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Performance Analysis on Homogeneous LEACH and EAMMH Protocols in Wireless Sensor Network

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Abstract
Wireless sensor network establishes a network with randomly distributed sensor devices that are connected together through some types of wireless communication networks. Such sensors are responsible for recognizing the physical or environmental conditions for multipurpose usability and ease of deployment. This network has some limitations such as prone to network failure, and limited power and capacity of sensor devices. Several routing strategies have been originated by the researchers to improve many applications for such a network. Among the routing techniques, the clustering algorithm can increase the life span and efficiency of the network. The main feature of a cluster-based network is to minimize energy dissipation and delay of the system. This paper investigates the performance of two cluster-based routing protocols namely homogeneous Energy-Aware Multi-Hop Multi-Path Hierarchical (EAMMH), and Low-Energy Adaptive Clustering Hierarchy (LEACH) routing strategies for homogeneous nodes, sink nodes, dead nodes and other common scenarios. In this research paper, we observe that LEACH works better for small networks where there is a small number of nodes, while EAMMH works better for larger networks consisting of a large number of nodes.

Keywords Clustering · Energy efficiency · Homogeneous node · Heterogeneous node · Multi-path · Multi-hop · LEACH · EAMMH

1 Introduction

The constructive development of wireless sensor network (WSN) has become an emerging topic of interest nowadays in the arena of communication. This network has randomly distributed sensors, which transmit their data to sink nodes through the network where data can be accessed and analyzed as shown in Fig. 1. Basically, a sink node is treated as an interface to interact between a user and a network. Using radio signals, one sensor node

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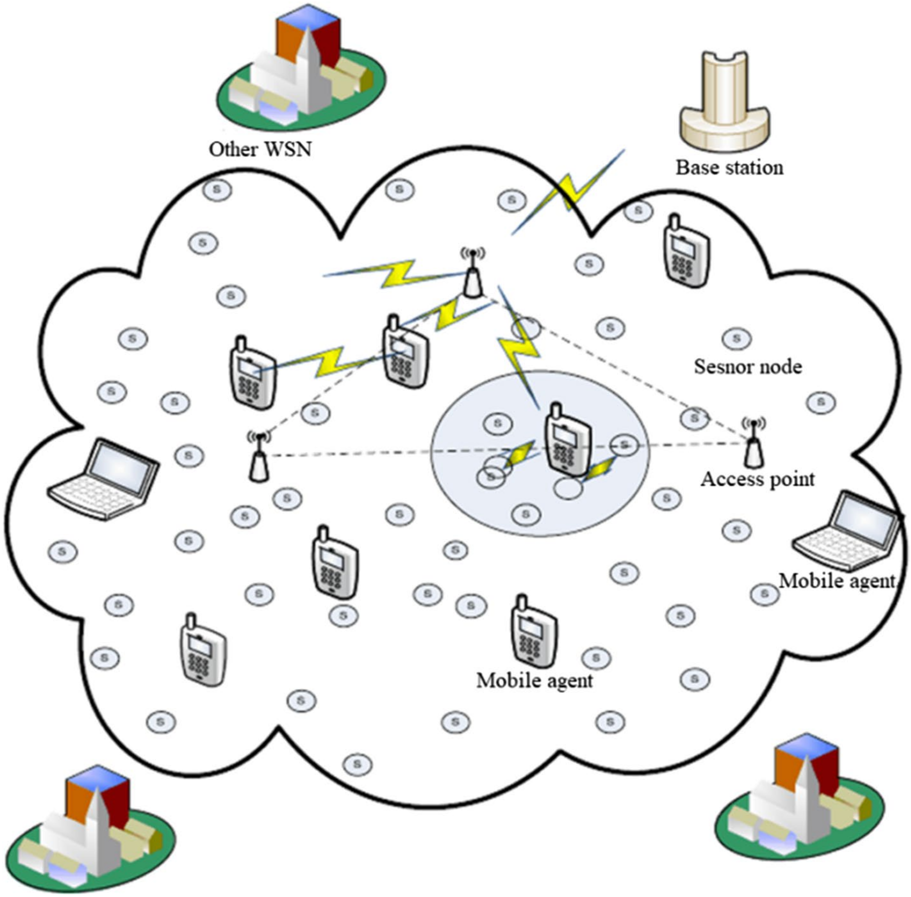


Fig. 1 Wireless sensor network [3]

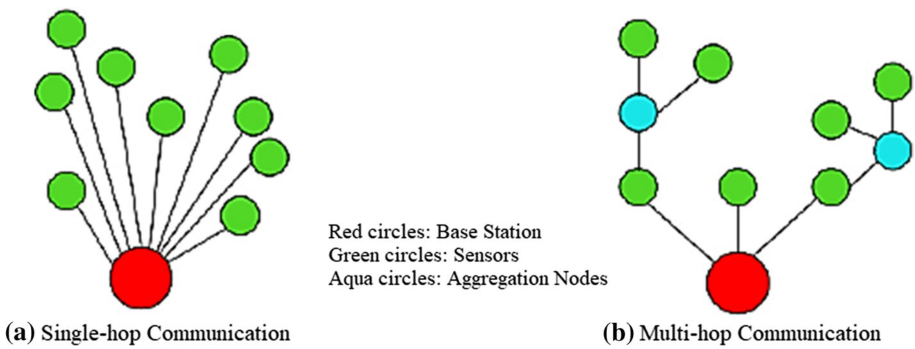


Fig. 2 Single and multi-hop communication [4]

can contact another node. After deploying these nodes, sensors create a suitable infrastructure with multi-hop or single-hop communication (Fig. 2). They also have a lack of power due to the narrow processing speed and storage capacity. To ensure a higher network life span, long-distance communication should be kept away [1, 2].

Clustering is a technique to arrange the nodes in such a way that beneficial energy efficiency is achieved. Nodes within a cluster can transmit their messages to the cluster head (CH) destined for the base station (BS) as demonstrated in Fig. 3. CH helps to share data between BS and nodes [5].

Clustering can be established into two types of networks, i.e., homogeneous and heterogeneous. In WSN, sensor nodes having similar characteristics are called homogeneous nodes and the nodes with different characteristics are known as heterogeneous nodes. Homogeneous nodes are similar in terms of energy stored, memory space, processing capability, etc. While, heterogeneous nodes are dissimilar in one or more features like energy stored, memory space, processing capability, etc. [6]. To upgrade the functioning of various applications in WSN, the dissimilar routing protocols are required. Most of which depend on a single path. Transferring data based on hop increases the overhead on routing table management. This will bring down the overall life span of nodes, which are closed to BS. The established network does not survive. Several approaches are recommended to beat this problem. The clustering approach selects a serving node arbitrarily from sensors and attempts to reach the gateway for the energy usage and expansion of the network [7]. Paper is arranged as follows: Sect. 2 contains an investigation of the basics of LEACH approach. It also covers the key features, advantages, and limitations of LEACH.

