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Lifetime enhanced energy efficient wireless sensor networks using renewable energy

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ABSTRACT

In this paper, we consider a remote environment with randomly deployed sensor nodes, with an initial energy of E0 (J) and a solar panel. A hierarchical clustering technique is implemented. At each round, the normal nodes send the sensed data to the nearest cluster head (CH) which is chosen on the probability value. Data after aggregation at CHs is sent to the base station (BS). CH requires more energy than normal nodes. Here, we energize only CHs if their energy is less than 5% of its initial value with the use of solar energy. We evaluate parameters like energy consumption, the lifetime of the network, and data packets sent to CH and BS. The obtained results are compared with existing techniques. The proposed protocol provides better energy efficiency and network lifetime. The results show increased stability with delayed death of the first node. The network lifetime of the proposed protocol is compared to the multi-level hybrid energy efficient distributed (MLHEED) technique and low-energy adaptive clustering hierarchy (LEACH) variants. Network lifetime is enhanced by 13.35%. Energy consumption is reduced with respect to MLHEED-4, 5, and 6 by 7.15%, 12.10%, and 14.975% respectively. The no. of packets transferred to the BS is greater than the MLHEED protocol by 39.03%.

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1. INTRODUCTION

The enormous research and development in the field of semiconductor technology, communication, and natural science have led to a global distribution of wide-range wireless sensor networks (WSNs). We are witnessing the next generation of WSNs that vary substantially from the networks set up as recently as 5 to 10 years ago. Now, it is possible to accommodate many sensor nodes with advanced processing and communication abilities. Further, the networking standards equipped with security, confidentiality, and the least latency have led to the expansion of WSN into the field of control and monitoring the area [1]. Basically, a WSN comprises tiny nodes which are positioned in inhospitable, inaccessible environments to sense the physical parameters of the environment [2]. These nodes have limited resources in terms of bandwidth, memory, and energy The WSNs are classified into homogeneous and heterogeneous networks [3], [4]. When the nodes have the same functional capabilities in terms of sensing and initial energy, they are called homogeneous networks or heterogeneous. Although heterogeneous networks require more network energy, they provide large network lifetime when compared with homogeneous networks [5]. Further, when we consider renewable sources of energy like solar energy for energizing the nodes, we achieve clean energy consumption and support to green environment and at the same time achieve a large network lifetime.

In this research work, we consider a two-level heterogeneity wherein all the nodes will have the same initial energy at first. At each round of cluster head election based on probability using a hierarchical clustering approach. All normal nodes will have the same initial energy while the cluster head nodes will have initial energy plus solar energy only in case their energy level is equal to or less than 0.01 J. We illustrate the simulation results using MATLAB 2020a for a WSN using renewable sources of energy i.e., solar energy to energize only the required cluster heads selected in each round. We evaluate the performance of the network by comparing the proposed protocol with the multi-level hybrid energy efficient distributed (MLHEED) technique. The MLHEED protocol proposed in [5] showed a heterogeneity up to 6 levels which used the remaining energy of the nodes and its density to select the cluster head (CH). The proposed protocol works using the probability parameter for CH selection. We evaluate the stability period, network lifetime, energy efficiency, and the number of packets transferred to the CH and base station (BS) using the proposed protocol and compare it with the results of existing techniques in this work.

