Adaptive Thresholding in TDEEC to Achieve Energy Saving and Long Life of WSNs

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ABSTRACT

Wireless sensor networks (WSNs) have become a technology foundation in the new era of technological ecosystems and can be used in multiple fields. Nevertheless, sensor nodes are energy-constrained, and network stability and lifetime are directly dependent on the energy capacity of the sensor nodes. Routing protocols based on clustering have been popular to resolve energy efficiency issues, but they still face limitations. To solve these issues, the current study suggests an improved Threshold Distributed Energy Efficient Clustering (TDEEC) protocol, which will add a dynamic and adaptive threshold-based CH election mechanism. This adaptive technique will guarantee a fairer allocation of Cluster Head (CH) roles, minimize the premature mortality of nodes as well as provide equalized energy consumption in the network. The results showed that the improved TDEEC protocol has high stability, long network lifetime, and high throughput. The findings reflect sluggish first-node fatality, enhanced energy efficiency, and augmented data packet volume that has been efficiently conveyed to Base Station (BS) by 25% more than the original protocol. Improved TDEEC overcomes the weaknesses of current models.

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1. INTRODUCTION

Wireless Sensor Networks are a network of distributed nodes that jointly sense and report data regarding physical or environmental conditions, e.g., temperature, humidity or movement, to a Base Station (BS). WSNs have become an essential part of the environmental monitoring, healthcare, industrial automation, smart cities, and military surveillance applications [1].The researchers are heavily focused on improvement various aspects of Wireless Sensor Networks (WSNs) to facilitate more intelligent, efficient, and secure deployments, particularly in IoT and cyber-physical systems [2], [3]. A typical WSN consists of numerous sensor nodes distributed over a geographical area to detect, analyses, and transmit environmental information to a Base Station (BS) [4]. Due to their inherent limitations, minimal battery capacity, and often non-rechargeable nature in hostile or hard-to-reach deployment environments, these nodes are highly resource-constrained. Consequently, energy efficiency is the most critical concern in WSN design, directly influencing the network's reliability, scalability, and longevity [5]. Clustering protocols such as the DEEC, DDEEC and especially Threshold DEEC have further improved energy efficiency through the choice of CHs with the help of residual energy and average network energy. Nevertheless, TDEEC continues to perform poorly in strongly heterogeneous settings because of uneven energy loss, earlier failure of low-energy nodes and reduced stability times. Recent methods have involved the 3D-aware ETDEEC-3D protocol that uses multidimensional scaling to optimize energy spending and reduce network lifetime in uneven environments [6].

IoT-DEEC that changes the threshold function to achieve substantial improvements in packet delivery and node survival, reaching over 843% higher packets forwarded and over 30,000 rounds of node lifetime [7], and fuzzy logic-based clustering, which optimizes load balancing and energy expenditure by choosing CHs based on inputs such as node distance, node density and remaining energy [8]. Although these innovations exist, a majority of the methods either have a high computational cost or do not dynamically scale to different degrees of heterogeneity. In spite of having a number of upgrades to DEEC such as ETDEEC and TEDDEEC, such variants continue to have ineffective energy balancing of sensor nodes, which can trigger premature node death and decrease the network lifetime. The paper proposes an adaptive thresholding process to enhance the process of selecting cluster head in TDEEC. The suggested approach dynamically varies the threshold based on residual energy and average network energy, which will enhance the energy allocation and increase the network lifetime. The major findings of this paper can be summarized as follows:

- Suggesting an adaptive thresholding system on cluster head selection.
- Enhancing the energy balancing of nodes.

The proposed method introduces an adaptive threshold mechanism that dynamically adjusts the cluster head selection probability based on residual energy and node-to-base station distance. This adaptive mechanism balances energy consumption across the network and significantly prolongs the lifetime of the Wireless Sensor Network compared with the conventional TDEEC protocol.

