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AN IMPROVED ENERGY-EFFICIENT CLUSTERING PROTOCOL TO PROLONG THE LIFETIME OF THE WSN

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Abstract:Wireless sensor networks (WSNs) are essential in modern projects, particularly those involving IoT applications. However, the limited energy resources of sensor nodes in WSN-based projects pose a significant challenge. Clustering protocols have emerged as a promising solution to mitigate this challenge, aiming to reduce energy consumption and extend the network lifespan by organizing nodes into clusters. Despite their potential, existing clustering protocols often face inefficiencies in their mechanisms, limiting their overall effectiveness. Our enhanced energy-efficient clustering protocol (IEECP) offers a more optimized approach compared to traditional routing protocols like Low-Energy Adaptive Clustering Hierarchy (LEACH), which may encounter inefficiencies in cluster formation and energy consumption

IEECP starts by determining the optimal number of clusters to ensure balanced energy utilization. It then employs a modified fuzzy C-means algorithm to establish balanced static clusters, effectively minimizing energy imbalances among sensor nodes. Additionally, our protocol introduces a novel cluster head (CH) selection rotation algorithm. This algorithm dynamically rotates the CH role among cluster members using a timer mechanism for selection and a rotation mechanism for Cluster Heads. Implementing these strategies, addresses the drawbacks of traditional CH selection methods, ensuring more efficient energy utilization throughout the network.

***Keywords*— WSN, clustering protocol, Alive nodes, network lifetime.**

Ⅰ. INTRODUCTION

In today's era of modern technology, sensor nodes play a critical role in contemporary communications by enabling seamless collection and transmission of data across various applications. These networks, consisting of interconnected sensor nodes equipped with sensing, processing, and communication capabilities, are extensively utilized in diverse fields such as environmental monitoring, healthcare systems, industrial automation, and smart infrastructure. The emphasis on developing efficient communication protocols, signal processing algorithms, and low-power hardware designs highlights the importance of WSNs in facilitating reliable and energy-efficient data transmission [1]. Researchers and engineers are dedicated to optimizing network performance, improving data reliability, and reducing energy consumption through innovative approaches. By leveraging advancements in wireless communication technologies, signal processing techniques, and embedded systems design, professionals significantly contribute to the evolution and progress of WSNs, ensuring their continual relevance and effectiveness in modern communication systems [2].

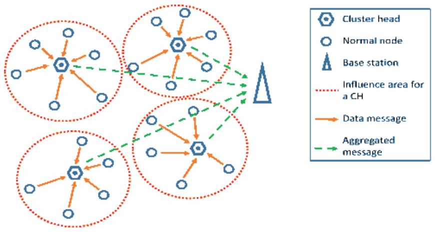


Figure 1 LEACH protocol for WSN

This paperwork proposes an Enhanced Energy-Efficient Clustering Protocol (IEECP) specifically tailored for WSN-based projects. The protocol comprises three main components. Firstly, an optimal number of clusters is determined to form overlapping balanced clusters.Secondly, it employs a fuzzy C-means algorithm with modifications to create balanced static clusters, effectively minimizing and distributing energy consumption among sensor nodes [10].Lastly, the selection and rotation algorithm of cluster Heads is introduced, integrating both a back-off timer mechanism for CH selection and a rotation mechanism for CH rotation to select optimal cluster heads (CHs)[5]. By optimizing the clustering structure, we are proposing a protocol that significantly reduces and balances node energy usage, making it particularly suitable for WSN-based projects with extended lifespans [12].Evaluation results demonstrate that IEECP outperforms existing protocols in terms of efficient improvement of energy and increases the performance of the network.

II. Related Work

A. LEACH

LEACH consists of two main stages: the initialization phase and the stable phase. In the cluster setup phase, each node utilizes a decentralized algorithm to evaluate its qualification as a cluster head (CH) for the ongoing round. This evaluation involves generating a random number within the range of 0 to 1, comparing it against a predefined threshold value, and opting to become a CH if the generated number surpasses this threshold; otherwise, the node remains in a listening state for CH transmissions. The calculation of the threshold incorporates a formula that considers various parameters including the proportion of CHs within the overall node population, the current round iteration, and the subset of nodes that have not previously served as CHs in recent rounds.