Efficient energy consumption and increased network lifetime have always been important areas for research in the field of WSN. Here, we present some works carried out by researchers in achieving the said requirements. The concept of heterogeneity in the WSNs with multi-levels helps in increasing the network lifetime. Singh [5] provided a 6-level heterogeneity and achieved an increase in network lifetime wherein the last node was alive up to the 2,997th round but the total energy of the network utilized was 36.8 J. Elshrkawey *et al.* [6] clearly highlighted, that heterogeneity helped in increasing the network lifetime and proved to be better than the existing protocols like low-energy adaptive clustering hierarchy (LEACH), modified LEACH, energy efficient clustering and data aggregation (EECDA), distributed stable cluster head election (DSCHE). Qing *et al.* [7] proposed distributed energy-efficient clustering (DEEC) protocol, where the nodes with high initial and residual energy would be selected as cluster heads. The results showed that DEEC achieved a longer network lifetime. Further, Javaid *et al.* [8] worked on an enhanced developed distributed energy-efficient clustering scheme (EDDEEC) for heterogeneous WSNs. Results achieved longer lifetime and stability period. Next, heterogeneous WSN routing protocols DEEC and enhanced distributed energy efficient clustering (EDEEC) were compared in [9] and the results showed that the EDEEC protocol provided better performance values than DEEC. The concept of a green wireless sensor network is the latest trend in the area of WSN. López-Ardao *et al.* [10] provided a survey of the different ways to achieve energy balancing and identified the main trending topics. An extensive survey of all the available heterogeneous wireless sensor networks was provided in [11]. Otu [12] proposed an energy coverage ratio clustering protocol (E-CRCP) that utilized a regional coverage area ratio to minimize the consumption of energy. The protocol was tested for different a number of nodes, and rounds. The results showed better lifetime, load balancing, and overall energy consumption. El-Sayed [13] proposed a method for CH selection that was energy efficient and thus increased the life of the network. Zayed *et al.* [14] provided an in-depth understanding of the hierarchical clustering-based protocols namely MODLEACH and mobile sink improved energy-efficient power-efficient gathering in sensor information system-based routing protocol (MIEEPB) protocols. The results upheld the performance of MIEEPB. Heinzelman *et al.* [15], [16] implemented different clustering techniques The results proved that the change in the parameters like a number of nodes, area, and a number of rounds affect the efficiency and lifetime of WSN. Saini and Sharma [17] provided a three-tier approach heterogeneity to enhance network lifetime using an enhanced threshold approach. Junior *et al.* [18] provided a method to use residual energy and solar energy to increase the lifetime of the network. In [19], the method and usefulness of using MATLAB to carry out the simulations for wireless sensor networks were discussed. The results show that MATLAB helps in providing accurate simulation details for the network. Sagare *et al.* [20] showed a basic understanding of the use of clustering and the role of probability in selecting the cluster head.

From the literature review, it is learned that the multilevel heterogeneous network models offer better network lifetime. Singh [5] suggests that increased network energy is more favorable than adding more nodes to the network. However, in our proposed clustering technique we consider a same number of nodes as in [5] and develop a network model which promises not only an increased network lifetime but also reduced network energy requirement. Further, we energize a few nodes to bring in the concept of heterogeneity in the network by making use of solar energy. Also, this paper gives a comparison of the proposed protocols: modified LEACH (mod-LEACH) [21], LEACH [22], extended-MODLEACH (E-MODLEACH) [23], and DEEC [24].

This paper is organized as follows: section 2 presents the proposed method i.e., a novel clustering technique using renewable energy for a WSN; which discusses the assumptions made, initial parameters for the network, the algorithm, and the flowchart. Section 3 presents the simulated results using MATLAB 2020a. In section 4, we present the results and discussion by carrying out the comparison between the proposed protocol and MLHEED protocol and outcomes. Further, the comparison results with other protocols like mod-LEACH, LEACH, E-MODLEACH, and DEEC are presented. The evaluation parameters considered are the first dead node round number, last dead node round number, alive nodes, packets sent to CH, and packets sent to BS. Finally, section 5 gives the concluding remarks for this paper.

2. PROPOSED METHOD

Here, the novel clustering technique network model using solar energy for WSN is elucidated in detail. The novel clustering technique follows the hierarchical clustering technique with heterogeneity introduced in terms of node energy (in Joules). All the nodes with the same initial energy will participate in the CH selection and then the selected CH will be responsible for collecting the sensed data from other nodes, performing data aggregation, and further transmitting the aggregated data to the BS. The CH with its energy of less than 5% of its initial energy will get charged using the solar panel. The following subsections describe the technique with the assumptions made, the model, and the algorithm.

2.1. Assumptions

Each node is deployed randomly and is stationary. The location of the base station is fixed. The nodes are randomly placed in a pre-defined network area and not location aware as we cut down the cost of the network by not using global positioning system (GPS) enabled nodes. All the nodes initially have the same energy and resources (central processing unit or CPU and memory) but at each round after cluster head election, the CH will be energized by the solar panel, if its energy is less than 5% of its initial energy value. Thus, bringing in heterogeneity in the network. Each node is equipped with a solar panel to energize itself to 0.35 times the initial energy of the node. The data aggregation takes place only in the CH where the compression of data packets takes place. The node is considered dead when its energy becomes 0 J after energy dissipation. The base station is located at the center of the area under consideration. The energy consumed in transmitting or receiving a data packet is considered the same. There are only 2 energy levels in the network. Level 1-with nodes having the same initial energy. Level 2 of the cluster heads whose remaining energy is less than 5% of their initial value will be energized by solar energy.

