Hindawi
Wireless Communications and Mobile Computing
Volume 2018, Article ID 4618056, 12 pages
https://doi.org/10.1155/2018/4618056

Research Article

Threshold Balanced Sampled DEEC Model for Heterogeneous Wireless Sensor Networks

Sercan Vançin and Ebubekir Erdem

Department of Computer Engineering, Firat University, Elazig 23100, Turkey

Correspondence should be addressed to Ebubekir Erdem; aberdem@firat.edu.tr

Received 23 March 2018; Revised 31 August 2018; Accepted 10 October 2018; Published 6 November 2018

Academic Editor: Luca De Nardis

Due to the restricted hardware resources of the sensor nodes, modelling and designing energy efficient routing methods to increase the overall network lifetime have become one of the most significant strategies in wireless sensor networks (WSNs). Cluster-based heterogeneous routing protocols, a popular part of routing technology, have proven effective in management of topology, energy consumption, data collection or fusion, reliability, or stability in a distributed sensor network. In this article, an energy efficient three-level heterogeneous clustering method (DEEC) based distributed energy efficient clustering protocol named TBSDEEC (Threshold balanced sampled DEEC) is proposed. Contrary to most other studies, this study considers the effect of the threshold balanced sampled in the energy consumption model. Our model is compared with the DEEC, EDEEC (Enhanced Distributed Energy Efficient Clustering Protocol), and EDDEEC (Enhanced Developed Distributed Energy Efficient Clustering Protocol) using MATLAB as two different scenarios based on quality metrics, including living nodes on the network, network efficiency, energy consumption, number of packets received by base station (BS), and average latency. After, our new method is compared with artificial bee colony optimization (ABCO) algorithm and energy harvesting WSN (EH-WSN) clustering method. Simulation results demonstrate that the proposed model is more efficient than the other protocols and significantly increases the sensor network lifetime.

1. Introduction

Wireless sensor networks (WSNs) include small-sized sensor nodes that can transmit data through data sensing, computation and wireless channel communication capabilities [1]. One of the major problems in the WSN is the limited battery power at the sensor nodes. Routing protocols around the work areas of the WSN are an important area. In addition to prolonging the life of the sensor nodes, it is also desirable to distribute the existing energy homogeneously to the WSN. Due to the limited power supply in the sensor nodes, the energy consumption of the power source is an important concept in the WSNs. Maximum energy is used when data is transmitted to other nodes via sensor nodes. For all these reasons, a number of studies have been conducted to develop routing algorithms to extend a sensor network lifetime [2].

1.1. Problem Definition. To extend the lifespan of sensor networks, sensor networks are on the basis of the commonality of sensors by providing energy saving and scalability called aggregation. In this sense, nodes in the WSN work in cooperation by separating into clusters [3]. However, in a few literature studies, the advantages of distributing energy in a more balanced way over the network have been discussed. By the heterogeneous structure of the nodes in the network, whether the nodes are close to BS or not, different cluster size structures are the issues that should be taken as basis. In some studies only homogeneous nodes were used, while in some studies the concept of distributed energy was not taken into account. Our aim in this study is to consider all these problems in an integrated way, to overcome them and to make energy efficient networks more qualified.

1.2. Related Works. In the literature, there are many studies on energy efficient clustering of protocols for WSNs. In one study [4], a routing algorithm with LEACH clustering adaptation is presented for homogeneous WSNs, where sensor nodes are randomly determined as CHs (Cluster Heads) and the energy load of the system is shared with the WSN. In [5], a new routing protocol based on LEACH for energy optimization is proposed. It is understood that this algorithm is more efficient than the LEACH algorithm by selecting cluster heads equally. The paper [6] presents a modified LEACH derived from the LEACH algorithm. In [7], a mobile sink improved energy efficient algorithm is presented and compared with mod-LEACH and PEGASIS [8]. In [9], a new energy efficient (EE) clustering based method is proposed for single pass, heterogeneous WSNs. Simulations in MATLAB show that the mentioned method has a 1.62-1.89 times better stability than known protocols such as LEACH, DEEC, and SEP. In [10], the stability of the cluster is reduced because the LEACH protocol on an irregular network causes a decrease in aggregate data efficiency. For this reason, this article [10] suggests a method of selecting a cluster head to improve the LEACH protocol in order to increase cluster head stability. For this purpose, an LEACH variant combined with HEED and LEACH protocol is proposed and this method is approved by simulation. In [11], two energy efficient route planning routing protocols are proposed for three levels of heterogeneous WSNs, namely, Central Energy Efficiency Clustering (CEEC) with Two-Hop Heterogeneity awareness (THCEEC) and Advanced Equalization (ACEEC). Comprehensive simulation results have provided CEEC, ACEEC, and THCEEC central cluster deployments with improved reliability and energy efficiency performance, providing better network lifetime and successful data transmission than LEEC, SEP, ESEP, and DEEC's traditional distributed routing protocols. In addition, ACEEC performs CEEC and provides more network stability time. Analytical evaluation shows that THCEEC performs CEEC, ACEEC, and other existing road planning routing protocols. The study [12] suggests an efficient method of collecting data with a support vector in the WSN. In [13], performance evaluation of clustering protocols is presented in WSNs. Clustering of sensor nodes is an effective technique in reaching these targets. With this technique, other clustering models (LEACH, LEACH-C, and HEED) were evaluated and compared. At the end of these, clustering methods are compared with depending on several criteria such as convergence speed, cluster stability, cluster overlap, location awareness, and node mobility support. In another study [14], the study of various routing models for sensor networks offers a survey with classification on behalf of kinds of models. The three main categories examined are data-centric, hierarchical, and location-based. Routing methods and algorithms each have a common purpose to better output and extend the useful life of the sensor network. A comparison was made between flood and direct diffusion, two routing protocols based on network throughput and lifetime. Simulation of AODV (Ad Hoc on Demand Distance Vector) was also performed on two topologies with the same source and target nodes. The study [15] presents random coverage and connectivity analysis in heterogeneous WSNs with three-dimensions. The study [16] suggests that the SEP algorithm in which each sensor node in a two-level heterogeneous sensor network independently identifies itself as a CH on the basis of the first energy relative to the other sensor nodes of the sensor network. The study [17] presents a method named DEEC by which the CH selection is considered to depend on the ratio of the remaining energy of the node and the average energy of the sensor network. In a study [18], the DDEEC protocol is presented based on the recalibration of the energy for CH. This protocol has been optimized by the public wireless network. In this sense, it is more likely that advanced nodes will be chosen as CH in the first broadcast rounds. Also, when energy is reduced, these sensor nodes will have the same probability of CH selection as normal sensor nodes. The study [19] demonstrates EDEEC, a clustering method with a three-level heterogeneous structure that yields a high amount of energy level called super sensor nodes. In one study [20], a clustering protocol known as EDDEEC was introduced. CH selection probability is dependent on the remaining energy quality of the sensor nodes with the average energy of the WSN. In one study, the opportunity of each node to be chosen as a CH is determined towards to its energy level and to the amount of depleted energy. Nodes with higher opportunity have less delay times. The node with the smallest time delay comparing to its neighbours is chosen as CH. After choosing a CH and forming a cluster, all nodes of each cluster begin to send packets to the CH depend on energy-aware multihop routing. Then CH sends these packets to the BS by means of multihop routing [21]. The aim of paper [22] is to analyse the performance of artificial bee colony optimization algorithm (ABCO) depending on clustering method utilized to improve the network lifetime. The node with highest energy in a cluster is chosen as CH in a determined period and the all field is reclustered depending on the selected CHs. In one paper [23], an energy efficient routing protocol for wireless sensor networks is recommended. This method consists of a routing algorithm for the transmission of data, CH choosing algorithm, and a scheme for the formation of clusters.

