Energy efficient routing protocol for enhancing the network lifetime in wireless sensor network

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ABSTRACT

Wireless sensor networks (WSNs) confront significant challenges related to battery capacity, as sensor nodes operate on limited energy resources. To address this issue, low energy adaptive clustering hierarchy (LEACH) protocol is commonly employed for power management in WSNs. LEACH is commonly used for power management. Here, sensing region is divided into clusters and sectors, placing a gateway node at the center to minimize energy consumption during data transmission. It employs one-hop, two-hop, or three-hop pathways based on node proximity to the base station (BS) to optimize energy usage. Network performance is assessed using rounds, throughput, and energy usage. MATLAB simulations compare the proposed approach with dual layer LEACH (DL-LEACH) and LEACH, showing significant improvements in network lifetime. The proposed scheme outperforms LEACH by 515% and 347% for 20% and 50% node depletion, respectively. Compared to DL-LEACH, it extends network lifetime by 27% and 59% under similar scenarios. Sectoring, clustering, and multi-hop communication reduce energy consumption, enhancing network lifetime and addressing WSN challenges effectively.

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1. INTRODUCTION

The wireless sensor network (WSN) is a network of inexpensive, tiny, battery-powered sensor nodes that can collect, analyses, send, and receive data and are dispersed over an area. between the base station (BS) and the sensor nodes. In or outside of the sensing field, the BS is possible. The deployed sensor nodes may be put to a variety of uses, such as thermal, biomedical, agricultural, security surveillance, and health monitoring. The key traits of a successful WSN are lower energy consumption, higher throughput, longer network lifetime, and cost efficiency [1]. WSN are composed of several sensor nodes that can gather, receive, and transfer data from far locations and convey the gathered information to sink node. Since few nodes are placed at incredibly remote locations and the sensor nodes battery life is constrained, batteries can't be changed or recharged. The sensor node may relay the detected data straight to the BS in a single hop. However, a sensor nodes and a BS's radio communication distance determines how much energy is expended while transmitting the data. Extensive study has been done in order to develop algorithms that can lower power usage. One of these is clustering. Clustering is used to split the sensing region into several groups. The cluster head (CH) receives data from sensors and transfers it to the BS.

LEACH is one of the hierarchical routing protocols. The network region is split into a number of little clusters using this protocol, and the leader of each cluster is chosen from among the nodes inside it. CHs gather data from all sensor nodes in the cluster and transmit it to the BS. CHs consume more energy than other nodes, hastening battery drain. To achieve a constant battery usage pattern, CHs' roles are rotated. Every node transforms into a CH for at least one round [2].

LEACH runs for a number of rounds. The selected CH delivers the advertisement message to adjacent nodes during the cluster creation phase. In response, the node that is interested joins the cluster. The nodes transmit data to the CH during the data transmission phase in the designated time division multiple access (TDMA) slot [3]. Following LEACH, a plethora of hierarchical-based routing protocol approaches were created. The main goal of all of these techniques is to extend the lifespan by carefully choosing the CH for the sensor network, segmenting the region into numerous sectors and clusters, choosing the right sector and cluster types, and their shapes and using data transfer with several hops.

Challenges faced in designing energy efficient routing protocol are, cluster leaders are chosen entirely based on likelihood, without considering the nodes' remaining energy, the separation between the BS and the node density [4]. The algorithms designed [5] are appropriate for only homogeneous networks and not appropriate for heterogenous networks. Game theory based dual CH mechanism [6] consumes more power because of lot of data redundancy present in the data packets. Genetic algorithms [7] used in finding the optimum path for data transmission increases the complexity and overhead of CH selection process. Distributed clustering method [8] generates isolated nodes and network performance gets affected because of the poor coordination between CHs and cluster members. The literature on energy-efficient routing protocols for WSNs encompasses various methodologies aimed at optimizing CH selection and data transmission [9]-[12]. These methodologies include approaches such as artificial bee colony optimization, genetic algorithms, game theory integration, and fuzzy logic-based algorithms. Each method addresses different aspects of energy consumption, CH selection criteria, and network optimization.

Some approaches focus on optimizing CH selection based on factors like residual energy, distance from BSs, and network topology [13]-[18]. Others propose distributed clustering methods with dynamic parameters and improved communication routing to enhance energy utilization and eliminate network hotspots [19]-[22]. Additionally, techniques such as encryption-based optimization and rechargeable battery utilization aim to reduce energy consumption during data transmission and extend network lifespan [23]-[25]. Some researchers contributed to load balancing and energy management [26], [27] in wireless sensor networks, thereby reducing energy consumption and enhancing network lifetime.

The scope for further research in networking encompasses addressing critical challenges such as packet loss, node failure, end-to-end delay, and energy optimization in heterogeneous networks. Packet loss affects the reliability of data transmission, while node failure disrupts network connectivity and functionality. End-to-end delay influences the responsiveness of applications and user experience. Moreover, optimizing energy usage in heterogeneous networks is essential for prolonging device battery life and enhancing network sustainability. This study investigates the effects of segmenting the sensing region into sectors and clusters on the network lifetime. One-hop, two-hops, and three-hops data communication are used for transmitting the data packets. While earlier studies have attempted to minimize energy consumption through various methods such as unequal clustering and dual CHs, they have not utilized multiple-hop data communication to reduce radio communication distance and, consequently, energy consumption.

Organization of the paper is as follows. Section 1 discusses the issues in energy consumption of sensor nodes and related work carried out by different researchers. In section 2 discusses the methods used to save energy, contributions of the paper, goals of the design and development, radio energy model, experimental setup and different categorization types. In section 3 discusses the simulation results obtained, discussion of the results and comparison with LEACH and DL-LEACH protocols. Section 4 presents the summary of the work carried out and directions for future research.

