ISSN: 2617-5517 (issn.org)
Al-Farabi Journal of Engineering Sciences
https://iasj.rdd.edu.iq/journals/journal/view/97
مجلة الفارابي للعلوم الهندسية تصدرها جامعة الفارابي

E-LEACH: A Euclidean Distance-Based Clustering Approach for Extending Network Lifetime in IoT-Enabled Wireless Sensor Networks

Aber aziz kareem alsaadi
Mustansiriyah University
Basic Education College
Computer Science Department
aber8177@gmail.com

Ali Moeen Esmaeel
Lattakia University
Informatic Enginering College
Computer Network and Systems Department
alimoeenesmail@gmail.com

Abstract

Wireless Sensor Networks (WSNs) have strict energy resource problems that affect their lifetime in IoT environments. This work proposes E-LEACH, an improved version of Low Energy Adaptive Clustering Hierarchy that alleviates these issues by incorporating two effective strategies: a new threshold function with a denominator square for decreasing the rate of rotation for cluster heads, and Euclidean-distance clustering for improving communication across clusters. Network simulation experiments using MATLAB with different network densities (100-500 sensors) in 1000x1000 m^2 topologies showed significant improvements. Compared with standard LEACH, E-LEACH showed 88% improvement in network lifetime extension, 71.86% improvement in energy consumption efficiency, and 49.5% improvement in throughput performance. Packet Delivery Ratio was improved from 0.00955 to 0.01001, while average delay was reduced from 2.45 to 2.01 seconds.

Keywords: Energy efficient routing protocols, LEACH improvement, Euclidean distance clustering, Internet of Things enabled wireless sensor networks, network lifetime improvement

Introduction

The proliferation of Internet of Things (IoT) technologies has spurred the unprecedented integration of the physical and the digital domains, making Wireless Sensor Networks (WSNs) important enablers for intelligent monitoring and control systems [1]. WSN consist of spatially distributed autonomous sensor nodes that cooperatively observe environmental phenomena, transmit sensed data and allow various applications in the areas of smart cities, precision agriculture, healthcare monitoring and industrial automation [2]. Recent projections predict exponential increase in deployments of IoT where billions of interlinked devices will produce enormous data streams to enable real-time decision making systems [3].

Despite their life-changing potential, WSNs exhibit inherent energy limitations that are very demanding on the lifespan [4]. Sensor nodes often live off small sources of power, where battery replacement or recharging may often be impractical depending on the deployment location (e.g. remote, dangerous, on a large scale) [5]. Energy depletion directly affects network functionality, data quality and application reliability, making energy efficiency the most important design issue for WSN protocols [6]. This is a tougher challenge in IoT scenarios, because heterogeneous devices with different amounts of processing power must operate continuously while conserving energy resources [7].

Hierarchical clustering protocols, specifically Low-Energy Adaptive Clustering Hierarchy (LEACH) has become a leading candidate among the energy-efficient WSNs operations [8]. LEACH transforms networks into clusters including cluster heads (CHs) that are in charge of data aggregation and communication with base stations which allows the energy consumption to be distributed to the nodes in a probabilistic manner with CH rotation [9]. However, standard LEACH shows critical limitations such as random CH selection without residual energy consideration, uneven cluster distribution and excessive energy overhead because of frequent cluster reformation [10].

Recent developments in WSN's research have been directed to the improvement of LEACH via machine learning integration [11], fuzzy logic based CH selection [12], and also optimization algorithms [13]. El-Sayed et al. [11] demonstrated 20-fold improvement in lifetime improvement using neural network based CH selection, while Gangal et al. [14] proposed distributed AHP based routing with improved load balancing. Despite these innovations, however, there are considerable gaps in the distance-based clustering optimization and threshold functions refinements.