2.2. The model

Even though a lot of work is carried out in the field of energy efficiency, increasing lifetime and energy harvesting in WSN, no specific work of using solar energy to energize only the CH is available in the literature reviewed. In the proposed technique, a large number of sensor nodes (100 in our case) equipped with solar panels are randomly placed in a 100×100 m^2 area. The BS is located at the center of this area i.e., (50, 50) location. Solar energy which is a renewable source of energy is used to energize the solar panels of the sensor nodes. The proposed model is depicted in Figure 1.

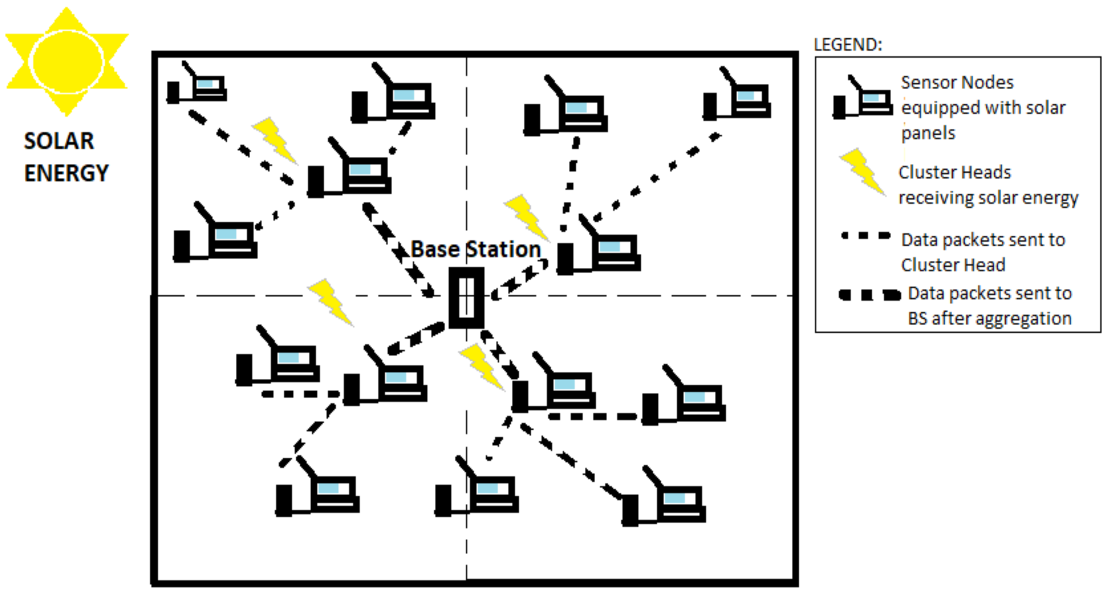

Figure 1. Depiction of the predicted network model

At each round of the CH election, based on probability the CH is selected. The other nodes in the cluster are informed about the CH node via a broadcast message. Thus, on sensing the physical parameters, the normal nodes transmit the sensed data in the form of data packets to their nearest CH. CH in turn performs data aggregation wherein the redundant data packets are discarded, and the remaining data packets are transmitted to the BS for further data analysis and evaluation. All the sensor nodes as well as the BS are static. The sensor nodes have an initial energy of 0.2 J each. The energy model obeys the same radio model used in [15] as given in (1) and (2).

$$Et(b,d) = \begin{cases} (Ee \times b) + (Efs \times b \times d^2), & d \leq d0 \\ (Ee \times b) + (Eam \times b \times d^4), & d > d0 \end{cases} \tag{1}$$

$$d0 = \sqrt{(Efs/Eam)} \tag{2}$$

where $Et(b,d)$ is the energy consumed by the transmitter; in transmitting b bits at a transmission distance of d, Ee is the energy consumed by the electronic devices, Efs is the energy consumed in amplification (in free space), Eam is the power amplifier value, and $d0$ is the threshold distance. The probability for CH selection is 0.1. Table 1 gives the simulation parameters for the proposed protocol. All the parameters are set in accordance with the parameters as set in [5] to make the comparison more apt and relatable.

