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Research Article

Energy-Efficient QoS-Aware Intelligent Hybrid Clustered Routing Protocol for Wireless Sensor Networks

Parvinder Singh[1] **and Rajeshwar Singh**[2]

[1]*Research Scholar, Department of ECE, IK Gujral Punjab Technical University, Jalandhar, India*
[2]*Director, Doaba Group of Colleges, Rahon, SBS, Nagar, India*

Correspondence should be addressed to Parvinder Singh; er.parvinder@gmail.com

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A wireless sensor network consists of numerous low-power microsensor devices that can be deployed in a geographical area for remote sensing, surveillance, control, and monitoring applications. The advancements of wireless devices in terms of user-friendly interface, size, and deployment cost have given rise to many smart applications of wireless sensor networks (WSNs). However, certain issues like energy efficiency, long lifetime, and communication reliability restrict their large scale utilization. In WSNs, the cluster-based routing protocols assist nodes to collect, aggregate, and forward sensed data from event regions towards the sink node through minimum cost links. A clustering method helps to improve data transmission efficiency by dividing the sensor nodes into small groups. However, improper cluster head (CH) selection may affect the network lifetime, average network energy, and other quality of service (QoS) parameters. In this paper, a multiobjective clustering strategy is proposed to optimize the energy consumption, network lifetime, network throughput, and network delay. A fitness function has been formulated for heterogenous and homogenous wireless sensor networks. This fitness function is utilized to select an optimum CH for energy minimization and load balancing of cluster heads. A new hybrid clustered routing protocol is proposed based on fitness function. The simulation results conclude that the proposed protocol achieves better efficiency in increasing the network lifetime by 63%, 26%, and 10% compared with three well-known heterogeneous protocols: DEEC, EDDEEC, and ATEER, respectively. The proposed strategy also attains better network stability than a homogenous LEACH protocol.

1. Introduction

In this technological era, the design of sophisticated smart sensor devices has revolutionized the field of remote sensing and communication. It has changed the method of gathering information in remote geographical areas which otherwise cannot be accessed by human beings. [1, 2]. The recent development and advances in sensor devices lead to applications such as wildlife monitoring, undersea monitoring, intelligent infrastructure monitoring, and traffic intensity monitoring [3–8]. These microsensor devices are distributed in a real-world terrestrial environment to sense various environmental changes. Sensor devices exhibit limited energy; therefore, segregated data from the environment are immediately sent to the sink. The sink is a vital node which is curious to collect data from the sensor node. It scrutinizes and decreases the resemblance among received data which is then utilized for some conclusive decision making. In addition to this, the sink not only further utilizes the data locally but, if necessary, also conveys collected information to some remote area networks. In WSN, the procedure of assembling data from microsensors and sending them to a base station is termed as data aggregation [9, 10].

However, WSN performance is degraded from considerable constraints such as limited storage capability, nonrechargeable and lean batteries, limited computational capability, and low security. Power consumption in a WSN depends deeply upon applications [11–13]. These networks are intermittently installed in an inhospitable environment where an individual cannot restore the power unit of a sensor node. So, batteries indicate the lifetime of WSNs. In a wireless scenario, energy is consumed mostly during the data

transmission process [14–16]. Therefore, the design of an energy-efficient routing mechanism is the need of the hour.

In the last decade, a large number of power-saving techniques were proposed. Authors initiated research from the physical layer to the link layer and then to the network routing layer depending upon data-accessing techniques [17]. In contrast to this, clustering protocols [18] were engaged by a handful of authors. These techniques divided the data sensing, aggregation, and transmitting phases into two mechanisms as the setup phase and the steady state phase. Cluster member nodes perceive and relay data towards a CH in an organized way. Wireless media is shared between various nodes in a cluster. The cluster head establishes the schedule of data aggregation and conveys this to all the member nodes. This aggregation process is carried out through a TDMA access technique. The CH is accounted for redundant data reduction and applies compression techniques to decrease data size and progress towards base station.

LEACH [19] is considered as the benchmark in cluster-based routing. It encapsulates an energy balancing cluster-based data-forwarding technique and a medium access technique. The purpose behind LEACH was to improve the network lifespan by saving sensor node energy. The first round is called a setup phase; in this round, a cluster is formed and a CH is elected based on initial node energy. The CH is elected based on threshold function $T(n)$, which is compared with a random number assumed by nodes. The node which generates a random number lesser than the threshold value will become a cluster head. $T(n)$ is given as follows:

$$T(n) = = \begin{cases} \dfrac{p}{1 - p \times [r \bmod (1/p)]}, & \text{if } n \in G, \\ 0, & \text{elsewhere}, \end{cases} \tag{1}$$

where P is the probability of cluster head selection, r is the round value, and G is the current round of nodes which has not become a cluster head in the $1/p$ round.

Although LEACH conserves the energy of sensor nodes, it still exhibits a few drawbacks such as the following:

(i) Expansion of a network may lead to an energy-distance trade-off between a cluster head and the base station

(ii) Unequal distribution nodes among different clusters lead to a faster energy drain particularly where there are lesser nodes per cluster

(iii) TDMA technique incorporates restrictions on time slot per frame

(iv) Due to a random number concept, there are no reservations on nodes to become a CH, which further affect their energy efficiency

(v) Lesser security of data transmission

(vi) Heterogeneity among nodes in terms of energy, computational capability, and link reliability is not considered

(vii) Other than energy parameters, no other QoS parameters like delay, packet delivery ratio, and throughput are considered

The fitness function includes node distance from a base station (BS) while selecting a CH, number of nodes per cluster, number of neighboring nodes, number of times a node remains a cluster head, and residual and average energy of the node. The main contribution of this work is summarized as follows:

(i) Node distribution and cluster head selection based on fitness function enhances the energy efficiency of a wireless sensor network

(ii) A redesigned TDMA schedule guarantees the same energy dissipation in each node despite the variable number of nodes in different clusters. Hence, it enhances network lifetime

(iii) A new hybrid clustered algorithm is proposed for heterogeneous as well as homogenous networks. It improves the quality of the service (QoS) parameters of WSNs

The remainder of the paper is organized as follows: Section 2 explores the related research to our proposed work. Section 3 demonstrates the network model, the radio energy consumption model, and the optimum number of cluster head calculation. Section 4 describes the proposed protocol architecture, redesigned CH selection criteria, homogenous threshold function, heterogonous threshold function, and redesigned TDMA schedule. Section 5 discusses the experimental results of the proposed approach. Lastly, Section 6 concludes the proposed work.