During the stable phase, cluster members transmit their data to the CH using Time Division Multiple Access (TDMA). Subsequently, the CH aggregates and forwards the collected data to the base station (BS) employing a data fusion technique. Although LEACH effectively manages network energy consumption and prolongs network lifespan, it encounters certain limitations.Firstly, the cluster setup phase does not account for the energy levels and spatial positions of individual nodes, potentially leading to suboptimal CH selection. Secondly, the reliance on single-hop transmission from CHs to the BS during data transmission can result in uneven energy depletion among nodes, leading to poor energy balancing across the network. Lastly, the random rotation of CHs and frequent updates to cluster configurations contribute to excessive energy consumption, further impacting network longevity.

$$T(n) = \begin{cases} \dfrac{p}{1 - p * (r \bmod ((1/p)))}, & n \in G, \\ 0, & n \notin G, \end{cases}$$

Let p represent the proportion of CHs about the total number of nodes, r denotes the current round number, G denotes the group of nodes that have not served as CHs for the past 1/p rounds, and n refers to the individual node. The "mod" symbol denotes modular arithmetic.

B. *Related working on LEACH Algorithms*

The Optimized LEACH (OLEACH) protocol represents an advanced version of the Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm, designed to enhance the functionality of Wireless Sensor Networks (WSNs). OLEACH introduces centralized cluster formation, where the Base Station (BS) takes charge of selecting Cluster Heads (CHs) based on energy profiles and network dynamics. By employing techniques like simulated annealing, OLEACH ensures a more equitable distribution of energy among nodes, thereby improving overall cluster efficiency and prolonging network lifespan. This strategic improvement addresses the inherent limitations of traditional LEACH, such as energy disparities and premature node exhaustion, thus promoting more sustainable operation of WSNs. By optimizing cluster structure and resource utilization, OLEACH represents a significant advancement in enhancing the reliability and durability of WSN deployments across various applications, including environmental monitoring and industrial automation.

Ⅲ . Proposed Model Work to Improve Algorithm

A. Introduction to Improved Algorithm

The Enhanced Energy-Efficient Clustering Protocol (IEECP) aims to prolong the operational lifespan of WSN systems by tackling key issues related to energy usage and cluster arrangement. It consists of three core components. Firstly, it proposes an improved mathematical model that considers multi-hop communication and overlapping clusters to determine the optimal cluster count. Secondly, it introduces a modified fuzzy C-means algorithm (M-FCM) to ensure the formation of well-balanced clusters, thereby reducing intra-distance costs. Thirdly, it develops a novel CH selection and rotation algorithm (CHSRA), which combines a back-off timer mechanism for CH selection with a rotation mechanism among cluster members.

The protocol is divided into three sections: determining the optimal cluster count using an enhanced mathematical model, forming balanced clusters with M-FCM, and selecting and rotating CHs with CHSRA. It addresses critical aspects such as optimal cluster count determination, balanced and stable cluster formation, equitable distribution of selected CHs, and CH rotation based on threshold values. Previous studies have not adequately tackled these factors, leading to performance limitations in clustering protocols. Therefore, IEECP represents a significant advancement in addressing these challenges, thereby improving the efficiency and effectiveness of WSN systems.

B. *Cluster Determination*

Determining the optimal number of clusters in wireless sensor networks (WSNs) is crucial for efficient data transmission and energy conservation. Mathematical modeling provides a time-efficient approach, allowing for the pre-definition of clusters before node deployment, which is suitable for real-time applications. Typically, a disk model is utilized to represent the distance to the cluster head (CH), and the selection of the radius significantly impacts the cluster count. In practical scenarios, overlapping clusters exhibit varying radii. When N nodes are randomly deployed within an M^2 sensing area, it becomes necessary to consider the average number of nodes per cluster (N/K). Cluster heads are responsible for managing data transmission to the base station (BS) located outside the area, often employing multi-hop communication to optimize energy consumption.