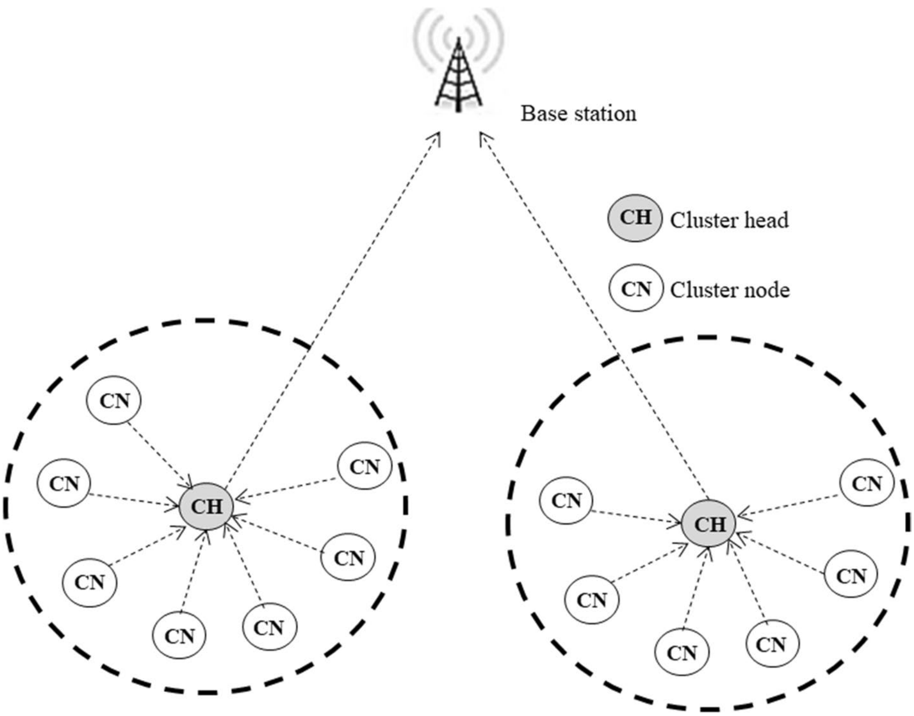


Fig. 3 Clustering in WSN

Section 3 provides a brief description of EAMMH approach. The outcome and discussion are included in Sect. 4. Summary with future activities are written in Sect. 5.

2 Low Energy Adaptive Clustering Hierarchy (LEACH) Routing

LEACH is a clustering-based routing that spreads energy equally to all sensors and increases the life span of the network presented in Fig. 4. It separates the sensor nodes within a cluster. Cluster node is a high energy sensor node, which is chosen randomly based on the probability among the different groups of nodes. Each node decides to join in CH requiring the minimum energy for conveying data. After having organized by all nodes into the cluster, CH generates and manipulates a TDMA schedule and sends the message in CDMA. This approach is cut into rounds. Each round has two steps: set-up and steady-state phase [8].

2.1 Set-Up Phase

The objective of the set-up phase is to create a cluster and choose CH for each cluster by selecting a sensor node with higher energy. Following are the basic steps of this phase:

(a) CH advertisement
(b) Set up a cluster
(c) Creation of broadcast schedule

(a) CH Advertisement

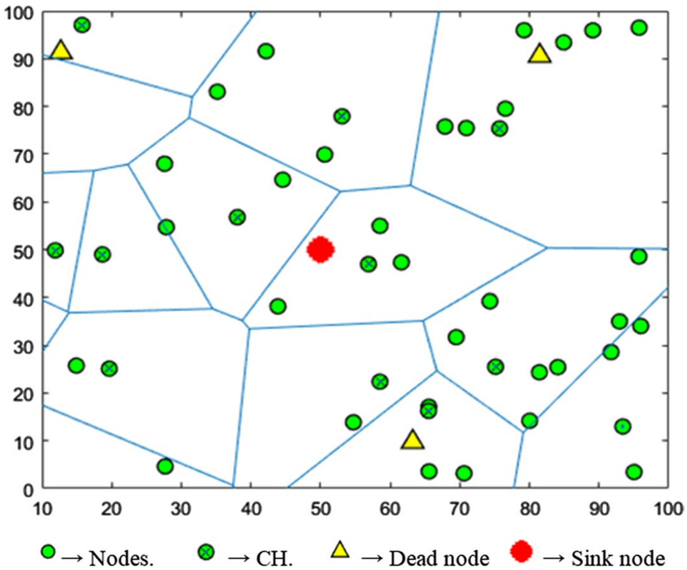


Fig. 4 Homogeneous LEACH protocol

In this phase, when the clusters are formed, each node determines whether it will be a CH for the present round. The finding is made by determining the percentage of CH. A node m makes a conclusion by randomly choosing a value from 0 to 1. If the value is below a fixed threshold, $T(m)$, for the present round, m becomes CH. It can be represented by Eq. 1.

$$T(m) = \begin{cases} \frac{p}{1-p\left(r mod \frac{1}{p}\right)} & if\ m \in G \\ 0 & otherwise \end{cases} \tag{1}$$

where G represents those number of nodes that cannot be considered as CHs in previous $1/p$ rounds, p becomes the percent of CH, r denotes the present round. A node can be CH only in 1 round and cannot be in the next $1/p$. A node named itself as CH transmits the message to all nodes in the network about its role. The non-CH nodes must retain their recipients and receive this advertisement. For the present round, a particular cluster is formed by the sensor nodes after getting that message. The formation of a cluster is related to the frequency of received signals. The non-CH nodes having higher signal strength enter into CH. Therefore, lower energy is needed to interact between non-CH and CH nodes.

(b) Set up a cluster

Here, the non-CH nodes collect the CH declaration and send the request to that CH where they are a member of a group under the CH. Non-CH nodes reserve much energy when the transmitter is closed at all times.

(c) Creation of broadcast schedule

Upon getting a message from all the nodes wanting to be included in the cluster, the CH is arising a TDMA schedule on the basis of the number of nodes and notifying the nodes when to send data [9].

2.2 Steady-State Phase

Here, cluster nodes transmit the message to the CH. Data transfer begins after forming a cluster and TDMA schedules. A node transmits data to CH within the allocated time schedule. The nodes are in a sleep state to the rest of the time to minimize energy consumption. Sensor nodes and CH can communicate with each other using single-node data transmission. By aggregating all the received data, CH transmits the message to the sink node. After the pre-determined time, the network returns to the previous phase, i.e., the set-up phase. LEACH does not require managing information from the sink node. Nodes also do not require knowing the network where the routing techniques are operated [10]. But, for big networks, it is not satisfactory.

2.3 Characteristics of LEACH

LEACH has the following features [8, 11]:

1. It is a cluster-based protocol.
2. Its operation is cut into rounds.
3. CH is chosen randomly per round.
4. CH must have greater energy than all sensor nodes in a cluster. CH collects data from member nodes. Then, it sums and compresses to transmit.