Methodology

The proposed E-LEACH framework is developed on the basis of hierarchical wireless sensor networks with appropriately considered operational parameters and environmental assumptions. The network deployment is done on a square terrain measuring 1000 x 1000 m^2 with random distribution of the sensor nodes according to a uniform probability distribution. The chosen size of the deployment area is 1000 x 1000 m^2 to efficiently simulate real-world environmental monitoring, staying computationally tractable at the same time. Finally, the base station placed at coordinate (500, 500) at the center of the deployment area corresponds to the central data collection station.

The network topology incorporates a number of basic assumptions that are essential to the experimental validity and applicability of the proposed protocol. All sensor nodes in the network are stationary after the initial deployment. This accurately reflects real-world scenarios of wireless sensor network deployment. The network is homogeneous with respect to hardware parameters. All sensor nodes have the same initial amount of energy, transmission power behavior, sensing range, and processing abilities. This homogeneity is incorporated in order to ensure that the experimental evaluation provides insight pertinent to the proposed protocol's clustering and energy management strategy.

The energy model used in this work is similar to the first-order radio model. This is because the first-order radio model is among the accurate models that can well define the overall energy expenditure behavior in wireless sensor networks. Each node's initial energy is :

$$E_0 = 2 \text{ Joules} \quad (1)$$

This is chosen to ensure that there is a reasonable operational time. The model uses equal costs for sending and receiving energy and is represented by the expression:

$$E_{TX} = E_{RX} = 50 \times \frac{10^{-10}\text{ J}}{\text{bit}} \quad (2)$$

According to the transmission energy model, there exist two propagation modes depending on the communication distance D and a threshold distance d0. For short-range communication with D < d0, a free-space propagation model is applicable. In this scenario, the total energy expenditure for a data packet transfer is expressed as:

$$E_{diss} = E_{TX} + \varepsilon_{fs} D^2 L \quad (3)$$

where $\varepsilon_{fs} = 10 \times 10^{-12}$ J/bit/m^{2}is the free space amplification energy coefficient, and L is the packet size measured in bits. When it comes to a distant communication range with D = d0, the multipath fading model is applicable to consume energy given by:

$$E_{\text{diss}} = E_{TX} + \varepsilon_{mp} D^4 L \quad (4)$$

where $\varepsilon_{mp} = 1.3 \times 10^{-15}$ J/bit/m^{4}is the coefficient of multipath amplification. This two-region model correctly reflects the real-world behavior of radio propagation in outdoor sensor networks.

For the reception and data aggregation operations conducted at the cluster heads, the energy used is given by:

$$E_{aggr} = E_{RX} + E_{DA} L \quad (5)$$

where $E_{DA} = 5 \times 10^{-9}$ J/ bit / signal is the data aggregation energy cost. This data aggregation energy cost is taken into account for the computational processing done to aggregate multiple data streams received from members of the clusters to send to the base station. Figure 1. is the baseline wireless sensor network model employed in this research. This model indicates the distribution of wireless sensor nodes and the position of the central base station. This model is necessary because it provides insight into data communication between the sink station and the wireless sensor nodes.

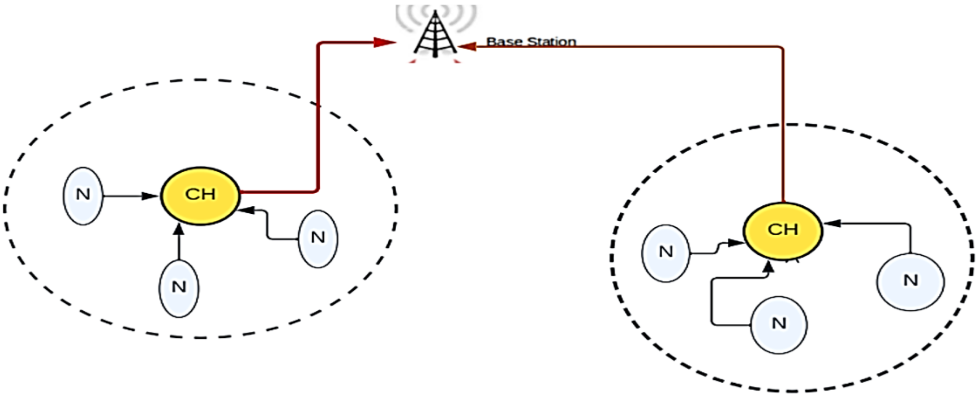

Figure 1: WSN base network model showing node distribution, base station placement, and communication topology

The improved LEACH protocol contiguous to three innovations that each enforce the limitations in standard LEACH while keeping the implementation simple and using little computation power.