1.3. Contributions and Motivations. Our main contributions can be listed as follows:

(i) The proposed method (TBSDEEC) is a DEEC-based, energy efficient three-level heterogeneous clustering model named TBSDEEC for distributed sensor networks.

(ii) The proposed method uses an EDDEEC-like network model. However, while the energy consumption model is designing, the threshold energy level differs from other protocols.

(iii) In this study, we describe a balanced value called threshold balanced sample energy (TBSE) which was proposed and contributed to the calculation of the threshold value.

(iv) Contrary to other studies, the model we proposed provides more accurate and precise solutions for the selection of the CH and the threshold value using the more balanced and sampled average energy of the network and remaining energy of the nodes.

(v) In this study, the threshold value was better adjusted and CH selection was made faster. In this way, the energy of all heterogeneous nodes has been utilized as much as possible.

In this study, designing the threshold energy model, unlike heterogeneous algorithms such as other DEEC, EDEEC, EDDEEC, HDEEC, and TBSE is derived from both a mean and a residual energy of a node in the network. In this study, the proposed model was compared with DEEC, EDEEC, and EDDEEC as two different simulations using the MATLAB program for network performance, throughput of the network, energy consumption of the system, number of packets received by BS, and average latency. Also, the proposed model was compared with EH-WSN and ABCO for alive nodes in the network and energy consumption of the system as different simulations. All the parameters used in programming the three methods are identical. The results show that the proposed model prolongs the network lifetime and is better than the other three clustering protocols in terms of energy efficiency.

The rest of the paper is listed as follows: Section 2 presents the basis of the energy efficient model in detail on behalf of the three protocols and proposed model. Proposed model is presented in a separate Section 3. Simulation design and comparison of the results are presented in Section 4. Finally, Section 5 concludes the paper in briefly.

2. Energy Efficient Modelling

Clustering is important when designing energy efficient WSN models. The components of the clustering network structure are explained as follows: sensor nodes perform tasks such as data detection, data memory management, data routing, and processing of the data. Clusters are the collection units of the WSNs. Large sensor networks should be divided into clusters to perform energy efficient WSNs. Cluster heads (CHs) are the leaders of the clusters. CHs implement activities can be grouped into data aggregation, communication organization within the cluster, and communication with the base station (BS). BS sensor node is the point where data obtained from the network is collected. BS provides communication link between end user and sensor network. The end user is a person accessing the WSN and using the obtained data in various applications [24].

Figure 1 shows a clustering structure heterogeneous model in WSNs.

DEEC, EDEEC, EDDEEC, and the proposed model are explained in detail in this section. First, we present a two-level heterogeneous model for the DEEC protocol, then a three-level heterogeneous network model for both EDEEC and EDDEEC protocols, and finally the heterogeneous and energy consumption model of the proposed algorithm.

2.1. DEEC Model. Heterogeneous WSNs consist of two, three, or multiple types sensor nodes in terms of energy levels, hardware structure, and other special properties [20]. The DEEC protocol is based on a two-level heterogeneous WSN in which the sensor nodes are assumed to have normal and advanced battery levels [11]. However, multilevel heterogeneity can be considered for DEEC. E_0 and $E_0 a$ represent the initial energy of a normal and advanced sensor node, respectively. a indicates how many times energies advanced node has been relative to the normal node. The numbers of normal and advanced nodes in the network are N_{nml} and N_{advcd}, respectively. So, total numbers of nodes (N) in WSN are defined in

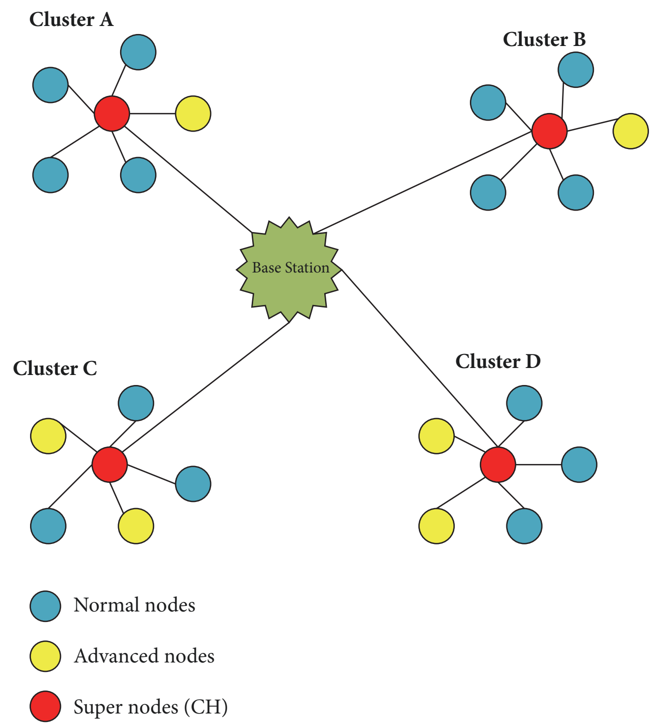

Figure 1: A clustering heterogeneous WSN model.

$$N = N_{nml} + N_{advcd} \quad (1)$$

The total first energy (E_{nml}) of the normal nodes in the WSN is given in

$$E_{nml} = N_{nml} E_0 \quad (2)$$

The total first energy of the advanced nodes in the WSN (E_{advcd}) is given in

$$E_{advcd} = N_{advcd} E_0 a \quad (3)$$

Thus, the total first energy of the two-level heterogeneous WSNs is calculated as given in

$$E_{total} = E_{nml} + E_{advcd} \quad (4)$$

Heterogeneous WSN becomes homogenous after many rounds due to the different energy dissipation of the sensor nodes. CH consumes more energy than sensor nodes and other member nodes. After several rounds, the energy level of all sensor nodes changes relative to each other. For this reason, a clustering network protocol that operates with heterogeneity is more significant than a homogeneous network method [20]. Energy consumption of a sensor node involves models that consume energy so that it can perform specific functions such as sensing, processing and wireless communication of collected data [25–27]. These models have become functional by making energy consumption

Table 1: Simulation parameters.