5. CH and Sink node establishes a single-hop transmission.
6. Nodes create contact with CH by applying TDMA.

2.4 Advantages of LEACH

LEACH has some important advantages as mentioned below:

1. It is distributed.
2. It does not require any control information from BS.
3. Nodes do not require knowledge of the wide network.
4. It distributes the load equally among all the nodes within the cluster.
5. There is no collision in CH for using TDMA.
6. Energy consumption is minimized due to the completion of communication within the fixed schedule.

2.5 Disadvantages of LEACH Protocol

There are some disadvantages of LEACH as below:

1. This protocol performs single-hop communication. For this reason, it is not supported by large networks.
2. If there is different initial energy then the load will not be equal for every member node in the cluster.

3 Energy-Aware Multi-hop Multi-path Hierarchical (EAMMH) Routing

EAMMH is an energy-aware and multi-hop intra-cluster hierarchical pathway protocol where the hierarchy level relies on network size [12].

3.1 Functioning of EAMMH

Figure 5 illustrates the homogeneous EAMMH approach [13, 14]. It is mostly heuristic because it executes the hop process depending on the energy left by the adjacent nodes. The functioning of EAMMH has been discussed with the help of a flowchart shown in Fig. 6. The client must provide input in the form of the number of nodes. These nodes have a finite amount of nodal energy. Their positions are allocated and displayed randomly for the nodes generated. Once the nodes are deployed, each node can discover its neighboring nodes using the neighbor discovery algorithm. After that, a cluster is selected on which the nodes will join. To extend the Wireless Network's lifetime, this approach avoids the choice of those sensor nodes, which have low energy during data transmission. This approach transmits data in different paths and continues the data communication depending on the nodal energy. It gathers data from different neighboring nodes using a table, which holds all the details like the node's data, energy, hop count, and signal strength. Updating this table with time, data transfer is possible from one node to another using a multi-hop structure. In this way, this routing generates a path when necessary to minimize the load of communication. The cluster head is selected to collect the information from all other member

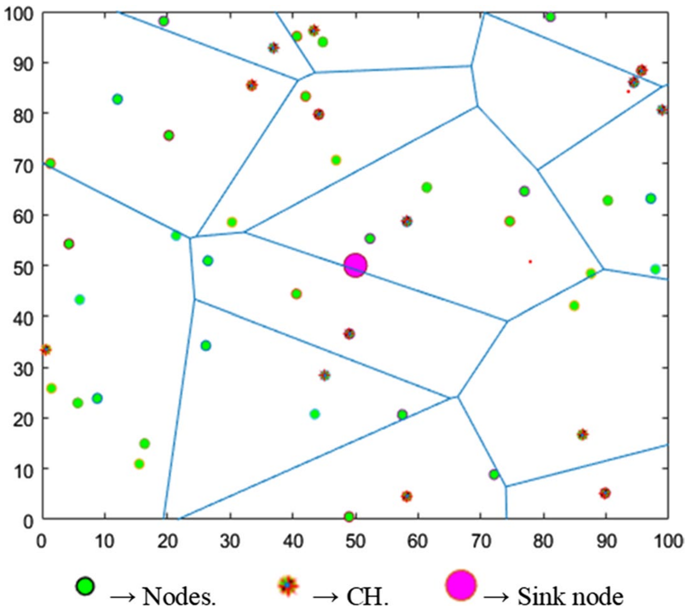


Fig. 5 Homogeneous EAMMH protocol

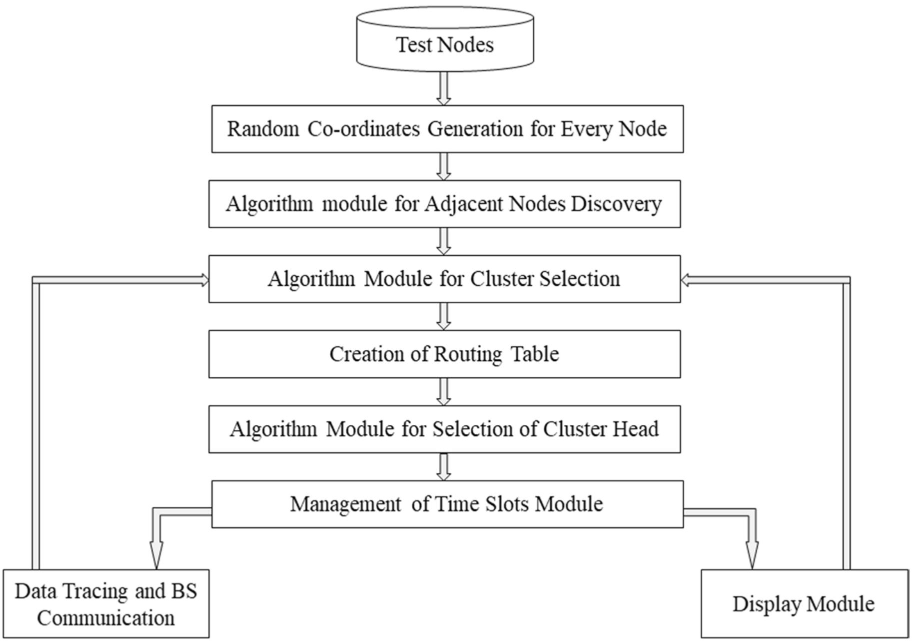


Fig. 6 Flowchart of EAMMH protocol

nodes. Multiple nodes may share the same frequency channel by splitting the signal into different time slots. Then, the cluster head aggregates the information and transmits it to the base station. EAMMH approach is cut into rounds. Each round starts with-

- Set-up phase where clusters are arranged.
- The steady-state phase where information travels to the BS.

3.1.1 Setup Phase

Here, the discovery of neighboring nodes takes place just after deploying the nodes. This procedure is conducted using various processes like the k-of-n method, beacon messaging, etc. Then, the adjacent nodes are discovered and a cluster is created after the selection of CH by nodes for the present round. The randomly chosen number by the nodes can be CH if the number is less than $T(m)$, which can be found by Eq. 1.

3.1.2 Steady-State Phase (Data Transmission Phase)

Here, time slots are assigned for each sensor node and data are transferred at regular intervals. Nodes follow a heuristic method for efficient data transmission by Eq. 2.

$$H = K(E_{avg}/h_{min} \times t) \tag{2}$$

where E_{avg} indicates the mean energy of the present path, K is a fixed value, t denotes traffic in the present route, h_{min} means the minimum hop count.

$$E_{min} = E_{avg}/K \tag{3}$$

The value of E_{min} is accepted as the highest heuristic value if it is less than $T(m)$.

3.1.3 Periodic Update

After a while, information about the path and route table enters into each node and it becomes stale. Estimated values calculated on outdated information often cause erroneous judgments. Nodes are therefore required to be supplied with the latest information from time to time [15]. This will increase the accuracy and timing of the heuristics function. The necessary information exchange is done at regular intervals [16].