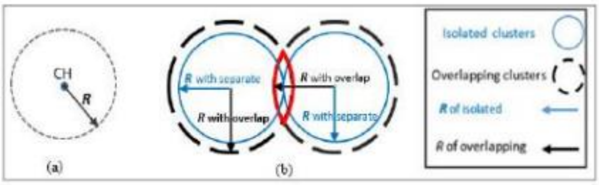


Figure 2(a) Model in Disk, and 2(b) Overlapping clusters have smaller radii due to shared regions, while separate clusters have larger radii with distinct boundaries.

The ideal number of clusters can be determined as follows:

$$K = \sqrt{\frac{1.262N}{2\pi}\frac{M}{d_{BS}}}.$$

C. Balanced cluster formation:

To achieve balanced cluster formation, this study introduces a modified fuzzy C-means algorithm (M-FCM) by integrating FCM with a centralized approach. Before delving into the proposed algorithm for creating balanced clusters, the conventional FCM algorithm is outlined in the following section to offer a basic understanding.

1) Overview of fuzzy C means Algorithm

The FCM algorithm has been extensively used in the clustering processes for WSN cluster formation.This algorithm was first presented by Dunn(31).The thing of FCM is to form better clusters by reducing the totality of distances between the objects(N) and the cluster centers(C) by using the objective function.In WSN, the objects relate to wireless sensor nodes that are formerly distributed in the seeing area.The FCM's ideal function for organizing wireless sensor nodes into clusters in the WSN can be formulated as

$$J_{FCM} = \sum_{i=1,2\ldots N, j=1,2\ldots K}^{n} \sum_{j=1}^{k} \mu^m d(x_i, x_c)^2.$$

The normalization condition is

$$\times \sum_{j=1}^{K} \mu_{ij} = 1,\ \mu \in [0,1]$$

$$\mu_{ij} = \frac{1}{\sum_{j=1}^{k} \left(\frac{d(x_i, c_j)}{d(x_i, q)}\right)^{\frac{2}{m-1}}},$$

$$C_j = \frac{\sum_{i=1}^{n} (\mu_{ij})^m * d(x_i, c)}{\sum_{i=1}^{n} (\mu_{ij})^m},$$

In the clustering process, K represents the cluster count, N denotes node quantity, and µ signifies node membership to clusters, determined by the Euclidean distance (d) between nodes and cluster centroids (Cj). A fuzzifier (m) influences the clustering crispness; commonly set as 2 to avoid fuzziness. Termination employs a small threshold (e.g., 0.001) at iteration (t). Random node deployment often leads to unbalanced clusters, affecting energy consumption and network longevity. Previous approaches adjusted node memberships, but inefficiencies arose due to increased intra-cluster distances. This study proposes a modified algorithm, prioritizing actual centroid distances over node memberships for Creating clusters that are well-balanced while minimizing the amount of similarity within each cluster. distances.

2) Modification of FCM into Modified FCM

The proposed clustering algorithm is executed at the BS and consists of two phases1) original cluster formation, which is grounded on the FCM.

2) balanced cluster formation, which is grounded on the CM.In the original cluster formation, the FCM is applied to form the clusters as shown in the algorithm, and also the process shifts to the alternate phase.The balanced cluster formation phase consists of two sub-phases.The first sub-phase consists of the following way

1) The cluster threshold(Thcluster) is determined grounded on the below equation

2) Clusters are sorted based on size. The minimal cluster size is compared with that of the Thcluster.still, also the FCM creates balanced clusters If the size is lesser than the Thcluster.else, the process shifts to the alternate subphase

$$Th_{\text{cluster}} = \frac{N * Pe}{K}$$

where Pe is the permittivity value equal to 0.85, and K signifies the number of clusters. In the alternate sub-phase, CM considers the final centroids of the clusters that were produced from the former phase (FCM phase) as original points to form balanced clusters. The way of the CM are as follows

1. The distance between the original points and nodes is determined.
2. Nodes are arranged based on their distance from the original points.
3. The original points elect the nearest number of nodes that are equal to the threshold of the cluster value to join it.
4. The remaining nodes that are still non-jointed join the nearest original point to construct the final clusters.
5. Each cluster determines the new centroid grounded on the means for knot locales. This procedure ensures that the minimal cluster size is equal to or lesser than the threshold cluster range with a lower intra-cluster distance.

