Energy and Density-Based Stable Election Routing Protocol for Wireless IoT Network

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Abstract

In battery-based wireless sensor networks (WSN), routing protocols are crucial for enhancing energy efficiency and prolonging network lifetime. These protocols should maximize the discharge times of cluster heads (CH) and sensors for data collection. To maximize the WSN lifetime, the number of clusters, the distance between the base station and the CH, and the remaining battery of sensors should be carefully considered. This study proposes energy and density-based stable election protocol (SEP) for cooperative communication in WSNs to address these challenges. By considering the remaining battery capacity of each sensor, the optimal number of clusters within the WSN is determined, and the cluster head is elected to increase the energy efficiency of routing. This approach extends the network lifespan. The simulation results demonstrate that the proposed protocol improves performance in terms of total energy consumption and network lifetime.

Keywords: Wireless sensor network, Stable election protocol, Low energy adaptive clustering hierarchy, Distributed computing, Internet of Things

1. Introduction

The wireless sensor network (WSN) is a fundamental technology within the framework of the Internet of Things (IoT), which facilitates the detection and extraction of meaningful information from objects or environments using sensors or smart devices [1]. In WSN-based IoT systems, diverse wireless sensors collect data, which are then transmitted to users for reliable and real-time data analysis with high accuracy [2]. Leveraging its ease of construction, cost-effectiveness, and autonomous operation in challenging or hazardous environments, WSN-based IoT is applied in various 5G/6G domains, including smart transportation, military reconnaissance, industrial monitoring, construction site survey, and health monitoring systems [3, 4, 5, 6].

Typically, a WSN-based IoT system comprises a base station (BS) with a high-processing unit, ample storage capacity, rechargeable battery, and multiple sensor nodes (SNs). These SNs detect and transmit data such as temperature, pressure, and humidity to the BS. The BS processes the data received from the SNs and delivers them to the user, as illustrated in Fig. 1. However, deploying WSN-based IoT systems presents technical challenges, including limited sensor battery life, communication efficiency, routing optimization, quality of service (QoS), fault tolerance, and security issues [7]. WSNs have to detect and extract meaningful information from objects or environments in real-time and then transmit it to the BS. Therefore, if any of the SNs deployed in the WSN are discharged, the stability and reliability of the WSN will decrease because complete information cannot be collected. As a result, the time until the first node of a WSN is discharged is defined as the lifetime of the WSN, and many previous studies have been conducted to increase this lifetime [2, 8]. Addressing these challenges is critical because of the difficulty and expense of replacing or recharging SNs. Prolonging the network lifetime is a major challenge in WSN-based IoT and energy-efficient routing schemes are a key technique to achieve this objective [9].

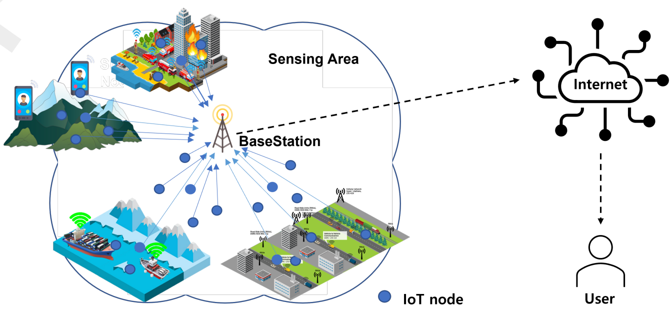


Figure 1: Scenario of Wireless Sensor Network (WSN).

Routing protocols, which are essential for designing WSN-based IoT systems, include cluster-based hierarchical routing, location-based routing, data-driven routing, and QoS awareness [8]. Cluster-based hierarchical routing which is exemplified by clustering protocols that organize SNs into small clusters, is effective for reducing energy consumption and extending the network lifetime by minimizing long-distance communication for each SN [10]. Various hierarchical structures, such as grids, chains, trees, and backbones, have been proposed previously [11]. Cluster-based hierarchical routing protocols are suitable for WSN-based IoT due to their scalability management, energy efficiency, load balancing, and reduced overhead. Because this study aims to prolong the overall network lifespan, we focus on a cluster-based hierarchical routing protocol, which is known for its energy efficiency.

The cluster-based hierarchical routing technique causes a hot-spot problem in which SNs near a static BS experience increased energy consumption [12]. To alleviate this problem, the cluster head can be changed periodically, or multi-hop communication can be employed to prevent an increase in workload at a specific node. The low energy adaptive clustering hierarchy (LEACH) [13] protocol is a representative cluster-based hierarchical routing protocol in a WSN-based IoT network for mitigating hot-spot problems [9]. In this protocol, the network is partitioned into multiple clusters, each having a cluster head (CH) responsible for receiving and transmitting SN data to the

To address these challenges, this paper proposes a protocol to enhance the routing path between a sensor node and a BS. The objective of this study is to maximize the energy efficiency of the network and extend its lifespan by setting an optimal number of clusters, improving CH selection, and optimizing data transmission methods. In contrast to conventional methods, the proposed approach allows for the extension of the WSN-based IoT lifetime through accurate clustering, which contributes to improved energy consumption.

In environments where WSNs are connected to the Internet of Things (IoT), the traditional approach of randomly selecting a CH may not be appropriate, particularly in extensive setups. An integrated IoT environment often results in a heterogeneous network in which each sensor node possesses varying energy levels. To account for this, our proposed network model introduces medium nodes with energy levels between regular and senior nodes. LEACH, designed for homogeneous networks, may not be directly applicable in such scenarios [14]. Building upon the Stable Election Protocol (SEP) [14], a variant of LEACH in which certain nodes (senior nodes) possess slightly more energy than others (normal nodes) [15], this paper proposes an extended protocol applicable to WSN-based IoT networks. The extension protocol incorporates a threshold level in the CH selection process, determines the optimal number of clusters, and optimizes the transmission path based on distance to maximize the network lifetime and throughput. However, these methods may cause energy waste by forcibly creating an excessive number of CHs as SNs that are not elected as CHs within a certain period of time. The primary objective of the proposed protocol is to significantly broaden the application scope of WSN-based IoT by extending the lifespan of battery-dependent WSN-based IoT nodes.