4 Results and Discussion

In this section, the considered protocols have been coded and simulated using MATLAB. Following parameters have been selected to compare these protocols:

- The number of round versus average energy of each node (with varying probability).
- Round number versus the number of dead nodes (with varying probability).
- The number of round versus average energy (with varying nodes) of each node.

- The number of round versus dead nodes (with varying nodes).

4.1 Assumptions

Some concepts have been made to simplify the simulation process of these two protocols. These are:

- There are homogeneous nodes in the network.
- Nodes have the same initial energy.
- Nodes have to always forward the information.
- Nodes failure due to electrical fatigue.

4.2 Simulation Parameters

We have set up the following simulation details as shown in Table 1.

4.3 Simulation on Different Probabilities

We have analyzed the performance of homogeneous LEACH and EAMMH routing techniques using different probabilities, e.g., 0.05, 0.1, 0.2 and 0.4.

4.3.1 Simulation on 0.05 Probability

Homogeneous LEACH and EAMMH approaches are simulated on the probability of 0.05, which are shown in Figs. 7, 8, 9 and 10. This means that 5% of the total nodes can be used as CH. Figures represent the average energy of each node against 100 rounds, which consist of 50, 100, 150 and 200 nodes, respectively.

Table 1 Simulation setup

Parameters	Values
Simulation area	100 * 100
Base station location	(150,50)
Channel type	Wireless channel
Energy model	Battery
Initial energy (E_o)	0.1 J
Packet size	4000 bits
The probability to be a CH	0.05, 0.1, 0.2, 0.4
Probability of special nodes (m)	0.0
Efs	10 pJ
Emp	0.0013 pJ
Data aggregation energy (EDA)	5 nJ/bit
Transmission energy (ETX)	50 nJ/bit
Receiving energy (ERX)	50 nJ/bit

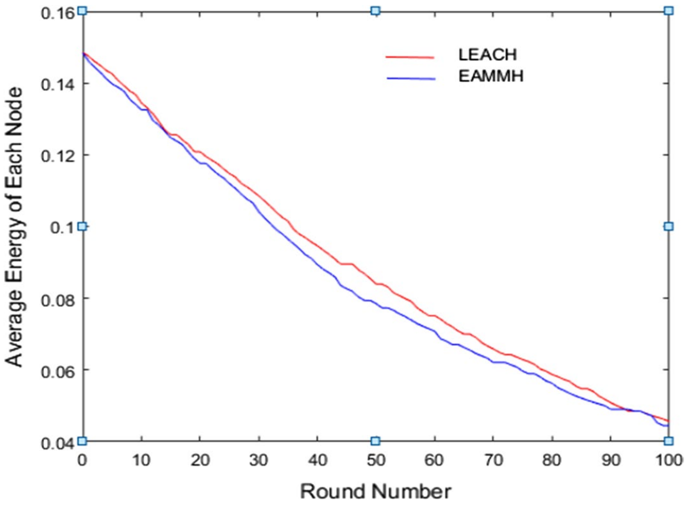


Fig. 7 Average energy for 50 nodes

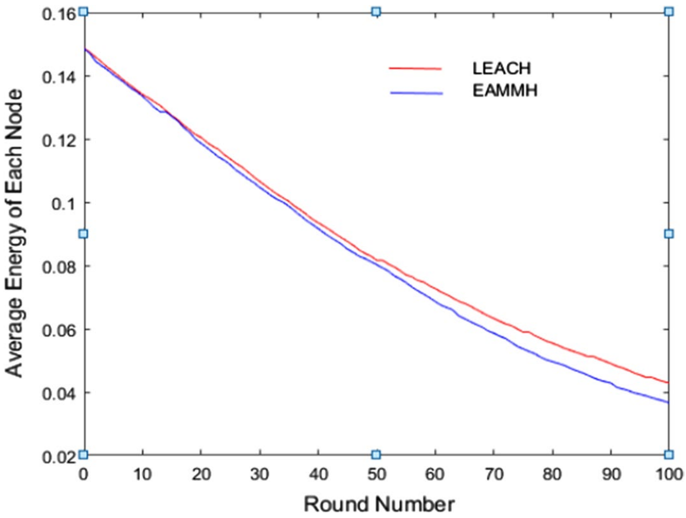


Fig. 8 Average energy for 100 nodes

In Figs. 7 and 8, the average energy of each node in LEACH and EAMMH is nearly closer to each other and LEACH has slightly better average energy. With the increase of the number of nodes, two approaches are very close but still, EAMMH has slightly better average energy than LEACH protocol as shown in Figs. 9 and 10.

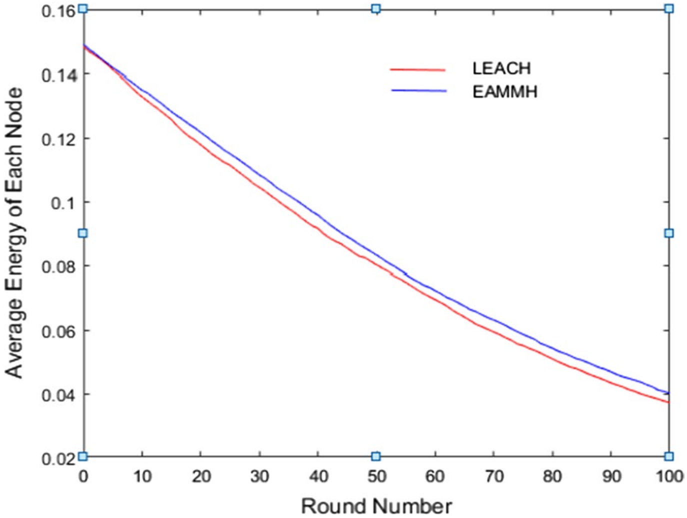


Fig. 9 Average energy for 150 nodes

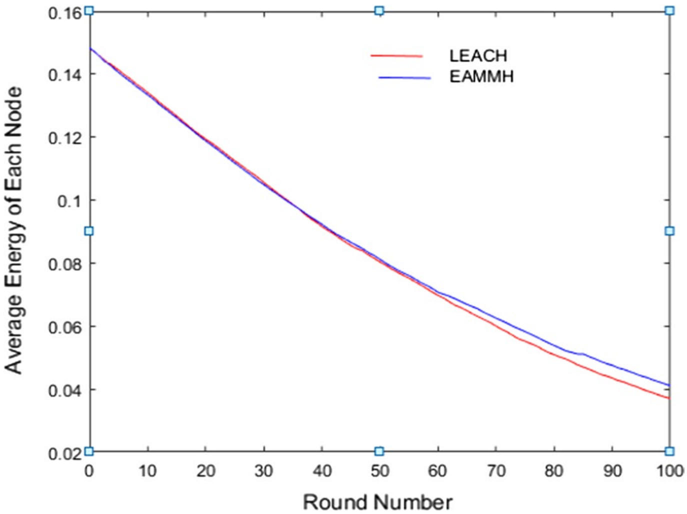


Fig. 10 Average energy for 200 nodes

Figures 11, 12, 13 and 14 represent the number of dead nodes for both approaches against the round numbers for varying the number of nodes, i.e., 50, 100, 150 and 200. Figure 11 represents that LEACH generates fewer dead nodes than EAMMH. With the increase of the number of nodes, EAMMH provides fewer dead nodes than LEACH as shown in Figs. 12, 13 and 14.