2. METHOD

The LEACH protocol, which divides the sensing region into numerous clusters, allows each cluster's nodes to connect with its CH, which then relays the information to the BS. Nodes in a cluster transfer data through the CH even though they are closer to the BS and have the ability to send it there directly. Consequently, the CH uses more energy. In the suggested solution, a gateway node that can gather data from other nodes and CHs is placed in the sensing region. In addition, it sends the data obtained to the BS. Sectors and clusters are used to segment the supplied sensing region. Sectors are made up of the nodes in the sensing area that are located relatively close to the BS or gateway node, whereas clusters are made up of the nodes in the remaining region of the sensing area. The nodes that communicate with BS via the gateway node and CH.

A gateway node is considered in the sensing region, which can receive data packets from sensor nodes and CHs, aggregate the data packet and forward to the BS. Gateway node is powered continuously and it does not have any energy limitation. As the effective radio communication distance for the data packet reduces because of gateway node, energy consumption is reduced thereby increasing the network lifetime.

The sensing area has nodes that are dispersed at random. It is assumed that the gateway node is inside the sensing region and the BS is outside. Based on their distance from the gateway node and BS, nodes in the proposed technique are divided into clusters and sectors. Sector 1 nodes are those closest to the BS, and sector 2 nodes are those closest to the gateway node. Clusters 1 and 2 are evenly split into the remaining space. CHs are chosen using the traditional LEACH process.

In the proposed algorithm, data transmission scheme is different in each of clusters and sectors. Sector 1 has a BS-to-node distance that is within the range of radio communication for the nodes. Hence, the nodes send the data packets straight in one hop to BS. Sector 2 nodes transmit the gateway node their data packets, which the gateway node then sends to the BS. Data must make two hops to get to the BS in this case. CHs receive data packets from nodes in clusters 1 and 2, and the gateway node then transmits the packets to the BS. Data must make three hops in this instance to reach BS.

Contributions of this paper are as follows:
- An energy efficient clustering and routing protocol is proposed by dividing the sensing area into multiple sectors and clusters.
- Sensor nodes are deployed randomly and data packets are transmitted form sensor nodes to BS using on hop, two hops and three hops depending on the distance from the BS.
- Radio energy model is used for the computation of energy parameters and Euclidian distance is used to calculate the distances among BS, sensor nodes, CH and gateway node.
- A novel algorithm is proposed to minimize the energy consumption in data transmission.
- A comparative analysis of performance parameters of the proposed method with those of LEACH and DL-LEACH protocols prove that the proposed scheme is better that LEACH and DL-LEACH.

Goals of the design and development are:
- To propose a new way of dividing the sensing area into clusters and sectors based on the distance from the BS.
- To reduce the energy consumption in data transmission by implementing one hop, two hops and three hops communication.
- To compare the throughput and energy consumption of different types of categorizations.
- To compare the performance of proposed scheme with LEACH and DL-LEACH protocol.

2.1. Radio energy model

Data transmission and reception energy consumption is computed using the radio energy model. Figure 1 shows the radio energy model used to compute the amount of energy spent in transmitting and receiving a data packet. A constant called d_0 is used as the threshold distance in the model. The free space model is used to determine the energy consumption if there is less than d_0 between the transmitter and the receiver. However, the multipath attenuation model is employed if the distance between the transmitter and the receiver is greater than or equal to d_0.

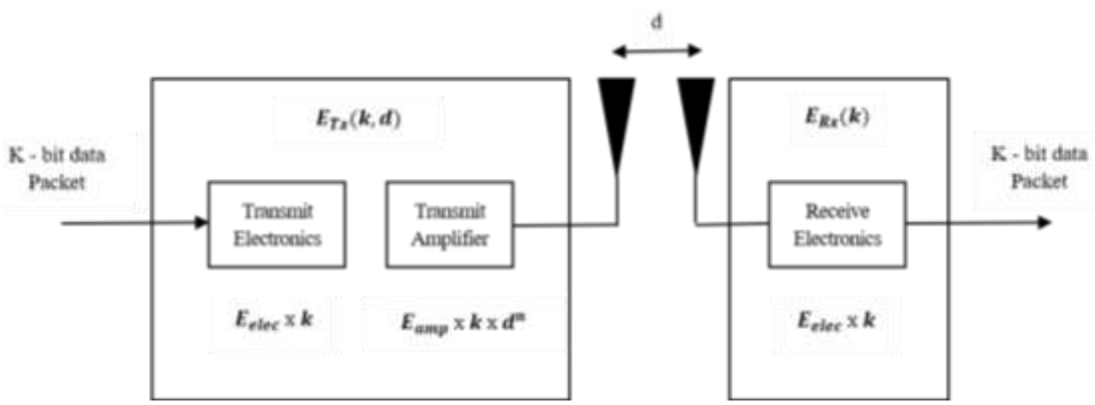

Figure 1. Radio energy model

The overall energy consumed $E\ (k, d)$ is obtained as (1).

$$E(k, d) = E_{elec}(k) + E_{amp}(k, d) \quad (1)$$

In (1) is used to calculate the overall energy spent by combining the amount of energy spent in transceiver circuit and amplifier circuit. 'k' is the message size and 'd' is the distance between transmitter and receiver. Where, $E_{elec}(k)$ is the energy consumed in transceiver circuit and is obtained as (2).

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

In (2) is used to compute the energy consumption in the transceiver circuit to send and receive a data packet of 'k' bits.

$E_{amp}(k, d)$ is the energy consumed by the amplifier circuit and is obtained as (3).

$$E_{amp}(k, d) = \begin{cases} k\mathcal{E}_{fs}d^2 & d < d_0 \\ k\mathcal{E}_{mp}d^4 & d \geq d_0 \end{cases} \quad (3)$$

In (3) is used to compute the amount of energy consumed in the amplifier circuit, where, $\mathcal{E}_{fs}$ is the energy consumed by the amplifier with free space model and $\mathcal{E}_{mp}$ is the energy consumed by the amplifier with multi-channel attenuation model.