Table 1. Simulation parameters for proposed protocol

Simulation Parameters	Values
Network area	100×100 m^2
Base Station	(50, 50)
Number of nodes: *n*	100
Initial Energy: *E0*	0.2 J
Threshold Distance: *d0*	70 m
Energy consumed in electronics circuit: *Ee=Etx=Erx*	50 nJ/bit
The nodes probability to become cluster head	0.1
Energy consumed in amplification: *Efs*	10 pJ
Multi path loss: *Emp*	0.0013 pJ
Energy spent in CH for data aggregation: EDA	5 nJ
Total number of rounds: *rmax*	5000

The algorithm for the proposed protocol is based on these steps.

1) All the nodes equipped with solar panels are randomly deployed in an area of 100×100 m^2.
2) The location on the BS and all the parameters for the network are set.
3) The CH is selected based on probability.
4) The CHs' selected information is broadcasted to all neighboring nodes to send the sensed data to the nearest CH.
5) If the node is CH, then follow steps 6 and 7 else go to step 9.
6) The CH node performs data aggregation on received data packets.
7) The data packets are sent to base station.
8) The CH gets energy from the solar panel for that round if its node energy is less than 0.01 J. Then it is energized as $S_{(i)}.\ E=S_{(i)}.\ E+0.35*E_0$.
9) The nodes send the data packets to CH.
10) E_t estimates the total energy (due to battery alone) of the network. ($E_t=E_t+E_{(i)}$, where *i* is the round number).
11) *Re* estimates the renewable source of energy used. ($R_e=R_e+R_{(i)}$, where *i* is the round number).
12) *Te* estimates the total energy used in the network: $T_e=E_t+R_e$.
13) The first dead node is observed for the round number and accordingly its flag is set. (When $S_{(i)}.\ E<=0$).
14) Then the tenth dead node is observed when 10 percent of the total number of nodes are dead and accordingly its flag is set. when $S_{(i)}.\ E==0.1xn$.
15) Repeat steps 3 to 12 until all the rounds considered *rmax* for the network are carried out.
16) Total number of alive nodes and dead nodes after *rmax* number of rounds is estimated.
17) Number of data packets sent to BS and CH are evaluated.
18) All the figures for different parameters are plotted.
19) Total energy consumed and network lifetime is evaluated.
20) Comparative study on the observed results is carried out.

2.3. The flowchart

Figure 2 depicts the flow of events in the proposed protocol. The process in the diagram repeats for the number of rounds selected for the protocol. Finally, when all the nodes are dead it stops. As long as there are active nodes the data packets will be sent to the CH and BS.