D. CH SELECTION AND ROTATION ALGORITHM

Researchers are actively addressing challenges related to CH selection and rotation. The CHSRA algorithm, introduced in this study, integrates a back-off timer for both CH selection and rotation. It accurately selects the CH within the cluster, balances CH distances among neighboring clusters using routing data, and maintains energy equilibrium for successive CHs. CHSRA comprises two phases: CH selection through the back-off timer mechanism and CH rotation via the dynamic threshold mechanism. Operating exclusively within the cluster, it aims to minimize overhead while ensuring balanced energy usage, thereby contributing to effective cluster management in wireless networks.

1) Selection Phase of Cluster Head

The timer for back-off, a distributed mechanism of the network, selects CHs with minimal overhead and delay. Nodes set timers based on an objective function (F), becoming CH or CM upon receiving ADV messages or timeout. This mechanism, newly applied within cluster members, increases time and energy consumption but enhances CH selection efficiency. A novel objective function considers distances to forward (FCH) and backward (BCH) CHs and node residual energy, ensuring optimal CH placement. Unlike previous approaches, it balances FCH and BCH distances, guaranteeing efficient CH distribution. This objective function outperforms solely residual energy-based methods. See the figure for distance effects on the selection of Cluster Head.

$$T_{\mathrm{b}} = 1/F$$

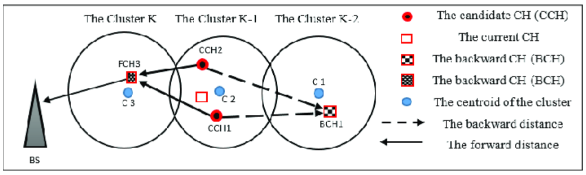


Figure 3 Refine the process of selecting cluster heads by considering both forward and backward distances

Accordingly, each knot in certain clusters computes the following parameters to define the objective function F, which is residual energy Erto help opting CH with low energy. The current value of energy in a knot after entering or transmitting routing packets is the residual energy.

1) Euclidean distance from the nearest forward CH (d_FCH) to reduce the energy consumption for the seeker CH(j).
2) Euclidean distance from the nearest backward CH (d_BCH) to reduce energy consumption for backward CH(j- 1).
3) ACD for the knot; this measure is responsible for showing the balance of distance between FCH and BCH.

Formulas for (1),(2)&(3) respectively

1)

$$E_r = E_{\mathrm{ini}} - E_{\mathrm{con}},$$

(where Eini refers to the initial energy and Econ refers to the consumption energy of the node)

2)

$$d_{FCH} = \begin{cases} \min(\|x_i - CH_j\|) d_{BS} > d_F \\ < d_0, \text{othenwise} \\ \|x_i - BS\| \end{cases}$$

3)

$$ACD = \frac{\min(d_{FCH}, d_{BCH})}{\max(d_{FCH}, d_{BCH})}$$

4)According to these parameters, the objective function F for CH selection is

$$F_i = \frac{E_r}{d_{FCH} + d_{BCH}} + ACD.$$

The named CH grounded on this proposed algorithm overcomes the following two issues

1) The energy outflow(additional energy cost) in the CH selection process is minimized by using the reverse-off time medium with members of the cluster rather than using allnodes in the network as in the current studies.
2) The CH is named optimally because the needed criteria for balanced energy consumption in the selection are considered

2)Rotation Phase of Cluster Head

In addressing the issue of uneven energy distribution among successive CHs within the cluster, we introduce a dynamic threshold for the CH rotation mechanism. Unlike fixed thresholds in previous studies, ours incrementally adjusts with each CH reselection, based on energy consumption and its ratio to the initial energy (T). Upon selection, the chosen CH first computes its rotation threshold (ETH).