2. Related Work

Still, energy efficiency is the primary goal of routing protocols and topology control protocols in WSN. Due to the composite real environment, an energy-efficient clustering algorithm is more challenging to depict in a heterogeneous WSN than in a homogenous WSN. In a heterogeneous environment, the network dispenses with dissimilar sensors, turbulent links, and nearby interference. Luckily, there has been extensive work proposed in the last decade on energy-aware HWSN.

Kumar et al. [20] consider the benefit of node energy heterogeneity in WSN through the design of an EEHC (Energy-Efficient Heterogonous Clustered) protocol for a trilevel network. It elects a cluster head based on sensor node residual energy through a probability threshold function. As a heterogeneous technique, EEHC is more successful than LEACH in terms of network lifetime improvement. Similarly, Sharma et al. [21] developed an energy paradigm and proposed a traffic and energy-aware routing (TEAR) to refine the stability interval, while assuming sensor nodes with arbitrary initial energies and discrepancies in traffic origination rate beneficial to prevail over the limitation of system complexity.

In addition, Dutt et al. [22], Tanwar et al. [23], and Hong et al. [24] developed CREEP (cluster-head restricted energy-

efficient protocol), LA-MHR (automata-based multilevel heterogeneous routing), and EDCS (efficient and dynamic clustering scheme) protocols, respectively, for heterogeneous clustering networks. CREEP focuses on reducing the number of cluster heads per round to improve network lifetime through two-level heterogeneity. The comparison results ameliorate network lifespan as compared to mobile and stationary HWSN scenarios. LA-MHR introduces a multilevel heterogeneous node concept based upon automatic learning. During the operation of LA-MHR, an S-model dependent learning algorithm is employed for cluster head election and the cognitive radio spectrum is assigned to elect CHs by the base station. They eventually assessed network lifetime and its firmness, while taking into consideration the energy hole issue.

On the other hand, EDCS proposes an energy forecasting scheme to conserve node energy and improve network lifetime. However, real network conditions are dynamic and complex, so, it is not easy to accurately assess network lifespan.

Hong et al. [25] developed a clustering-tree topology control based on the energy forecast (CTEF) for network load balance and saving energy while considering multiple factors (e.g., PLR and link reliability) into consideration. In addition to a conventional CH selection mechanism and cluster formation, both central theorem and log normal distribution procedures are applied for accurately forecasting the mean energy of the network in respect of the differentiation between the actual and ideal average residual energy.

Moussaoui and Boukeream [26], Yang et al. [27], and Wang et al. [28] critically analyzed the characteristics of QoS-based routing protocols for WSNs. He et al. [29] presents a geographic location-based QoS protocol called SPEED. In this protocol, a neighbor table concept has been introduced. The neighbor tables reserve the neighbor location and delay of single-hop neighbors for every node. The trade-off between optimal delay delivery and load balancing is also considered.

Kavi et al. [30] propose a multiobjective and multiconstraint optimization routing technique. The traffic load, link quality, and residual energy parameters are considered as the performance parameters to estimate routing protocol quality. It guaranties fast packet delivery and link reliability.

Chen [31] presents a hard real-time protocol called SHE (Self-stabilizing Hop-constrained Energy efficient). In this technique, after a cluster-formation phase, the traffic packets from CHs to the base station are routed through different paths. AT (Aging Tag) is specified and used to acquire QoS need.

Faheem and Gungor [32] put forward an energy-aware QoS routing protocol (EQRP) clustering technique. This protocol is influenced by actual bird mating optimization (BMO) and depends on extremely reliable infrastructure. The presented routing protocol can enhance throughput and network reliability, reduce excessive packet retransmissions, improve packet delivery ratio, and reduce end-to-end delay for WSNs.

Li et al. [33] developed a bi-hop neighborhood information-dependent routing protocol. Energy balancing and a two-hop velocity concept are integrated into one paradigm. Finally, its suitability is proven through QoS parameters in a real time scenario.

Linping et al. [34] present a multihop chain-based protocol called PEGASIS, which is represented as a LEACH extension. The idea is to improve network lifetime by reducing transmission distance between sensor nodes. Chain leaders are randomly chosen during the aggregation and transmission processes. However, chain-based protocols are subjected to longer delay and high overhead.

Mishra et al. [35] proposed an intelligent modified chain technique. The idea is to enhance network lifetime more than that achieved by PEGASIS by electing a cluster leader near the base station. In addition, information for BS is transmitted through members of the overlying chain technology.

Qing et al. [36] and Javaid et al. [37] developed the DEEC (Developed Distributive Energy-Efficient Clustering) and EDDEEC (Enhanced Developed Distributive Energy-Efficient Clustering) protocols, respectively. In DEEC, the average network energy and node initial energy-based probability function is formulated. The nodes having a high energy ratio are designated as cluster heads. However, DEEC does not consider the network energy in each round. EDDEEC expanded further the threshold function based upon a super node, an advanced node, and a normal node. A new threshold function is presented for each of the three categories of nodes.

Singh and Verma [38] designed an average threshold energy-efficient routing technique called ATEER. In this work, the authors compared the results with previous heterogeneous methods and described the suitability of this protocol for proactive- and reactive-based networks.