The primary contributions of the proposed study are:

- In this paper, we aim to improve existing sensor network routing protocols. Our inspiration comes from SEP and LEACH, the most popular protocols for extending the lifetime of battery-operated wireless sensor networks. The proposed scheme tries to overcome the fundamental shortcomings of most protocols based on SEP and LEACH.
- Due to the strength of wireless signals decreasing in inverse proportion to the square of the distance, energy consumption increases exponentially when the cluster head and BS are far apart. Therefore, energy consumption can be reduced through multi-hop communication via clustering. Therefore, LEACH and SEP-based protocols try to overcome the energy hole problem by electing nodes as CHs that are not elected as CHs for a certain period through mod calculations in a distributed manner. However, this method causes too many clusters in certain rounds and wastes energy due to excessive multi-hop communication. To overcome the problem, our proposed scheme adjusts the upper bound of the appropriate number of clusters depending on the network size and the number of sensor nodes. This cluster limitation helps decrease energy consumption by preventing excessive multi-hop communications while maintaining a distributed manner.
- In addition, we introduce a novel CH election technique to exploit the energy heterogeneity of each node to solve the energy hole problem. In this paper, we propose a new cluster head election technique and increase energy efficiency by controlling the number of CHs.

A brief analysis of related work is provided in Section 2. Section 3 explains the network model, and the proposed technique is presented in Section 4. Section V discusses the simulation results and problem-related analysis. Finally, we present the conclusions and our future work in Section 6.

2. Related Work

Energy is a critical resource for WSN nodes. These networks employ various protocols and routing-based clustering algorithms. However, the limited power capacity of sensing nodes remains a significant challenge in WSN architectures. Sensor nodes can be configured in two ways: heterogeneous and homogeneous. In the heterogeneous mode, each node has a different energy level, while in the homogeneous mode, all nodes have the same energy level. Effective cluster-based routing for heterogeneous networks is a complex task [16]. Cluster-based protocols create an effective clustering structure, thereby reducing the consumed energy and providing balanced energy usage [10]. The first proposed clustering protocol is the LEACH protocol [17]. The fundamental concept of the LEACH protocol involves selecting a CH in a distributed manner during each round, which allows nodes to join the nearest CH to form a dynamic cluster. In the workflow of the LEACH protocol, each step completes a task in a cycle, which is referred to as a "round." Each round consists of two phases: the cluster building phase and the stable operation phase. In the cluster-building phase, CH selection and clustering occur. However, the LEACH protocol faces the following challenges:

- The LEACH protocol randomly selects CHs, which leads to CH clustering without considering the efficient distribution of CHs. Clustering results in early node death. When CHs are scattered far apart, long transmission paths consume excessive energy and cause network resource wastage and communication congestion.
- The method of selecting CHs using thresholds and random numbers reduces the probability of specific nodes being repeatedly elected as CHs. However, it does not account for the energy consumption differences between the CHs and cluster member (CM) nodes. Therefore, energy imbalance may occur, affecting the stability of CH node elections.
- LEACH maintains a fixed number of CHs throughout the rounds. This approach decreases the number of surviving sensor nodes over time. Thus, the number of available CM nodes for sensing in the cluster decreased.
- LEACH performs well in homogeneous networks but faces challenges in heterogeneous environments.

To solve the last problem, researchers proposed the Stable Election Protocol (SEP) in [7]. This protocol elects CH based on the initial energy levels, similar to the LEACH protocol, but incorporates variables reflecting the starting energy of the nodes [18]. This protocol adjusts the threshold weight according to node type to ensure random CH selection based on election probability. Sensor nodes are classified as advanced and normal nodes (referred to as senior nodes in this study). Advanced nodes have more energy than normal nodes. Advanced nodes with more energy than normal nodes have a higher probability of being selected as CHs, leading to more efficient energy use across all nodes [19].

Given that energy consumption increases exponentially with data transmission distance, some studies have considered the distance between the final data destination and the CH. In [20], energy efficiency was improved through multi-hop routing by dividing the WSN into an even number of sectors based on the BS. However, the approach of designating an entire sector as a single cluster also results in energy inefficiency because it does not consider the 1-hop routing of nodes close to the BS. In another study, [21] proposed a hybrid cluster routing protocol using 1-hop and 2-hop communication simultaneously, considering the distance between SN and the BS. The energy efficiency was improved by optimizing the number of 2-hop communication clusters. In [22], the CH location was determined based on the distance between the CH and the BS and the average energy of the sensor nodes using the Archimedes optimization algorithm. However, this method requires moving the positions of the SNs designated as CHs through the application of a virtual force in each round, which is a disadvantage.

Recently, [23, 24] proposed a routing algorithm in a mobility environment. In [23], the stability of the cluster was increased by grouping vehicles moving in the same direction into one cluster, and in [24], an appropriate cluster head was selected based on the maximum stable set problem, and vehicles were assigned to clusters based on a link reliability model. In [25], a routing algorithm based on reinforcement learning was proposed to reduce communication delay and message overhead, and in [26], energy consumption was reduced by selecting the cluster head and routing path based on residual energy and distance to neighboring nodes. However, the above algorithm has clear disadvantages due to the learning overhead and computational complexity of the ant colony algorithm. In addition, [27, 28] a clustering algorithm using fuzzy theory and the Gray Wolf algorithm, but there are still limitations due to algorithm complexity.

Each of the aforementioned protocols introduces a novel CH selection approach. Given that the proposed protocol is based on the SEP, an examination of specific issues was conducted. In the SEP routing algorithm, periodic CH selection and cluster formation occur in each round. The classical SEP algorithm elects a CH based on an initial threshold, disregarding the current energy level or the distance from the BS. This oversight failed to consider variations in the communication energy consumption based on distance, potentially leading to a scenario in which a node with lower energy becomes a subsequent CH, thereby reducing the network's lifespan. Recognizing these drawbacks in SEP, researchers have been motivated to explore and establish more efficient CH substitution methods.

3. System Model

We consider a WSN with N sensors placed in a square network field with a length and width of S. In particular, N sensors are randomly placed through a uniform distribution in the network field, and the BS is assumed to be placed in the center of the network field.

3.1. Network model

Fig. 2 shows the network model of the proposed scheme. The details of the network model are as follows.