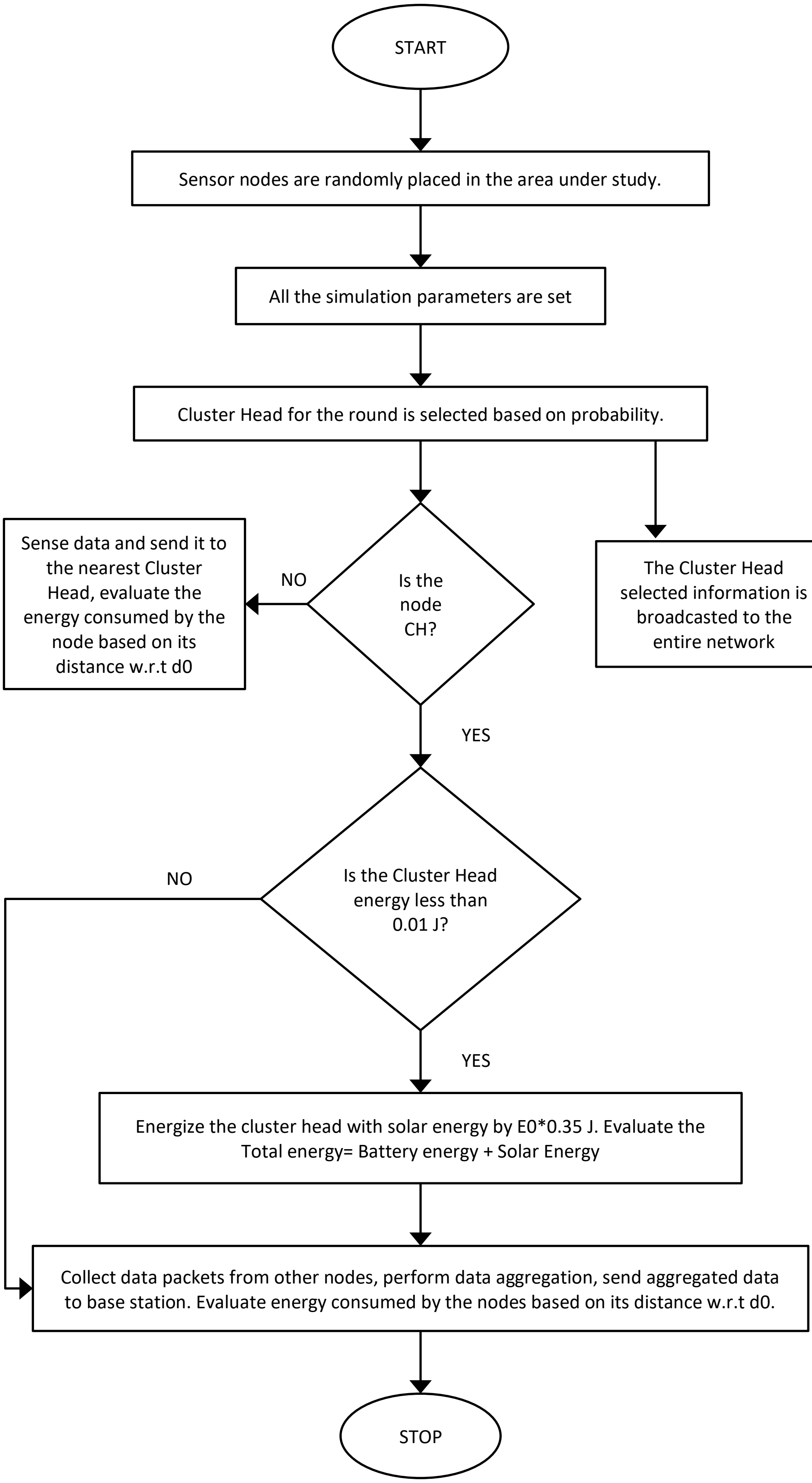

Figure 2. Flowchart of the proposed protocol

3. SIMULATED RESULTS

The results of the proposed protocol are presented in this section. Here, we observe the results for a number of dead nodes, alive nodes, packets sent to CH, packets sent to BS, number of CHs at each round. MATLAB 2020a version is used in this research work to carry out all the required simulations [25]. We obtain the simulated results for the following parameters the number of dead nodes at each round, the number of alive nodes, the number of packets sent to CH and BS, and the number of CHs at each round. The results clearly show that the proposed protocol provides a longer network lifetime, and a large number of data packets are transmitted at relatively low usage of network energy.

3.1. The number of dead nodes at each round

The simulation result in Figure 3 shows that with 100 nodes in a 10,000 sq. m area and for 5,000 rounds, the first dead node is observed at the 473rd round. Further, at the 525th round, 10% of the total number of nodes is dead. This shows a good stability period. Further, all nodes die by 3 the 459th round. Thus, exhibiting that the proposed protocol provides a longer network lifetime.

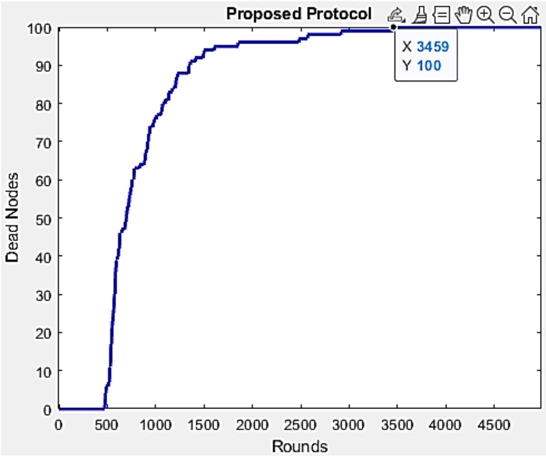

Figure 3. The number of dead nodes at each round

3.2. The number of alive nodes at each round

Similarly, the simulation result in Figure 4 shows that for given parameters; the proposed protocol has active nodes even at the 3,500th round depicting a longer network lifetime. Thus, the use of solar energy keeps the cluster head nodes active for a larger number of rounds. The data aggregation at the CH further reduces the energy consumed in sending even the redundant data packets to the BS. Hence, this all again leads to an increase in the network lifetime.