Therefore, overall energy consumed can be written as (4).

$$E(k, d) = E_{elec}(k) + E_{amp}(k, d) = \begin{cases} kE_{elec} + k\mathcal{E}_{fs}d^2 & d < d_0 \\ kE_{elec} + k\mathcal{E}_{mp}d^4 & d \geq d_0 \end{cases} \quad (4)$$

In (4) computes the total amount of energy consumed for transmitting a 'k' bit message over the distance 'd'. By effectively utilizing the node energy, the suggested unique clustering, sectoring, and data transmission mechanism extends the network's lifespan. Figure 2 depicts the categorization of sectors and clusters inside the sensing area, and the data transmission paths in the proposed method along with those in the LEACH protocol.

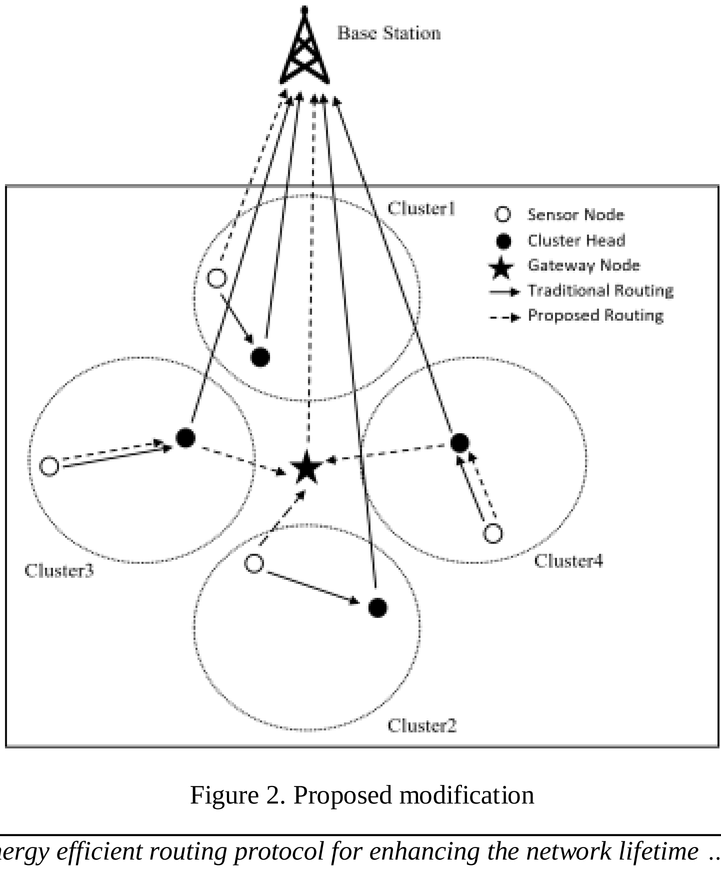

Figure 2. Proposed modification

Figure 3 shows the flow diagram of the proposed work. As discussed earlier, sensing areas near BS or gateway node are considered as sectors and the sensing areas way from BS and gateway node are considered as clusters. Nodes in sector transmit their data packet to the BS in either one-hop or two-hops, whereas the nodes in clusters communicate to the BS in three hops.

a) Algorithm for sector-based clustering and routing
Step 1: Deployment of nodes in the given sensing area.
Step 2: Deployment of BS and gateway node.
Step 3: Segregation of nodes into clusters and sectors.
Step 4: Selection of CH.
Step 5: Transmission of data using one-hop, two-hops and three-hops communication.
Assumptions made in this work are:
- The deployment of sensor nodes is random within given sensing area and they remain static after the deployment.
- BS and the gateway nodes do not have energy restrictions.
- Once installed, the locations of the BS and gateway node-which are both located beyond the sensing area-are static.
- The starting energy of each sensor node is the same.

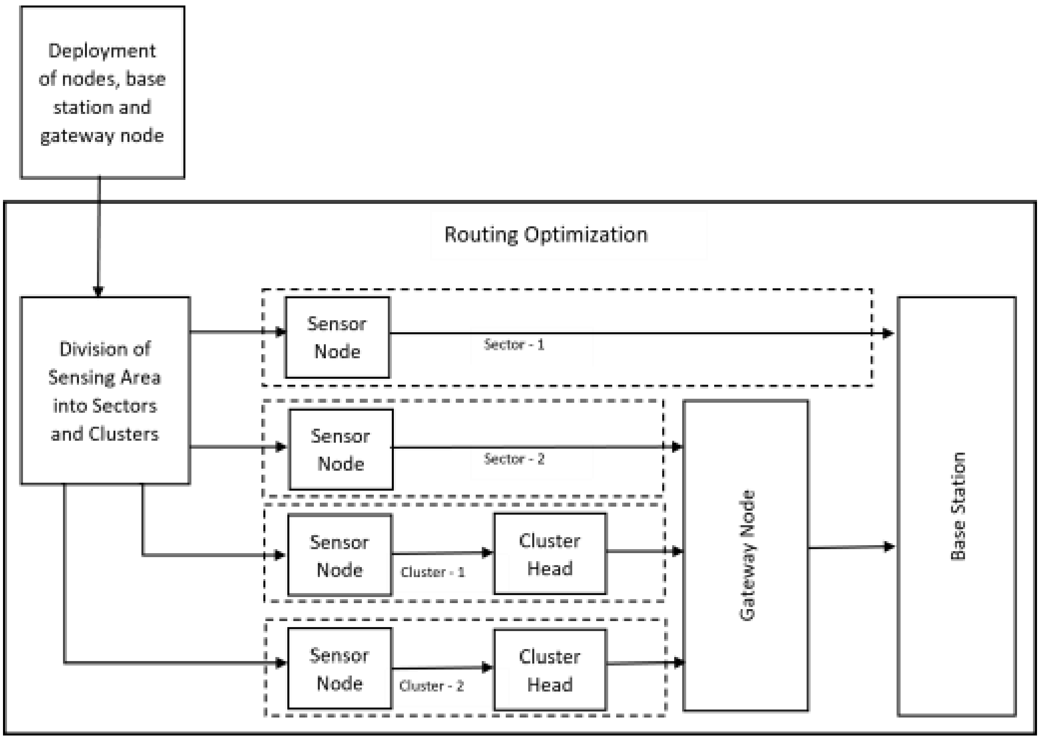

Figure 3. Flow diagram of proposed work

b) Experimental setup

Using the MATLAB programmed (version R2018a), the simulation is run on a Windows 10 platform with an Intel Core i3 CPU and 4 GB of RAM. The parameter settings for the proposed method are shown in Table 1. By changing one parameter while holding the other values constant, simulation results for various feature combinations may be achieved. The parameters varied are the number of sensor nodes, initial node energy, message size, average probability and BS location.