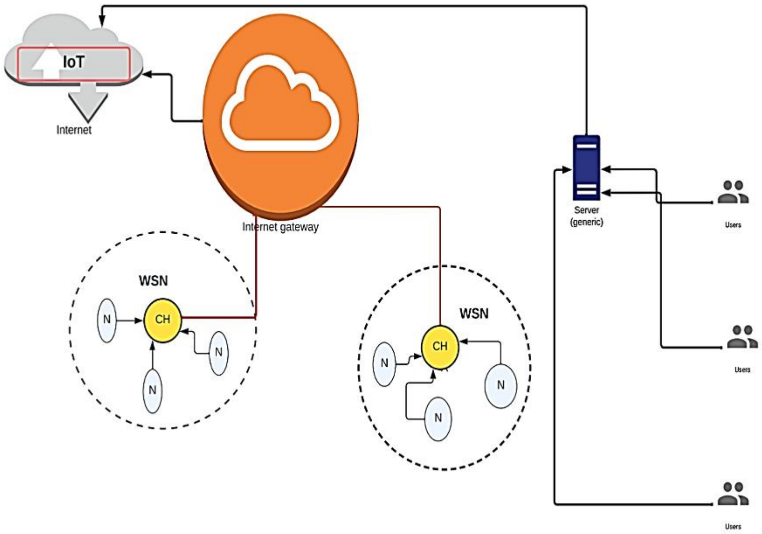

Figure 2: WSN/IoT approach diagram

The conceptual diagram of the WSN/IoT ecosystem showing E-LEACH in relation to it, is given in Figure 2. It indicates that the optimizations of the protocol allow the IoT applications with a long autonomy time to do energy-efficient data collection.

The overall architectural layout of the proposed E-LEACH architecture is presented in Figure 3. This architecture highlights the three-stage E-LEACH framework discussed above. This includes improved Cluster Head Selection, Euclidean Distance-based Cluster Formation, and finally Sender-Receiver Verification. This is done to show the interaction between the information flows and how they fit in the overall communication architecture.

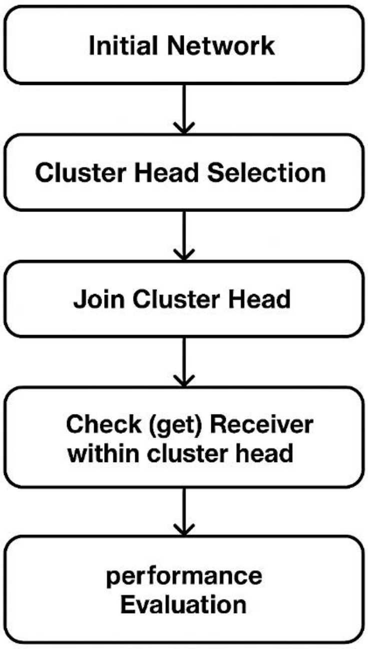

Figure 3: Proposed system structure showing three-stage E-LEACH framework

The first and most basic innovation involves the method of selecting a cluster head, which is a critical function in energy distribution within the network. The basic LEACH protocol uses a probability threshold function to select the cluster head. This mathematical function is presented as:

$$T(n) = \frac{p}{1-p\times \mathrm{mod}\left(n,\mathrm{round}\left(\frac{1}{p}\right)\right)} \qquad (6)$$

Here, p indicates the percentage required for forming the cluster heads (which includes 5-10% of the total nodes in general cases) and n symbolizes the current round. This method ensures random rotation with respect to the formation of cluster heads. However, it introduces high variations in the rate of rotating between the heads of the clusters. This results in high energy consumption because of continuous advertisement, formation, and scheduling processes.