Although the ATEER protocol outperforms the DEEC and EDDEEC protocols in preserving energy in a heterogeneous environment and improving network lifespan, it still has the following drawbacks:

(i) It does not consider the distance between the cluster head and base station. The cluster heads that are far away from the base station consume more energy

(ii) Unequal sensor distribution among clusters may result in a smaller cluster drain energy at a faster rate than a bigger cluster

(iii) There are no restrictions on the number of times a node can become a cluster head

(iv) The TDMA schedule of data transmission is neither considered nor modified. This factor can play an important role in achieving energy efficiency

(v) The Effect of channel parameters like noise, link quality, and interference are ignored during data transmission

(vi) Except for energy efficiency, no other QoS parameter is considered

3. Network Model and Assumptions

The proposed work scenario consists of two models, the network model and the energy dissipation model. The network model accounted for microsensor deployment, election

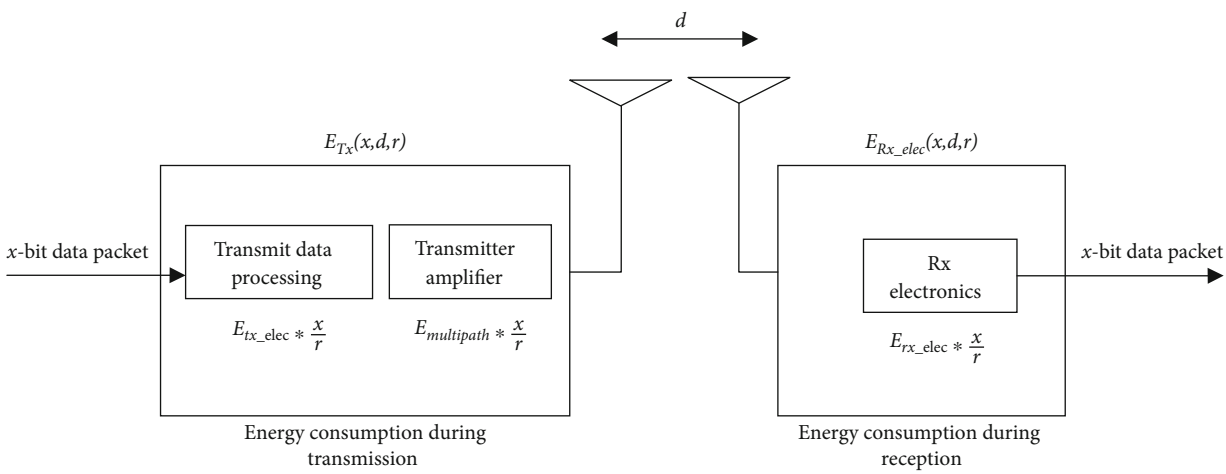

Figure 1: Proposed radio energy consumption model.

of cluster head, data aggregation, and data dissemination to BS, whereas an energy model accounts for energy dissipation due to transmission, reception, and aggregation of sensed data from member nodes to CH nodes.

The following assumptions are considered while implementing the proposed network model:

(i) All nodes including BS are nonmobile after deployment, and each node is recognized by a unique ID

(ii) The processing and communication capabilities of nodes are similar but are heterogeneous in terms of battery energy

(iii) Each node is capable of compressing multiple data units in one packet, normally called the data aggregation property

(iv) Nodes are operated in power control mode depending upon the receiving node distance

(v) Nodes in the network are nonchargeable and are heterogeneous in terms of initial energy

(vi) The physical link of communication among nodes is symmetric so that data rate and energy consumption of packet transmission from node X to Y is same as Y to X

(vii) The base station (BS) is positioned at a centralized location and free from memory, energy, and computational capability constraints

(viii) Nodes are deployed on an elliptical Gaussian distribution model throughout the network area

The node positioning in SNs is contemplated as a serious issue due to its effect on energy, security, and routing. Network lifespan depends heavily on the deployment method. The nodes nearer to BS normally drain their battery at a faster pace than nodes away from it. To overcome this issue, a 2D Gaussian distribution function is considered in our model to overcome the energy hole problem in wireless sensor networks. The standard deviation parameter of this function plays an important role in energy balancing and network lifespan.

The N nodes are distributed in $\mathrm{M} \times \mathrm{Mm}^2$ area. The Gaussian function of this distribution is derived as follows:

$$F(u,v) = \frac{1}{2\pi\sigma_u\sigma_v} \exp - \left(\frac{(u-u_o)^2}{2\sigma_u^2} + \frac{(v-v_o)^2}{2\sigma_v^2} \right), \quad (2)$$

where $(u_o v_o)$ denotes the positional coordinates of every node and σ_u and σ_v denote the standard deviation for u and v proportion, respectively.

3.1. Radio Energy Model. The radio energy model is shown in Figure 1. This model incorporates both the free space and multipath fading models [13] depending upon the distance between the transmitter and the receiver. To transmit x (bit) bit data packet to distance d at data rate r (bit/s), the radio energy uses can be calculated as follows:

$$\begin{aligned} E_{Tx}(x,d,r) &= E_{Tx\_\mathrm{elec}}(x,r) + E_{Tx\_\mathrm{amp}}(x,d,r) \\ &= \begin{cases} E_{tx\_\mathrm{elec}} * \dfrac{x}{r} + \varepsilon_{fs} * \dfrac{x}{r} * d^2 \text{ for } d < d_o, \\ E_{tx\_\mathrm{elec}} * \dfrac{x}{r} + \varepsilon_{mp} * \dfrac{x}{r} * d^4 \text{ for } d > d_o, \end{cases} \\ E_{Rx\_\mathrm{elec}}(x,d,r) &= E_{rx\_\mathrm{elec}} * \frac{x}{r}, \end{aligned} \quad (3)$$

where $E_{Tx}(x,d,r)$ is the total dissipated energy for a single transmission of a packet (impact of packet retransmission is considered as a future work), $E_{Tx\_\mathrm{elec}}(x,r)$ is the electronic energy account for digital source coding and channel coding, $E_{Tx\_\mathrm{amp}}(x,d,r)$ is the power amplifier energy consumption at distance d, ε_{fs} is the energy per bit dissipation in a transmitter power amplifier for a free space model, ε_{mp} is the energy per bit dissipation in a transmitter amplifier for a multipath model, $E_{Rx\_\mathrm{elec}}(x,d,r)$ is the total dissipated

energy for a single packet reception, and E_{rx_elec} is the energy dissipated per bit to run the receiver circuit.

