_{adv}}{1 - p_{adv}\left(r \bmod \dfrac{1}{p_{adv}}\right)}, & \text{if } S_{adv} \in G'; \\ 0, & \text{otherwise}; \end{cases} \tag{7}$$

where r represents the number of the current round, G is the set of nodes which have not been CHs in the last $1/p_{nrm}$ rounds, and G' is the set of advanced nodes that have not been CHs in the last $1/p_{adv}$ rounds.

The stable period and network life of a WSN can be improved through the use of advanced nodes. However, the selection of CHs using SEP is still done randomly, meaning that there is the potential to generate imbalances in the energy distribution across the network.

4.2 Proposed protocol: SEP-FLDT

Fuzzy logic, first introduced by Zadeh in 1965, is an extension of classical logic that allows for reasoning with uncertain, imprecise, or vague information [31]. Unlike traditional binary logic, which operates with clear true/false (1 or 0) values, fuzzy logic deals with degrees of truth, ranging from 0 to 1, making it well-suited for real-world systems where data may not always be crisp or precise. It uses linguistic variables and a set of rules which simulate the human decision-making process which makes decision-making possible in uncertain environments where data could be inadequate [32].

Fuzzy logic is a common preferable approach in WSNs especially when it comes to decision-making about power consumption and network performance. The WSNs include sensor nodes having restricted implementation resources like low energy, and low computational power, hence it's important to enhance the energy utilization effectively for the purpose of increasing the usable existence of the system. Hence, applying of fuzzy logic in WSNs can help to make intelligent decision about node's operation, for instance, CHs selection or data transmission depending on the residual energy, distance from the BS, and network load. Fuzzy Inference System (FIS) can solve this problem by enabling the network to adapt to these conditions, allow optimal resource utilization and elongation of the lifespan of the network [33, 34].

This paper presents a new technique that enhances SEP by integrating fuzzy logic and a dynamic threshold into the protocol, called SEP-FLDT (illustrated in Fig. 3). This improves SEP by incorporating a chance calculation that defines the probability of each node to become a CH. This stands in contrast to SEP, where CHs are elected randomly, which may lead to poor energy balancing across the network. In the proposed scheme, the threshold $T(s)$ for CH selection is optimized using a fuzzy logic F_{value}. Optimization is achieved by determining distinct thresholds for the different types of nodes (normal and advanced), as shown below in (8) and (9)

$$T(s_{nrm}) \leq \frac{p_{nrm}}{F_{value}}, \tag{8}$$

$$T(s_{adv}) \leq \frac{p_{adv}}{F_{value}}. \tag{9}$$

A FIS is used for advanced and normal nodes. To calculate the CH selection probability for each node, the fuzzy logic model takes two variables as input, namely the distance to the BS (d_{toBS}) and the residual energy ($E_{residual}$), and a linguistic representation of the input variables is used to allow for the generation of effective fuzzy inferences within the system. As shown in Figs. 4, 5 and 6, the parameters d_{toBS} and $E_{residual}$ (for the advanced and normal nodes) have values in the ranges 0–120, 0–0.5, and 0–1.5, respectively. The output variable (F_{value}) has a range of 0–1, as shown in Fig. 7. By fuzzifying the input variables, the fuzzy logic model transforms their values into linguistic variables; then, rather than directly connecting the input parameters to the output values, an alternative approach using if-then rules with linguistic variables can be used. In this case, 25 if-then rules are executed as shown in **Table 1**, based on the two input variables. The defuzzification process is then applied, where the center of area method is used to convert the results to output values (F_{value}) [35].