The proposed E-LEACH changes this threshold function to include a squared term in the denominator as given below:

$$T(n) = \frac{p}{1 - p \times \text{mod}\left(n, \text{round}\left(\frac{1}{p}\right)\right)^2} \qquad (7)$$

This mathematical improvement greatly slows down the rate of cluster head rotation, hence minimizing the energy consumed during the process of forming new clusters, with the basic idea of distributed energy usage still intact. The square denominator introduces a slower rate of decay to the threshold value to allow high-energy nodes to have their turn to be a cluster head for a longer duration.

The third innovation introduces a holistic sender-receiver verification mechanism, which optimizes the efficiency of communication by avoiding superfluous transmission attempts. In the proposed framework, there are two kinds of possible communication scenarios: intra-cluster transmission directed to cluster heads, and inter-node communication for nodes outside

Results and Discussion

Network Lifetime Analysis The network lifetime performance showed a notable improvement with E-LEACH algorithm. After 100 iterations, E-LEACH was able to keep 76% of the nodes alive whereas the traditional LEACH had a 0% survival rate. Figure 4. gives a visual comparison of the alive nodes against the rounds for both methods.

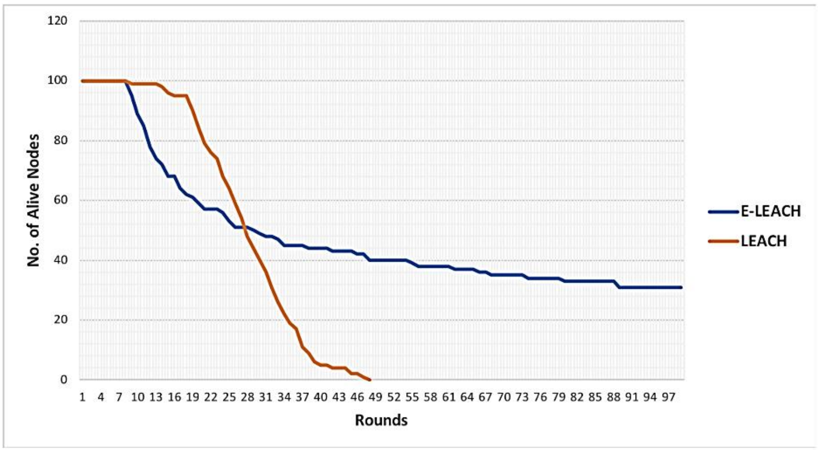

Figure 4: Comparing LEACH and E-LEACH alive nodes vs rounds

The First Node Death (FND) event happened in round 42 for LEACH, while E-LEACH managed to get up to round 68, which is a 61.9% increase in the period of stability. The Half Node Death (HND) point was at round 58 for LEACH and round 87 for E-LEACH, respectively, showcasing the protocol's capability in distributing the energy consumption evenly throughout the network.

Energy Efficiency Performance The energy consumption analysis gave a better value for E-LEACH protocol in terms of network resource conservation. The total residual energy per round for both protocols is displayed in Figure 5. E-LEACH showed 71.86% effectiveness in terms of energy saving, the network resources getting exhausted around the 60th iteration as opposed to the standard LEACH where it was about 35 iterations.