1.1. Background studies

The global range of clustering-based routing protocols have been presented over the last twenty years to overcome the long-term problem of energy efficiency in WSNs. Since sensor nodes are generally energy constrained and placed in resource limited environments, extending network life combined with controlling energy usage has been a key research goal. In their study, relied on power-dependent clustering techniques in heterogeneous WSNs, focusing on transmission energies to determine CHs. Specific power threshold functions were employed for each node to select the most suitable CHs and optimize power efficiency. However, dynamic adaptation was not incorporated into the head selection process due to the network's inherent characteristics [9]. They based their study on the IoT-DEEC protocol, focusing on improving network stability and extending network lifespan by modifying threshold variables related to head selection and power level adjustments. Their model demonstrated good performance, but it may be less effective in wide area networks, with performance potentially being negatively impacted by this modification [7]. They conducted a comparative study of four WSN protocols: LEACH protocol, DEEC protocol, DDEEC protocol, The comparison focused on several aspects, including performance, network lifetime, and energy efficiency. The researchers used simulations in their experiments, and the results showed that some protocols outperformed LEACH in terms of both performance and efficiency [10]. In their study, developed a model for three-level heterogeneous networks. This model incorporates a variable that can be classified as heterogeneous level 1, heterogeneous level 2, or heterogeneous level 3. The model demonstrated good efficiency and excellent performance with low power consumption. However, applying this model to large-scale networks may lead to increased power consumption [11]. In their study, they proposed improving the DEEC protocol in WSNs using fuzzy logic. The proposed model achieved superior performance and energy efficiency compared to other protocols. However, the method relies on intensive computation, making it less suitable for networks with limited resources and environments requiring rapid decision-making [12].

They developed an improved DEEC protocol model for WSNs called I-DEEC. This model features a two-layer network and uses a CH selection mechanism based on the node's distance from the BC and the remaining power after consumption. The protocol also leverages varying power levels between nodes to improve overall performance [13]. They presented an improved version of the DEEC protocol in WSNs, which they named the O-DEEC Improved Protocol, with the aim of enhancing performance and efficiency. To achieve this, they relied on a set of criteria, such as average regional power and threshold functions, etc. A study was conducted using two sets of samples, each containing twenty samples. Their results showed that the O-DEEC protocol outperformed the DEEC protocol. This protocol demonstrated a significant reduction in latency of approximately 19%, along with a 4% increase in network lifetime. However, the number of samples used in the study is quite limited, suggesting that applying the protocol to a larger number of samples might result in lower efficiency and performance [14]. In order to overcome these drawbacks, recent works have centered on lightweight extensions to protocols based on DEEC. As an example, The DEEC protocol is based on the idea of the energy efficiency of the protocol that chooses cluster heads based on their remaining energy. The DDEEC and EDEEC protocols, in turn, enhance the allocation of energy among inhomogeneous sensor nodes. TDEEC includes a threshold-based head selection criterion on clusters; however, still, it suffers energy imbalance on later rounds.

To provide a clearer overview of differences between the most commonly used clustering protocols in Wireless Sensor Networks and the new one, Table 1 gives a comparative summary. The table is a prelude to the cluster head selection mechanism, energy-awareness capability, and the main constraints that each protocol has.

Table 1. Comparison of clustering protocols in Wireless Sensor Networks

Protocol	Cluster Head Selection	Energy Awareness	Limitation
LEACH	Random	No	Energy imbalance
DEEC	Residual Energy	Yes	Not adaptive
TDEEC	Threshold-based	Yes	Fixed threshold
Improved TDEEC	Adaptive Threshold	Yes	Improved energy balance

2. METHOD

Full Enhanced TDEEC Clustering protocol is an advanced protocol of the traditional TDEEC model, which is specifically designed to overcome the weakness of the existing model in the highly heterogeneous WSN. Standard TDEEC applies a statical thresholding model that is based on the ratio of residual energy to average network energy, which is often an unfair energy depletion and premature node death strategy when applied to a heterogeneous situation. To mitigate these shortcomings, Enhanced TDEEC uses a dynamic, adaptive thresholding device that adjusts the probability of cluster-head election, on a per-round basis, and considering four key variables, i.e., the residual energy of individual nodes, the averages in the network, the number of rounds finished, and the current energy consumption rates. This methodological improvement ensures that there is a balanced selection of CHs, balanced energy consumption, and reduced cluster-head loss and that its computation remains simple.