3.2. Expression for Optimum Number of Cluster Heads. Suppose N nodes are distributed in a sensing area and are divided into N_c clusters, there are N/N_c average nodes per cluster. Energy dissipation in a CH node in one frame is given by

$$E_{\text{CH}} = \frac{x}{r} E_{rx\_\text{elec}} \frac{N}{N_c} + \frac{x}{r} E_A \frac{N}{N_c} + \frac{x}{r} \varepsilon_{mp} d_{\text{BS}}^4, \tag{4}$$

where E_A is the energy consumed during data aggregation and d_{BS}^4 is the CH node to BS average distance.

However, energy dissipation in member nodes for packet transmission is given by

$$E_{\text{non\_CH}} = E_{tx\_\text{elec}} * \frac{x}{r} + \varepsilon_{fs} * \frac{x}{r} * d_{\text{CH}}^2, \tag{5}$$

where

$$d_{\text{CH}}^2 = \frac{M^2}{2\pi N_c}, \tag{6}$$

which is the distance of member nodes to their CHs. The radius of the network is R and the cluster area is M^2/N_c, whereas, $\text{M}/\sqrt{N_c}$ is the cluster radius.

Therefore, overall energy dissipated in a cluster during single-frame transmission is represented as follows:

$$E_{\text{CLUSTER}} = E_{\text{CH}} + \frac{N}{N_c} E_{\text{non\_CH}}. \tag{7}$$

Total dissipated energy in the network in one round is given by

$$E_{\text{Tot}} = N_c E_{\text{CLUSTER}}. \tag{8}$$

After differentiating E_{Tot} w.r.t to N_c and equating to zero, the optimal cluster head value will be calculated as follows:

$$N_{c\_\text{optimal}} = \frac{\sqrt{N * \varepsilon_{fs}}}{\sqrt{2\pi}} \frac{1}{\varepsilon_{mp}} \frac{M}{d_{\text{BS}}^2}. \tag{9}$$

4. Proposed Protocol Architecture

Although the ATEER protocol outperforms the DEEC and EDDEEC protocols in terms of network lifetime and energy efficiency under a heterogeneous environment, it still exhibits certain drawbacks which could be rectified. The first drawback deals with ignorance of the effect of distance factor on threshold function. It is not recommended to select CH if it is far away from BS. The greater the distance between a cluster head and BS increases energy cost. Secondly, it does not consider the number of times a node becomes a cluster head. Thirdly, data redundancy is not considered, which results in continuous sensed-data transmission within the cluster during a steady state phase. Ignorance of these factors causes depletion of network lifespan.

The proposed method focuses altering the cluster head selection criteria by amending threshold function $T(n)$ and selecting a genuine cluster head node. Moreover, only updated sensed information is allowed to be sent, because it is impractical to transfer information without being updated. In addition to these, a variation of the sensor nodes among clusters that causes energy unbalance is solved via a redesigned TDMA schedule.

4.1. Redesigned CH Selection Criteria. The CH selection criteria play an important role in WSN performance. The first round is started with the election of a cluster head after the deployment of nodes in the sensing area. Our proposed method considers important factors which were not mentioned by the ATEER, DEEC, and EDDEEC protocols. These factors include network node average energy, separation between base station and CH nodes, neighbor node quantity, and number of sending nodes per cluster.

As reported in [39], nodes are observed as neighbors of other nodes only if they fall in the neighborhood radius. The node having a higher number of neighboring nodes has a high probability of becoming a cluster head. The neighborhood can be stated as follows:

$$R_{\text{Neighbour}} = \frac{M}{\sqrt{\pi * N_c}}. \tag{10}$$

The average distance between CH nodes to their member nodes and the average distance between CHs to the base station is given by equations (11) and (12), respectively:

$$d_{\text{CH}} = \frac{M}{\sqrt{2 * \pi * N_c}}, \tag{11}$$

$$d_{\text{BS}} = 0.377\,\text{M}. \tag{12}$$

The proposed fitness functions in equation (13) include various critical parameters and are merged into the threshold function as per their trade-off values. There is a trade-off between nodal residual energy and cluster head distance to BS in every round. In addition to this, cluster head threshold value can be further expanded by considering the number of times a node remains cluster head and number of neighboring nodes.

$$\begin{aligned}\text{Fitness function} = E_{\text{res}} &+ \left(1 - \frac{1}{E_{\text{avg}}}\right) + \frac{1}{d_{\text{BS}}} \\ &+ \left(\frac{Ng_n}{\text{CH}_t} \times (1 - \log_{10} d_{\text{sr}})\right).\end{aligned} \tag{13}$$

E_{res} is the newly elected cluster head residual energy, E_{avg} represents the average energy of sensor nodes, d_{BS} represents cluster head to base station distance, Ng_n represents the number of neighboring nodes of n nodes, CH_t is the often times a node remains a cluster head, and d_{sr} is the distance among the sending and receiving nodes.

The fitness function maintains the priority between node residual energy, communication distance between cluster

head and base station, number of neighboring nodes, and node repetition as a cluster head.

4.2. Threshold Function for Homogenous Scenario. In homogenous environment, every node possesses same initial energy. So, the probability p in equation (1) considered as reference value. The resulting threshold function for homogenous network can be expanded by equation (14).

$$T(n)_{\text{Homo}} = \begin{cases} T(n) \times \text{fitness function}, & \text{if } n \in G, \\ 0, & \text{elsewhere}. \end{cases} \tag{14}$$

By putting the value of fitness function from equation (13), equation (14) can be rewritten as follows:

$$T(n)_{\text{Homo}} = \begin{cases} T(n) \times \left[E_{\text{res}} + \left(1 - \frac{1}{E_{\text{avg}}}\right) + \frac{1}{d_{\text{BS}}} + \left(\frac{Ng_n}{\text{CH}_t} \times (1 - \log_{10} d_{\text{sr}})\right) \right], & \text{if } n \in G, \\ 0, & \text{elsewhere}. \end{cases} \tag{15}$$

where each sensor node assumes a random number (R_{random}) having a value between 0 and 1. The threshold cost acquired from the formula is compared with a random number value. If the random number value is less than the threshold value, that node becomes a cluster head in the current round.