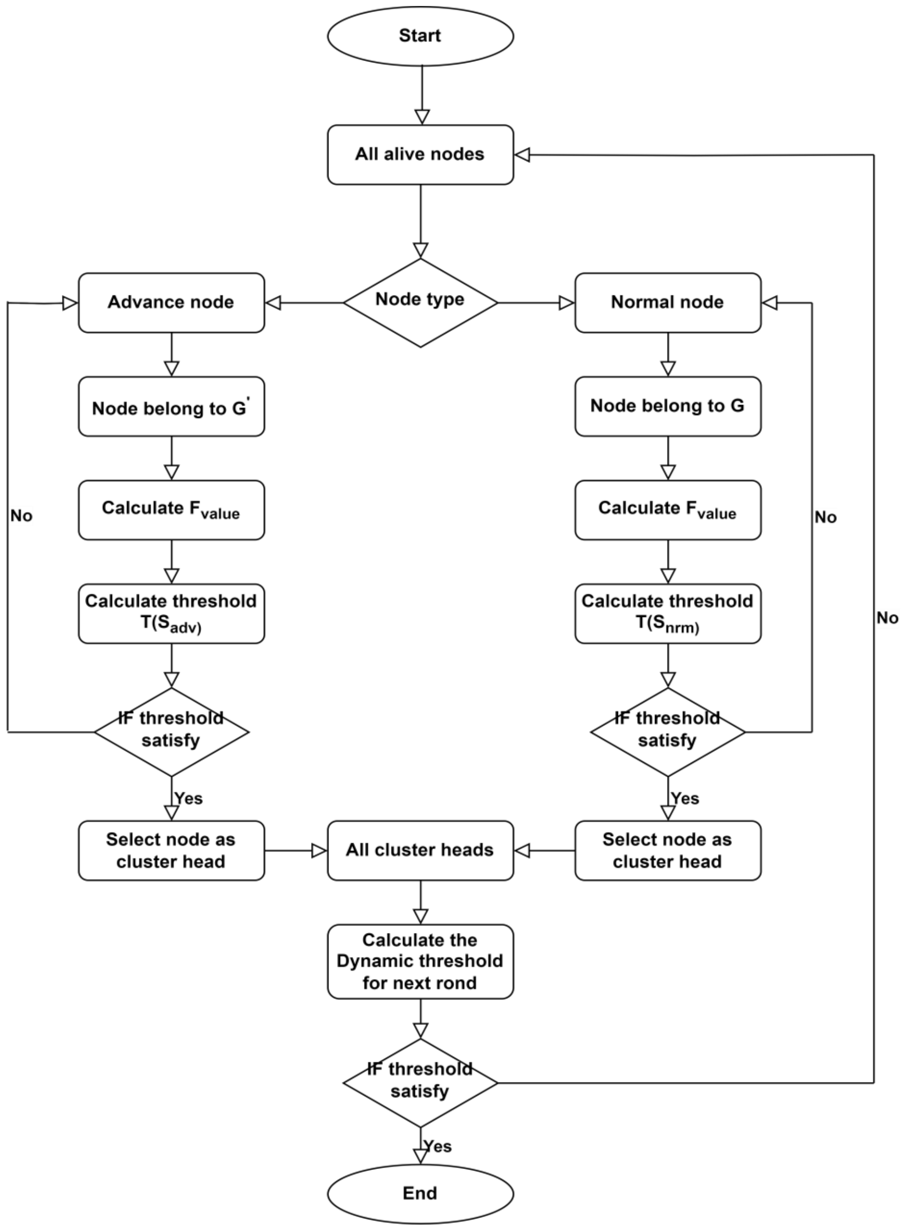

Fig. 3 – *The flowchart of the proposed SEP-FLDT protocol.*

The protocol calculates the probability that each sensor node in the cluster will act as the CH in each iteration, for both advanced and normal nodes. The selected node declares itself to be a CH if its maximum calculated probability drops below the predefined threshold value *T*(*s*). When the remaining nodes receive this notification, they compute their own distances from the selected CH and transmit a join request to the CH.