Figure 1. Workflow of proposed system.

The efficiency of adaptive thresholding and hybrid clustering schemes in prolonging network lifespan and load balancing has been supported according to ETSDEEC, lifetime has increased by 37.7% in comparison with TDEEC [15], although other hybrid and region-based schemes have also performed exceedingly well in terms of performance advantage and energy savings [16], [17]. In addition, the research has shown that fixed or semi-fixed thresholds often promote asymmetric energy loss and global instability [18], [19]. In as much as adaptive variants like TEDDEEC [20] improve stability and throughput, they equally introduce extra complexity or offer partial support to heterogeneity. Such a strategy provides critical uniform dispersal of CHs, equal fighting of network energy, and continuous stability of networks, thus successfully mitigating the chronic energy imbalance problem with DEEC-based clustering protocols and enhancing reliability and scalability of the heterogeneous WSNs.

2.1. System Model

The suggested Enhanced TDEEC protocol is tested within the framework of a heterogeneous WSN model with a range of realistic assumptions that capture the deployment presence conditions. In particular, the N sensor nodes are placed randomly on a two-dimensional square field (e.g., 100 m × 100 m) to mimic irregular topologies that occur in the context of the environmental monitoring and smart city use. The BS can be located within the sensing field or be placed externally, which can be both near-field and long-range communication cases. In contrast to the homogeneous networks where each node has the same initial energy, the network under consideration is considered as heterogeneous with each node having different initial energy values to represent advanced, intermediate and normal nodes. After deployment, sensor nodes are not mobile, which is in line with the reality of WSNs being embedded or being spatially fixed. Each node can estimate both its residual energy and the average energy of the network per round, both of which are basic to CH election in DEEC-based protocols. Figure 1 shows the study workflow.

It has been stressed in previous research that heterogeneity-conscious system models are much better at performance since they extend the stability times and postpone the initial death of a node than homogeneous counterparts. Nevertheless, the majority of clustering protocols including the baseline TDEEC continue to have constraints like high rate of advanced node depletion due to repeated CH selection, inefficient multi-tier heterogeneity scaling, and poor integration of BS distance in energy cost functions. In order to address these problems, the Enhanced TDEEC system model will use the adaptive thresholding mechanisms, which consider residual node energy, network-wide average energy, rounds elapsed, and distance to the BS.

This guarantees that selection of CH is not only energy-conscious but also context-sensitive to minimize premature node death and to balance energy usage across the entire network. With these mechanisms incorporated in a heterogeneous system model, Enhanced TDEEC directly solves the deficiencies of traditional TDEEC, extending network lifetime, delivering more packets to the BS and enhancing resilience to a wide range of deployment conditions.

2.2. Radio Energy Model

The proposed Enhanced TDEEC protocol is based on the first-order radio model that has been extensively utilized in clustering-based WSN protocol as part of estimating the cost of communication energy. The amount of energy used in transmission in this paradigm relies largely on the size of the data packet (k) and the distance (d) between the transmitting and receiving nodes. The model differentiates between two propagation regimes: the free-space model (used when the distance of transmission is less than a threshold) and the multi-path fading model (used when the distance of the transmission is greater than the threshold). The distance d energy used to transmit a message with k bits is:

$$E_{tx}(k,d)=\begin{cases} k.E_{elec}+k.\epsilon_{fs}.d^2, & \text{if } d<d_0 \\ k.E_{elec}+k.\epsilon_{mp}.d^4, & \text{if } d\geq d_0 \end{cases} \tag{1}$$

The energy required to receive a k-bit message is defined as:

$$E_{RX}(k)=kE_{elec} \tag{2}$$

Where:

- Eelec: energy dissipated to operate transmitter or receiver circuitry.
- ∈fs : amplifier energy factor for the free-space model.
- ∈mp: amplifier energy factor for the multi-path fading model.
- d0: threshold distance, defined as d0: √("∈" _"fs" /"∈" _"mp")
- k: size of the data packet (in bits).
- d: Transmission distance.