1. All sensor nodes have three levels of initial energy: normal (E_{nrm}), medium (E_{med}), and senior (E_{sen}).
2. All sensor nodes are randomly located and remain fixed after placement.
3. The distances between the BS and all nodes are calculated as Euclidean distances.
4. The BS knows the location information of all nodes, and all nodes also know the location of the BS. Therefore, one node knows its location, the location of other nodes, and the location of the BS. To know distances, we assume that an ultra-wideband (UWB) based localization method with high location accuracy of sensor nodes is utilized [29, 30].

5. Sensor nodes in the cluster transmit data to CH using single-hop communication[1]. CH transmits data from the source node to BS through single-hop communication.

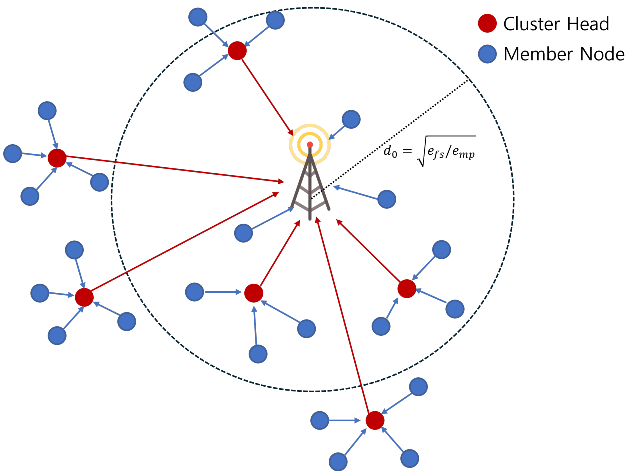


Figure 2: Network model of the proposed scheme.

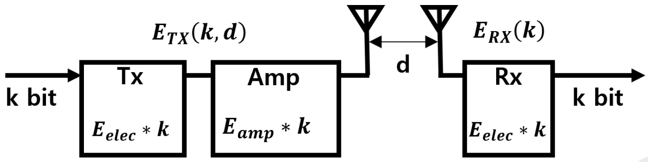


Figure 3: Energy consumption model for data transmission/reception.

3.2. Energy Consumption model

In the proposed protocol, the energy heterogeneity model [31] is used to calculate the energy consumption when each node transmits and receives data, as illustrated in Fig. 3. It is assumed that each sensor node has a transmitter, receiver, and power amplifier that consume energy. Given the distance d between two nodes and the data size k to be transmitted, the total energy consumption ($E_{total}(k,d)$) is given by

$$E_{total}(k,d) = \sum_{i=1}^{N} \left\{ E^{i}_{TX}(k,d) + E^{i}_{RX}(k,d) \right\}. \tag{1}$$

The energy consumption of a sensor node depends on the distance and the amount of data transmitted[2]. When the distance between two nodes is d, the energy consumed by the transmitting node to transmit k bits of data is as follows:

$$E_{TX}(k,d) = \begin{cases} E_{elec} \cdot k + e_{fs} \cdot k \cdot d^2, & if\ d\ \le\ d_0, \\ E_{elec} \cdot e_{mp} \cdot k \cdot d^4, & if\ d\ >\ 0, \end{cases} \tag{2}$$

[1]Basically, for short distance communication, multi-hop communication is less efficient than single-hop communication in terms of energy efficiency due to frequent use of amplifiers and is vulnerable to the energy hot spot problem, so only single-hop is assumed in intra-cluster.

[2]Note that, the energy consumed when a node is in the sensing, idle, and listen states is small compared to the transmitting and receiving states, so it is ignored in this paper.

Table 1: Summary of Parameters and Variables

Symbol	Description
N, k	The number of sensor nodes and data size
S	The size of WSN
G, G_{alive}	The group of sensor nodes and alive nodes
E_{nrm}, E_{med}, E_{sen}	The energy level of normal, medium, senior nodes
e_{fs}, e_{mp}	Energy consumption for amplifiers type for free-space and multi-path
E_{TX}, E_{RX}	Energy consumption for data transmission/reception
CH_{opt}	The optimal number of CH
P_n	The probability of CH election for each nth node
T_n	The CH election for each nth node

$$d_0 = \sqrt{e_{fs}/e_{mp}}, \tag{3}$$

where E_{elec} denotes the energy consumption per bit during data transmission and reception in the node. In addition, d_0 is a distance constraint. The energy consumption varies based on the relationship between the actual distance d and the specified distance constraint d_0, particularly in free-space channel propagation and multipath channel propagation scenarios. The consumed energy per bit on the receiving side is as follows:

$$E_{RX}(k) = E_{elec} \cdot k + E_{DA} \cdot k, \tag{4}$$

where E_{DA} is the consumed energy per bit for processing the data received from the sensor node in the CH. Finally, the consumed energy by the entire sensor is expressed as follows:

$$E = E_{TX} + E_{RX}. \tag{5}$$

4. Proposed Scheme

This study introduces advanced techniques for routing data in heterogeneous networks, prioritizing energy efficiency and balance as crucial parameters for designing WSN routing algorithms. The primary aim is to enhance the lifetime of the sensor network by adjusting the CH selection. This is achieved through the proposal of a multi-hop communication protocol tailored for heterogeneous networks, which is determined by the optimal number of clusters. To regulate the energy dispersion, this paper incorporates a three-stage heterogeneity approach for the initial node energy. In this setup, all nodes are stationary, and the energy distribution follows a hierarchical pattern, with senior nodes receiving energy α $(0 \le \alpha \le 1)$ times that of medium nodes and medium nodes receiving energy β $(0 \le \beta \le 1)$ times that of normal nodes. The probabilities s_s and s_m represent the likelihood of having a node with high and intermediate energy levels, respectively, with senior and medium nodes having higher energy levels than normal nodes.