Type of parameters	Symbol	Value
Energy depletion of the booster to deliver at a shorter distance	e_{fs}	10nJ/bit/m^2
Energy depletion of the booster to deliver at a longer distance	e_{amp}	0.0015pJ/bit/m^4
Energy depletion of the node's electronics circuit to transmit or receive the signal	E_{elec}	60nJ/bit
Energy for data aggregation	E_{DA}	5nJ/bit/signal
Threshold distance	d_0	70m
Desired probability of CH	p_{opt}	0.1
Total rounds number	R	5000
Data size	l	5000 bits
Network size	-	100 x100
Sink node position	-	(50,50)
Number of sensor nodes	N	100
Normal node numbers	N_{nml}	25
Advanced node numbers	N_{advcd}	35
Super node numbers	N_{super}	40
Network deployment	-	Randomly

calculations. For the DEEC model, it includes the idea of the probabilities of the nodes dependent on the start and the remaining energy, in addition to the average energy of the network when the CH selection is performed. The average energy of the network is given as in (5) for r. round.

$$E_{avg} = \frac{1}{N} E_{total} \left(1 - \frac{r}{R}\right) \tag{5}$$

As seen in (5), E_{avg} is found as E_{total} is the total energy of the N nodes and r. round in all rounds R is defined as the number of rounds predicted according to the available energy and energy consumed at the current round is given by (6). E_{round} refers to the energy consumed for each round.

$$R = \frac{E_{total}}{E_{round}} \tag{6}$$

At the beginning of each round, the decision as to whether or not the nodes are CH is decided by the threshold value. The threshold value is recommended as in (7). It is important to note that desired probability (p_i) is between 0 and 1, which is the fraction remaining in the inverse of the $p_i$with r. This is why mod is used. This residual is subtracted by 1 and $T(K_i)$ is calculated.

$$T(K_i) = \begin{cases} \dfrac{p_i}{1 - p_i(\mathrm{mod}(r, 1/p_i))} & if\ S_i \in G \\ 0 & otherwise \end{cases} \tag{7}$$

The selection for CH, G includes the appropriate set of nodes, and p_i is the desired possibility for CH. S_i is i. node within the cluster. The possibilities for CH selection in the DEEC model are given in (8). $E_i(r)$ is the energy of the node. p_{opt} is used constant probability for CH. In (8), because E_{avg} is recalculated for each round, E_{avg} is important to be here. If it is also assumed to be $E_i(r) p_{opt} = E_{avg}$, then the sum of all possible states of p_i is 1. This case is also true for (11).

$$p_i = \begin{cases} \dfrac{E_i(r)\, p_{opt}}{(1+a)\, E_{avg}} & if\ normal\ node \\ \dfrac{E_i(r)\, p_{opt} a}{(1+a)\, E_{avg}} & if\ advanced\ node \end{cases} \tag{8}$$

In this study, the DEEC model was designed as three levels because the equilibrium heterogeneous structure was considered in the simulation comparisons. Moreover, the probability of CH selection in a multilevel heterogeneous network model is as in

$$p_{multi-level} = \frac{p_{opt} N (1+a)}{\left(N + \sum_{i=1}^{N} a_i\right)} \tag{9}$$

p_{opt} is constant and given value of this in Table 1. It only used a coefficient as we show the multilevel heterogeneous network. When the N a is in the case of a denominator, $p_{multi-level}$ is found. In this case, the probability of $p_{multi-level}$ is in only one multiplication factor in N nodes.

2.2. EDEEC Model. EDEEC uses the idea of three levels of heterogeneous sensor networks. This is different from the DEEC model in this sense. The EDEEC model is based on a three-level heterogeneous WSN where sensor nodes are thought to have normal, advanced, and super-battery levels. E_0, $E_0 a$, and $E_0 b$ represent the starting energy of a normal, advanced, and super sensor node, respectively. The numbers a and b determine how many times more energy is advanced and super nodes are more than normal nodes [19]. Since N is the number of nodes in the network, the numbers of normal, advanced, and super nodes in the network are N_{nml}, N_{advcd}, and N_{super}, respectively. Thus, the total first energy of the three-level heterogeneous WSNs is calculated as given in

$$E_{total} = E_{nml} + E_{advcd} + E_{super} \tag{10}$$

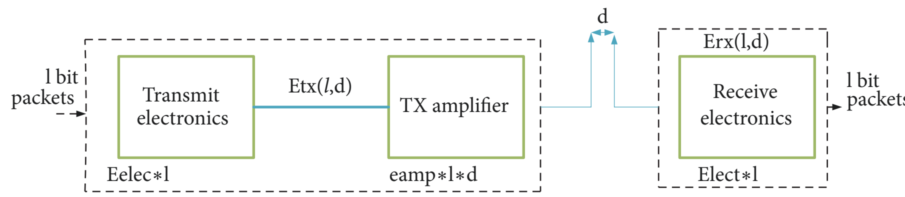

Figure 2: Energy dissipation model.

Also, the proposed probabilities for the CH selection for the EDEEC model are given in (11).

The threshold used to select CH in the EDEEC model is proposed as in (7) for any types of nodes.

$$p_i = \begin{cases} \dfrac{E_i(r)\,p_{opt}}{(1+a+b)\,E_{avg}} & if\ normal\ node \\ \dfrac{E_i(r)\,p_{opt}a}{(1+a+b)\,E_{avg}} & if\ advanced\ node \\ \dfrac{E_i(r)\,p_{opt}b}{(1+a+b)\,E_{avg}} & if\ super\ node \end{cases} \quad (11)$$

2.3. EDDEEC Model. DDEEC model utilizes the same network structure with other energy models like EDEEC. When a bit of data is sent or received for energy consumption and distance for the proposed model, the energy dissipation of the sensor node E_T is calculated as (12). Figure 2 shows the network energy consumption model. l is data size. E_{elec} refers to the energy consumption per bit of the sensor to electronically operate the transmitter or receiver; e_{fs} and e_{amp} denote types of radio amplifiers for free space and multiple paths, respectively. $E_{TX/RX}(l,d)$ refers to the energy consumption in sending and receiving data for l bits.

$$E_T = E_{TX/RX}(l,d) = \begin{cases} lE_{elec} + le_{fs}d^2, & d < d_0 \\ lE_{elec} + le_{amp}d^4, & d \geq d_0 \end{cases} \quad (12)$$

This method is based on the EDEEC model. The model includes the idea of the probabilities dependent on the start and the remaining energy of the nodes in addition to the average energy of the network when CH is selected. The average energy of the network is given as (4) for r.round. R is given by (6).