This model describes the large influence of the distance between communicators on energy use because transmission over long distances d≥d0 and above costs a vastly higher amount of energy because of the d4 term. Previous research established that improper choice of CH without considering distance to BS results in quick energy depletion and reduced network life.

2.3. Average Energy of the Network

The average residual energy of the network at round r is defined as:

$$E_{avg}(r)=\frac{1}{N}\sum_{i=1}^{N} E_i(r) \tag{3}$$

Where $E_i(r)$: residual energy of node i at round r. N : total number of sensor nodes.

2.4. Cluster Head Selection Probability in TDEEC
In the conventional TDEEC protocol, the probability of node i becoming a cluster head is :

$$P_i = P_{opt} \frac{E_{i(r)}}{E_{avg(r)}} \tag{4}$$

Where P_{opt}: optimal probability of cluster head selection.
This ensures that nodes with higher residual energy have a higher chance of becoming cluster heads.

2.5. Threshold Function in Conventional TDEEC
The threshold function that determines whether a node becomes a cluster head is:

$$T_i(r) = \begin{cases} \frac{P_i}{1-p_i\left(r \bmod \frac{1}{p_i}\right)}, & , i \in G \\ 0 & \end{cases} \tag{5}$$

Where G represents the set of nodes that have not been selected as cluster heads in the last $\frac{1}{p_i}$ rounds.

2.6. Proposed Adaptive Threshold Mechanism
To further enhance energy efficiency and prolong network lifetime, an adaptive threshold factor is introduced. This factor considers both the residual energy of the node and its distance to the base station.

$$a_i = \frac{E_i(r)}{E_{max}} \tag{6}$$

Where E_{max} is the initial maximum node energy.

$$\beta_i = \frac{d_{avg}}{d_i} \tag{7}$$

Where d_i : distance between node i and the base station.
d_{avg}: average distance of nodes from the base station.

2.7. Proposed Adaptive Threshold Equation
The improved threshold function is formulated as:

$$T_i^{adaptive}(r) = \begin{cases} \frac{P_i * A_I}{1-p_i\left(r \bmod \frac{1}{p_i}\right)}, & , i \in G \\ 0 & \end{cases} \tag{8}$$

This adaptive mechanism dynamically adjusts the cluster head selection threshold based on the node's current energy status and its distance from the base station.

2.8. Improved Cluster Head Probability
The cluster head probability can also be enhanced as follows:

$$p_i^{adaptive} = p_{opt} \frac{E_i(r)}{E_{avg}(r)} \left(1 + \gamma \frac{d_{avg}}{d_i}\right) \tag{9}$$

Where: $0<\gamma<1$
This modification ensures that nodes closer to the base station have a slightly higher probability of becoming cluster heads, thereby reducing long-distance transmission energy.

3. RESULTS AND DISCUSSION

Previously, MATLAB had numerous uses as the universal test platform to test the operation of clustering-based routing protocols like LEACH, SEP, DEEC and TDEEC because it could simulate communication energy models, test routing performance, and test algorithmic routing performance in a controlled environment. Although the original TDEEC had significantly improved over DEEC and DDEEC due to the addition of a dynamic threshold in CH selection, it was also challenging in terms of unbalanced energy use and early node death in highly heterogeneous conditions. Some authors tried to overcome these shortcomings with fuzzy logic, machine learning and meta-heuristic optimization methods. But such solutions usually impose a computational load that is infeasible in resource-constrained WSNs.