Let the initial energy of the normal node be E_{i}. Then, the initial energy of the senior node can be expressed as $E_{\text{i}}(1 + \alpha)$, and the initial energy of the intermediate node can be expressed as a medium node can be expressed as $E_i(1+\beta)$. The total energy of each node type can be written as

$$E_{\mathrm{nrm}} = N \cdot E_i(1 - s_s - s_m), \tag{6}$$

$$E_{\mathrm{med}} = N \cdot s_m \cdot E_i(1+\beta),\ (\beta = \alpha/2) \tag{7}$$

$$E_{\mathrm{sen}} = N \cdot s_s \cdot E_i(1+\alpha), \tag{8}$$

where E_{nrm}, E_{med}, and E_{sen} represent normal, medium, and senior nodes, respectively. Then, the total energy can be expressed as

$$\begin{aligned} E_{\mathrm{total}} =& N \cdot E_i(1 - s_s - s_m) \\ &+ N \cdot s_m E_i(1+\beta) + N \cdot s_s E_i(1+\alpha) \\ &= N \cdot E_i(1 + \alpha s_s + \beta s_m). \end{aligned} \tag{9}$$

Within the framework of this study's protocol, the process for selecting CH is similar with the simplified SEP. This involves classifying nodes based on type, assigning a random number value to each node, and electing a CH if the random number value exceeds a predefined threshold. Similar to SEP, this study calculates the selection probability of each node type. The threshold is then determined through a weighted computation that accounts for both energy levels and distances. A departure from traditional approaches, such as LEACH and SEP, this study addresses the issue of cluster imbalance by incorporating the number of sensor nodes within a cluster. In contrast to previous methodologies that fix the number of clusters based on predetermined ratios, this study aims to achieve a more balanced distribution. Existing research underscores the impact of packet size length and transmission distance on the energy consumption models of WSNs. Notably, the CH consolidates data from the sensor nodes, and the data length is influenced by the number of sensor nodes within the cluster, as it represents merged information transmitted to the base station. This work is inspired by the method proposed by [32] for determining the proper probability for cluster election, considering the sensor field size (S) and the distance constraint value (d_0). The formula for calculating the optimal number of clusters is:

$$CH_{\mathrm{opt}} = \sqrt{\frac{1.262 \cdot S}{\pi}} \cdot \frac{N}{D_{avg}} \tag{10}$$

where D_{avg} represents the average distance from all nodes to BS. The probability of election for each n-th node is obtained using the ratio of the cluster heads obtained as:

$$P_n = \frac{E_{\mathrm{cur}}}{10 \cdot E_{\mathrm{avg}}^{\mathrm{init}}}, \tag{11}$$

where E_{cur} and $E_{\mathrm{avg}}^{\mathrm{init}}$ are the current energy level in each round and the average initial energy level of all nodes, respectively. Furthermore, P_n is used to represent the threshold for CH election in each round. To determine the election threshold, we initially calculate it through the election probability of each node type in accordance with SEP as the following:

$$T_n = \frac{P_n}{1 - P_n(r\ mod\ (1/P_n))},\ \text{if } n \in G_n, \tag{12}$$

where T_n denotes the election threshold for normal, medium, and senior nodes, respectively. What makes our approach different from previous works is that it better reflects the remaining energy of each node. In this case, r represents the current round, and G represents a group of nodes of each type. We found that the energy consumption varies according to the relationship between d and d_0, the distance between the node and the BS through the previous network and energy models. That is, when a node whose distance to the BS is longer than d_0 is elected as CH, it can be seen that the energy consumption is d^4, which increases compared to d^2. This shows that close nodes have a higher survival rate than nodes that are far away. In addition, in the case of the existing LEACH and SEP protocols, since the CH is elected regardless of the amount of energy of the current node, a node with a small amount of energy becomes the CH, resulting in faster First Node Death (FND) and Tenth Node Death (TND) rounds. In the worst case, since a node distant from a BS with low energy may be elected as a CH, the probability of becoming a CH should be adjusted according to the current amount of energy. Therefore, we want to reset the threshold by giving additional weight to energy and distance for efficient and balanced use of energy. That is, the threshold is reset by additionally considering 1) the energy of the current node and 2) the distance between the node and the BS in addition to the existing threshold. The newly considered weight equation is as follows:

$$\tau = w_1 \cdot [\frac{E_{cur}}{E_{avg}^{init}}] + w_2 \cdot [\frac{D_{avg}}{D_{bs}}],\ \ (w_1 + w_2 = 1), \tag{13}$$

$$D_{bs} = \sqrt{(n_x - BS_x)^2 + (n_y - BS_y)^2},\ \ n \in G_{\mathrm{alive}}, \tag{14}$$

the network in the current round, D_{avg} is the average distance between all surviving nodes and the BS, and D_{bs} is the distance between the current node and the BS. According to the equation, the higher the current energy and the closer the distance to the BS, the higher the weight. Therefore, the new threshold including the weight is as follows:

$$TD_n = \tau \cdot T_n,\ \text{if } n \in G_n. \tag{15}$$

The protocol finally proposed is similar to SEP and LEACH, but with the addition of calculation of the optimal number of clusters, weights according to energy distance, and dynamic variable P_n. Despite these improvements, since cluster heads are elected randomly, the same node can be elected to the CH repeatedly in succession. In order to prevent power consumption from being concentrated on a specific node, it is necessary to prevent a sensor node from being re-elected to the CH continuously and repeatedly. To overcome this problem, we introduce a new threshold that prevents a node that has once become a CH from being re-elected for several rounds based on the density of total sensor nodes in the network, its current energy level, and the distance as follows:

$$T_{n,r}^{th} = \frac{10 \cdot d_0 \cdot \sqrt{N}}{S},\ \ n \in G_{\mathrm{alive}}. \tag{16}$$

A sensor node that has once become a CH will have T_n^{th}. Also, from the next round onwards, T_n^{th} will decrease in each round using the following:

$$T^{th}_{n,r+1} = T^{th}_{n,r} - \left(\frac{E_{\mathrm{cur}}}{E^{\mathrm{init}}_{\mathrm{avg}}} \cdot \sqrt{N}\right), \quad n \in G_{\mathrm{alive}}. \tag{17}$$

All nodes are eligible for CH election participation when $T^{th}_n \leq 0$. That is, sensors with $T^{th}_n \geq 0$ greater than 0 do not participate in the CH election. Through (16) and (17), nodes with more residual energy are given more opportunities to participate in the CH election, and nodes with less residual energy are given fewer opportunities to participate in CH election.

The protocol finally proposed is similar to SEP and LEACH, but with the addition of calculation of the optimal number of clusters, weights according to energy distance, and multi-hop communication and CH election according to conditions. Algorithm 1 shows the description of our proposed scheme. The following explains the operation of the proposed algorithm for each phase.

1. CH selection step: In the first step, the sensor nodes manage the network in the form of a cluster in which one node serves as the CH. Determined using Eqs. (15) and (16).