3. Proposed TBSDEEC (Threshold Balanced Sampled DEEC) Model

In the proposed model, a three-level heterogeneous network structure is considered in the same way as the EDDEEC model. The total energy is calculated in the same way as in (10). When a bit of data is sent or received for energy consumption and distance for the proposed model, the energy dissipation of the sensor node E_T is calculated in the same way as in (12). The proposed method is based on the EDDEEC model. The model includes the idea of the probabilities dependent on the start and the remaining energy of the nodes in addition to the average energy of the network when CH is selected. The average energy of the network is given as in (5) for r. round. R is given by (6). E_{round} is the energy consumed in a sensor network during a single round. At the beginning of each round, the decision as to whether or not the nodes are CH is decided by the threshold value. The threshold value is recommended as in (13) for any type of nodes. In this study, it is proposed to use the energy-balanced sampled value(τE_{sample}) for the threshold value ($T(K_i)$) calculation, which is the main contribution of our study. Also, E_{sample} depends on i.

$$T(K_i) = \begin{cases} \dfrac{p_i}{1 - p_i\left(\mathrm{mod}\left(r, 1/p_i\right)\right)}\left(\tau E_{sample}\right) \\ for\ any\ types\ of\ node \end{cases} \quad (13)$$

$$if\ S_i \in G$$

τ is value between 0 and 1, used as a weighted ratio, and is used together with the energy-balanced value (E_{sample}). In fact, it is not possible to know the value of τ because of the fact that network formation for the next network tour is not known. The appropriate value of τ can be determined by many simulations using random networks. In the first scenario of this study, the τ value was set at 0.65 for a simulation. In the second scenario, 1000 simulations were run for random networks and average values of all simulations were obtained. The energy balance value (E_{sample}) for the next round is given as in

$$E_{sample}(i) = \left|1 - \frac{E_{avg}}{E_i(r)}\right| \quad (14)$$

The aim of this equation in our study as different from others is to minimize and balance the energy depletion between the nodes, which will increase the stability period and the sensor network life. $E_{sample}(i)$ is calculated in equation (14) and is determined balanced of the nodes energy load using sampled with 1. In this sense, it has been sampled $E_{sample}(i)$ by dividing the average energy by the remaining energy. Also, if $E_i(r)$ is less than E_{avg} then $E_{sample}(i)$ will be negative, so we use the absolute form of the expression in the $E_{sample}(i)$. If $E_i(r)$ equals E_{avg}, then $E_{sample}(i)$ will be zero and we consider that $T(K_i)$ has already become balanced. There is no need to use the (τE_{sample}) expression in the threshold equation. So, more precise threshold energy $T(K_i)$ was obtained in this study. In addition, after some tours, the super and advanced nodes remain at the same energy level as normal nodes. In this sense, DEEC cannot use advanced nodes well and cannot manage advanced nodes

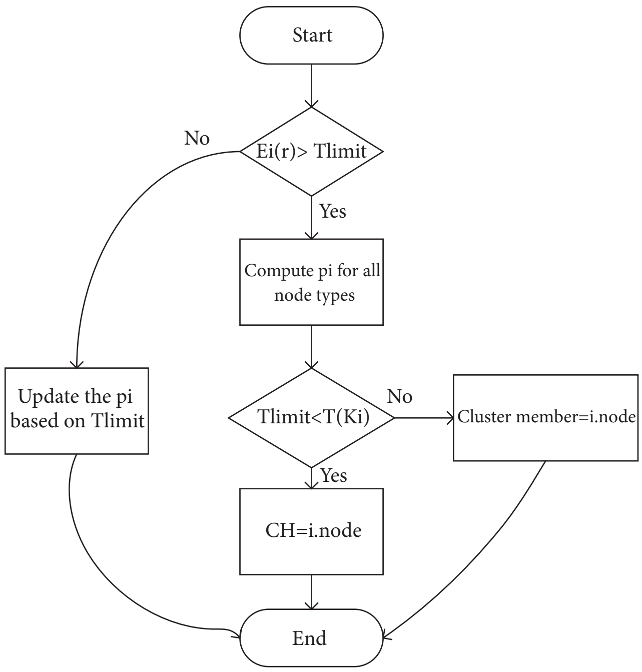

Figure 3: The flowchart of the working mechanism of proposed model.

(1) For r=1:1:MaxRound
(2) Compute $E_i(r)$ and E_{avg}
(3) Compute E_{sample} according to equation (14)
(4) Compute p_i according to equation (15)
(5) if (node $\in$ G) then
(6) $T(K_i) \longleftarrow \dfrac{p_i}{1-p_i(\operatorname{mod}(r,1/p_i))}(\tau E_{sample})$
(7) Else then
(8) Goto (4)
(9) End if
(10) End for

Algorithm 1: The pseudocode of the $T(K_i)$.

(1) Compute all alive nodes
(2) Compute the CH percentage
(3) For r=1:1:MaxRound
(4) Compute $E_i(r)$ and E_{round}
(5) Compute E_{avg} at current round
(6) If ($E_i(r) > T_{limit}$) then
(7) Compute p_i for all node types
(8) Else then
(9) Update the p_i based on T_{limit}
(10) End if
(11) if (node $\in$ G) then
(12) if ($T_{limit} < T(K_i)$ then
(13) CH $\longleftarrow$ i. node
(14) Else then
(15) Cluster member $\longleftarrow$ i. node
(16) End if
(17) Else then
(18) Goto (14)
(19) End if
(20) End For

Algorithm 2: The proposed algorithm.

such as EDEEC super nodes well. Also EDDEEC may not have guaranteed a balanced and adapted threshold for CH selection. To solve this disadvantage problem in a three-level, heterogeneous network and to prevent the super and advanced nodes from being wasted, the changes defined by the proposed method have been presented in the threshold function. This change depends on the constant limit level (T_{limit}). This value indicates that the advanced and super nodes have the equal energy as their normal nodes. From this idea, it can be understood that under T_{limit}, all normal, advanced, and super nodes are equally likely to be chosen as CH. In the proposed model, the probabilities proposed in CH selection are given in (15). The pseudocode of the proposed method and flowchart are given in Algorithm 2 and Figure 3, respectively. As shown in the line (12) of the algorithm, when T_{limit} is smaller than the $T(K_i)$, i. node is chosen as CH. In another case, i. node is chosen as cluster member.

The value of the energy level T_{limit} is calculated as in (16).

$$p_i = \begin{cases} \dfrac{E_i(r)\,E_0 p_{opt}}{E_{avg}E_{total}} & \textit{for normal nodes } (\textit{if}(E_i(r) > T_{limit}) \\ \dfrac{E_i(r)\,E_0 p_{opt}\mathrm{a}}{E_{avg}E_{total}} & \textit{for advanced nodes } (\textit{if}(E_i(r) > T_{limit}) \\ \dfrac{E_i(r)\,E_0 p_{opt}\mathrm{b}}{E_{avg}E_{total}} & \textit{for super nodes } (\textit{if}(E_i(r) > T_{limit}) \end{cases} \quad (15)$$

$$T_{limit} = \tau E_0 \quad (16)$$

The pseudocode of the $T(K_i)$ for each round is presented in Algorithm 1.