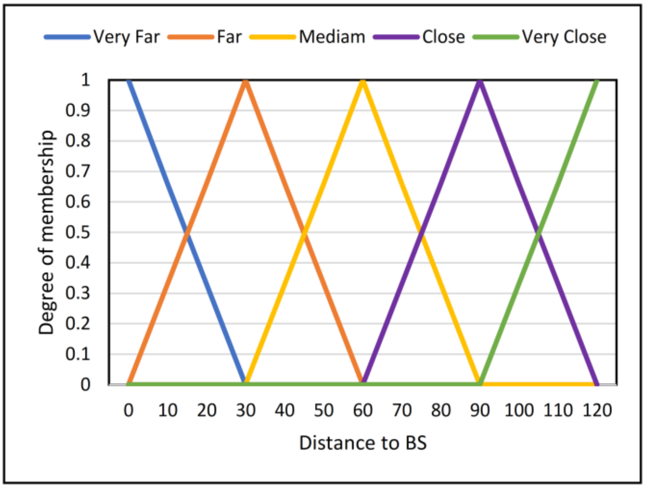

Fig. 4 – *The member function for d_{toBS} parameter.*

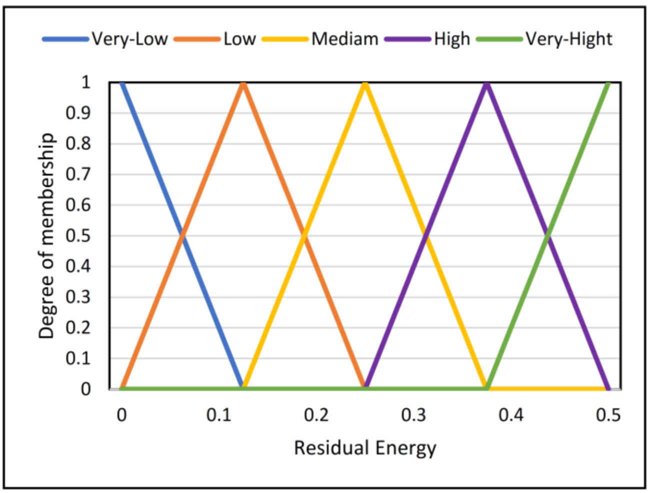

Fig. 5 – *The member function for $E_{residual}$ of normal nodes.*

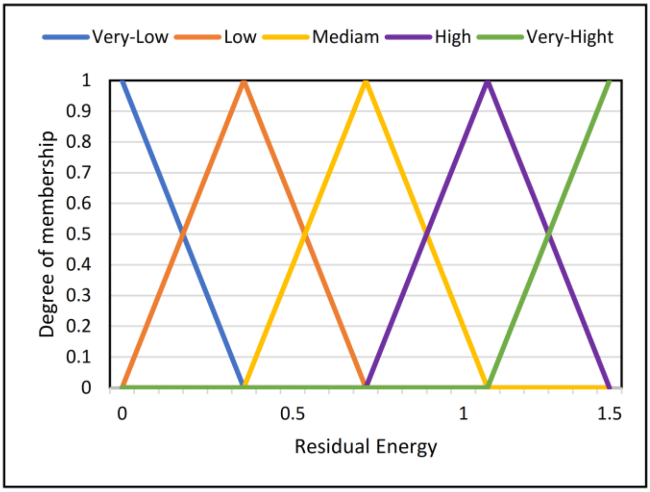

Fig. 6 – *The member function for $E_{residual}$ parameter of advanced nodes.*

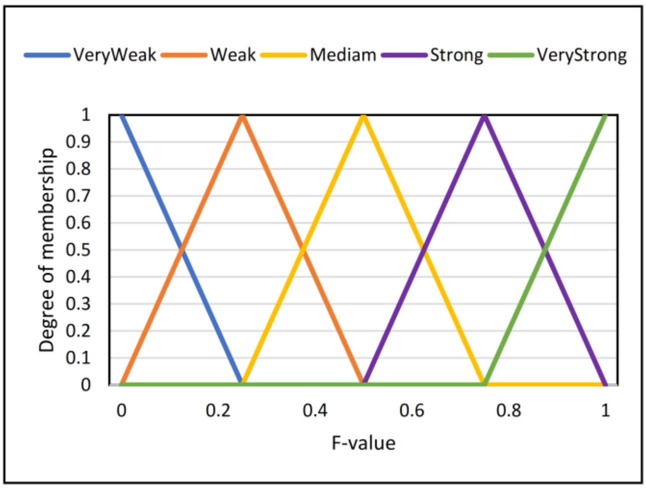

Fig. 7 – *The member function for output variables (F_{value}).*

In this paper, the fundamental fuzzy logic rules were optimized for WSNs by choosing suitable input variables and appropriate shape and sizes of the membership functions according to the nature of WSNs. The two inputs selected: the residual energy and distance to the BS, both have influence over the energy consumption and the communication rate of the sensor nodes. The membership functions of each of the variables were determined experimentally while taking into account typical energy and distances in WSNs. Furthermore, the rule base for the network configuring was developed with 25 if-then rules taking into account different conditions of the network and that CH selection criteria should be optimal under different circumstance. The optimization process involved iterative simulations, adjusting the fuzzy logic parameters to maximize network lifetime and minimize energy consumption, thus ensuring that the fuzzy logic system is fine-tuned for the specific challenges faced by WSNs. This approach offers a good trade-off in terms of concision and execution time so that SEP-FLDT can work smoothly in realistic environments.