The sensing area of 200 m×200 m, BS located at (100, 300) and gateway node at (100, 100) is considered. Sensing region is divided into four sub-regions, sector 1, sector 2, cluster 1, and cluster 2. Such five different types of categorizations are done as follows.

Table 1. Network parameters

Parameter	Value
Network field	200 m×200 m
Sensor nodes	50, 100, 200
Initial node energy	0.5 J, 0.75 J, 1 J
Average data aggregation energy (E_{Aggr})	5 nJ/bit/ message
Energy used for receiving data (E_{RCV})	50 nJ/bit
Energy used for sending data (E_{TRS})	50 nJ/bit
Multi-path amplification factor (α_m)	0.0013 pJ/bit/m^4
Free space amplification factor (α_f)	10 pJ/bit/m^2
Average probability (P_{avg})	0.1, 0.2, 0.3
Message size	1,000, 2,000, 4,000 bits
BS location	(100, 200), (100, 250), (100, 300)
Gateway node location	(100, 100)

2.3.1. Type–A categorization

In this type, all the nodes within the range (X–axis->0 to 200, Y–axis->160 to 200) are made to fall in the sector-1. All these nodes being close to the BS rather than the gateway node, communicate directly with the BS in single-hop. The nodes within the range (X–axis->70 to 140, Y–axis->0 to 160) are made to fall in the sector-2. The nodes that lie in this sector–2, will send the data to gateway nodes and in-turn the gateway node transmits it to the BS. Thus, all these nodes communicate with the BS in two-hops. Further, the nodes within the range (X–axis->0 to 70, Y–axis->0 to 160) are made to fall in the cluster-1, and the nodes within the range (X–axis->140 to 200, Y–axis->0 to 160) are made to fall in the cluster-2.

2.3.2. Type–B categorization

In this type, all the nodes within the range (X–axis->0 to 200, Y–axis->160 to 200) are made to fall in the sector-1. The nodes within the range (X–axis->70 to 140, Y–axis->60 to 160) are made to fall in the sector-2. Further, the nodes within the range (X–axis->0 to 70, Y–axis->0 to 160 and X–axis->70 to 100, Y–axis->0 to 60) are made to fall in the cluster-1, and the nodes within the range (X–axis->140 to 200, Y–axis->0 to 160 and X–axis->100 to 140, Y–axis->0 to 60) are made to fall in the cluster-2.

2.3.3. Type–C categorization

In this type, all the nodes within the range (X–axis->0 to 200, Y–axis->160 to 200) are made to fall in the sector -1. Nodes within the range (X–axis->70 to 140, Y–axis->60 to 160) are made to fall in the sector -2. Further, The nodes within the range (X–axis->0 to 70, Y–axis->0 to 160 and X–axis->70 to 100, Y–axis->0 to 60 and X–axis->60 to 100, Y–axis->140 to 160) are made to fall in the cluster -1, and the nodes within the range (X–axis->140 to 200, Y–axis->0 to 160 and X–axis->100 to 140, Y–axis->0 to 60 and X–axis->100 to 140, Y–axis->140 to 160) are made to fall in the cluster -2.

2.3.4. Type–D categorization

In this type, all the nodes within the range (X–axis->0 to 200, Y-axis->160 to 200) are made to fall in the sector -1. The nodes within the range (X–axis->0 to 200, Y–axis->50 to 120) are made to fall in the sector -2. Further, nodes within the range (X–axis->0 to 70, Y–axis->0 to 160 and X–axis->70 to 100, Y–axis->0 to 60 and X–axis->60 to 100, Y–axis->140 to 160) are made to fall in the cluster -1, and the nodes within the range (X–axis->140 to 200, Y–axis->0 to 160 and X–axis->100 to 140, Y–axis->0 to 60 and X–axis->100 to 140, Y–axis->140 to 160) are made to fall in the cluster -2.

2.3.5. Type–E categorization

In this type, categorization of the sensing area is same as that of type D except that the gateway node is move to center of the entire sensing area. The location of the gateway node is changed from (100, 80) to (100, 100). This helps to analyse the impact of BS location on the network lifetime.

3. RESULTS AND DISCUSSION

The simulation results for several feature combinations are examined in this part in terms of network lifetime and energy usage. The network stops working when 80% of the nodes are dead. The approximate age at which 80% of the nodes are dead is known as the network lifetime. Five different parameters are varied for the simulation and analysis. These parameters include message size, initial node energy, BS location, number of nodes and average probability. Tables 2 and 3 shows the simulation results obtained for different categorization types by varying five network parameters.

Table 2. Simulation results of different categorization types by varying message size, initial node energy and base station location

Network lifetime (in rounds)	Message size			Initial node energy			Base station location		
	1,000 bits	2,000 bits	4,000 bits	0.5 J	0.75 J	1 J	(100, 300)	(100, 250)	(100, 200)
Type A	6,336	3,043	1,571	3,043	4,744	6,505	3,043	3,176	3,681
Type B	5,559	2,792	1,457	2,792	4,350	5,850	2,792	3,055	3,621
Type C	5,242	2,565	1,317	2,565	3,703	6,144	2,565	2,847	3,612
Type D	5,517	2,791	1,356	2,791	4,302	5,589	2,791	2,808	3,573
Type E	5,436	2,769	1,407	2,769	4,146	5,426	2,769	2,895	3,282

Table 3. Simulation results of different categorization types by varying number of nodes and average probability