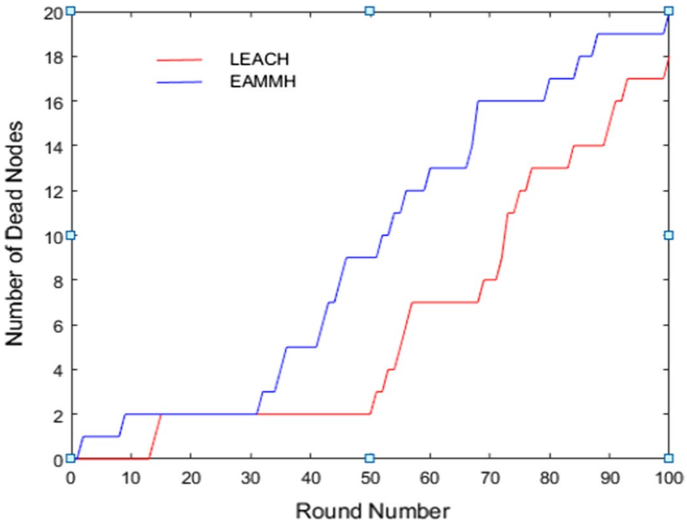


Fig. 11 Number of dead nodes for 50 nodes

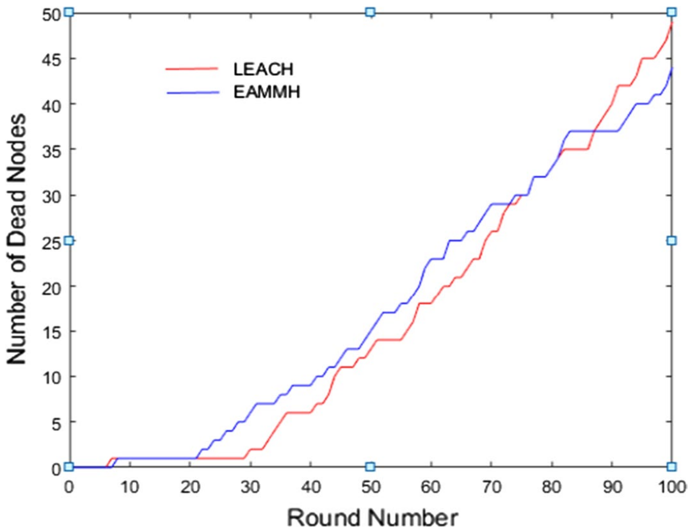


Fig. 12 Number of dead nodes for 100 nodes

4.3.2 Simulation on 0.1 Probability

The homogeneous LEACH and EAMMH routing protocols are simulated on the probability of 0.1, which are shown in Figs. 15, 16, 17 and 18. Actually, this indicates that 10% of the total number of nodes can be acted as CH. Figures represent the average energy of each node against the round numbers for varying the number of nodes, i.e., 50, 100, 150 and 200. Figures 15, 16 and 17 represent that EAMMH has better average

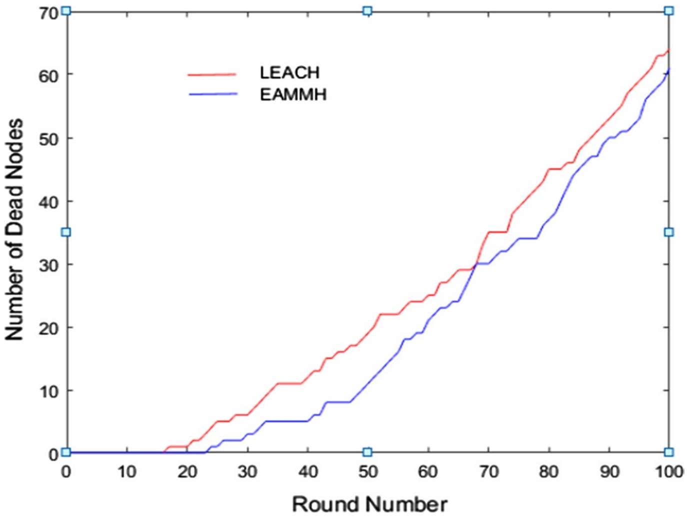


Fig. 13 Number of dead nodes for 150 nodes

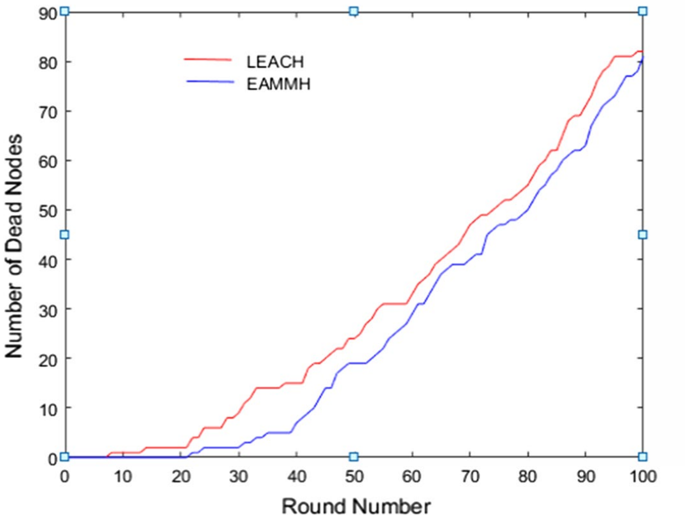


Fig. 14 Number of dead nodes for 200 nodes

energy than LEACH. In Fig. 18, the average energy of two approaches is very close to each other but still, EAMMH has slightly better average energy than LEACH.

Figures 19, 20, 21 and 22 represent the number of dead nodes against round numbers for varying the number of nodes, i.e., 50, 100, 150 and 200. Figure 19 shows that EAMMH generates fewer dead nodes than LEACH. Figure 20 shows that LEACH generates fewer dead nodes than EAMMH but with the increase of nodes, EAMMH generates fewer dead nodes than LEACH as shown in Figs. 21 and 22.