Table 1
If-Then rules.

No.	$E_{residual}$	d_{toBS}	F_{value}
1	$E_{verylow}$	$d_{veryfar}$	$F_{veryweak}$
2	$E_{verylow}$	d_{far}	$F_{veryweak}$
3	$E_{verylow}$	d_{medium}	$F_{veryweak}$
4	$E_{verylow}$	d_{close}	$F_{veryweak}$
5	$E_{verylow}$	$d_{veryclose}$	F_{weak}
6	E_{low}	$d_{veryfar}$	$F_{veryweak}$
7	E_{low}	d_{far}	F_{weak}
8	E_{low}	d_{medium}	F_{weak}
9	E_{low}	d_{close}	F_{medium}
10	E_{low}	$d_{veryclose}$	F_{medium}
11	E_{medium}	$d_{veryfar}$	F_{weak}
12	E_{medium}	d_{far}	F_{weak}
13	E_{medium}	d_{medium}	F_{medium}
14	E_{medium}	d_{close}	F_{medium}
15	E_{medium}	$d_{veryclose}$	F_{strong}
16	E_{high}	$d_{veryfar}$	F_{medium}
17	E_{high}	d_{far}	F_{medium}
18	E_{high}	d_{medium}	F_{strong}
19	E_{high}	d_{close}	F_{strong}
20	E_{high}	$d_{veryclose}$	$F_{verystrong}$
21	$E_{veryhigh}$	$d_{veryfar}$	F_{strong}
22	$E_{veryhigh}$	d_{far}	F_{strong}
23	$E_{veryhigh}$	d_{medium}	$F_{verystrong}$
24	$E_{veryhigh}$	d_{close}	$F_{verystrong}$
25	$E_{veryhigh}$	$d_{veryclose}$	$F_{verystrong}$

In order to determine when the CH in each cluster should change, the proposed protocol applies a dynamic energy threshold ($T_{Dynamic}$), as formulated in (10).

After each iteration, the BS calculates the $T_{Dynamic}$ value, and a CH will relinquish its position if its residual energy falls below this calculated value

$$T_{Dynamic} = \beta \frac{\sum_{1}^{N} E_{resCH}}{N}, \tag{10}$$

where E_{resCH} refers to the residual energy of each node in the cluster, N is the quantity of sensors in the cluster, and β is a constant. This approach was developed with the aim of improving the current state of energy-efficiency techniques in WSNs.

The efficacy of the SEP-FLDT protocol is greatly affected by the parameters of the fuzzy logic system and the dynamic threshold mechanism. Modifying the fuzzy membership functions that outline the mapping of input data, such as residual energy and distance to the BS, to linguistic terms may significantly influence energy usage and network stability. Expanding the membership functions for high energy and close proximity may result in the selection of more ideal CHs for energy reserves and transmission efficiency, thereby decreasing total energy consumption. Narrower membership functions may lead to frequent changes in cluster heads, hence increasing energy consumption owing to re-clustering activities. Likewise, the dynamic threshold mechanism, which ascertains when a CH should forfeit its position depending on remaining energy, may be calibrated to optimize energy efficiency and stability. An elevated threshold will result in more frequent CH rotations, so improving network stability by averting premature node failures, while possibly escalating energy usage. Conversely, a lower threshold might save energy by lowering the frequency of CH changes, but stability would be compromised since nodes can deplete unevenly. Hence by tuning these parameters the SEPFLDT protocol can be suitably designed to have a good tradeoff between energy utilization and network stability in different WSN applications.

5 Simulation Results

5.1 Evaluation metric and implementation details

To assess the efficacy of the SEP-FLDT protocol, an evaluation was undertaken using a MATLAB simulation network consisting of 100 nodes randomly distributed within a $100m^2$, $100m^2$, and $100m^2$ areas, where the initial energy levels were set to 0.5 J for normal nodes and 1.5 J for advanced nodes. The simulation was conducted over 3,000 rounds, and a comparative analysis was then performed by benchmarking the results against the LEACH [17] and SEP [18] techniques, with a focus on target metrics such as the energy consumption and network lifetime.

Table 2 shows additional simulation parameters.

Table 2

Simulation parameters.