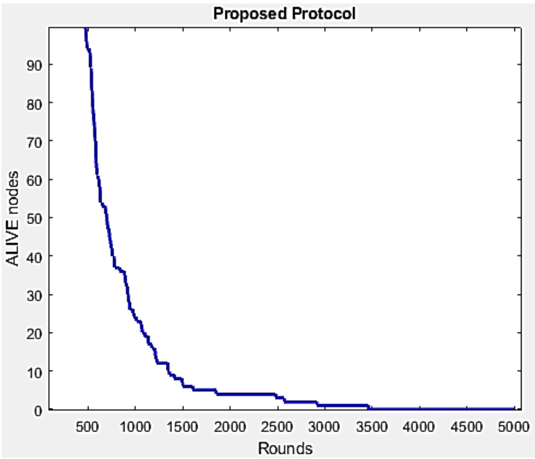

Figure 4. The number of alive nodes at each round

3.3. The number of data packets sent to cluster head

The simulation result in Figure 5 shows that for the given network, there is a steady increase in the number of data packets sent at each round, further a constant amount of data packets is transmitted to the CHs by the normal nodes. Totally, 45,740 data packets are sent to the CH by the end of 5,000 rounds. The results show that the network can carry a huge amounts of data packets across the nodes.

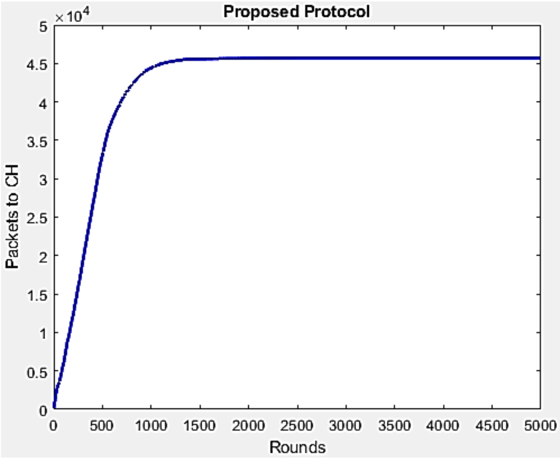

Figure 5. The number of packets sent to CH at each round

3.4. The number of data packets sent to base station

Next, the simulation result in Figure 6 shows that for the set parameters, out of 45,740 data packets received by the CHs only 41,060 data packets are sent to the BS. It shows that the CH performs data aggregation and sends only the non-redundant data packets to the BS. Again, the results show that the network can carry a huge amount of data packets from the CHs. Also, the energy of the network is efficiently utilized due to data aggregation at the CHs.

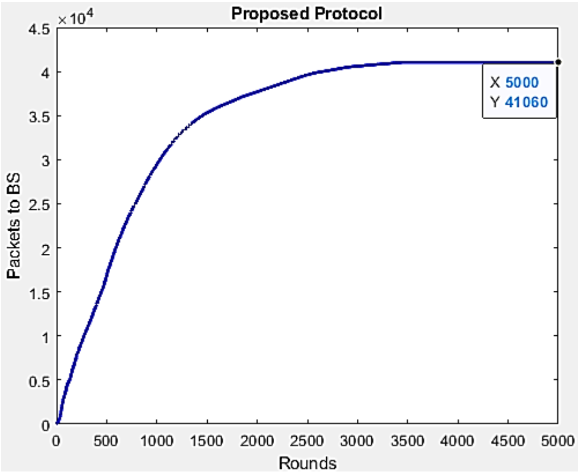

Figure 6. The number of packets sent to BS at each round

3.5. The number of cluster heads at each round

The simulation result in Figure 7 shows that for the given parameter, initially, the number of CHs is high, however with each round the number of dead nodes increases, and hence the number of CH selections for the given probability decreases. The results show that the protocol has active CHs till 3,459 rounds to send data packets to BS. For the first 500 rounds, there are a large number of CHs present in the network and then they decrease as the number of dead nodes in the network increase.