The Enhanced TDEEC protocol simulation experiments were performed in MATLAB R2018b with Signal Processing Toolbox on a windows 10 operating system with the Signal Processing Toolbox. MATLAB was chosen as the simulation platform because of its advanced numerical computations, matrices and the ease with which it can manipulate functional arrays that enable it to model WSNs accurately. Moreover, MATLAB helps to analyze errors, scientifically visualize and compare the performance through the creation of graphical representation of energy dissipation, CH distribution, and packet delivery statistics. Table 2 shows simulation context.

Table 2. Simulation setup

Parameter	Value/Description
Number of sensor nodes (N)	100
Network size	100 m × 100 m square region
BS position	Located at the center of the deployment area
Initial energy (E_0)	0.5 J per normal node
Node heterogeneity	Normal / Advanced / Super
Data packet size (k)	4000 bits per packet
Energy for electronics (E_{elec})	50 nJ/bit
Amplifier energy (ε_{fs})	10 pJ/bit/m²
Amplifier energy (ε_{mp})	0.0013 pJ/bit/m⁴
Threshold distance (d_0)	Calculated based on ε_{fs} and ε_{mp}

After applying the equations mentioned in the third part to the TDEEC protocol, the obtained results will be explained in this part. This study found that Enhanced TDEEC is a direct solution to these limitations, since it refines the threshold mechanism to incorporate residual energy, average network energy, distance-to-sink awareness as well as short-term rate of energy consumption. This allows more flexible and fair CH selection strategy, which helps to ensure better energy balance among heterogeneous nodes and prolongs the lifetime of the whole network. The simulation findings in this section underscore the fact that the proposed modifications are more stable than classical TDEEC and its variations in terms of stability period, throughput (packets sent to the BS) and energy efficiency.

A comprehensive comparative study was conducted on the original TDEEC protocol and the proposed Enhanced TDEEC algorithm, as defined by the results of MATLAB simulations. The analysis focuses on three key performance indicators (KPI) including (1) node mortality rate, (2) the number of packets that are successfully delivered to the BS and (3) the number of packets delivered to CHs. These performance measures have a direct impact on the stability, throughput and energy efficiency of the network.