4.3. Threshold Function for Heterogeneous Scenario. In a practical real-world scenario, the WSN network is heterogeneous. In a heterogeneous environment, different nodes possess different initial energies. So, according to [20], probability p can be replaced by p_i for three types of nodes, namely, the advanced node, the super node, and the normal node. Since p_i is only considered node initial energy and network average energy, therefore, it is obvious to replicate p_i by $p_{i\text{-}hetro}$ after considering the fitness function given by equation (13). $p_{i\text{-}hetro}$ is given in

$$p_{i\text{-}hetro} = \begin{cases} \frac{p}{1 + m_a \bullet (a + m_s \bullet s)} \times \text{fitness function} \in \text{for } n \text{ normal}, \\ \frac{p\,(1 + a)}{1 + m_a \bullet (a + m_s \bullet s)} \times \text{fitness function} \in \text{for } n \text{ advanced}, \\ \frac{p\,(1 + s)}{1 + m_a \bullet (a + m_s \bullet s)} \times \text{fitness function} \in \text{for } n \text{ super}. \end{cases} \tag{16}$$

The new CH selection threshold for every sensor node can be obtained by putting the value of $p_{i\text{-}hetro}$ from Equation (16) into Equation (1) and written as follows:

$$T(n)_{hetro} = \begin{cases} \frac{p_{i-hetro}}{1 - p_{i-hetro} \times [\text{rmod}(1/p_{i-hetro})]}, & \text{if } n \in G, \\ 0, & \text{elsewhere}. \end{cases} \tag{17}$$

This new formula guarantees that the node having a higher remaining energy has a higher probability to become a cluster head. Furthermore, with an increase in the distance between sensor node and cluster head, the probability of the cluster head selection in the current round decreased.

4.4. Redesigned TDMA Schedule. The proposed algorithm can conquer the drawback of both heterogeneous as well as homogenous protocols by decreasing the energy gap among nodes within a cluster. Heterogeneous and homogenous techniques differ in the setup phase but follow the same data transmission techniques in the steady state phase. Therefore, the TDMA access method as mentioned in the homogenous LEACH protocol was also accepted by heterogeneous protocols. So, after cluster head election, every cluster head publicized itself as a CH node. Depending upon the received signal strength, each node responds to the request to unite with that CH. So, after the setup period, every CH perceives the number of member nodes joined to it. Literally, the number of sensor nodes is different in each cluster. In the setup phase, each member node sends its data in the time slot assigned to it. After a certain period, the network again enters a new round with a setup and steady state phase. The clusters having a minimum number of nodes exhausted their energy more expeditiously than the clusters having a higher number of nodes.

To overcome this drawback, a newly redesigned TDMA scheme is recommended. The flow diagram of the proposed method is shown in Figure 2.

Step 1. Every cluster head enumerates its sensor nodes and broadcasts the number of nodes to every other CH in the network. In the end, every cluster head perceives the largest cluster head capacity.

Step 2. In the steady state phase, the implemented TDMA schedule duration is the same as the capacity of the biggest cluster.

Step 3. Every cluster node has its turn to transmit its data in the allocated slot as per the redesigned TDMA frame. Therefore, all the nodes send a similar amount of information in the allocated slot and consume the same amount of energy. However, smaller cluster nodes after finishing their turn in their round move into the sleeping mode in the remaining