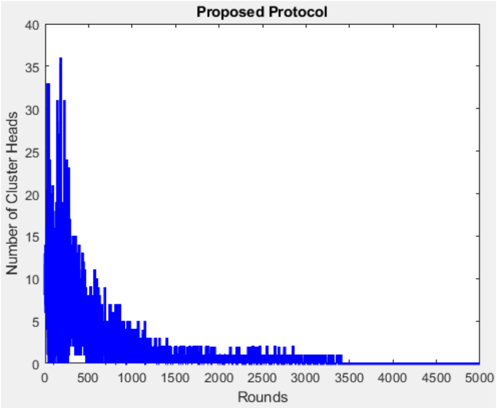

Figure 7. The number of CHs at each round

4. RESULTS AND DISCUSSION

Here, we discuss the results of the proposed protocol and compare them with results obtained from [5]. The simulation parameter set for the comparison between the MLHEED protocol, and the proposed protocol is maintained as shown in Table 1. The proposed algorithm and MLHEED [1] comparison for the evaluation parameters first dead and all dead round number is as shown in Table 2. The results show that the proposed algorithm shows a longer network lifetime. Also, the time for the first dead node is 473rd round which is better than MLHEED-1, 2, 3, 4 and 5 protocols. MLHEED-6 has its first dead node at round number 601 [5] compared to the proposed protocol which is the 473rd round but all the dead nodes for MLHEED-6 happened at 2,997 compared to 3,459 for the proposed protocol.

From Table 2, it is clear that the proposed protocol provides a longer network lifetime compared to all the MLHEED techniques. MLHEED-1, MLHEED-2, MLHEED-3, MLHEED-4, MLHEED-5, and MLHEED-6 remained active for 668; 1,156; 1,626; 2,092; 2,458; and 2,997 rounds respectively [5] while the proposed protocol remained active for 3,459 rounds. Thus, the percentage increase in network lifetime achieved by the proposed protocol with respect to the MLHEED-1, MLHEED-2, MLHEED-3, MLHEED-4, MLHEED-5, and MLHEED-6 is 80.68%, 66.57%, 52.99%, 39.52%, 28.93%, and 13.35% respectively.

Table 2. Round number for first and last node when dead

Protocol	First Dead Node	All Dead
MLHEED-1 [5]	167	668
MLHEED-2 [5]	192	1156
MLHEED-3 [5]	254	1626
MLHEED-4 [5]	365	2092
MLHEED-5 [5]	459	2458
MLHEED-6 [5]	601	2997
Proposed Protocol	473	3459

We now discuss the proposed protocol results when the number of rounds is varied. The results are tabulated in Table 3. It is observed from the table that for a different number of rounds the proposed technique provides better results in terms of network lifetime as well as energy consumption. The death of the first node is delayed in the proposed technique; hence the stability period of the network is increased.

Table 3. Results of the proposed protocol

Rounds	First Dead Node Round Number	10% Nodes Dead Round Number	All Dead at Round Number	Total Energy Consumed (in Joules)
5,000	473	525	3,459	31.2892 J
6,000	495	530	4,107	32.9428 J
7,000	481	556	2,993	33.6197 J

The proposed algorithm and MLHEED comparison for the evaluation of the amount of energy consumed by the network is shown in Table 4, which shows that the consumption of the network energy by the nodes in the process of sensing the physical parameters, sending the data to the CHs and further from the

CHs to the BS. The amount of energy required to transmit as well as receive the data packets is considered to be the same in the proposed model. The proposed protocol uses 20J of the node battery energy which is the same as MLHEED-1. In addition to this node battery energy, solar energy is consumed viz. 11.2892 J. However, the total energy consumed is 31.2892 J which is less than MLHEED-4, 5, and 6 protocols by 7.15%, 12.10%, and 14.975% respectively. Thus, paper [5] provided a great benefit in the enhancement of network lifetime but at an increased energy consumption of the node battery. However, the proposed technique provides an improved network lifetime at efficient energy consumption.