Network lifetime (in rounds)	Number of nodes			Average probability		
	50 nodes	100 nodes	200 nodes	0.1	0.2	0.3
Type A	2,954	3,043	3,090	3,043	3,104	3,374
Type B	2,974	2,792	2,875	2,792	3,036	3,109
Type C	2,604	2,565	2,714	2,565	2,856	2,824
Type D	2,888	2,791	2,787	2,791	2,914	2,800
Type E	2,767	2,769	2,801	2,769	2,770	2,996

3.1. Effect of varying the message size

Here, the fixed parameters are initial node energy:0.5 J, BS location:(100, 300), number of nodes:100, and average probability:0.1. Message size is varied as 1,000 bits; 2,000 bits; and 4,000 bits. Figure 4 demonstrates that, the type-A offers maximum network lifetimes of 6,336 rounds; 3,043 rounds; and 1,571 rounds for message sizes of 1,000 bits; 2,000 bits' and 4,000 bits respectively. Type-C provides minimum network lifetimes of 5,242 rounds; 2,565 rounds; and 1,317 rounds for message sizes of 1,000 bits; 2,000 bits; and 4,000 bits respectively.

3.2. Effect of varying the initial node energy

Here the fixed parameters are message size: 2,000 bits, BS location:(100, 300), number of nodes: 100, and average probability:0.1. Initial node energy is varied as 0.5 J, 0.75 J and 1 J. Figure 5 demonstrates that, Type-A provides maximum network lifetimes of 3,043 rounds; 4,744 rounds; and 6,505 rounds for node energies of 0.5 J, 0.75 J, and 1 J. Type-C offers a minimum network lifetime of 2,565 rounds for node energies of 0.5 J; 3,703 rounds for 0.75 J; and type-E offers a minimum network lifetime of 5,426 rounds for node energies of 1 J, respectively.

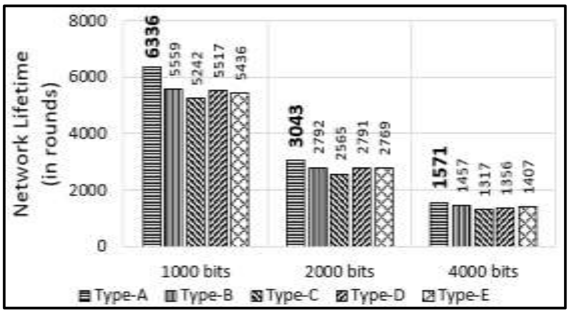

Figure 4. Network lifetime for different message sizes

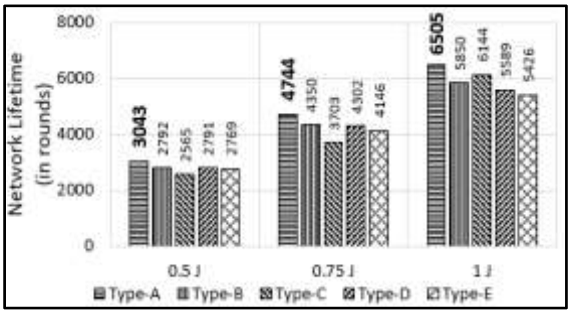

Figure 5. Network lifetime for different initial node energies

3.3. Effect of varying the base station location

Here, the fixed parameters are message size: 2,000 bits, initial node energy: 0.5 J, number of nodes: 100, and average probability: 0.1. There are three different BS locations (100, 300), (100, 250), and (100, 200). Figure 6 demonstrates that, type-A offers maximum network lifetimes of 3,043 rounds, 3,176 rounds, and 3,681 rounds, for BS locations of (100, 300), (100, 250), and (100, 200), respectively. Minimum network lifespan obtained with type-C at 2,565 rounds, type-D at 2,808 rounds, and type-E at 3,282 rounds.

3.4. Variation in number of nodes

Here, the fixed parameters are message size: 2,000 bits, initial node energy: 0.5 J, BS location:(100, 300), and average probability:0.1. Number of nodes is varied as 50 nodes, 100 nodes and 200 nodes. Figure 7 demonstrates that, type-B provides maximum network lifetime of 2,974 rounds, type-A provides maximum network lifetime 2,974 rounds, 3,043 rounds, and 3,090 rounds for 50 nodes, 100 nodes and 200 nodes respectively. Type-C provides minimum network lifetime of is 2,604; 2,565; and 2,714 rounds for 50, 100, and 200 nodes, respectively.

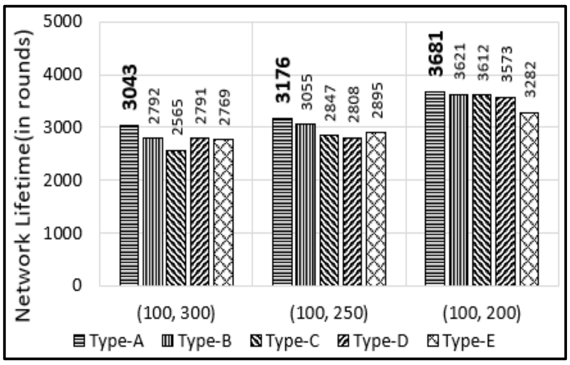

Figure 6. Network lifetime for different BS locations

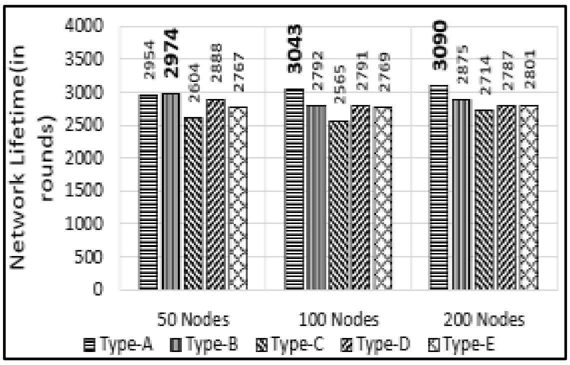

Figure 7. Network lifetime for different number of nodes

3.5. Variation in average probability

Here, the fixed parameters are message size: 2,000 bits, initial node energy:0.5 J, BS location:(100, 300), and number of nodes: 100. Average probability is varied as 0.1, 0.2, and 0.3. Figure 8 demonstrates that, type-A provides network lifetime of is 3,043 rounds; 3,104 rounds; and 3,374 rounds, respectively, for values of average probability of 0.1, 0.2, and 0.3. Type-C gives minimum network lifetime of 2,565 rounds, type-E gives minimum network lifetime of 2,770 rounds and type-D gives minimum network lifetime of 2,800 rounds for values of average probability of 0.1, 0.2, and 0.3 respectively.