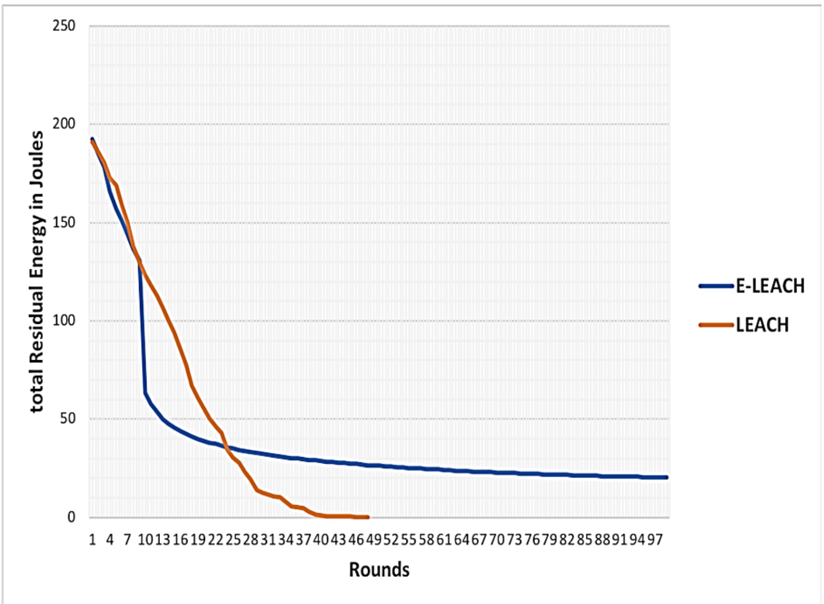

Figure 5: Comparing LEACH and E-LEACH total residual energy per round in Joules

The E-LEACH's cluster head selection strategy, based on the modified equation (Equation 1) for improving energy balance, led to prolonged cluster head cycles and thus lessened the overhead of cluster reforming and advertisement signaling messages.

The PDR performance showed dependency on the network density. For a network of 100 nodes the E-LEACH claimed value of 0.01001233 versus noticeable LEACH's one of 0.00955285, referring to a gain of 4.8%. The graph in Figure 7. indicates that in the situation of the densest networks, this benefit became even more visible, with E-LEACH holding the PDR practically unchanged (0.00269156 for 500 nodes) whereas LEACH suffered a more significant drop (0.00168697 for 500 nodes).

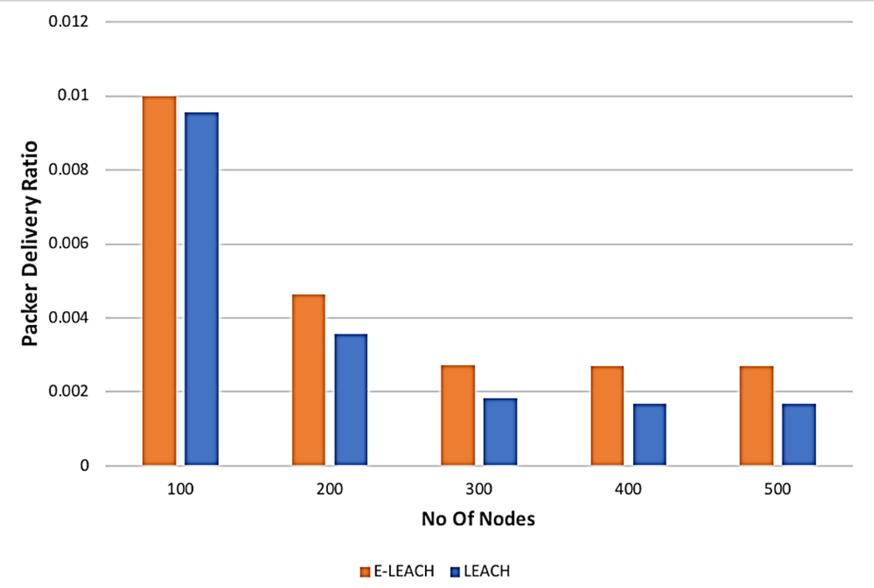

Figure 7: Comparing LEACH and E-LEACH PDR for different number of nodes

Time delays of the packets indicated that E-LEACH was better than others no matter how many nodes were used. The average delay for E-LEACH was 2.01 seconds for 100 nodes while LEACH had 2.45 seconds. The performance difference again illustrated by Figure 8. showing that with larger networks E-LEACH continued to have 10.95 seconds delay for 500 nodes while LEACH suffered 14.51 seconds.