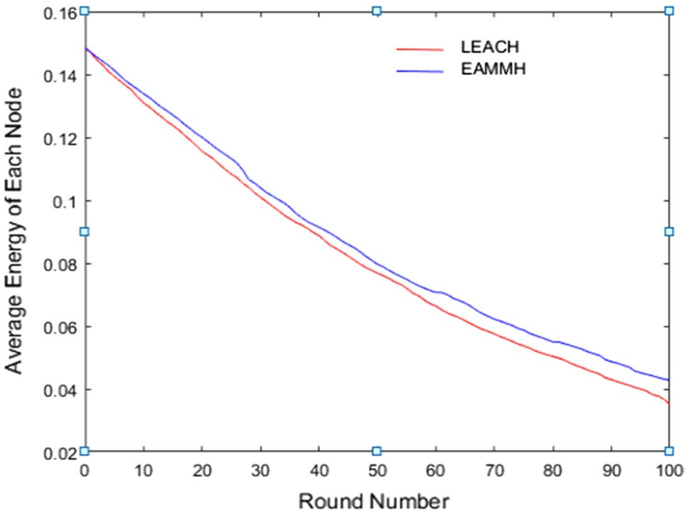


Fig. 15 Average energy for 50 nodes

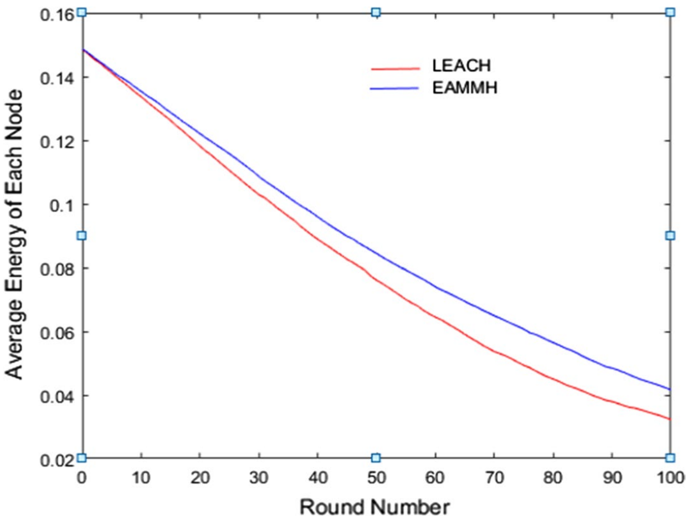


Fig. 16 Average energy for 100 nodes

4.3.3 Simulation on 0.2 Probability

The homogeneous LEACH and EAMMH routing protocols are simulated on the probability of 0.2, which are shown in Figs. 23, 24, 25 and 26. Actually, this probability indicates that 20% of the total number of nodes can be acted as CH. Figures represent the average energy of each node against the round numbers for varying the number of nodes, i.e., 50, 100, 150 and 200. Figure 23 shows that LEACH has better average

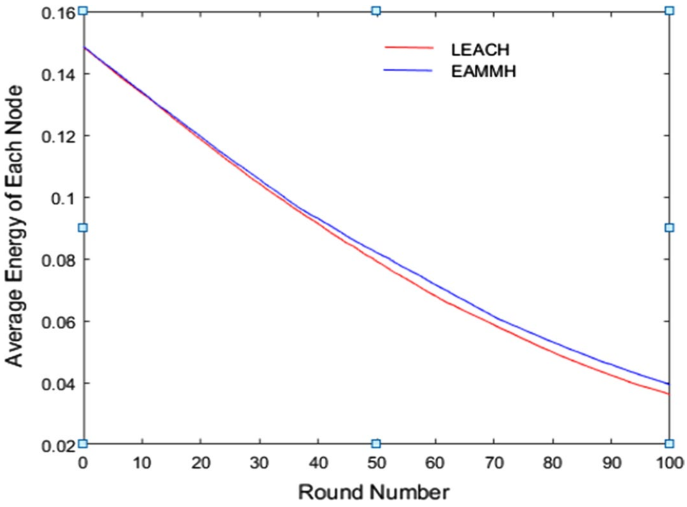


Fig. 17 Average energy for 150 nodes

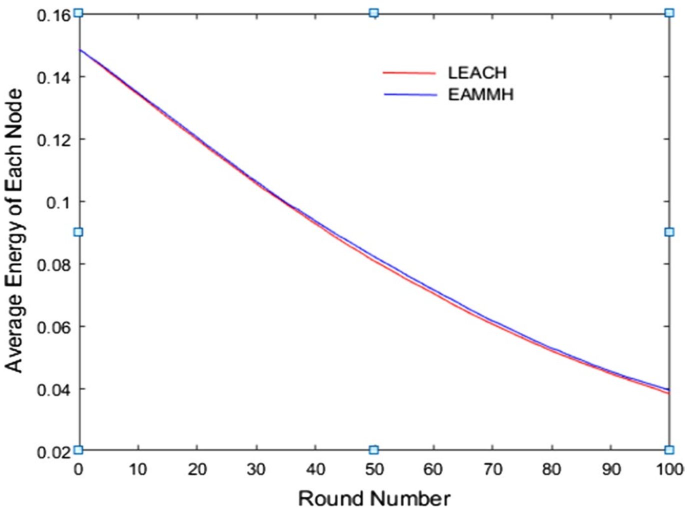


Fig. 18 Average energy for 200 nodes

energy than EAMMH. In Fig. 24, the average energy of each node in both protocols is very close but, EAMMH has slightly greater energy than LEACH. Figures 25 and 26 represent that EAMMH has better average energy than LEACH.

Figures 27, 28, 29 and 30 represent the number of dead nodes against the round numbers for varying the number of nodes, i.e., 50, 100, 150 and 200. Figure 27 shows that LEACH and EAMMH generate 17 and 25 dead nodes, respectively. So, LEACH generates less dead nodes. But, in Figs. 28, 29 and 30, EAMMH has fewer dead nodes than LEACH.