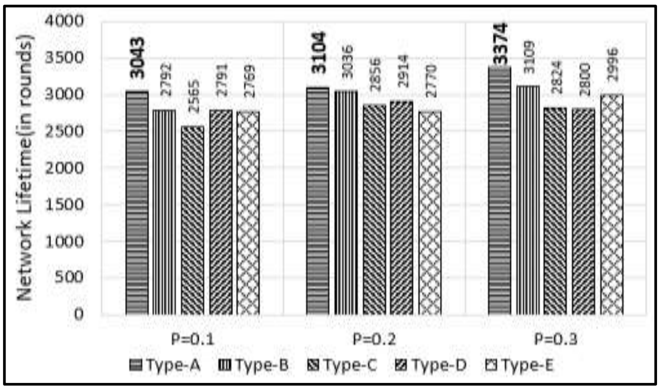

Figure 8. Network lifetime for different average probability

3.6. Overall comparison of different types

Here, the network performance of all categorization types of the proposed work is compared. Table 4 shows the simulation results of network performance considering different categorization types. Round values representing the first dead node, 20% dead nodes, 50% dead nodes, 80% dead nodes, and last dead nodes are taken into account while evaluating network performance. Figure 9 demonstrates that, the type-A offers a maximum network lifetime of 3,043 rounds with 80% of the node's dead, despite the fact that the first node dies at 268 rounds, whereas the type-C provides a minimum network lifetime of 2,565 rounds with the first node dying at 288 rounds.

Table 4. Network performance for different categorization types

	Type A	Type B	Type C	Type D	Type E
First node dead	268	273	288	276	301
20% nodes dead	1,130	1,245	1,256	1,208	1,086
50% nodes dead	2,029	2,054	2,058	2,067	2,010
80% nodes dead	3,043	2,792	2,565	2,791	2,769

Table 5 shows the consumed energy levels for different types. Different categorization types are compared by taking the percentage of energy consumed at 1,000 rounds; 2,000 rounds; and 3,000 rounds. Figure 10 demonstrates that, although the type-A consumes more energy at 1,000 rounds, it will be having more energy at round 3,000 in comparison with other types. Though the amount of energy consumed is nearly same for all types, type-A has consumed a minimum of 95.34% energy and still left with 4.66% of energy even after 3,000 rounds. Our study suggest that higher network lifetime is obtained by properly segmenting the sensing region into sectors and clusters based on the radio communication distance from base station. The proposed method benefits from having multiple hop data communication without adversely impacting throughput.

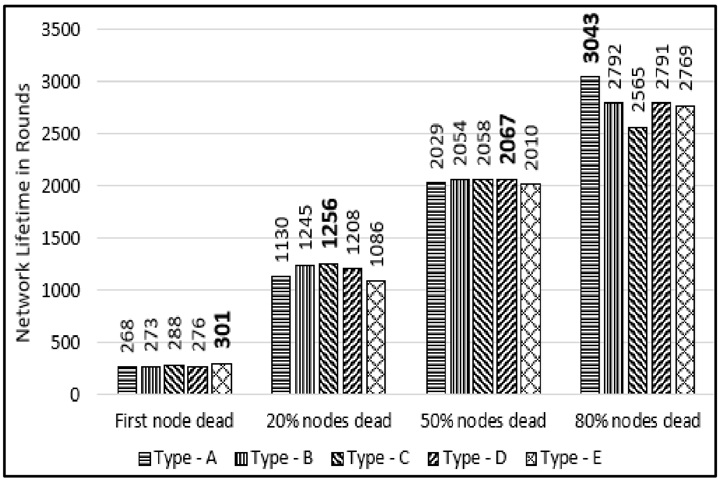

Figure 9. Comparison of different categorization types

Table 5. Percentage of energy consumed for different categorization types

	Type A	Type B	Type C	Type D	Type E
1,000 rounds	56.11%	55.57%	55.79%	56.03%	57.81%
2,000 rounds	86.45%	87.21%	87.94%	86.99%	87.57%
3,000 rounds	95.34%	95.86%	95.49%	97.17%	96.37%

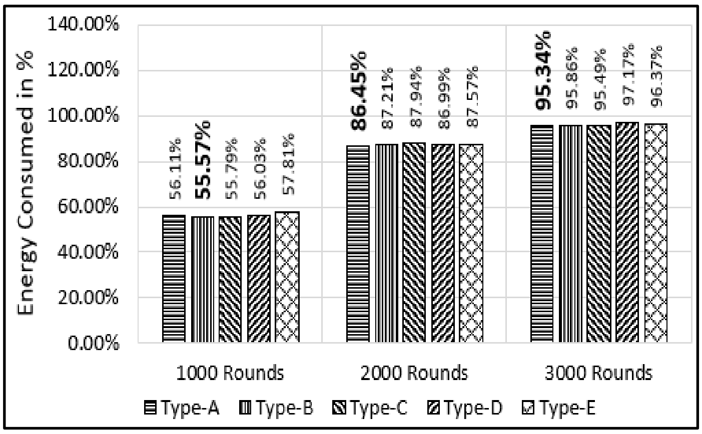

Figure 10. Energy consumption of different categorization types

3.7. Comparison of proposed scheme with LEACH protocol

Simulation results are obtained and network performance is analysed at several stages: the first node dead round, 20% nodes dead round, 50% nodes dead round, and 80% nodes dead round. These data are utilized to compare the performance of different categorization types proposed in our work. However, for comparison with existing protocols such as LEACH and dual layer LEACH, the network performance at the first node dead round, 20% nodes dead round, and 50% nodes dead round is considered. The exclusion of results at the 80% nodes dead round is due to the unavailability of data in the base journal paper referred to for comparison. As a result, our comparison focuses on the available rounds where data is accessible for both our proposed approach and the existing protocols. The network performance of LEACH protocol and dual layer LEACH protocol considering the FND, 20% nodes dead and 50% nodes dead are as shown in the Table 6. The proposed scheme is first compared with the results of LEACH protocol.