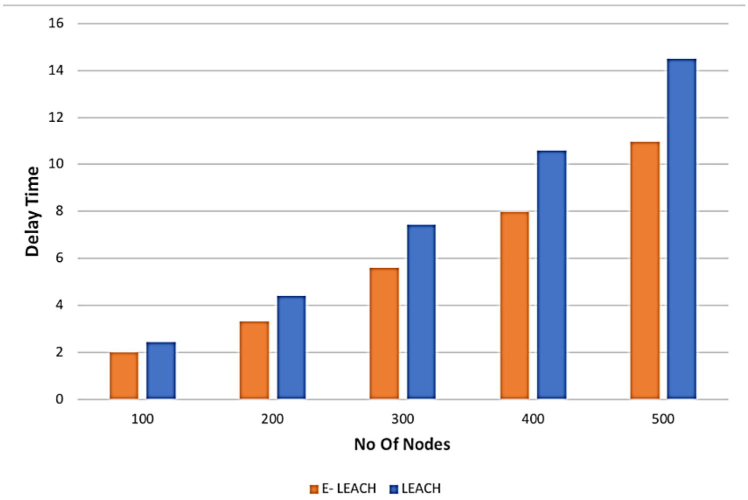

Figure 8: Comparing LEACH and E-LEACH delay time for different number of nodes

The results of the throughput analysis clearly show the data transmission capability of E-LEACH being significantly better. The following graph (Figure 9) shows total throughput comparison for different node densities. For 100 nodes, E-LEACH delivered 1.235 packets/second while LEACH delivered 0.826 packets/second which is a 49.5% gain. This benefit was maintained in all the configurations that were tested, as E-LEACH showed 0.2798 packets/second throughput with 500 nodes compared to LEACH's 0.1559 packets/second.

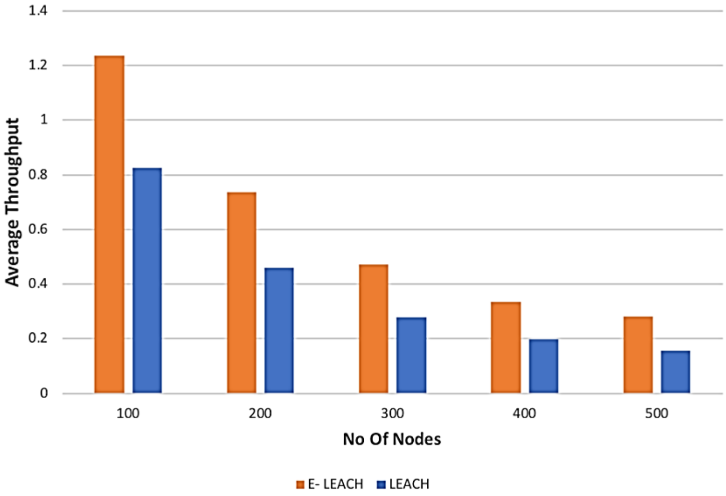

Figure 9: Comparing LEACH and E-LEACH average throughput for different number of nodes

The experimental tests proved the proposed E-LEACH protocol to be a very efficient method in overcoming main drawbacks of the standard LEACH protocol, such as energy consumption and network lifetime. The modified threshold function which adds a squared term in the denominator (Equation 3.1) has successfully slowed down cluster head rotations, thus cutting down the energy consumption that comes with frequent cluster formations.

Conclusion

This work successfully tackles significant energy efficiency issues for IoT-supported Wireless Sensor Networks by introducing the E-LEACH scheme, which is based on an improved hierarchical clustering algorithm. Combining Euclidean distance clustering with an efficient threshold selection for cluster formation and selection, this proposed scheme offers significant performance benefits for improved network lifetime, energy savings, and efficient data transfer. Despite having a predictable performance characteristic, this proposed scheme offers low computational complexity, which is appropriate and beneficial for energy-limited WoS sensor environments. Extensive comparative analyses confirm that this proposed scheme is positioned favourably with recent approaches. Thus, these experimental observations will play a significant role in advancing eco-efficient IoT infrastructure.