2. CH broadcasting phase: In the CH broadcasting phase, the state of the CH is broadcast to other sensor nodes in the network. In this phase, if the number of CHs exceeds CH_{opt} calculated via (10), the exceeded CHs are canceled, and (16) is not calculated for those nodes.

3. Cluster setup phase: Normal nodes are connected to CHs that want the minimum energy cost for data transmission. If the minimum distance is the BS, the node is directly connected to the BS and transmits data.

4. Creation of time-division multiple access (TDMA) Scheme: TDMA technology is used for communication between the CH and simple nodes. The CH schedules the TDMA scheme to allow data transmission through the node. This scheme helps avoid collisions between data. A time slot is assigned to the node.

5. Intercluster data transfer phase: Data transfer within the cluster occurs during this phase. Cluster member nodes send data to CHs in the cluster.

6. Data transmission: After receiving information packets from cluster member nodes, CH aggregates data before transmitting it to BS. After data aggregation, CH makes a single-hop data transmission to BS.

7. Cluster Balancing Step: The selection of CH in the next step is based on several factors, e.g., the residual energy of the nodes and distance from the BS. Threshold Eqs. (15), (16), and (17) are used for CH selection.

For the complexity analysis, the following symbols are revisited: R, CHs, and N denote the number of rounds, cluster head nodes, and sensor nodes, respectively. In Algorithm 1, the main computational complexity corresponds to $O(RN + RN \cdot CH_s + N)$, polynomial complexity.

Algorithm 1 Proposed Algorithm

Initialize:
Randomly deployed heterogeneous sensor nodes,
CHs $\leftarrow$ number of cluster head nodes,
$N \leftarrow$ number of nodes in WSN,
$R \leftarrow$ number of rounds,
$S \leftarrow$ size of WSN,
$D_{avg} \leftarrow$ average distance between node and BS,
$D_{bs}(n)$ the distance between node n and BS.
for $r = 1$ to R **do**
  $CHs = 0$
  calculate CH_{opt} using Eq.(10)
  for $i = 1$ to N **do**
    calculate P_n using Eqs(11)
    calculate T_n using Eqs(12)
    calculate τ by using Eqs (13)
    calculate TD_n using Eqs(15)
    $randVar = rand(0, 1)$
    if ($randVar > TD_n$) and $CHs < CH_{\mathrm{opt}}$ **then**
      $CHs = CHs + 1$
      update $T^{th}_{n,r}$ using Eq.(16)
    end if
  end for
  for $i = 1$ to N **do**
    for $j = 1$ to CHs **do**
      calculate distances to all CHs and BS
    end for
    send data to the nearest CH or BS
  end for
  for $i = 1$ to N **do**
    update $T^{th}_{n,r+1}$ using Eq.(17)
  end for
end for
End

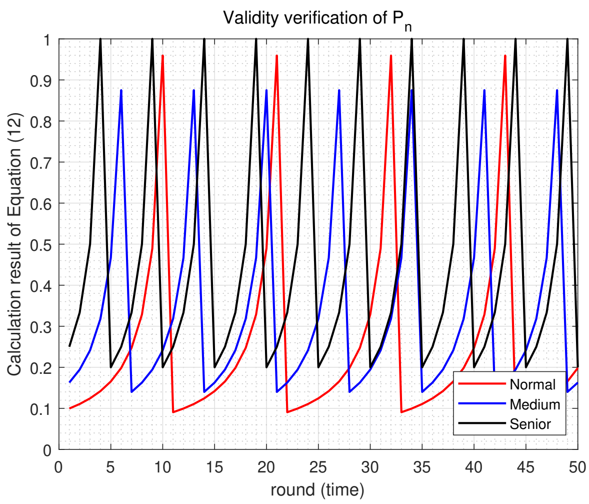


Figure 4: Validity verification of P_n and T_n.

5. Simulation Result

5.1. Simulation Setting

In this section, we evaluate the performance of our proposed protocol through simulation. We run our tests on PC with the

Table 2: Simulation Parameters

Parameters	Values
Network Area (m^2)	200×200 / 300×300
Number of Nodes	200 / 500 / 1000
Data Packet	4000 bits
E_{elec}	50 nJ/bit
e_{fs}	10 pJ/bit/m^2
e_{mp}	0.0013 pJ/bit/m^4
E_{DA}	5 nJ/bit/$signal$
Percentage of senior node	0.03
Percentage of medium node	0.07

following configurations: CPU core i9-13900K, RAM 64GB, GPU NVIDIA RTX 4090, and operating system Windows 10. First, we evaluate P_n for each node rather than a fixed P. We have three types of nodes: normal, medium, and senior nodes. When $E_{avg}^{init} = 0.5$J, the initial energy of each types are $E_{\text{sen}} = 1$J, $E_{\text{med}} = 0.75$J, and $E_{\text{nrm}} = 0.4528$J. Fig. 4 is T_n represented via (12) with P_n computed via (11) in round 1. Senior nodes with higher initial energy have a higher probability of being elected as CH than normal nodes, and the period for being forcibly elected as CH is also shorter. Medium nodes, which has an initial energy amount between normal and senior nodes, have an intermediate CH election probability and a period of being forcibly elected as a CH. In this way, nodes with more energy are elected as CHs more often and use more energy. Also, since this probability is calculated every round, nodes with less energy can avoid being elected as CHs as time goes by.

The evaluation of the performance involves a comparative analysis with LEACH [13], SEP [14], TS-I-LEACH [33], and MRETDC [34]. The simulation was performed in MATLAB[3], with 200, 500, and 1000 nodes, each with three energy types placed in a $200m \times 200m$ and $300m \times 300m$ network. It is assumed that the position of the BS is fixed to the center, and the energy of the BS is infinite. Other network parameters are written in TABLE. 2.

5.2. Performance Evaluation

We first calculate the transmission power according to the simulation parameter and plot the transmission power when each node transmits data to the BS. With our simulation parameters, the reference distance $d_0 = 87.7058m$. That is, if the distance is less than $87.7058m$, the transmission power is consumed along free space channel propagation, and if it is greater than $87.7058m$, the transmission power is consumed along multi-path channel propagation. The transmit power consumption according to distance is shown in Fig. 6. The Fig. 6 shows the transmit power energy increases significantly when the distance exceeds d_0. To capture this phenomenon, we simulate the network area $200 \times 200m^2$ and $300 \times 300m^2$.