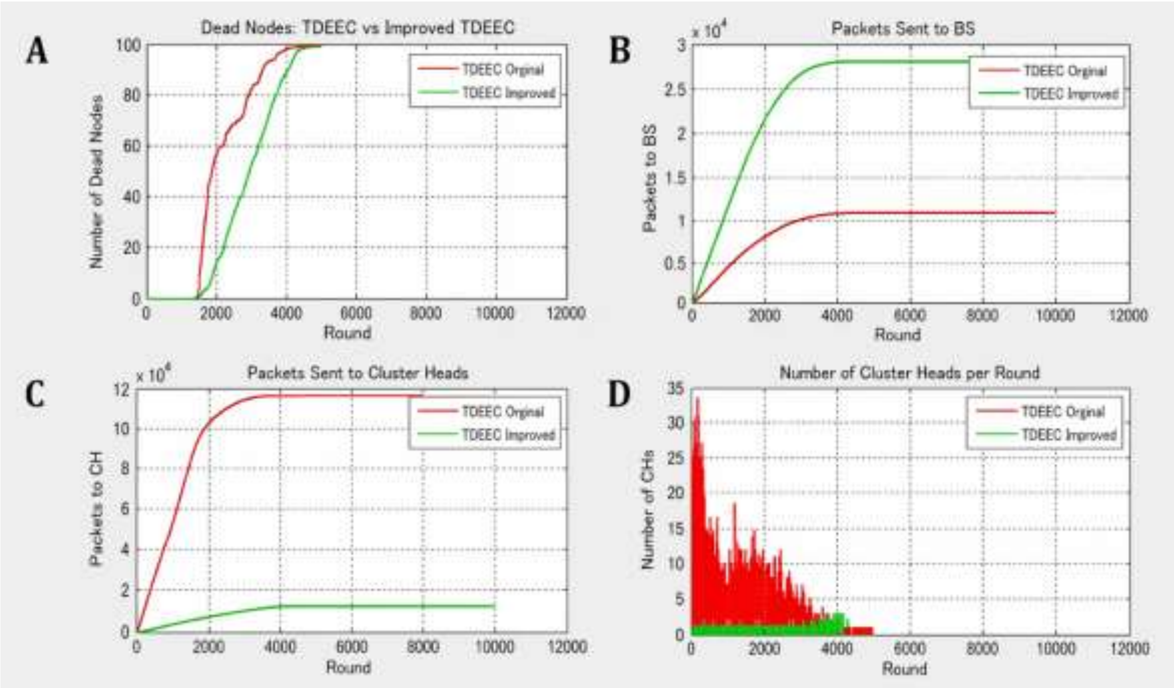

Figure 2. Simulation TDEEC protocol.

Figure 2 (A) shows the simulation round of dead nodes in both protocols. The initial TDEEC (red curve) indicates that the initial node (before the round 1500) dies early, then after the death of the nodes occurs very rapidly, and all nodes are dead at around the round 4500.

By contrast, the improved TDEEC (green curve) delays the initial node death greatly later almost to 2000 and keeps the network running longer, and the final node dying after almost 5000. This can be credited to the adaptive threshold feature that allocates CH tasks more fairly among nodes that have increased residual energy. The result is consistent with the recent reports which point out that adaptive CH election schemes minimize premature failures of nodes in heterogeneous WSNs. Figure 2(B) shows the amount of packets that were transmitted to the BS successfully. improved TDEEC (green curve) is by far superior to the initial TDEEC, with a greater number of packets being sent, which reaches over 3×10^5 packets, as opposed to the original 1.2×10^5 packets. This is a significant advancement in the throughput since the improved TDEEC guarantees a longer period of stability where more active nodes are transmitting data. Practically, it will result in more stable provision of applications that depend on WSNs (e.g., environmental monitoring or smart agriculture) and minimizing loss of information. These results are in line with the earlier studies that point out the fact that adaptive energy-conscious clustering protocols improve throughput in heterogeneous environments. Figure 2(C) shows the amount of packets sent to CHs. The initial TDEEC (red curve) is steep and reaches more than 1.2×104 packets early in the simulation meaning that there is more intra-cluster communication overhead. In contrast, the improved TDEEC (green curve) has fewer packet transmissions to CHs, and its level at 1.5x103. This shows that the protocol proposal minimizes unnecessary intra-cluster communications and prevents unnecessary use of energy during CH aggregation. The improved TDEEC can reduce redundant transmissions and consequently improve energy saving and overall network lifetime, which is also endorsed by recent work in clustering studies in heterogeneous WSNs. Figure 2(D) gives the number of CHs produced during each round. The initial TDEEC protocol has a high variability and too much CH formation resulting in imbalanced energy usage and early node death. On the other hand, the improved TDEEC has a more balanced and regulated CH distribution, which directly leads to better energy performance and network life cycle.

As seen in the comparative analysis in Table 3, the improved TDEEC protocol was better in performance than the original TDEEC. The proposed improvement is effective in overcoming the shortcomings of the baseline protocol by the addition of a dynamic and adaptive thresholding scheme, which is able to achieve a more equitable distribution of energy, less premature node mortality, and a better delivery of packets to the BS. The results of simulations verify that Enhanced TDEEC has a greater stability period, increased throughput and greater energy efficiency than TDEEC.

Table 3. Comparison of the improved TDEEC protocol with the original TDEEC protocol in terms of advantages

Metric	Original TDEEC	Improved TDEEC (Proposed)
Stability Period	Limited stability early node deaths occur due to static thresholding.	Prolonged stability through adaptive threshold adjustments, delaying first node death.
Network Lifetime	Shorter lifetime due to uneven energy consumption across heterogeneous nodes.	Extended lifetime by balancing load distribution among normal, advanced, and super nodes.
Energy Consumption	Higher energy dissipation caused by fixed CH selection criteria.	Reduced energy waste through dynamic CH election based on residual energy and consumption.
Throughput (Packets to BS)	Lower throughput due to premature node failures and inefficient CH distribution.	Higher throughput as more packets are delivered to BS before network segmentation.
Scalability	Limited adaptability to multi-level heterogeneity and large-scale deployments.	Supports scalability through flexible thresholding and dynamic CH adjustments.
Load Balancing	Unequal load on high-energy nodes, leading to early exhaustion.	Improved load balancing with adaptive CH rotation and equitable energy distribution.
Adaptation to Real Scenarios	Less effective in event-driven or uneven deployments.	Better adaptation through residual energy awareness and distance-sensitive clustering.