4. Simulation Results

In this study, the simulation results of DEEC, EDEEC, EDDEEC, and the proposed protocol for three levels of heterogeneous WSNs were analysed using MATLAB programming. Two different scenarios are considered in this study. While WSN was being constructed, 100 sensor nodes were randomly distributed in a 100 m by 100 m area with a centrally positioned BS. It is estimated that all the sensor nodes are in a fixed position and that there is no energy loss owing to the deterioration between the signals of all the nodes. The quality performance criteria utilized for analysis of models are live nodes in the network, number of packets received by BS, energy consumption, throughput, and average latency.

(i) **Alive nodes on the network:** the living nodes metric takes into account the fact that the first node is starting to die and all the nodes have died.

Table 2: Comparison of algorithms (Scenario 1).

Algorithms	First dying rounds of the nodes	Dead rounds of the all nodes
DEEC	1512	2813
EDEEC	2179	3654
EDDEEC	2557	4258
proposed	2761	4536

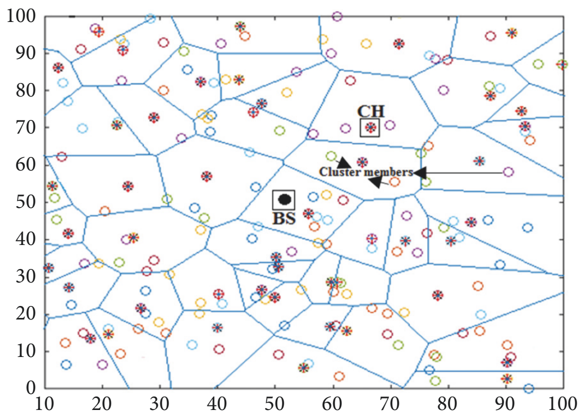

Figure 4: Cluster formation (Scenario 1).

(ii) **The number of packets received by BS:** with this performance metric, the total number of packets received by BS is considered.

(iii) **Energy consumption of methods:** with this performance metric, the total energy depletion over the lifetime of the network is considered.

(iv) **Throughput:** this performance metric tells us how accurately the data is transmitted and how accurate the data is delivered from the first bit to the last bit.

(v) **Average latency:** average latency is time delay when delivering data packets to the BS.

Table 1 shows the simulation parameters used in the scenarios.

4.1. Scenario 1. In this scenario, a network consisting of 25 normal nodes with E_0 initial energy is assumed in the sensor network. There are 35 advanced nodes with 2 more energies than that of normal nodes (a = 2) and 40 super nodes with 3 more energies (b = 3). In this scenario, the weighted ratio (τ) is 0.65. Figure 4 depicts sensor nodes, clusters, and CHs that are randomly distributed after the network's setup phase. The model is proposed as shown in Figure 5(b); the numbers of packets received by BS are approximately 6.0x 10^5, 6.25x 10^5, 7.5x 10^5, and 8.25x 10^5 for DEEC, EDEEC, EDDEEC, and the proposed method, respectively. As shown in Figure 5(c), it has performed better than the other network-based methods, taking into account the fact that network throughput drops to approximately 2530th round for DEEC, 2761th round for EDEEC, 4375th round for EDDEEC, and 4760th round for the proposed method. When the algorithm is executed, DEEC takes into consideration the energy of the sensor nodes and the average energy of the network; EDDEEC considers the remaining energy of the nodes. In the proposed model, one node contributes to a different threshold balanced energy level. All these ideas have a significant impact on CH selection criteria. As shown in Figure 5(d), the DEEC, EDEEC, EDDEEC, and suggested routing algorithms completely exhausted the remaining energy of the network at 2410, 2605, 3365, and 3674th rounds, respectively. Throughout, the proposed model lengthens the network lifetime better for longer rounds than the three clustering models.

Figure 5(a) illustrates the number of live nodes affecting the network life. For DEEC, EDEEC, EDDEEC, and the proposed model, the first node died in 1512, 2179, 2557, and 2761th rounds, respectively, and all nodes died in 2813, 3654, 4258, and 4536th rounds, respectively (see Table 2). The model proposed in as shown in Figure 5(b) demonstrates that the number of packets received by BS is more than the other protocols. As can be seen in Figure 5(e), as the number of rounds increases, average latency reduces for all methods.

For example, in the 2500th round, DEEC, EDEEC, EDDEEC, and the proposed algorithm are seen as 800, 750, 640, and 550 milliseconds, respectively. This means that the proposed algorithm delivers data packets with minimum latency owing to the fact that the proposed protocol deliver data packets to the BS with minimum relay after calculating the optimal possible distance for the next hop; moreover the CHs are placed at optimal distance to BS; thus the results obtained from the simulations show quality of this study.

4.2. Scenario 2. The main purpose of Scenario 2 is to bring T_{limit} in (16) to optimistic value. T_{limit} how sensitive is measured, *i.* node is more correctly assigned to the CH as accurately as expressed in lines (12) and (13) of Algorithm 2. In this way, this method makes it easier to increase the life of the network. In this sense, in Scenario 1, the value of τ was assumed to be a constant value of 0.65. In Scenario 2, τ is found 0.58 as a result of 1000 simulations. Thus, according to Table 2 as a result of Scenario 1, the first node in the network died in 2761th round, though according to Table 3, the results of Scenario 2, the first node in the network died in 2628th round. That is, the life of the network has increased by about 6%. As a result, energy usage and network life have had positive results in terms of all algorithms. All other parameters considered for the simulation are as in Table 1. Figure 6 depicts sensor nodes, clusters, and CHs that are randomly distributed after the network's setup phase