Table 6. Comparison of proposed scheme with LEACH protocol

	LEACH	Type A	Type B	Type C	Type D	Type E
First node dead	99	268	273	288	276	301
20% nodes dead	204	1,130	1,245	1,256	1,208	1,086
50% nodes dead	460	2,029	2,054	2,058	2,067	2,010

Figure 11 demonstrates that, the first node dies at round 99 in LEACH protocol and in the proposed scheme, first node dies after round 268. In LEACH protocol, 20% nodes die at round 204 where as they die after round 1,086 in the proposed scheme. Further, 50% nodes die at round 460 in LEACH protocol, they die after round 2,010 in the proposed scheme which shows an improvement in the network lifetime over the LEACH protocol.

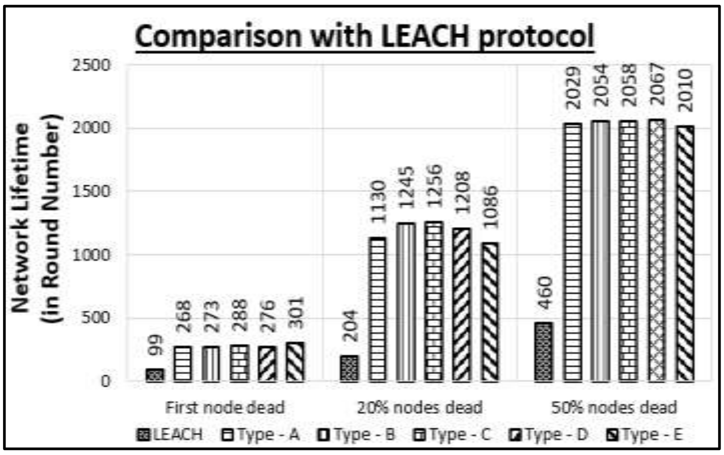

Figure 11. Comparison of proposed scheme with LEACH protocol

Considering the 20% nodes dead and 50% nodes dead, the improvement obtained through the proposed scheme over the LEACH protocol in percentage is calculated and the Table 7 shows the details. Figure 12 demonstrates that an improvement of 453%, 510%, 515%, 492%, and 432% is provided by type-A, type-B, type-C, type-D, and type-E categorizations respectively over the LEACH protocol. Further, Figure 13 demonstrates an improvement of 341%, 346%, 347%, 349%, and 336% provided by type-A, type-B, type-C, type-D, and type-E categorizations over the LEACH protocol.

Table 7. Improvement over LEACH protocol

	LEACH	Proposed scheme				
		Type A	Type B	Type C	Type D	Type E
Network lifetime in terms of number of rounds	204	1,130	1,245	1,256	1,208	1,086
Percentage improvement in network lifetime (Considering 20% nodes dead)	---	453.92%	510.29%	515.68%	492.16%	432.35%
Percentage improvement in network lifetime (Considering 50% nodes dead)	---	341.08%	346.52%	347.39%	349.34%	336.96%

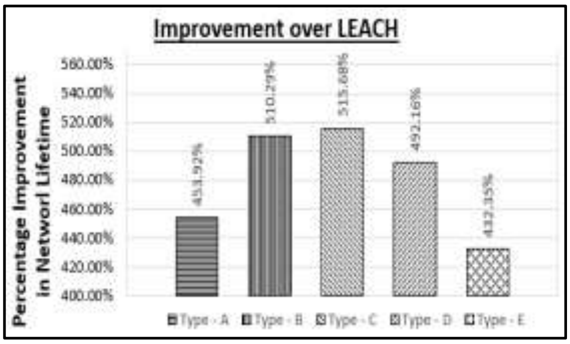

Figure 12. Improvement over LEACH protocol considering 20% nodes dead

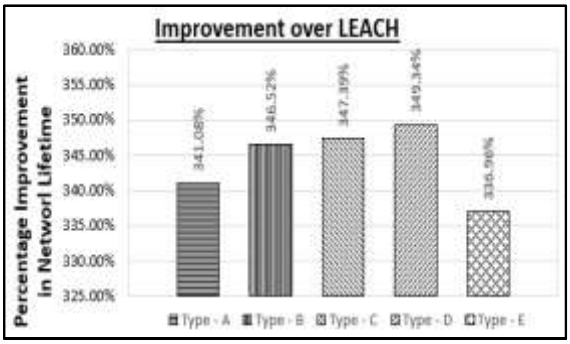

Figure 13. Improvement over LEACH protocol considering 50% nodes dead

3.8. Comparison of proposed scheme with dual layer LEACH protocol

Here, the results of proposed scheme are compared with dual layer LEACH protocol, a modified version of LEACH protocol. Table 8 shows the network performance by considering the FND, 20% nodes and 50% nodes dead. Figure 14 depicts the results of dual layer LEACH and proposed scheme. One interesting factor is although the first node dies early in the proposed approach compared to dual layer LEACH at round 533, proposed scheme gives much better results at 20% and 50% nodes dead. In dual layer LEACH, 20% nodes die at 989 rounds but in propsed scheme 20% nodes die after 1,086 rounds. Further, 50% nodes die at 1,293 rounds in dual layer LEACH protocol and they die after 2,010 rounds in proposed scheme.