4. CONCLUSION

This study presents an enhanced version of the TDEEC protocol designed to address energy efficiency and network longevity challenges in WSNs. The proposed approach incorporates adaptive mechanisms to better reflect real-world operating conditions and improve overall system performance. Extensive simulations were conducted to evaluate the effectiveness of the improved protocol under various network scenarios. The simulation outcomes proved that improved TDEEC extends the stability period significantly, postpones the death of the first node, and extends the duration of the network lifetime by 25% compared to the initial TDEEC. In addition, the protocol was successful in improving throughput as more packets were delivered to the BS successfully and evenly by distributing energy. Moreover, it proves that improved TDEEC goes beyond the initial TDEEC and further improves the performance of initial TDEEC by incorporating adaptive mechanisms that are more realistic to the real-world WSN conditions. In turn, the enhanced protocol provides a powerful, scalable, and energy-conscious solution to the next generation of WSN applications in which reliability, efficiency, and sustainability are of supreme importance.

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REFERENCES

[1] M. U. Mushtaq, H. Venter, A. Singh, and M. Owais, "Advances in Energy Harvesting for Sustainable Wireless Sensor Networks: Challenges and Opportunities," Hardware, vol. 3, no. 1, p. 1, Feb. 2025, doi: https://doi.org/10.3390/hardware3010001

[2] A. Oztoprak, R. Hassanpour, A. Ozkan, and K. Oztoprak, "Security Challenges, Mitigation Strategies, and Future Trends in Wireless Sensor Networks: A Review," ACM Computing Surveys, vol. 57, no. 4, pp. 1–29, Dec. 2024, doi: https://doi.org/10.1145/3706583

[3] Z. K. Maseer, R. Yusof, S. A. Mostafa, N. Bahaman, O. Musa, and B. Ali Saleh Al-rimy, "DeepIoT.IDS: Hybrid Deep Learning for Enhancing IoT Network Intrusion Detection," Computers, Materials & Continua, vol. 69, no. 3, pp. 3945–3966, 2021, doi: https://doi.org/10.32604/cmc.2021.016074

[4] Hassan, A. A. H., Shah, W. M., Iskandar, M. F., Al-Mhiqani, M. N., & Naseer, Z. K. (2018). Unequal clustering routing algorithms in wireless sensor networks: A comparative study. Journal of Advanced Research in Dynamical and Control Systems, 10(2 Special Issue), 2142-2156.

[5] S. Zhang, X. Liu, and M. Trik, "Energy efficient multi hop clustering using Artificial Bee Colony metaheuristic in WSN," Scientific Reports, vol. 15, no. 1, Jul. 2025, doi: https://doi.org/10.1038/s41598-025-12321-y

[6] O. Amenchar, M. Baghouri, S. Chakkor, and A. Dkiouak, "A new enhanced TDEEC protocol for 3D HWSN," e-Prime – Advances in Electrical Engineering, Electronics and Energy, vol. 10, p. 100863, Dec. 2024, doi: 10.1016/j.prime.2024.100863.

[7] H. H. El-Sayed and Z. M. Hashem, "Comparison of the new version of DEEC protocol to extend WSN lifetime," EURASIP Journal on Wireless Communications and Networking, vol. 2023, no. 1, Jul. 2023, doi: 10.1186/s13638-023-02265-0.