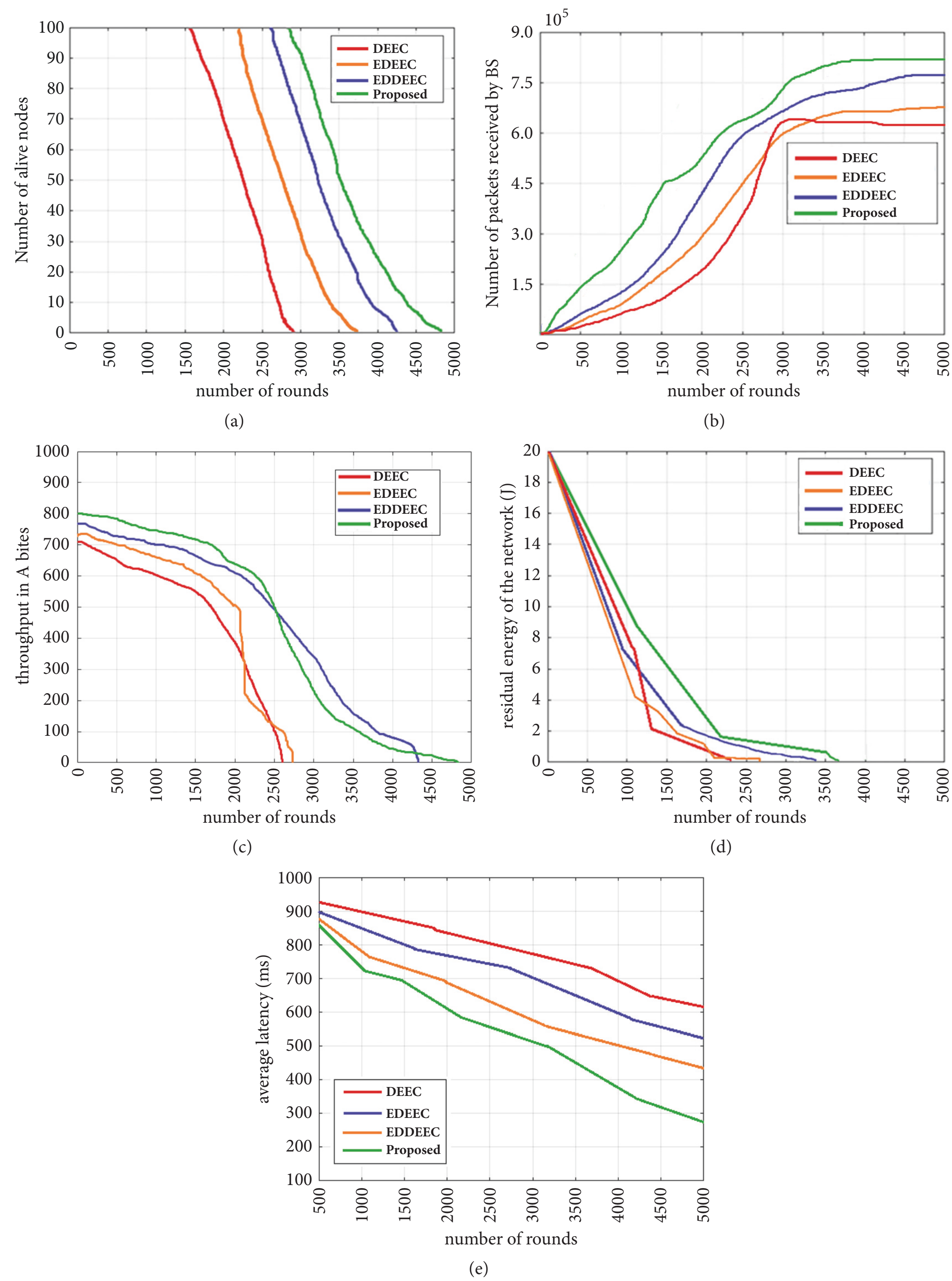

Figure 5: Simulation results of the proposed TBSDEEC model and the other methods (Scenario 1). (a) Number of alive nodes through network lifetime. (b) The number of packets received by BS. (c) Network throughput. (d) Network energy consumption. (e) Average latency.

for scenario 2. This scenario is the improved version of the scenario 1. This means we adjust the τ value in a fix status for achieving longer network lifetime and providing more performance on rounds.

Figure 7(a) shows the number of living nodes affecting the longevity of the network. For the DEEC, EDEEC, EDDEEC, and the recommended protocol, the first node died in 1556, 2265, 2614, and 2928th rounds, respectively, and all nodes

Table 3: Comparison of the algorithms (Scenario 2).

Algorithms	First dying rounds of the nodes	Dead rounds of the all nodes
DEEC	1556	2876
EDEEC	2265	3756
EDDEEC	2614	4305
proposed	2928	4827

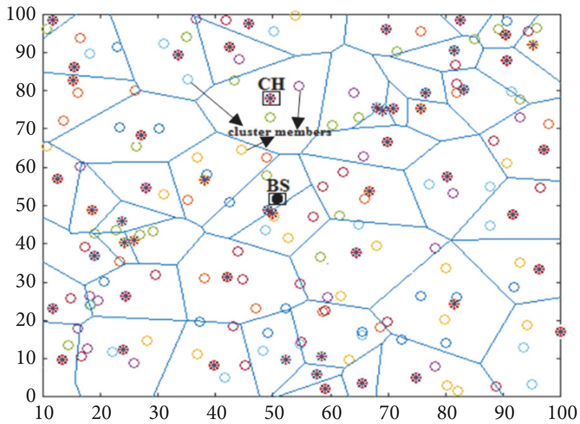

Figure 6: Cluster formation (Scenario 2).

died in 2876, 3756, 4305, and 4827th rounds, respectively (see Table 3). Figure 7(b) illustrates that the numbers of packets received by BS are more than 9.0 x 10^5packets, which is more for the proposed algorithm than the other protocols. It is also clear that, for all algorithms, BS has more packages than the first scenario. In Figure 7(c), the proposed method performed better than the other methods according to network throughput and was found to end after approximately 4910th round. For all algorithms, this scenario reflects the superiority of the first and has best results. The remaining energy of the network is shown in Figure 7(d). As seen in Figure 7(d), when the proposed protocol is used, it consumes all the energy of the network after 4920th round. In this sense, the proposed model extends the network lifetime better than the three clustering models for longer rounds. In addition, all simulation results show energy efficiency for longer rounds compared to performance criteria, which means that the network lifetime is longer.

As can be seen in Figure 7(e), as the number of rounds increases, average latency reduces for all methods. For example, in the 2000th round, DEEC, EDEEC, EDDEEC, and the proposed algorithm are seen as 700, 610, 480, and 400 milliseconds, respectively.

As shown in Table 4, we also analysed the influence of $E_i(r)$ based on $T(K_i)$. We derived energy consumption differences between proposed and the other algorithms as percentage using Tables 2 and 3 thanks to dead rounds of the all nodes. When τ and $T(K_i)$ are calculated and fitted to (13), the CH selection is made very often and more nodes become CH and energy is consumed in a balanced level. So, energy consumption decreases and the balanced state of $T(K_i)$ is taken into account. As seen in Table 4, the proposed

Table 4: The performance difference as percentage (%).

The other algorithms compared	The proposed algorithm	
	For Scenario 1	For Scenario 2
DEEC	36.5	39.2
EDEEC	17.64	21.42
EDDEEC	5.56	10.42

algorithm with Scenario 1 enhanced the network lifetime 36.5%, 17.64%, and 5.56% for DEEC, EDEEC, and EDDEEC, respectively. Also, the proposed algorithm with Scenario 2 prolonged the network lifetime 39.2%, 21.42%, and 10.42% for DEEC, EDEEC, and EDDEEC, respectively.

After that, we compared other two newly protocols with our proposed method according to alive nodes in the network and residual energy of the network. In this scenario, we execute the simulations based on scenario 1 and Table 1 parameters.

Figure 8(a) shows the number of living nodes affecting the longevity of the network. For the EH-WSN [21], ABCO [22], and the proposed protocol, the first node died in 2560, 2653, and 2761th rounds, respectively, and all nodes died in 4325, 4410, and 4536th rounds as seen in Table 5. It is clear that our method has the most performance.

As seen in Figure 8(b), when the proposed protocol is used, it consumes all the energy of the network after 3674th round. In this mean, because T_{limit} and $T(K_i)$ are calculated in the most accurate and balanced way and total energy is used in more balanced and distributed way while CH is chosen, the proposed method has shown superior performance compared to other existing methods. In this sense, the proposed model extends the network lifetime better than the two clustering models for longer rounds. In addition, all simulation results show energy efficiency for longer rounds compared to performance criteria, which means that the network lifetime is longer.