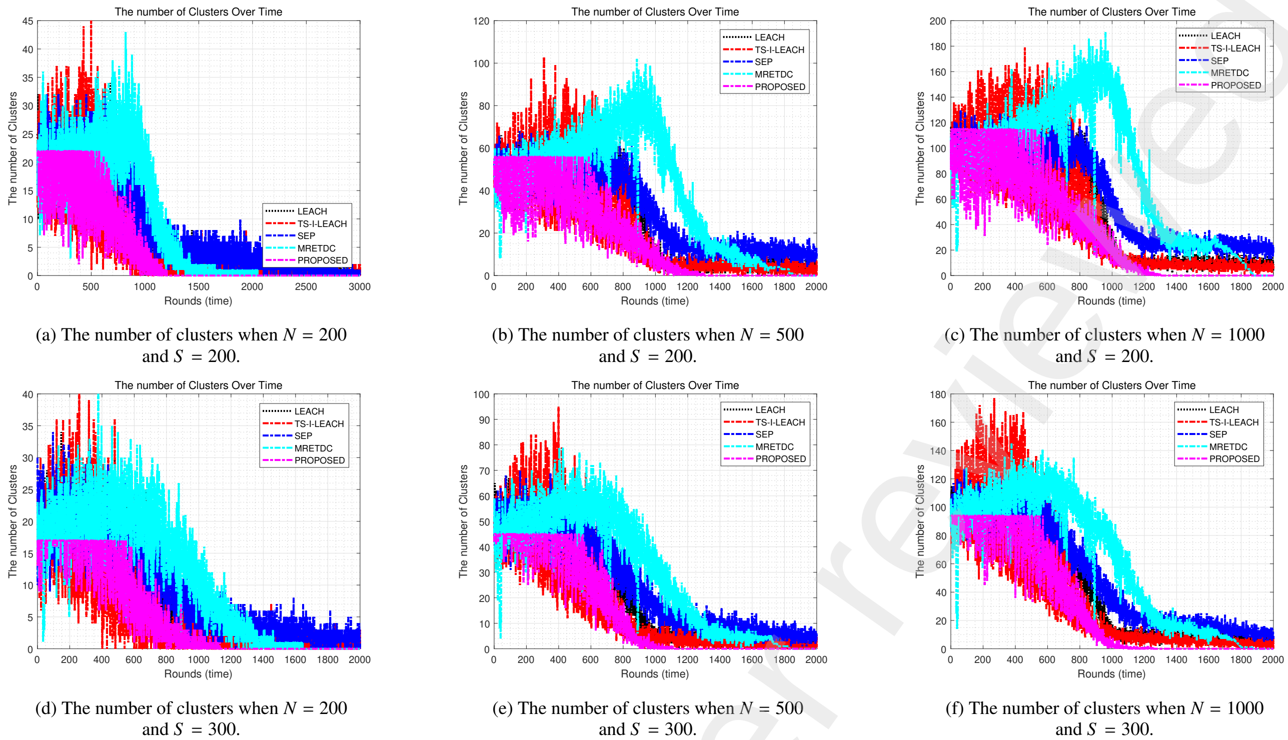
[3] In our MATLAB-based simulator, it does not define a detailed network protocol stack and is done with very basic channel modeling and MAC scheduling (TDMA-based). For data packet generation, we assumed that 4000-bit data packets are generated and transmitted per round [34].

Fig. 5 shows the number of clusters according to round. In existing works, as shown in Figure 4, nodes that have not been elected as CHs for several rounds are forcibly elected as CHs through mod calculation. Therefore, the number of CHs may be too large, resulting in unnecessary multi-hop transmissions. In the proposed work, the maximum number of cluster heads is determined based on the number of nodes, network size, and average distance. Therefore, an excessive number of cluster heads are not created, and unnecessary transmissions can be avoided.

To evaluate the performance numerically, we show a graph of the nodes that are first discharged round and the nodes that are 10% of the total nodes discharged round. To simplify the expression, the round in which the first node in the network is discharged is called FND, and the round in which 10% of all nodes are discharged is called TND. In addition, we call a round where all nodes are fully discharged AND. Fig. 7 shows the FND, TND, and LND when $S = 200$ and $N = 200$. The FND of the proposed scheme is 860, which is 15.75%, 26.28%, 17.81% and 1.18% better than LEACH with 743, TS-I-LEACH with 681, SEP with 730 and MRETDC with 851, respectively. Furthermore, the TND of the proposed scheme is 931, which is 16.87%, 15.94%, 13.54% and −1.97% better than LEACH with 797, TS-I-LEACH with 803, SEP with 820 and MRETDC with 913, respectively. Fig. 8 shows the number of nodes alive all rounds when $S = 200$ and $N = 200$. The proposed scheme shows that the first node discharges late, and other nodes transmit data for a long time without discharging. However, in Fig. 7 and Fig. 8, the proposed scheme is the fastest in rounds where all nodes are discharged because nodes with more energy are clustered more often and discharge faster. In our simulations, non-normal nodes, i.e., senior and medium nodes, account for 10% of the total. In Fig. 8, except for MRETDC and the proposed scheme, the other protocols continue to operate without discharging 10% of the nodes. This means that nodes with more energy do not use more energy appropriately.

The more nodes there are, the more pronounced this difference becomes. Therefore, we only show the results as line graphs, excluding bar graphs. Fig. 9 shows the number of nodes alive all rounds when $S = 200$ and $N = 500$. The FND of the proposed scheme is 902, which is 25.98%, 12.19%, 20.43% and 8.15% better than LEACH with 716, TS-I-LEACH with 804, SEP with 749 and MRETDC with 834, respectively. The difference with MRETDC is wider compared to when there are 200 nodes. This is because MRETDC does not consider the node density within the network. Therefore, these differences become more pronounced as the number of nodes increases. Fig. 10 shows the number of nodes alive all rounds when $S = 200$ and $N = 1000$. The FND of the proposed scheme is 911, which is 28.85%, 12.47%, 24.79% and 10.42% better than LEACH with 707, TS-I-LEACH with 810, SEP with 730 and MRETDC with 825, respectively.