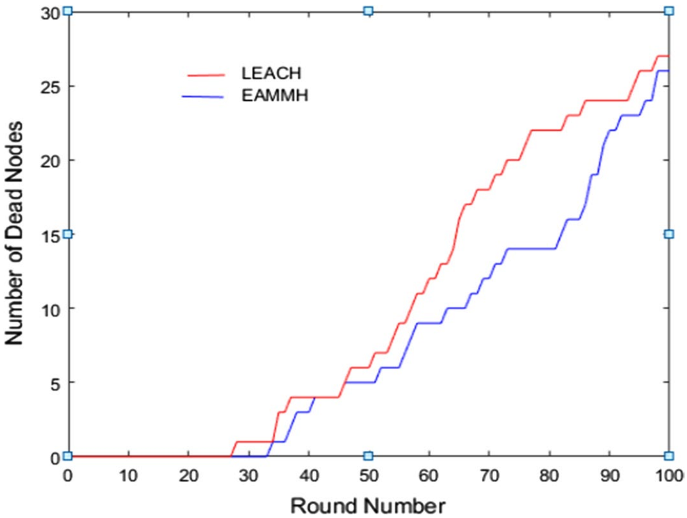


Fig. 19 Number of dead nodes for 50 nodes

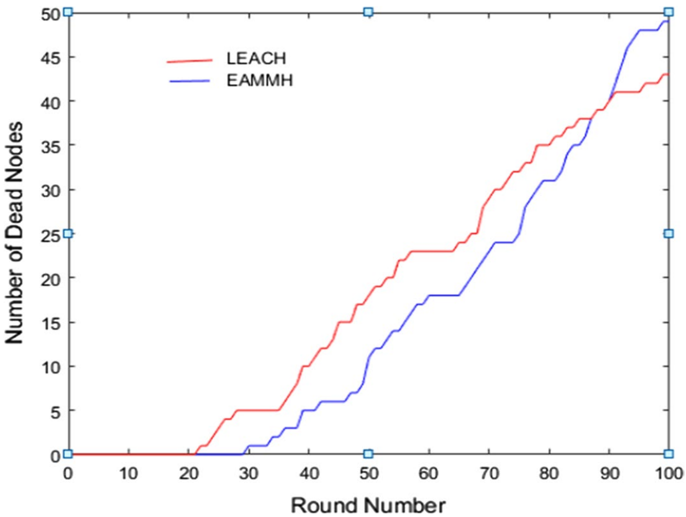
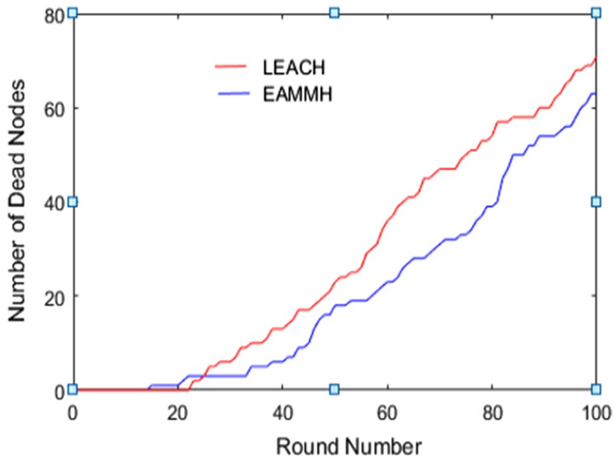


Fig. 20 Number of dead nodes for 100 nodes

4.3.4 Simulation on 0.4 Probability

The homogeneous LEACH and EAMMH routing protocols are simulated on the probability of 0.4, which are shown in Figs. 31, 32, 33 and 34. The probability indicates that 40% of the total number of nodes can be acted as CH. Figures represent the average energy of each node against the round numbers for varying the number of nodes 50, 100, 150 and 200. In Fig. 31, EAMMH has a slightly lower average energy than LEACH. Figure 32 shows that the average energy of each node of both protocols is very

Fig. 21 Number of dead nodes for 150 nodes



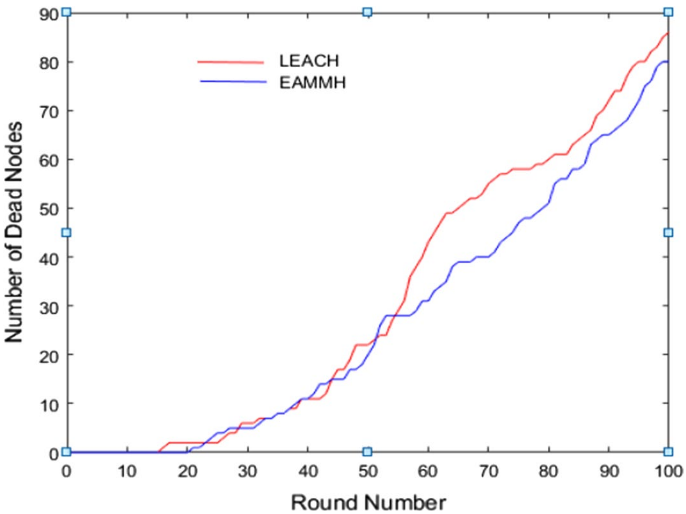


Fig. 22 Number of dead nodes for 200 nodes

close but, EAMMH has slightly greater average energy. Figures 33 and 34 represent that EAMMH has better average energy than LEACH.

Figures 35, 36, 37 and 38 represent the number of dead nodes against the round numbers for varying the number of nodes, i.e., 50, 100, 150 and 200. Figures 35 and 36 show that LEACH generates less dead nodes than EAMMH. In Fig. 37, the dead nodes generated by LEACH and EAMMH are 54 and 55, respectively. So, LEACH generates less dead nodes. For the higher number of nodes, EAMMH generates fewer dead nodes than LEACH as shown in Fig. 38.

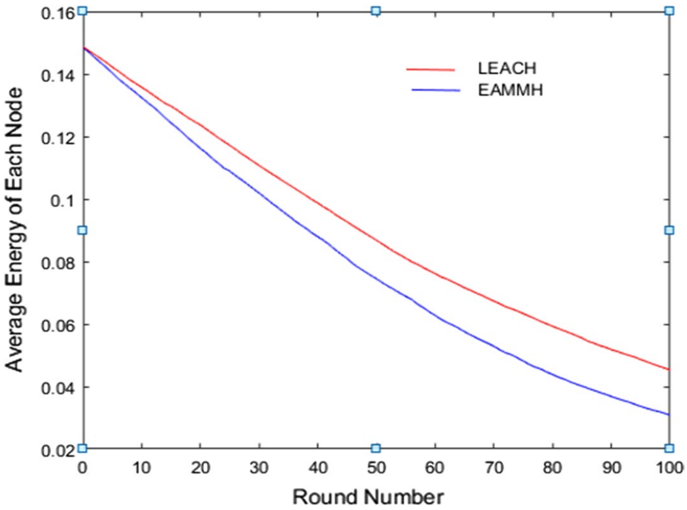


Fig. 23 Average energy for 50 nodes

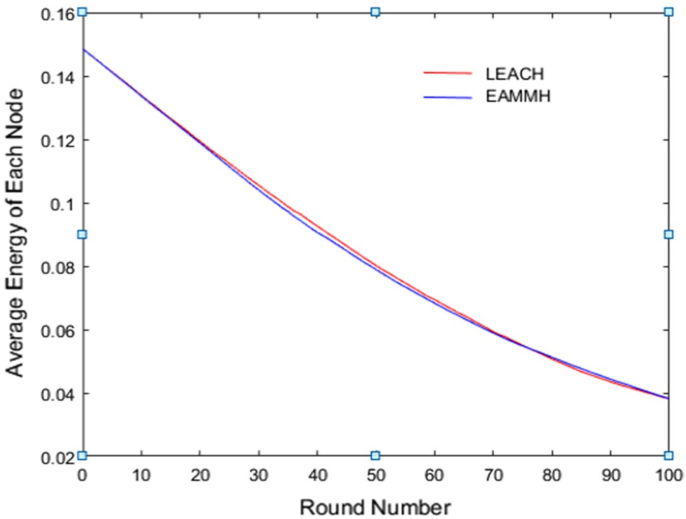


Fig. 24 Average energy for 100 nodes

4.4 Analysis of Homogeneous LEACH and EAMMH Protocols with the Comparison of Different Nodes at Different Probabilities

Figures 39, 40, 41, and 42 represent the analysis of homogeneous LEACH and EAMMH protocols for varying the number of nodes, i.e., 50, 100, 150 and 200 at 100 rounds. These figures represent the average energies for varying the considered nodes. These statistical figures have been used to represent the overall comparison discussed in Sect. 4.5.