5. Conclusions

This study presents an energy efficient clustering heterogeneous protocol based DEEC variants in distributed WSNs. We analysed the performances of the proposed protocol with different two scenarios in comparison with DEEC, EDEEC, EDDEEC, EH-WSN, and ABCO protocols in terms of criteria, alive nodes during the network life, and throughput of the sensor network, number of packets received by BS in the network, energy depletion, and average latency of the algorithms in MATLAB simulation environment. The

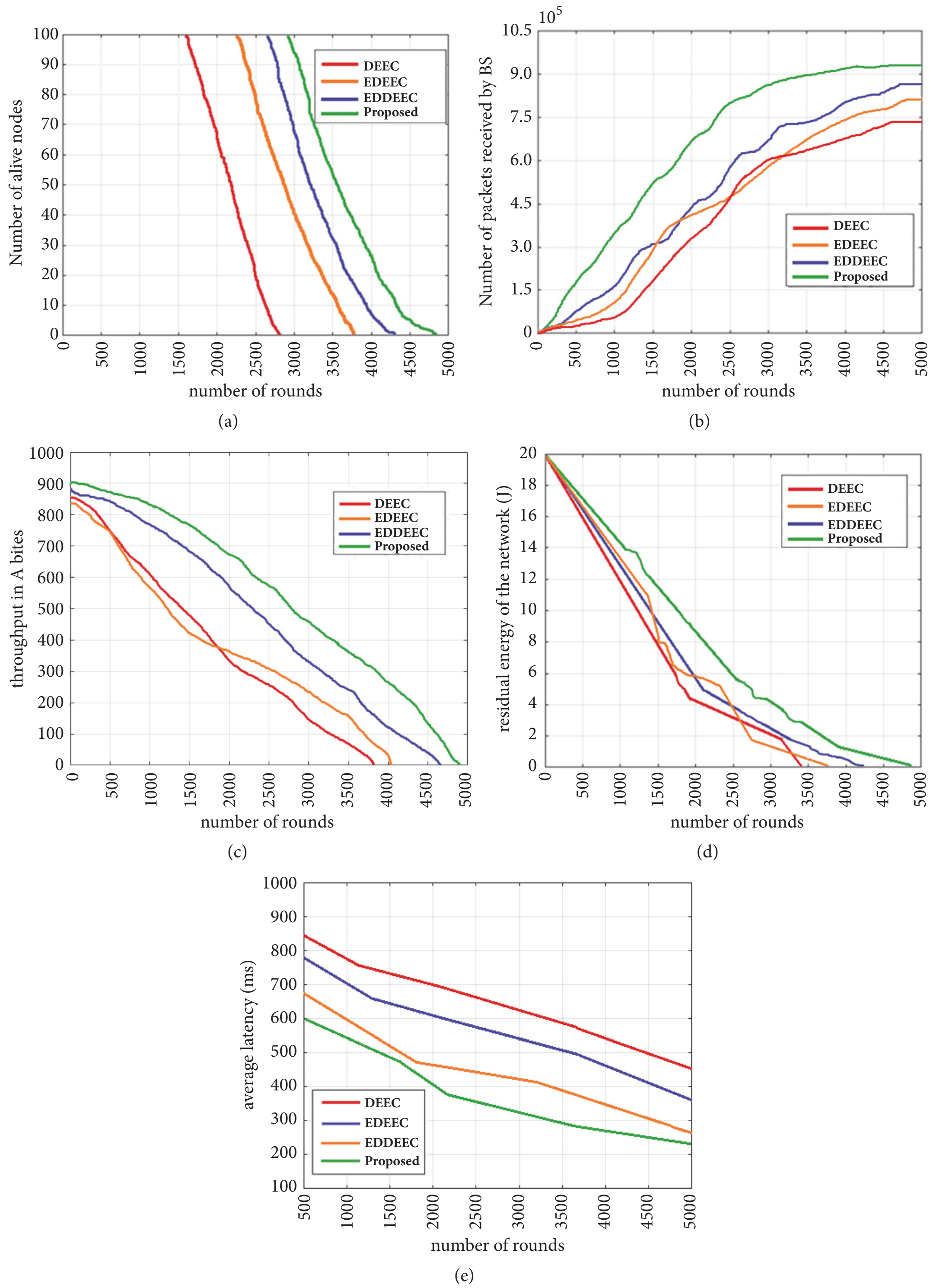

FIGURE 7: Simulation results of the proposed TBSDEEC model and the other methods (Scenario 2). (a) Number of alive nodes through network lifetime. (b) The number of packets received by BS. (c) Network throughput. (d) Network energy consumption. (e) Average latency.

proposed method (TBSDEEC) demonstrates its superiority over the other methods in terms of the parameters concerned and has been found to be advantageous with respect to energy consumption and threshold balanced sampled value considered. Also, the consumption of the first scenario as a result of the best balanced value obtained and prolonged the lifetime of the network. In this sense, we contribute a different energy consumption CH selection method to the

Table 5: Comparison of the other algorithms.

Algorithms	First dying rounds of the nodes	Dead rounds of the all nodes
EH-WSN [21]	2560	4325
ABCO [22]	2653	4410
proposed	2761	4536

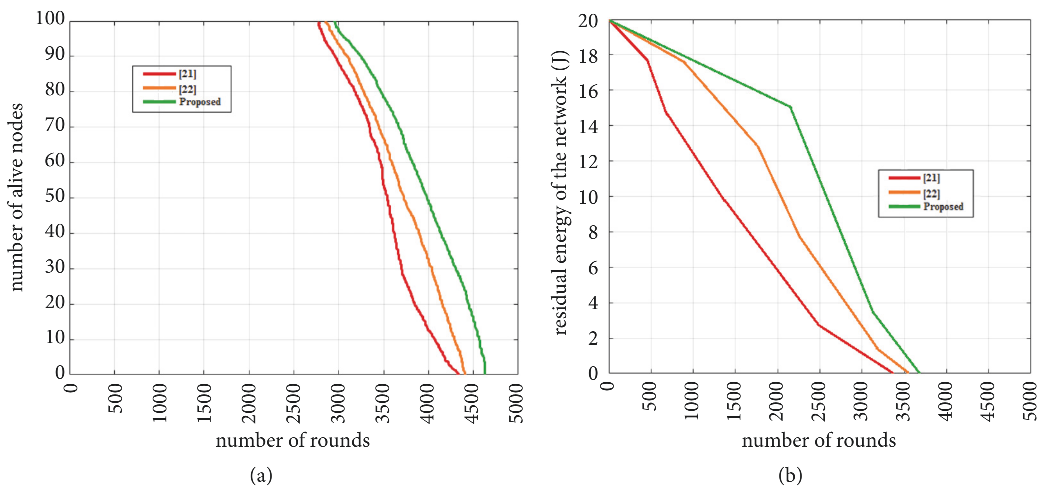

Figure 8: Other simulation results. (a) Number of alive nodes through network lifetime. (b) Network energy consumption.

heterogeneous WSNs and the proposed algorithm can inspire other researchers in the future works.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] S. Vancin and E. Erdem, "Implementation of the vehicle recognition systems using wireless magnetic sensors," *Sādhanā*, vol. 42, no. 6, pp. 841–854, 2017.