We also performed simulations at $S = 300$ to evaluate performance according to network size. Fig. 11 shows FND and TND when the network sizes $S = 300$ and $N = 200$. Compared to Fig. 7, where the network size is small, FND and TND are reduced in all protocols. This is because as the network size in-



(a) The number of clusters when $N = 200$ and $S = 200$.

(b) The number of clusters when $N = 500$ and $S = 200$.

(c) The number of clusters when $N = 1000$ and $S = 200$.

(d) The number of clusters when $N = 200$ and $S = 300$.

(e) The number of clusters when $N = 500$ and $S = 300$.

(f) The number of clusters when $N = 1000$ and $S = 300$.

Figure 5: The number of clusters according to round.

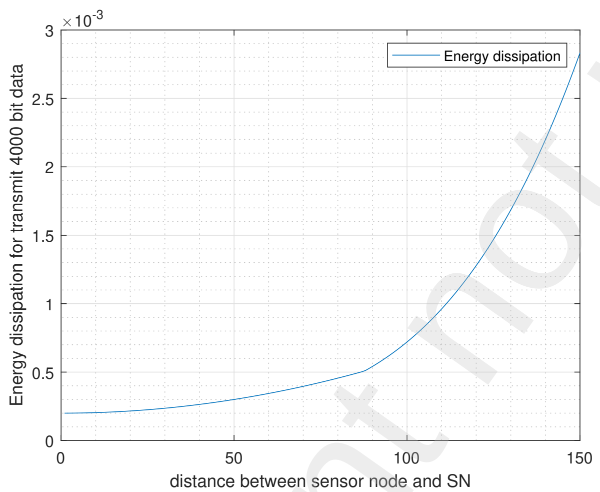


Figure 6: Transmission power consumption according to distance and parameters based on Table. 2.

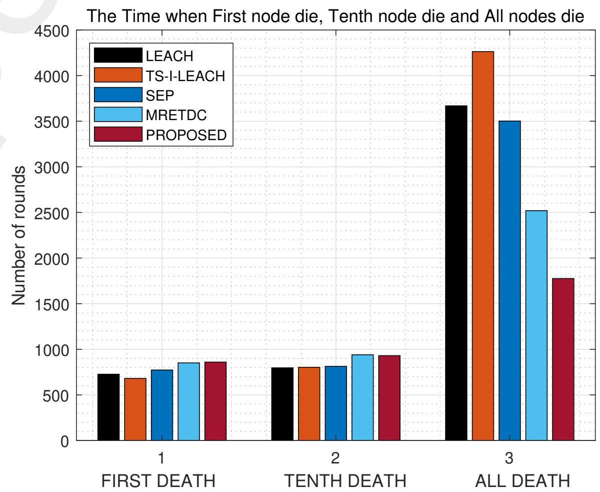


Figure 7: Comparison of FND, TND, and LND for each protocol when $S = 200$ and $N = 200$.

creases, the average distance between nodes and BS increases, and more energy is consumed when transmitting data. However, the proposed scheme also considers network size when electing CHs. The FND of the proposed scheme is 381, which is 36.56%, 26.58%, 23.70%, and 13.06% better than LEACH with 279, TS- I-LEACH with 301, SEP with 308, and MRETDC with 337, respectively. Furthermore, the TND of the proposed scheme is 554, which is 20.17%, 22.84%, 13.29% and 1.84% better than LEACH with 461, TS-I-LEACH with 451, SEP with 489 and MRETDC with 554, respectively.

Fig. 12 shows that the FND of the proposed scheme is 585, which is 86.90%, 35.73%, 67.14%, and 51.95% better than LEACH with 313, TS- I-LEACH with 431, SEP with 350, and MRETDC with 385, respectively. Furthermore, Fig. 13 shows that the FND of the proposed scheme is 571, which is 83.60%, 35.95%, 65.03% and 51.46% better than LEACH with 311, TS-I-LEACH with 420, SEP with 346 and MRETDC with 377, respectively.

As a result, as can be seen in Fig. 7 to 13, the proposed scheme shows the best performance for WSN lifetime not only

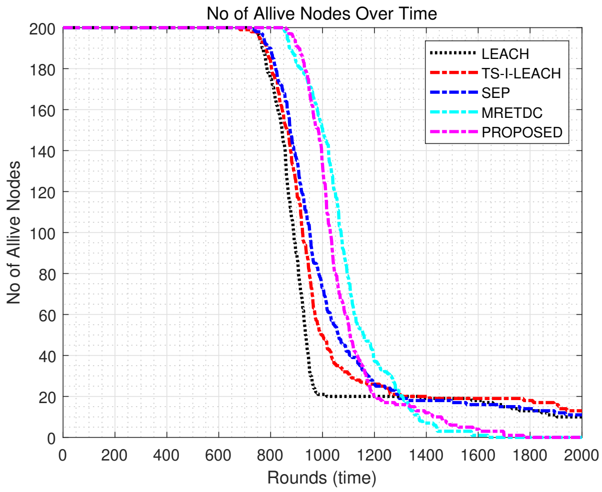


Figure 8: Comparison of the number of nodes that have not discharged during the total round for each protocol when $S = 200$ and $N = 200$.

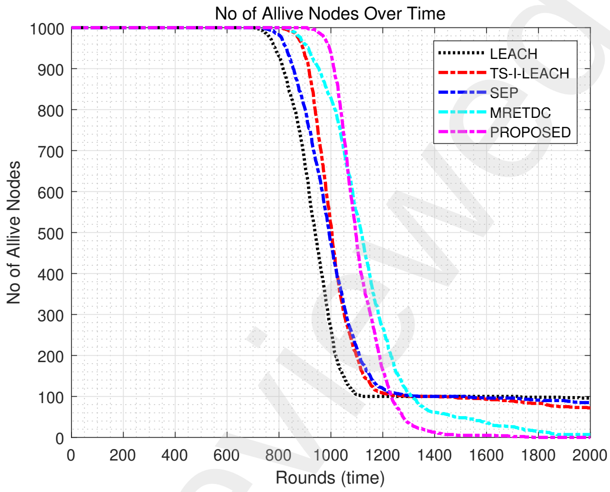


Figure 10: Comparison of the number of nodes that have not discharged during the total round for each protocol when $S = 200$ and $N = 1000$.