Parameters	Value
Network size	$100\ m^2$, $200\ m^2$, $250\ m^2$
Number of nodes	100, 500, 1000
r	3000
Initial energy E_0	0.5J
Initial energy for advanced node	$E_0\ (1+\alpha)$
E_{elec}	50nJ/bit
E_{DA}	5 nJ/bit/message
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{mp}	0.0013 pJ/bit/m^4
K	4000
p_{otp}	0.1
m	0.1
α	2

5.2 Results and discussion

The simulation results of the SEP-FLDT protocol, were evaluated against two existing protocols, LEACH and SEP, in terms of energy efficiency and network lifetime. In this paper, the concept of network lifetime is identified as the time until the first node becomes non-functional. To illustrate the behavior of the network under different scenarios, Figs. 8, 9 and 10 summarizes the longevity of nodes in each protocol over 3,000 rounds for experiments with 100, 500, and 1000 nodes, respectively, and **Table 3** explains the number of rounds at the first node's death. The outcomes demonstrate that SEP-FLDT outperforms both LEACH and SEP by consuming significantly less energy and prolong the network lifetime. Specifically, the first node in LEACH exhausts its energy by round 984, whereas in SEP, the first node becomes non-functional at round 1051. In contrast, the first node in SEP-FLDT manages to sustain operation until round 1154, indicating a substantial improvement in energy preservation.

Table 3

First node dies.

Method	First node dies 100 nodes	First node dies 500 nodes	First node dies 1000 nodes
LEACH	984	251	236
SEP	1051	758	423
SEP-FLTD	1154	870	943