Table 4. Comparison of energy consumed by the protocols

Protocol	Total Network Energy
MLHEED-1 [5]	20.0 J
MLHEED-2 [5]	28.0 J
MLHEED-3 [5]	31.4 J
MLHEED-4 [5]	33.7 J
MLHEED-5 [5]	35.6 J
MLHEED-6 [5]	36.8 J
Proposed Protocol	20 J+11.2892 J=31.2892 J

Next, we change the number of nodes for the proposed protocol and present the observed results in Table 5, which suggests that the network lifetime is improved as the number of nodes is increased at the cost of increased network energy. However, it should be noted that around 20% of this increased energy consumption is a renewable source of energy, and the battery energy consumption is around 30 J (average). Further, the number of packets sent to the base station by the MLHEED-6 protocol is 27,900 bits per second while in the proposed protocol is 45,740 bits per second which increase the percentage of the number of data packets sent to the base station by 39.003%.

Table 5. Results of the proposed protocol for different number of nodes and at 5000 rounds

Nodes	First Dead Node Round Number	10% Nodes Dead Round Number	All Dead at Round Number	Alive Nodes	Total Energy Consumed (in Joules)
100	473	525	3,459	0	31.2892 J
200	429	525	NIL	1	74.0231 J
300	438	511	NIL	4	120.3301 J

Next, we compare our proposed technique with other protocols like LEACH and its variants [26]. We implemented mod-LEACH, LEACH, E-MODLEACH, and DEEC along with our proposed protocol for the following simulation parameters area 100×100 m^2, 100 nodes with an initial energy of 0.5 J, and the simulation are run for 5,000 rounds. The BS is located at (50, 50) and the threshold distance d0 is 70 m. Table 6 presents the proposed protocol results for the same simulation parameters with other protocols like mod-LEACH, LEACH, E-MODLEACH, and DEEC. The highlights of the proposed protocol are that it provides a longer network lifetime and also the number of packets sent to BS, CH is more compared to the other protocols. The stability period of the proposed protocol is more. Also, at the end of 5,000 rounds, there are no dead nodes.

Table 6. Results of the proposed protocol comparison with other protocols

Protocols	First Node Dead	All Dead	Packets to BS	Packets to CH
mod-LEACH	938	1,612	14,272	108,569
LEACH	990	1,397	12,211	105,433
E-MODLEACH	1,052	1,514	21,020	103,873
DEEC	1,087	1,498	45,677	86,270
Proposed	1,179	0	119,268	143,562

5. CONCLUSION

In this work, the proposed protocol uses the heterogeneity concept by having two different types of nodes in the network. The normal nodes have 0.2 J initial energy, while the cluster heads with less than 0.01 J energy would be again energized with renewable energy which adds 0.07 J of energy to the remaining cluster head energy. The protocol is evaluated based on two important parameters namely the lifetime of the network and the energy consumption in the network. The proposed protocol provides a longer network lifetime compared to all MLHEED techniques. MLHEED-1, MLHEED-2, MLHEED-3, MLHEED-4, MLHEED-5, and MLHEED-6 remained active for 668; 1,156; 1,626; 2,092, 2,458; and 2,997 rounds respectively, while the proposed protocol remained active for 3,459 rounds. Thus, the percentage increase in network lifetime achieved by the proposed protocol with respect to the MLHEED-1, MLHEED-2, MLHEED-3, MLHEED-4, MLHEED-5, and MLHEED-6 is 80.68%, 66.57%, 52.99%, 39.52%, 28.93%, and 13.35% respectively.

The total energy consumed is 31.2892 J by the proposed protocol which is less than MLHEED-4, 5, and 6 protocols by 7.15%, 12.10%, and 14.975% respectively. The results show that for a different number of rounds, the proposed technique provides better results in terms of network lifetime as well as energy consumption. However, it should be noted that around 20% of this increased energy consumption is a renewable source of energy, and the battery energy consumption is around 30 J (average). Also, the no. of data packets transferred to the base station using the proposed protocol is greater than the MLHEED-6 protocol by 39.03%. The proposed protocol provides better energy efficiency and network lifetime when compared with protocols like mod-LEACH, LEACH, E-MODLEACH, and DEEC. The future scope would be to implement the protocol in different scenarios like in a dynamic environment. Thus, the proposed technique improves the network lifetime and provides efficient energy consumption in a wireless sensor network.

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