References

[1] Kandris, D., Nakas, C., Vomvas, D., & Koulouras, G. (2020). Applications of wireless sensor networks: An up-to-date survey. Applied System Innovation, 3(1), 14. https://doi.org/10.3390/asi3010014

[2] Singh, A. P., Luhach, A. K., Gao, X.-Z., Kumar, S., & Roy, D. S. (2020). Evolution of wireless sensor network design from technology centric to user centric: An architectural perspective. International Journal of Distributed Sensor Networks, 16(8), 1550147720949138. https://doi.org/10.1177/1550147720949138

[3] Ali, Z. (2025). Enhancing the energy efficiency of wireless sensor networks in IoT. International Journal of Advanced Engineering Management and Science, 11(2), 1-12. https://doi.org/10.22161/ijaems.112.1

[4] Yetgin, H., Cheung, K. T. K., El-Hajjar, M., & Hanzo, L. (2017). A survey of network lifetime maximization techniques in wireless sensor networks. IEEE Communications Surveys & Tutorials, 19(2), 828-854. https://doi.org/10.1109/COMST.2017.2650979

[5] Ayanoglu, M. B., & Uysal, I. (2023). ML approach to improve the costs and reliability of a wireless sensor network. Sensors, 23(9), 4303. https://doi.org/10.3390/s23094303

[6] Tossa, F., Abdou, W., Ansari, K., Ezin, E. C., & Gouton, P. (2022). Area coverage maximization under connectivity constraint in wireless sensor networks. Sensors, 22(5), 1712. https://doi.org/10.3390/s22051712

[7] Gulati, K., Boddu, R. S. K., Kapila, D., Bangare, S. L., Chandnani, N., & Saravanan, G. (2021). A review paper on wireless sensor network techniques in Internet of Things (IoT). Materials Today: Proceedings, 51, 161-165. https://doi.org/10.1016/j.matpr.2021.05.067

[8] Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, 1-10. https://doi.org/10.1109/HICSS.2000.926982

[9] Kandris, D., Tsioumas, P., Tzes, A., Nikolakopoulos, G., & Vergados, D. D. (2009). Power conservation through energy efficient routing in wireless sensor networks. Sensors, 9(9), 7320-7342. https://doi.org/10.3390/s90907320

[10] Chan, L., Chavez, K. G., Rudolph, H., & Hourani, A. (2020). Hierarchical routing protocols for wireless sensor network: A compressive survey. Wireless Networks, 26(5), 3291-3314. https://doi.org/10.1007/s11276-020-02260-z

[11] El-Sayed, H. H., Abd-Elgaber, E. M., Zanaty, E. A., Alsubaei, F. S., Almazroi, A. A., & Bakheet, S. S. (2024). An efficient neural network LEACH protocol to extended lifetime

of wireless sensor networks. Scientific Reports, 14, 26943. https://doi.org/10.1038/s41598-024-75904-1

[12] Mehra, P. S., Doja, M. N., & Alam, B. (2020). Fuzzy based enhanced cluster head selection (FBECS) for WSN. Journal of King Saud University - Science, 32(1), 390-401. https://doi.org/10.1016/j.jksus.2018.04.031

[13] Gul, H., Ullah, S., & Kim, K.-I. (2024). A traffic-aware and cluster-based energy efficient routing protocol for IoT-assisted WSNs. Computers, Materials & Continua, 80(2), 1831-1850. https://doi.org/10.32604/cmc.2024.052841

[14] Gangal, V., Cinemre, I., & Hacioglu, G. (2024). A distributed LEACH-AHP routing for wireless sensor networks. IEEE Access, 12, 19307-19319. https://doi.org/10.1109/ACCESS.2024.3359750