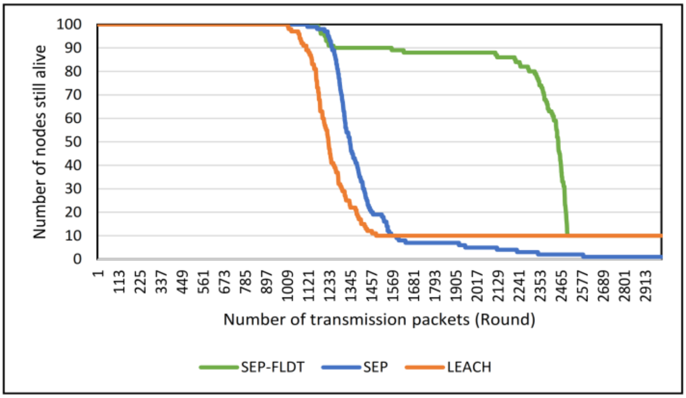

Fig. 8 – *The number of active nodes over 3,000 rounds for 100 nodes.*

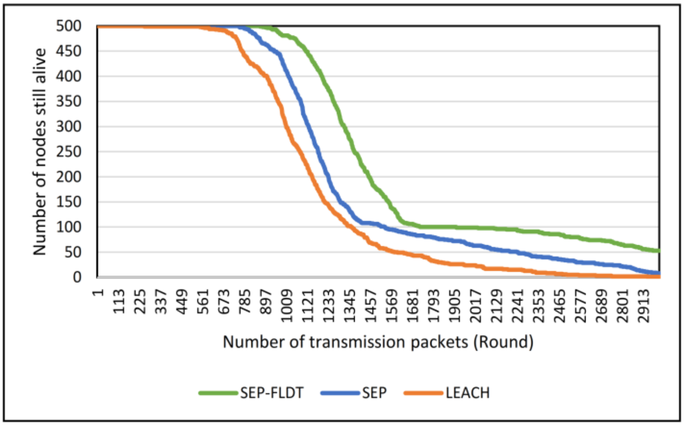

Fig. 9 – *The number of active nodes over 3,000 rounds for 500 nodes.*

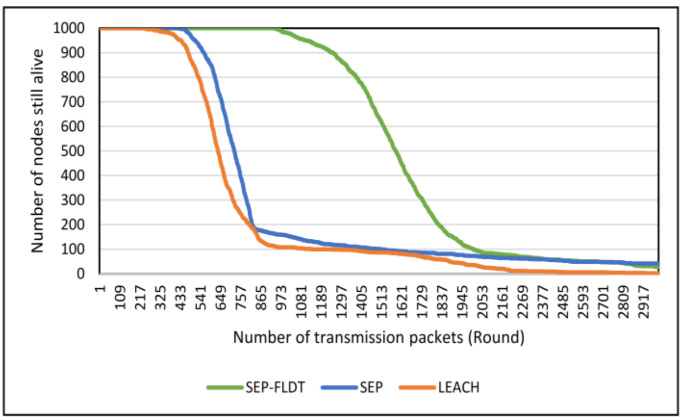

Fig. 10 – *The number of active nodes over 3,000 rounds for 1000 nodes.*

Figs. 11, 12 and 13 provides a comprehensive comparison of energy consumption among the protocols, based on measures of energy efficiency. Under the proposed approach, the network consumes less energy than in other approaches, and offers a considerably longer lifetime compared to other algorithms. SEP-FLDT achieves better energy efficiency through the use of fuzzy logic and a dynamic threshold to optimize the CH selection. The fuzzy logic intelligently considers both the energy levels and the distance to the BS when selecting the most suitable CH, thereby ensuring a well-informed decision-making process. The use of a dynamic threshold mechanism improves the efficiency of CH selection within the clusters, which allows for timely and adaptive changes in CHs depending on the changing conditions of the network, thus ensuring optimal performance and resource distribution across the network.