[8] C. Sureshkumar and S. Sabena, "Fuzzy-based secure authentication and clustering algorithm for improving the energy efficiency in wireless sensor networks," Wireless Personal Communications, vol. 112, no. 3, pp. 1517–1536, Jan. 2020, doi: 10.1007/s11277-020-07113-8.

[9] K. Maheshwar, S. Veenadhari, and M. Almelu, "Energy efficient heterogeneous WSN clustering using machine learning," SMART MOVES Journal IJOSCIENCE, vol. 7, no. 6, pp. 24–29, Jun. 2021, doi: 10.24113/ijoscience.v7i6.391.

[10] P. Mehrotra and D. Bhardwaj, "Evaluating energy efficiency and performance of WSN routing protocols: A comparative study of LEACH, DEEC, DDEEC, and EESAA," in Algorithms for Intelligent Systems. Singapore: Springer, 2025, pp. 91–100, doi: 10.1007/978-981-96-3333-3_8.

[11] S. Singh and A. Malik, "Heterogeneous DEEC protocol for prolonging lifetime in wireless sensor networks," Journal of Information and Optimization Sciences, vol. 38, no. 5, pp. 699–720, Jul. 2017, doi: 10.1080/02522667.2016.1220083.

[12] S. Neelakandan, A. Mardani, P. Mani, A. R. Mishra, and P. Ezhumalai, "A fuzzy logic and DEEC protocol-based clustering routing method for wireless sensor networks," AIMS Mathematics, vol. 8, no. 4, pp. 8310–8331, Jan. 2023, doi: 10.3934/math.2023419.

[13] V. Nehra, A. K. Sharma, and R. K. Tripathi, "I-DEEC: Improved DEEC for blanket coverage in heterogeneous wireless sensor networks," Journal of Ambient Intelligence and Humanized Computing, vol. 11, no. 9, pp. 3687–3698, Oct. 2019, doi: 10.1007/s12652-019-01552-3.

[14] Krishna and C. Senthilkumar, "An effective delay reduction routing protocol for WSN using optimized distributed energy efficient clustering (O-DEEC) protocol compared with DEEC protocol," AIP Conference Proceedings, vol. 3082, p. 060008, Jan. 2024, doi: 10.1063/5.0186148.

[15] N. F. Omran, N. M. M. Abdelnapi, E. M. Mohamed, and N. M. Labib, "Design of an enhanced threshold sensitive distributed energy efficient clustering routing protocol for WSN-based IoT," International Journal of Electronics, vol. 110, no. 8, pp. 1373–1392, Jun. 2022, doi: 10.1080/00207217.2022.2087919.

[16] M. Bilal, E. U. Munir, and F. K. Alarfaj, "Hybrid clustering and routing algorithm with threshold-based data collection for heterogeneous wireless sensor networks," Sensors, vol. 22, no. 15, p. 5471, Jul. 2022, doi: 10.3390/s22155471.

[17] N. Tripathi, "Performance analysis of Mod-LEACH, LEACH, DEEC, EDEEC, TDEEC in wireless camera sensor network," IMRJR, vol. 2, no. 2, Mar. 2025, doi: 10.17148/imrjr.2025.020205.

[18] S. Bhushan, R. Pal, and S. Antoshchuk, “Energy efficient clustering protocol for heterogeneous wireless sensor network: A hybrid approach using GA and K-means,” in Proc. IEEE DSMP, Aug. 2018, doi: 10.1109/DSMP.2018.8478538.

[19] D. W. Sambo, B. Yenke, A. Förster, and P. Dayang, “Optimized clustering algorithms for large wireless sensor networks: A review,” Sensors, vol. 19, no. 2, p. 322, Jan. 2019, doi: 10.3390/s19020322.

[20] G. M. Tamilselvan, “TEDDEEC: Threshold enhanced developed distributed energy-efficient clustering for heterogeneous wireless sensor networks,” Journal of Applied Research and Technology, vol. 22, no. 3, pp. 336–350, Jun. 2024, doi: 10.22201/icat.24486736e.2024.22.3.2301.

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