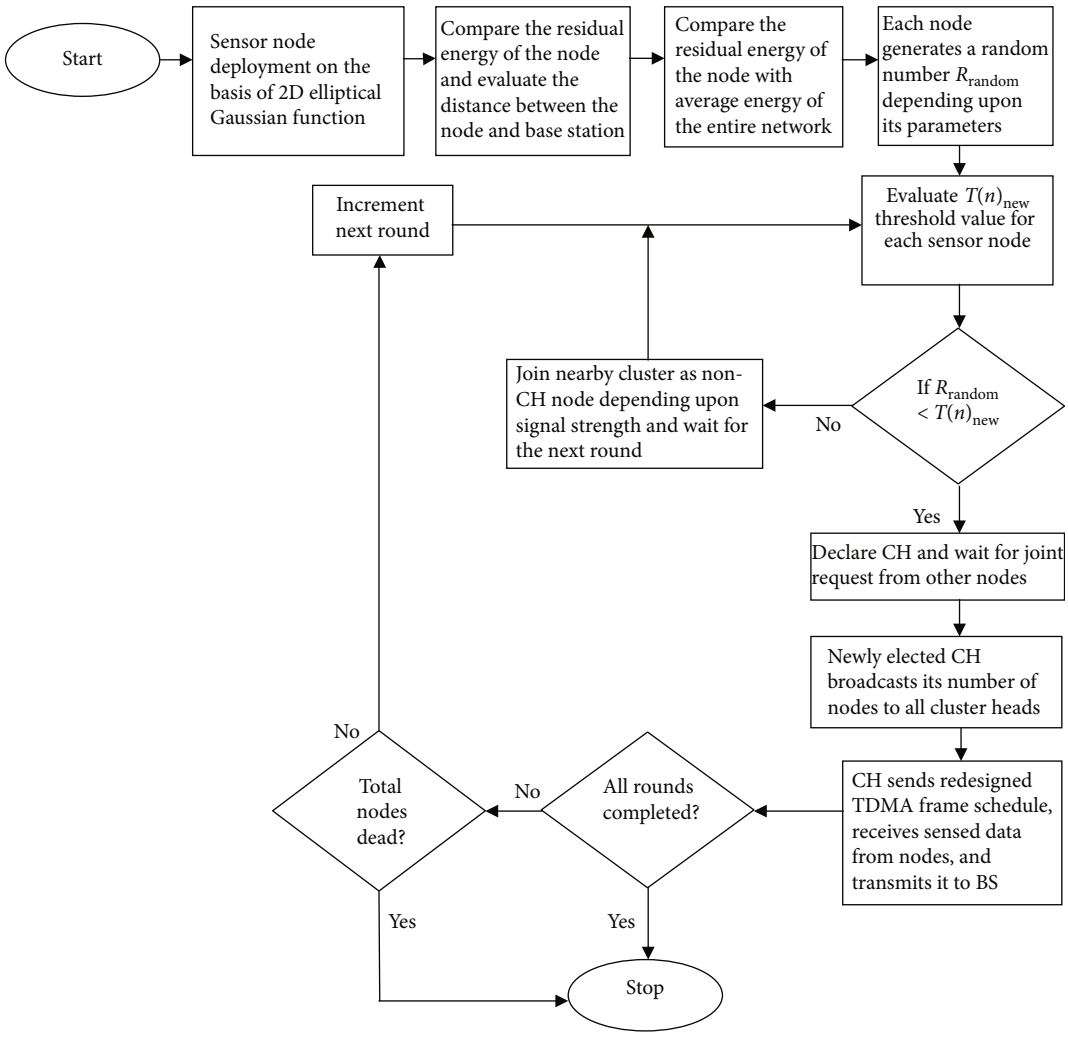

Figure 2: Process of protocol implementation.

W	5	7	2	13	12	6	8	10	Largest cluster
X	1	3	11	14	In sleep mode				
Y	4	2	9	In sleep mode					
Z	18	20	In sleep mode						Smallest cluster

Figure 3: Redesigned TDMA frame format of the proposed protocol.

W	5	7	2	13	12	6	8	10	Largest cluster
X	1	3	11	14	1	3	11	14	
Y	4	2	9	4	2	9	4	2	
Z	18	20	18	20	18	20	18	20	Smallest cluster

Figure 4: TDMA frame format of the LEACH protocol.

period of the steady state phase. The redesigned TDMA frame is shown in Figure 3.

The homogenous LEACH can be compared to the proposed approach in the subsequent example. The LEACH TDMA scheme considers 25 nodes from 4 clusters during a single round. Every sensor node is recognized by ID 1 to 25. The LEACH TDMA schedule is shown in Figure 4. In cluster W, the first slot is allocated to node 5 and goes up to

Table 1: Simulation parameters.

Parameters	Value
E_{tx_elec}	50 nJ/bit
E_{Rx_elec}	20 nJ/bit
ε_{mp}	0.0014 pJ/bit/m^4
ε_{fs}	10 pJ/bit/m^2
E_A	5 nJ/bit/message
Data packet size	3000 bits
Number of nodes	100
Number of rounds	8000
Initial node energy	4 J
d_o	85.5 m
Control packet size	200 bits
E_{Tx_amp}	0.0013 pJ/bit/m^4

node 10 to transmit its data. Each node sends only once per frame. However, clusters X, Y, and Z contain only 4, 3, and 2 nodes, respectively; they transmit more data than cluster W in the same phase. So, energy consumption is not uniform among every cluster.

In contrast to this, in the proposed method, the cluster head transmits a redesigned schedule to their member nodes. Every node is aware about its time slot and sends information to its cluster head. Moreover, the sensor nodes are aware when to switch off their energy to accept the sleep mode. As displayed in Figure 3, in cluster W, node 5 transmits the same data one time per frame and in cluster Z, node 18 also sends the data one time only. None of the nodes send data higher than another node in the network. Hence, this approach saves node energy due to inefficient dissipation.

5. Simulation Results and Discussions

The WSN considered in our results consists of 100 nodes deployed through Gaussian distribution with a square area of $100 \times 100\,\mathrm{m}^2$. Simulations are performed in MATLAB software. The performance metric such as optimum quantity of CHs in different rounds, fraction of alive nodes, network lifetime, delay, throughput, average energy consumption for each node, and percentage of dead nodes are analyzed through multiple time simulations.

The proposed mechanism is simulated through various network domains. Various simulation parameters are shown in Table 1. Since the proposed technique is hybrid in nature, it consists of both homogenous and heterogeneous nodes. Thus, the proposed clustering routing techniques have been compared with previous homogenous LEACH protocols and heterogeneous DEEC, EDDEEC, and ATEER protocols.

5.1. Optimum Number of Cluster Heads. The number of cluster heads per round always impacts energy consumption. A higher CH value results in a high consumption of energy because more data aggregation processes will be carried out by these nodes. However, lesser cluster head nodes result in longer data delay since it supposes that every node has information to send towards BS. So, cluster head nodes should be optimal and require stability in its number during each consecutive round for better energy efficiency.

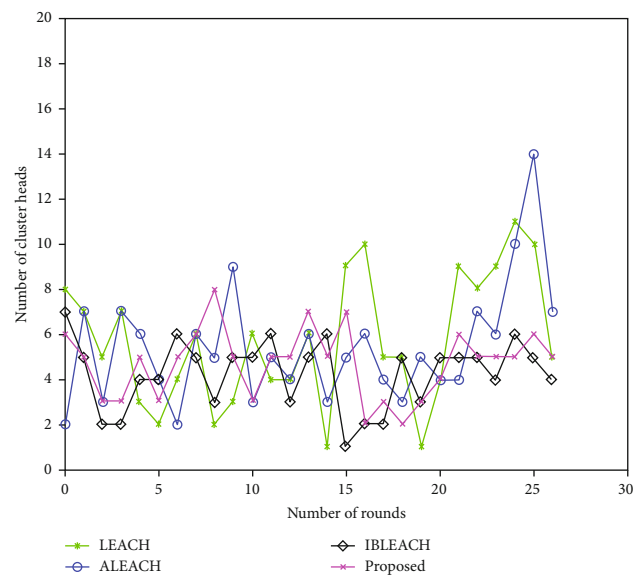

Figure 5: Cluster head number variation versus rounds.

Table 2: CH count for different communication rounds.