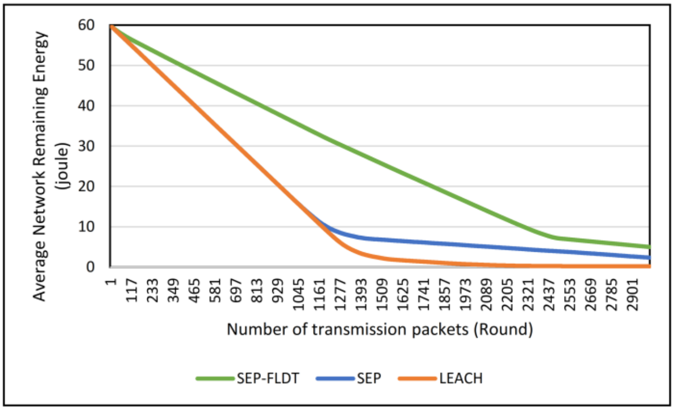

Fig. 11 – *The energy efficiency of all protocols for 100 nodes.*

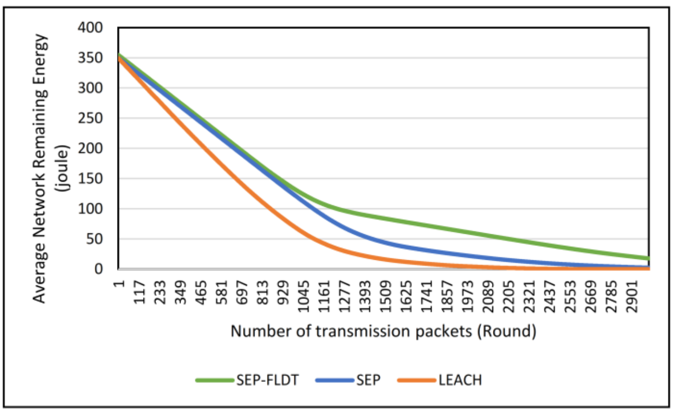

Fig. 12 *– The energy efficiency of all protocols for 500 nodes.*

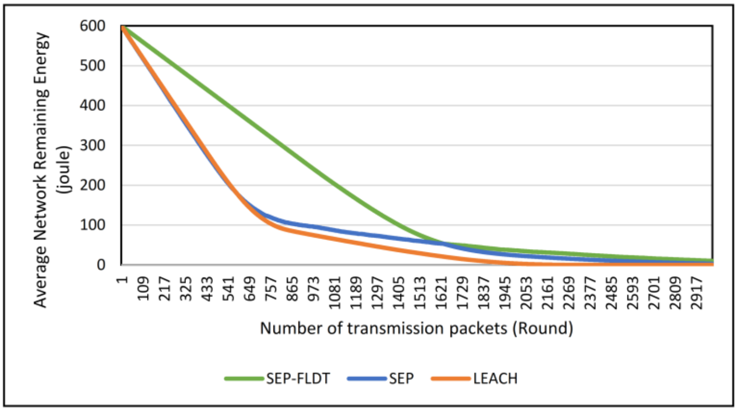

Fig. 13 – *The energy efficiency of all protocols for 1000 nodes.*

SEP-FLDT protocol proves to be very efficient in terms of time when compared to SEP and LEACH which are illustrated in the respective Figs. 14, 15 and 16. From the above time consumption metrics, it is clear that SEP-FLDT consumes less time in processing and transmitting data than the two other protocols because of its effective selection of CH based on fuzzy logic and use of a dynamic threshold. The use of intelligent criteria for choosing the CHs like residual energy and proximity to BS, the SEP-FLDT proposed reduces the frequency of re-clustering and therefore improves the network delay and throughput. SEP and LEACH, on the other hand, use more static or probabilistic methods for choosing CHs, which may result in ineffective cluster management, greater energy usage, and longer delays. Figures show that SEP-FLDT performs better than both protocols in a variety of network scenarios, making it a better option for applications that need low latency and rapid data processing.

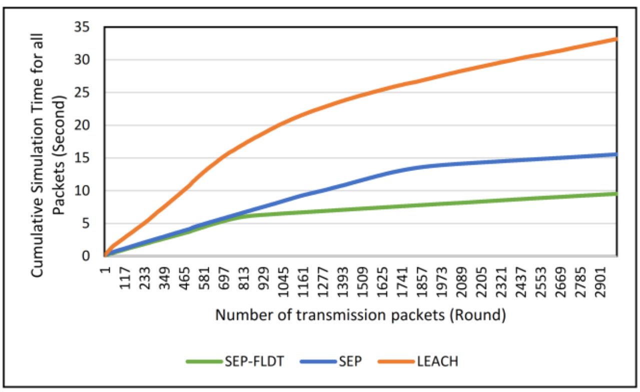

Fig. 14 – *The time consuming of all protocols for 100 nodes.*

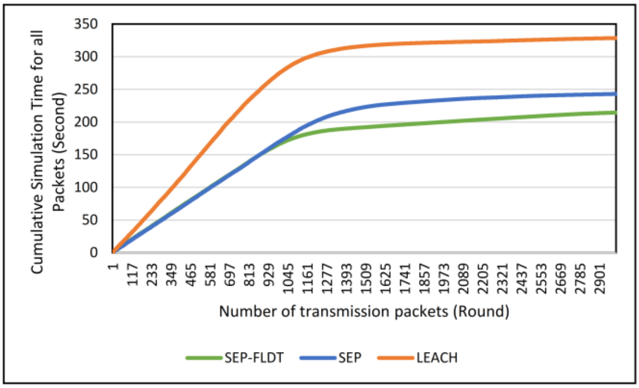

Fig. 15 – *The time consuming of all protocols for 500 nodes.*

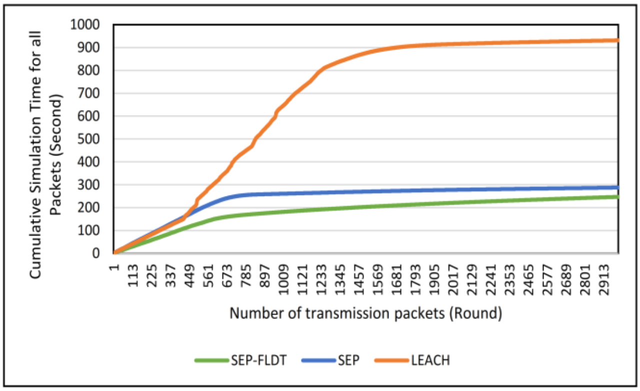

Fig. 16 – *The time consuming of all protocols for 1000 nodes.*

6 Conclusion

In this paper, we present the SEP-FLDT protocol, an enhanced version of SEP, in which fuzzy logic and dynamic threshold methods are used to address the issue of random CH selection at the SEP protocol level. To improve the performance, fuzzy logic is used to determine the different thresholds $T(s)$ for the two types of nodes (normal and advanced) in a heterogeneous network, and a dynamic threshold method to select the optimal time to change the CH rather than changing it after each iteration. An evaluation of this process shows that SEP-FLDT improves the network lifetime. Our approach increases the lifespan of the first node before it becomes nonfunctional, and reduces energy consumption, meaning that it is more efficient than the LEACH or SEP protocols. Overall, SEP-FLDT emerges as a promising protocol in which innovative techniques are leveraged to enhance the overall performance and energy efficiency of WSNs, thereby ensuring optimal performance and resource allocation.

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