Table 8. Comparison of proposed scheme with dual layer LEACH protocol

	Dual layer LEACH	Type A	Type B	Type C	Type D	Type E
First node dead	533	268	273	288	276	301
20% nodes dead	989	1,130	1,245	1,256	1,208	1,086
50% nodes dead	1,293	2,029	2,054	2,058	2,067	2,010

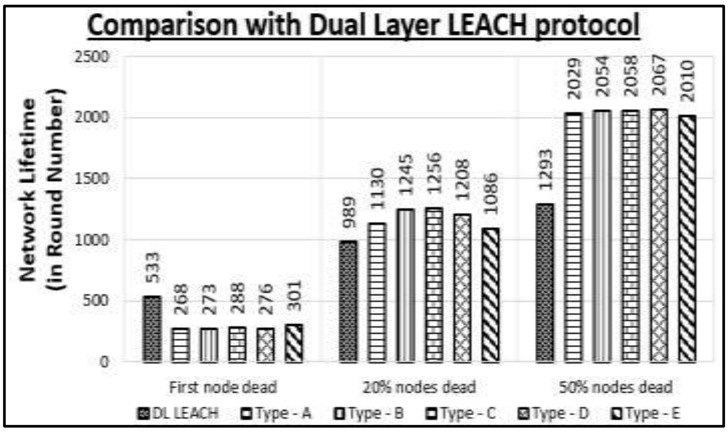

Figure 14. Comparison of proposed scheme with dual layer LEACH protocol

Considering the 20% nodes dead and 50% nodes dead, the imrovement obtained through the proposed scheme over the LEACH protocol in percentage is calculated and the Table 9 shows the details. Figure 15 demonstrates an improvemt of 14%, 26%, 27%, 22%, and 10% provided by type-A, type-B, type-C, type-D, and type-E categorizations respectively over the dual layer LEACH protocol. Further, Figure 16 demonstrates an improvement of 57%, 59%, 59%, 60%, and 56% provided by type-A, type-B, type-C, type-D, and type-E categorizations respectively. We found that network lifetime correlates with radio communication distance and proposed method provides an improvement up to 515% over the LEACH protocol and 27% over the DL-LEACH protocol in the optimal configuration.

Table 9. Improvement over dual layer LEACH protocol

	Dual layer LEACH	Proposed scheme				
		Type A	Type B	Type C	Type D	Type E
Network lifetime in terms of number of rounds	204	1,130	1,245	1,256	1,208	1,086
Percentage improvement in network lifetime (Considering 20% nodes dead)	---	14.25%	25.88%	26.99%	22.14%	9.80%
Percentage improvement in network lifetime (Considering 50% nodes dead)	---	56.92%	58.86%	59.16%	59.86%	55.46%

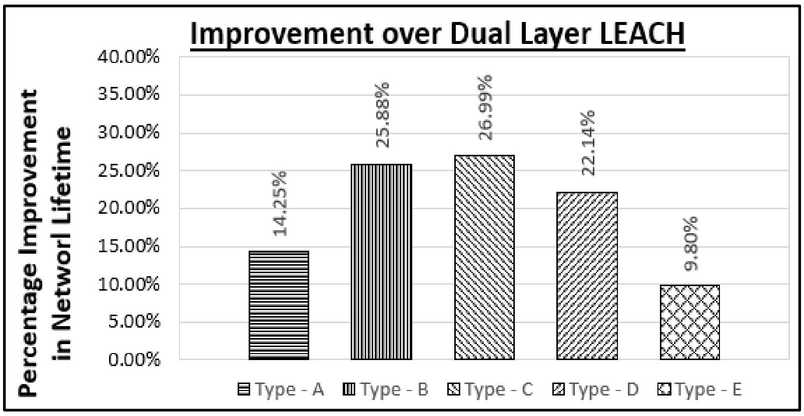

Figure 15. Improvement over dual layer LEACH protocol considering 20% nodes dead

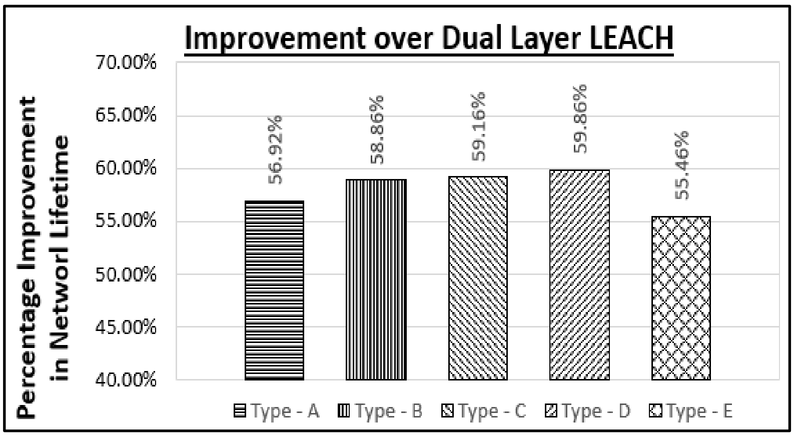

Figure 16. Improvement over dual layer LEACH protocol considering 50% nodes dead

4. CONCLUSION

This study explored a comprehensive routing approach with sectoring and clustering with the main objective of enhancing the network lifetime in homogeneous environment. However, further and in-depth studies may be needed to confirm its improved performance in heterogeneous network. Our study demonstrates that the gateway nodes are more resilient than normal sensor nodes. The energy capabilities of gateway nodes are significantly better than those of normal nodes. Future studies may explore the use of mobile gateway nodes and investigate feasible methods to increase network lifetime and throughput compared to stationary gateway nodes. It is worth noting that our study does not address certain network scenarios such as packet loss, node failure, energy optimization in heterogeneous networks, and minimizing end-to-end delay. These potential research issues could be considered to extend our work in the future.

Recent observations suggest that network lifetime can be increased by adopting a dual CH mechanism and developing inter CH communication. Our findings provide conclusive evidence that the proposed method enhances network performance through the use of multi-hop data communication and the inclusion of a gateway node within the sensing region. In summary, the proposed scheme not only surpasses existing protocols in terms of network lifetime but also demonstrates a holistic understanding of the energy dynamics within a wireless sensor network. The reduction in energy consumption, achieved through effective categorization and optimized routing, positions the proposed scheme as a promising advancement in the field, offering practical benefits for the deployment and longevity of wireless sensor networks in diverse real-world scenarios.

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