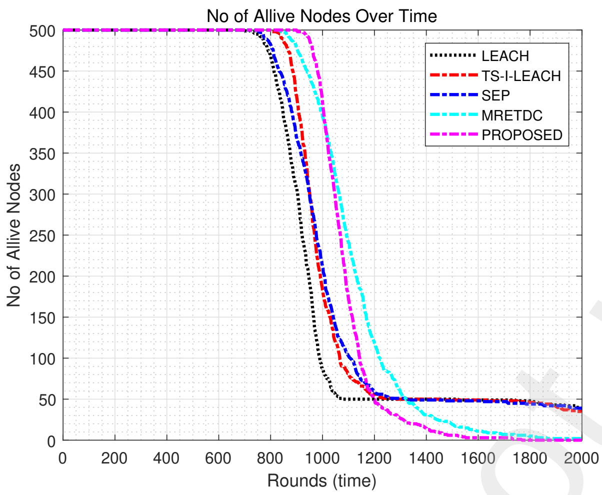


Figure 9: Comparison of the number of nodes that have not discharged during the total round for each protocol when $S = 200$ and $N = 500$.

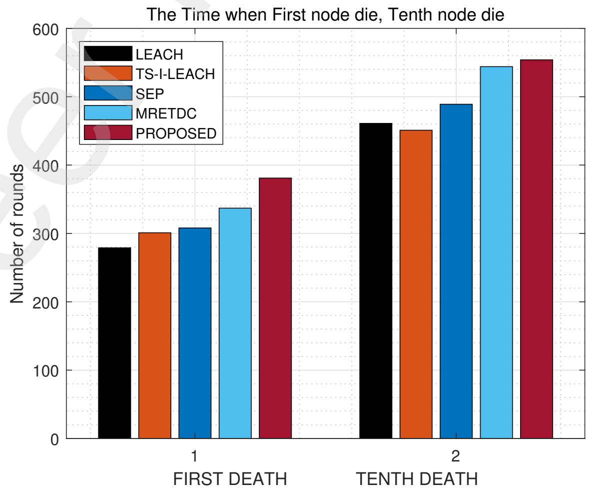


Figure 11: Comparison of FND and TND for each protocol when $S = 300$ and $N = 200$.

in small network sizes but also in large network sizes. It also shows the best performance in dense and sparse arrangements of sensor nodes.

6. Conclusion

In designing a WSN protocol, the primary considerations are stability, network lifetime, and throughput. Efficient energy use and enhanced network lifetime in WSNs are major design challenges during the development of routing protocols. To address these challenges, this study proposes a multi-hop-based enhanced SEP for cooperative communication in WSNs. To evaluate the proposed protocol, simulations were conducted based on node density in a limited-size network. The simulation results demonstrate that the proposed protocol is well-suited for heterogeneous networks with sensors of various energy levels. The proposed protocol, a modification of the SEP, is particularly effective for IoT-based environmental monitoring where diverse sensors are deployed. In addition, the proposed protocol contributes to enhancing network lifetime by dynamically adjusting the number of CHs based on the current network node conditions. CH selection is based on the residual energy of the sensor node and the distance between CHs and the BS. The elected CHs improve the network longevity by ensuring proper load balancing and energy consumption across nodes. The network maintains greater stability as the sensor node lifetime increases. The simulation results confirm that the proposed protocol outperformed existing protocols in terms of network lifetime and throughput regardless of node density.

The proposed protocol has the advantage of increasing the lifespan of all nodes in the entire network. Furthermore, the proposed protocol works well regardless of network size and node density. However, this study did not consider multi-hop routing between clusters in larger network sizes. To compensate for these weaknesses, energy-aware routing, sleep mode

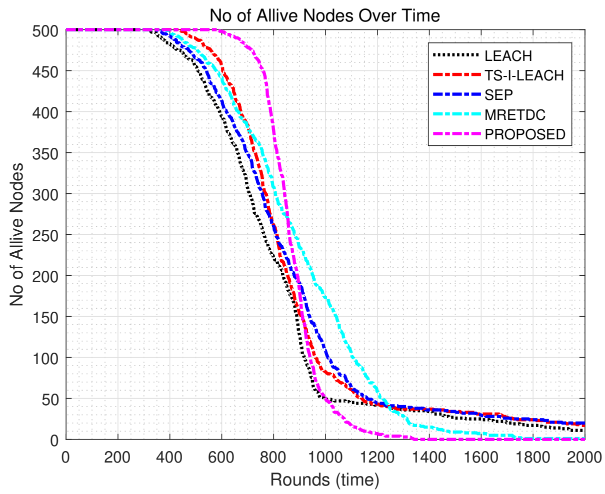


Figure 12: Comparison of the number of nodes that have not discharged during the total round for each protocol when $S = 300$ and $N = 500$.

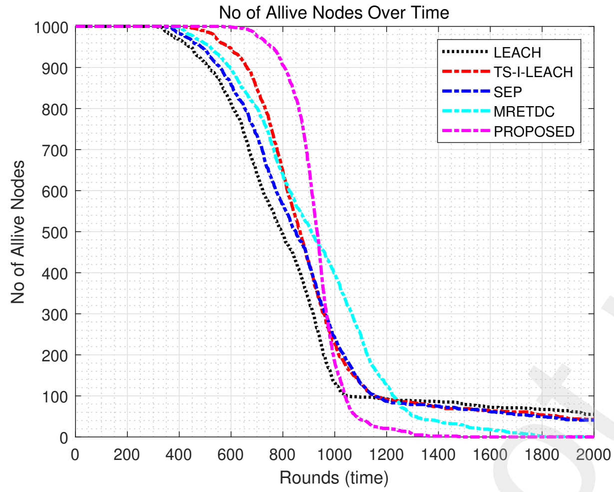


Figure 13: Comparison of the number of nodes that have not discharged during the total round for each protocol when $S = 300$ and $N = 1000$.

scheduling, and data aggregation techniques can be used. In addition, unmanned aerial vehicles as single or multiple can be optimally deployed to obtain the data from the sensor nodes and transmit to the BS via multi-hop transmission in future 6G networks. In such an environment, deploying aerial vehicles in areas densely located with sensor nodes with low energy levels or considering optimal travel paths will be a very important challenge. In our future research, we plan to investigate multi-hop-based energy-aware routing protocols and propose new technologies that can complement the above challenges.

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