[2] J. Burrell, T. Brooke, and R. Beckwith, "Vineyard Computing: Sensor Networks in Agricultural Production," *International Journal of Computer Applications (0975 – 8887)*, vol. 97, no. 7, pp. 9–16, 2014.

[3] R. Kumar and R. Kaur, "Evaluating the Performance of DEEC Variants," *International Journal of Computer Applications*, vol. 97, no. 7, pp. 9–16, 2014.

[4] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Siences (HICSS '00)*, vol. 2, IEEE, January 2000.

[5] T. Kang, J. Yun, H. Lee et al., "A Clustering Method for Energy Efficient Routing in Wireless Sensor Networks," in *Proceedings of the International Conference on Electronics, Hardware, Wireless and Optical Communications*, pp. 133–138, Corfu Island, Greece, 2007.

[6] J. Singh, B. P. Singh, and S. Shaw, "A new LEACH-based routing protocol for energy optimization in Wireless Sensor Network," in *Proceedings of the 5th IEEE International Conference on Computer and Communication Technology, ICCCT 2014*, pp. 181–186, September 2014.

[7] A. Kumar and V. Kumar Katiyar, "Intelligent Cluster Routing: An Energy Efficient Approach for Routing in Wireless Sensor Networks," *International Journal of Computer Applications*, vol. 110, no. 5, pp. 18–22, 2015.

[8] S. Lindsey and C. S. Raghavendra, "PEGASIS: power-efficient gathering in sensor information systems," in *Proceedings of the IEEE Aerospace Conference*, vol. 3, pp. 1–6, Big Sky, MT, USA, March 2002.

[9] N. AT and D. SM, "A New Energy Efficient Clustering-based Protocol for Heterogeneous Wireless Sensor Networks," *Journal of Electrical & Electronic Systems*, vol. 04, no. 03, 2015.

[10] J.-Y. Lee, K.-D. Jung, and D. Lee, "The routing technology of wireless sensor networks using the stochastic cluster head selection method," *International Journal of Control and Automation*, vol. 8, no. 7, pp. 385–394, 2015.

[11] M. Aslam, E. U. Munir, M. M. Rafique, and X. Hu, "Adaptive energy-efficient clustering path planning routing protocols for heterogeneous wireless sensor networks," *Sustainable Computing*, vol. 12, pp. 57–71, 2016.

[12] V. M. Mohammad and M. Noorian, "An Efficient Data Aggregation Method in Wireless Sensor Network based on the SVD," in *Proceedings of the The International Conference on Computing*

Technology and Information Management (ICCTIM), Society of Digital Information and Wireless Communication, 2014.

[13] S. Dhankhar and E. S. Singh, "Performance Comparison of LEACH & HEED Clustering Protocols in WSN using MATLAB-A Review," *International Journal of Technical Research*, vol. 5, no. 1, pp. 167–170, 2016.

[14] K. H. Krishna, Y. S. Babu, and T. Kumar, "Wireless Network Topological Routing in Wireless Sensor Networks," *Procedia Computer Science*, vol. 79, pp. 817–826, 2016.

[15] H. P. Gupta, S. V. Rao, and T. Venkatesh, "Analysis of stochastic coverage and connectivity in three-dimensional heterogeneous directional wireless sensor networks," *Pervasive and Mobile Computing*, vol. 29, pp. 38–56, 2016.

[16] G. Smaragdakis, I. Matta, and A. Bestavros, "SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor network," in *Proceedings of the Second International Workshop on Sensor and Actor Network Protocols and Applications (SANPA)*, vol. 97, pp. 1–11, 2004.

[17] L. Qing, Q. Zhu, and M. Wang, "Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks," *Computer Communications*, vol. 29, no. 12, pp. 2230–2237, 2006.

[18] B. Elbhiri, S. Rachid, S. El Fkihi, and D. Aboutajdine, "Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks," in *Proceedings of the 2010 5th International Symposium on I/V Communications and Mobile Networks, ISIVC*, pp. 1–4, Morocco, October 2010.

[19] P. Saini and A. K. Sharma, "E-DEEC - Enhanced distributed energy efficient clustering scheme for heterogeneous WSN," in *Proceedings of the 2010 1st International Conference on Parallel, Distributed and Grid Computing, PDGC - 2010*, pp. 914–919, October 2010.

[20] N. Javaid, T. N. Qureshi, A. H. Khan, A. Iqbal, E. Akhtar, and M. Ishfaq, "EDDEEC: Enhanced Developed Distributed Energy-Efficient Clustering for Heterogeneous Wireless Sensor Networks," *Procedia Computer Science*, vol. 19, pp. 914–919, 2013.

[21] S. M. Bozorgi, A. Shokouhi Rostami, A. A. R. Hosseinabadi, and V. E. Balas, "A new clustering protocol for energy harvesting-wireless sensor networks," *Computers and Electrical Engineering*, vol. 64, pp. 233–247, 2017.

[22] A. Gambhir, A. Payal, and R. Arya, "Performance analysis of artificial bee colony optimization based clustering protocol in various scenarios of WSN," *Procedia Computer Science*, vol. 132, pp. 183–188, 2018.

[23] M. K. Khan, M. Shiraz, K. Z. Ghafoor, S. Khan, A. S. Sadiq, and G. Ahmed, "EE-MRP: Energy-Efficient Multistage Routing Protocol for Wireless Sensor Networks," *Wireless Communications and Mobile Computing*, vol. 2018, 2018.

[24] S. Vancin and E. Erdem, "Performance analysis of the energy efficient clustering models in wireless sensor networks," in *Proceedings of the 2017 24th IEEE International Conference on Electronics, Circuits and Systems (ICECS)*, pp. 247–251, Batumi, December 2017.

[25] F. Engmann, F. A. Katsriku, J. Abdulai, K. S. Adu-Manu, and F. K. Banaseka, "Prolonging the Lifetime of Wireless Sensor Networks: A Review of Current Techniques," *Wireless Communications and Mobile Computing*, vol. 2018, pp. 1–23, 2018.

[26] M. Nicolae, D. Popescu, R. Dobrescu, and I. Costea, "Scheduling mechanism for energy-efficient communication in hybrid wireless sensor networks," *Control Engineering and Applied Informatics*, vol. 18, no. 2, pp. 95–102, 2016.

[27] A. A. Babayo, M. H. Anisi, and I. Ali, "A Review on energy management schemes in energy harvesting wireless sensor networks," *Renewable & Sustainable Energy Reviews*, vol. 76, pp. 1176–1184, 2017.