$$E_{TH} = \begin{cases} E_{\mathrm{con}} + \left(E_{\mathrm{ini}} - T\right) * E_{\mathrm{ini}} \text{ if } \left(E_{\mathrm{con}} + T * E_{\mathrm{ini}}\right) \\ \leq E_{\mathrm{ini}} \\ E_{\mathrm{con}} + E_r \text{ if } \left(E_{\mathrm{con}} + T * E_{\mathrm{ini}}\right) > E_{\mathrm{ini}}. \end{cases}$$

Econ represents the node's energy consumption, Eini denotes the initial energy of the node, Er indicates the remaining energy of the node, and T is a constant initial energy value that may vary depending on the number of members in the cluster. The T value is determined once for the cluster during the network's lifetime and can be calculated as follows:

T = (RCHs * Erth) / (RCHs * E(rnd) + Rn * E(n-rnd))

Where:
- RCHs refers to the rounds of all CHs in the cluster at the ETH,
- Erth is the residual energy of the node at the ETH value,
- Rn represents the rounds of the member nodes in the cluster at the ETH,
- E(rnd) is the energy consumption per round for the CH, and
- E(n-rnd) is the energy consumption per round for the nodes.

The threshold value (T) is determined where the rounds of CHs intersect with the rounds of members. At the end of each round, a CH compares its energy with the computed threshold. If the CH's energy is equal to or below the threshold, it changes; otherwise, it continues. These algorithms are integrated into the IEECP framework, the primary objective of this study. During data transmission, members send data directly to their CH, which then transmits to the BS using multi-hop, advantageous for long distances. The CH checks if its transmission distance to the BS is less than d0; if not, it selects the nearest forward CH to save energy, despite potential delays in data arrival.

E. Working of the Proposed Model

IEECP protocol execution:

BS Processing:

1) Determine the number of clusters using the modified mathematical model.
2) Create balanced clusters using the M-FCM algorithm.
3) Time complexity: O [(NK^2 x IFCM) + NK] for M-FCM.
   Where N represents the number of sensor nodes, K represents the clusters, and IFCM denotes FCM iterations.
4) Space complexity:
   No limitation at BS;
   O (K^2 + 50) for M-FCM.

Node Processing:

1) Implement CH selection and rotation using the CHSRA algorithm within clusters.
2) The time complexity for M-FCM is O((NK^2 × IFCM) + NK), where N is the number of sensor nodes, K is the clusters, and IFCM is FCM iterations.
3) Space complexity: O ([K^2 + 50]).
   (It is an acceptable contribution of the space complexity for the processes of CH selection and rotation).
4) Overhead complexity: O (1) due to CH broadcasting, which remains constant regardless of network size.

Parameters	Existing Method	Proposed Method
Alive Nodes	64	80
Dead Nodes	36	20
Energy Consumption	87(in joules)	15(in joules)
Throughput	4032585(in bits)	5645619(in bits)
Transmission Delay	40ms	37ms