Protocol	Rounds		
	Round 6	Round 13	Round 27
ALEACH	4	4	7
IBLEACH	4	3	4
Proposed	3	5	5
LEACH	2	4	5

Figure 5 shows the cluster head number in every round compared to ALEACH, IBLEACH, and LEACH protocols. The result shows that the optimal cluster head number is around 5. This stability is due to a redesigned CH selection method. Table 2 demonstrates the comparative analysis between different protocols in different rounds.

5.2. Load Balancing and Network Lifetime. Every node participates in sending its perceived information to BS in each round, which results in energy dissipation. Therefore, the performance of the wireless sensor network degrades with each successive round. A time will come when the first node dies and it measures in terms of the number of rounds. Network lifetime is the time elapsed between FND and LND. Figure 6 shows the WSN lifetime performance in terms of the number of dead nodes. The network lifetime of DEEC, EDDEEC, proposed, and ATEEER protocols are 2899, 5899, 7921, and 7123 rounds, respectively. This improvement is due to the implementation of a redesigned CH threshold function and a redesigned TDMA schedule during the steady state phase.

5.3. Number of Alive Nodes. Figure 7 shows the remaining alive nodes in WSN after every round for various protocols. The nodes which have enough energy to participate in a data

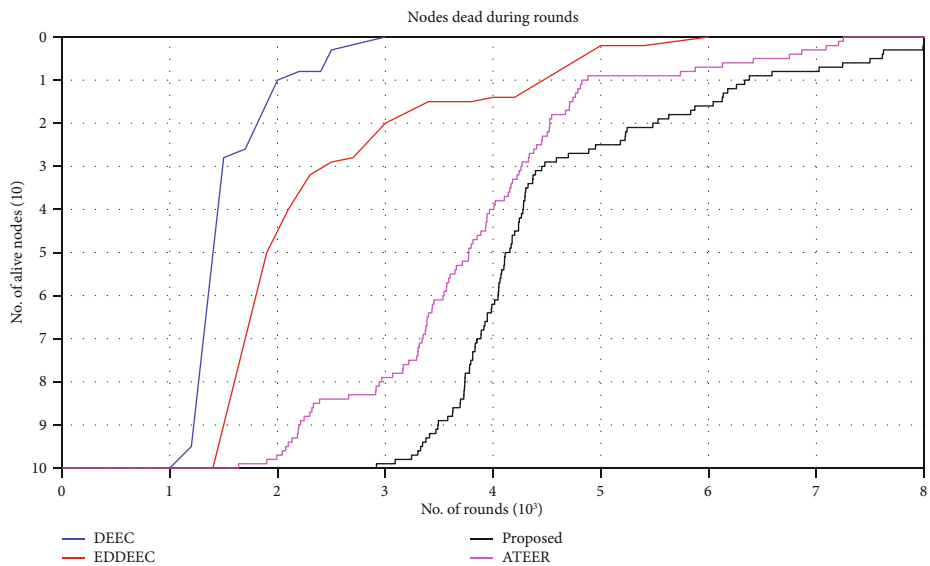

Figure 6: Network lifetime in terms of dead nodes.

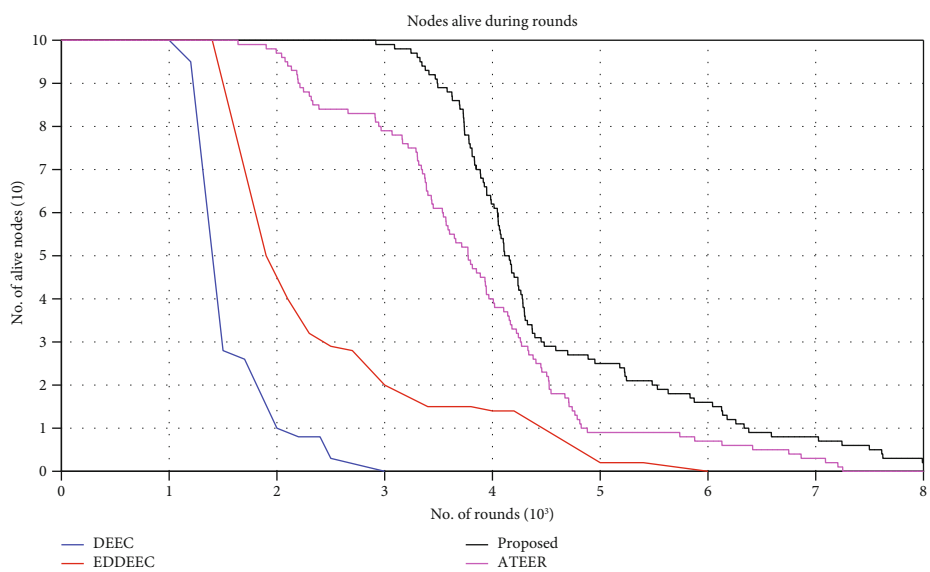

Figure 7: Network performance in terms of alive nodes.

transmission process are called alive nodes. It clearly demonstrates that the proposed protocol is superior in terms of the first node dead. Therefore, the proposed technique provides better network stability for a longer duration.

5.4. Network Throughput and Delay. The throughput can be considered as the total number of packets successfully received at the base station at some specific time. Based on the extension in the network lifetime due to the redesigned threshold, the throughput is enhanced. The enhanced number of packets received at the BS is evident in Figure 8. The network delay may be interpreted as the lapse period between the first data unit generated by a sensor node to the last data unit received by the BS in a given communication round.

Figure 9 shows the delay variation with respect to the number of communication rounds. The proposed technique delay is lesser than ATEER since the cluster head selection threshold include the distance between CH and BS. The node having lesser distance from BS is elected as CH.

5.5. Average Network Energy Cost. The network energy consumption can be defined as the total energy cost of the network for transmission, reception, and information aggregation. As evident in Figure 10, the proposed approach consumes minimum energy as compared to the ATEER protocol. The enhancement is achieved due to the sleep mode operation of nodes in the steady state phase. Ultimately, the sleep mode safeguards the member nodes from multiple transmissions in one frame and CH from shallow listening.