F. Flowchart for the proposed Algorithm

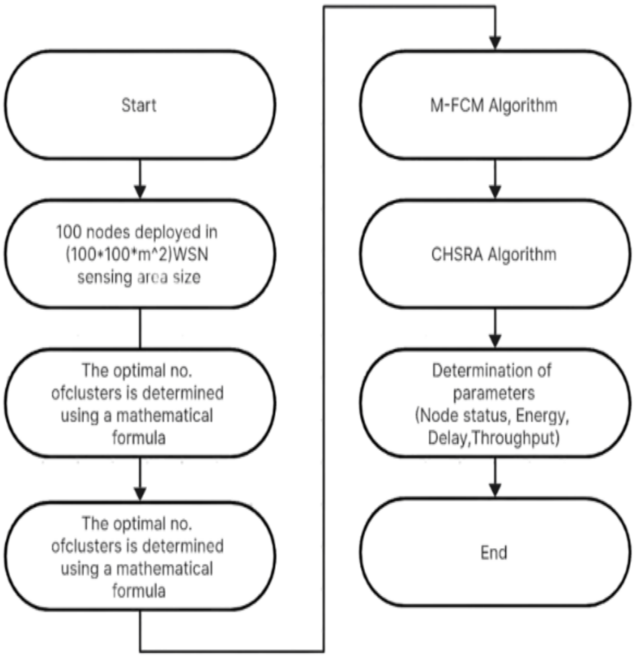


Figure 4 Flowchart for the proposed method

IV Simulations and Analysis

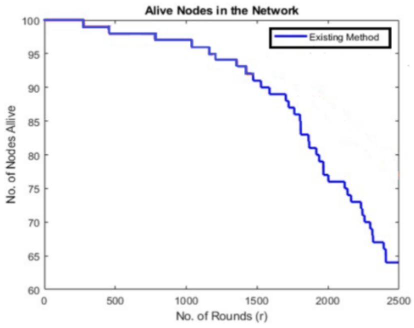
We are evaluating the improvements of the referred protocol using MATLAB and comparing its performance with OLEACH and the Proposed Model. The nodes are randomly deployed within the area of [100 meters * 100 meters] Then specific parameters are shown in Table 1.

Table 1: Parametric Measurements

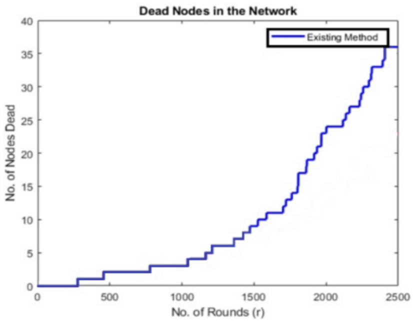
Parameters	Values
Network size	[100m x 100m]
Number of nodes	5000
BS position	(0.5,0.5)
Initial energy	0.5J
Data Packet	4000bits
Eelec	50(nJ/bit)
Efs	100((pJ)/(bit/m^2))
Emp	0.000013((Pj)/(bit/m^4))

Table 2: Simulated Results (Based on data from 5000 rounds)

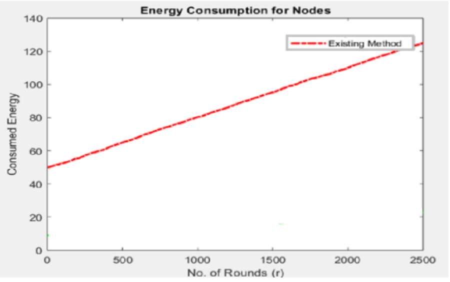
A. Simulation Results of Existing Method



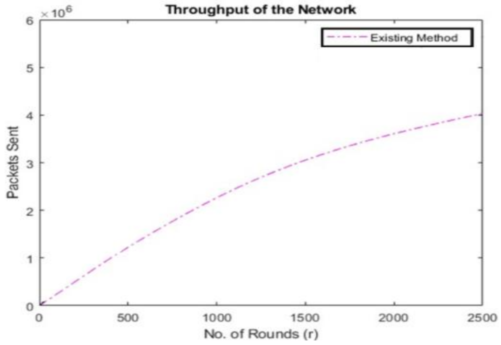
i) Detection of Survived nodes in the overall rounds inthe Existing method



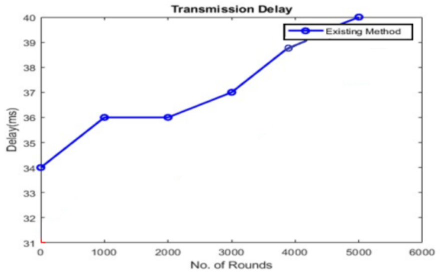
ii) Detection of Unsurvived nodes in the overall rounds inthe Existing method



iii) Detection of Utilized Energyof the network in the Existing method

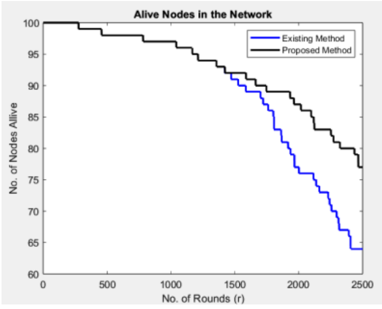


iv) Detection of Throughput of the Network in the Existing Method

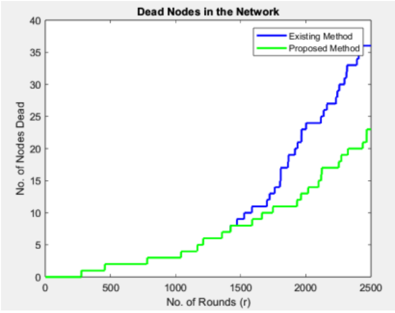


v) Detection of transmission delay in the existing model in the Existing Method

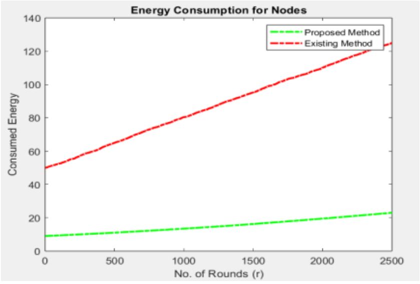
B. Comparison of Simulation Results of Current Method with Proposed Method



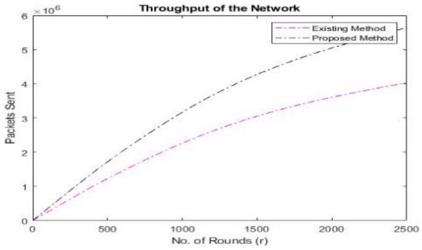
i) Comparisons of Survived nodes throughout the network with the Current model with the Proposed model



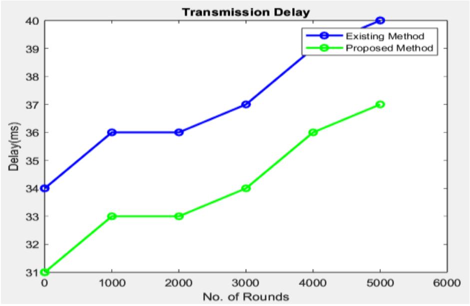
ii) Comparisons of Unsurvived nodes throughout the network with the Current model with the proposed model



iii) Comparisons of Utilized Energy throughout the network with the Current model with the proposed model



iv) Comparisons of throughput of the network with the Current model with the proposed model



v) Comparisons of transmission delay of the network with the Current model with the proposed model

CONCLUSION

In this study, we present a major improvement in energy-saving clustering protocols for Wireless Sensor Networks (WSN). The IEECP aims to solve problems in the clustering system that usually impact the performance of the protocol, ultimately prolonging the lifespan of the network. The suggested protocol effectively decreases and distributes node energy usage, making it well-suited for networks that need to operate for extended periods due to its improvement in clustering structure. Comparing various protocols, IEECP has shown superior performance, indicating its ability to greatly improve daily operations in different IoT applications that rely on WSN technology. The method used by the protocol involves examining the amount of energy the network uses to figure out the best number of clusters, particularly in situations where clusters overlap. This goal is accomplished by incorporating the Modified Fuzzy C-Means algorithm (M-FCM) along with a centralized approach to create stable and evenly distributed clusters. Furthermore, a new algorithm called CH Selection-Rotation Algorithm (CHSRA) is introduced. This algorithm integrates a back-off timer mechanism used for selecting CHs with a rotation mechanism for CHs. The Cluster Head Selection-Rotation Algorithm (CHSRA) has presented a new way to determine the best locations for Cluster Heads (CHs) by introducing an objective function that focuses on equalizing energy usage among CHs within clusters. Furthermore, it enforces a flexible limit for the rotation of Cluster Heads (CH) among members of a cluster, guaranteeing that energy usage is evenly distributed among consecutive CHs within the cluster.

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