6. Conclusion and Future Work

This paper presents an energy-efficient and QoS framework for heterogeneous as well as homogenous wireless sensor

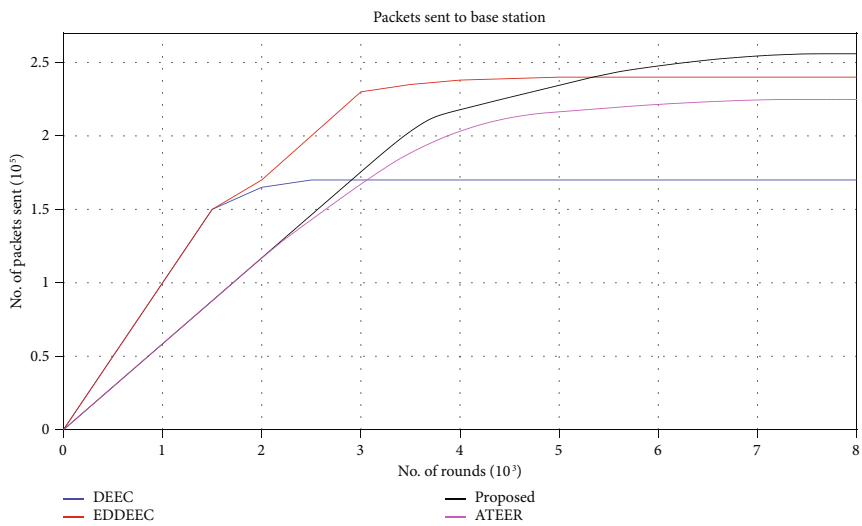

Figure 8: Comparison of network throughput.

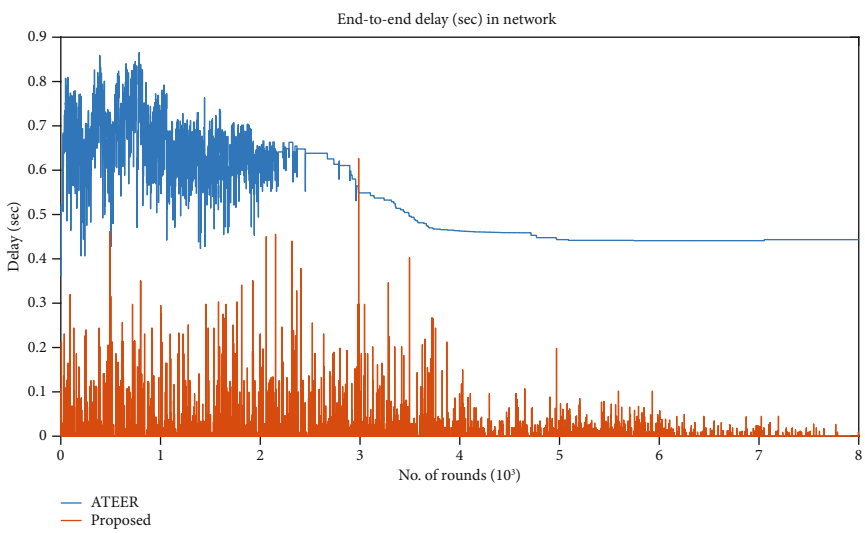

Figure 9: End-to-end network delay.

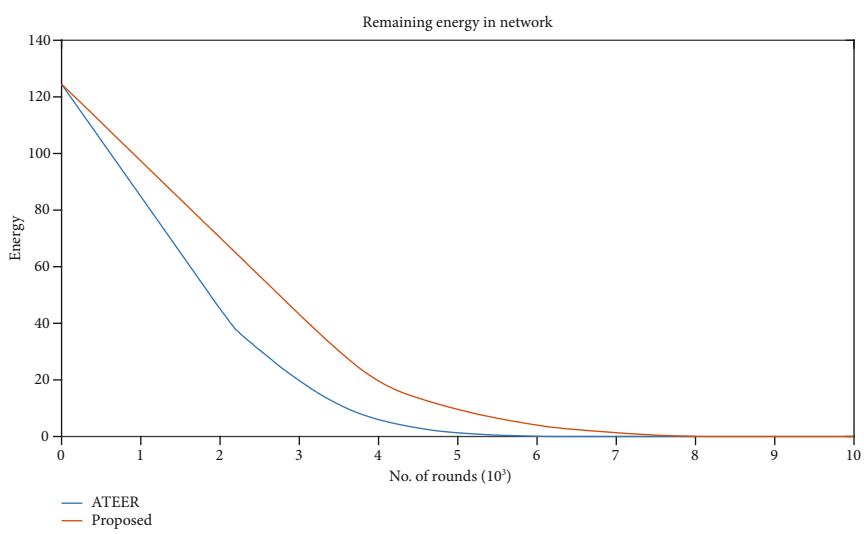

Figure 10: Average energy consumption.

networks. The proposed hybrid technique improves energy efficiency and network lifetime in addition to maintaining the quality of service integrity. A fitness function is designed which includes the number of nodes per cluster, the number of times a node remains the cluster head, a count of the neighboring nodes, the residual node energy, the average network energy, and the distance of the cluster head nodes to the base station. This fitness function influences the cluster head selection procedure after integrating it with the probability threshold function. The redesigned TDMA ensures the same number of packet traversal by nodes in each round in different clusters. The mathematical radio energy model is aimed at justifying transmission and reception energy consumption for a fixed packet size x (bits) at transmission rate r (bits/s).

The proposed method maintains stability in choosing the optimal value of the cluster head for a given round in comparison to LEACH and other previous homogenous protocols. After comparing it with previous heterogeneous protocols like DEEC, EDDEEC, and ATEER protocols, the proposed protocol shows superiority in terms of network lifetime, energy efficiency, and delay and network throughput. The experimental results conclude that the presented scheme exceeds EDDEEC, DEEC, and ATEER by 63%, 26%, and 10%, respectively, in terms of network lifetime and throughput.

So, we can say that the presented work is suitable for designing a wireless sensor network in a real-time scenario. In the future, we will attempt to extend this work in terms of security and privacy concepts. We will also try to implement this paradigm to a real-world environment.

Data Availability

There are no data available for this paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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