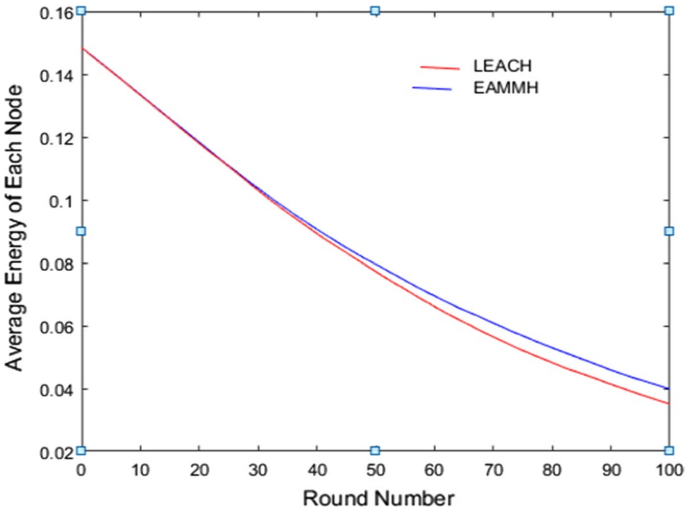


Fig. 25 Average energy for 150 nodes

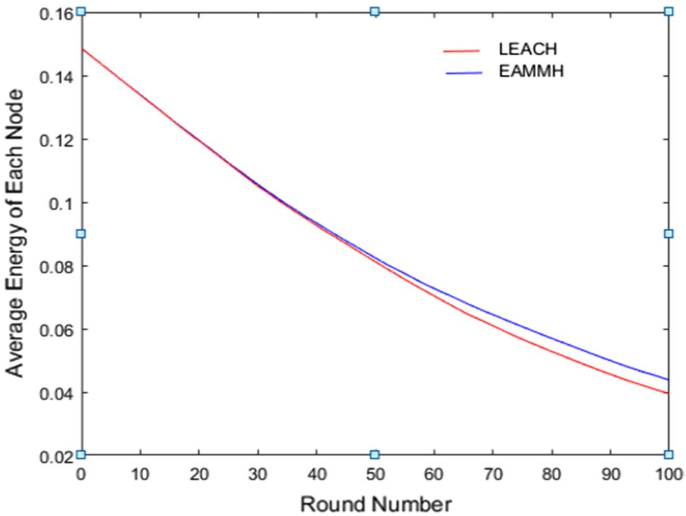


Fig. 26 Average energy for 200 nodes

The dead nodes for 50, 100, 150 and 200 nodes at the probabilities of 0.05, 0.1, 0.2 and 0.4 can be seen from the statistical Figs. 43, 44, 45 and 46. These statistical figures have been used to represent the overall comparison discussed in Sect. 4.5.

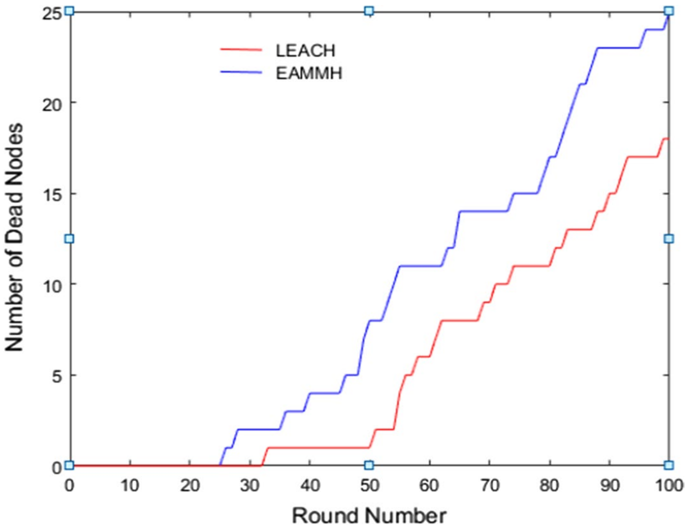


Fig. 27 Number of dead nodes for 50 nodes

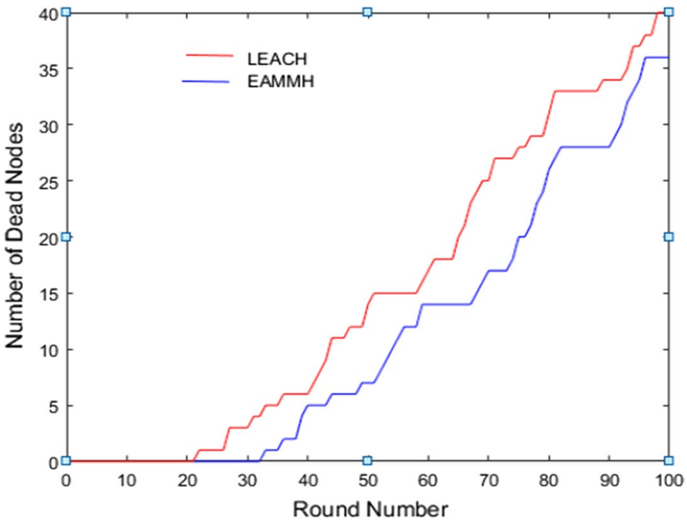


Fig. 28 Number of dead nodes for 100 nodes

4.5 Overall Comparison Between Homogeneous LEACH and EAMMH Protocols for Different Nodes

Tables 2, 3, 4 and 5 represent the summarization of simulation results of homogeneous LEACH and EAMMH routing protocols for different nodes on various probabilities. Through these tables, we can simply understand the performance of these two protocols.

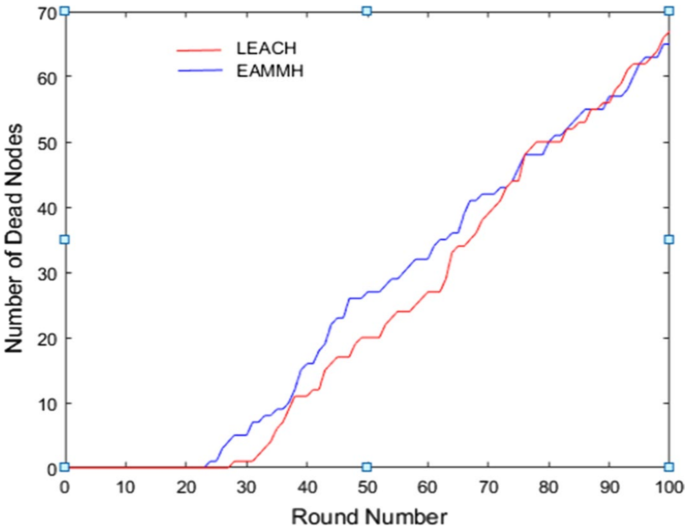


Fig. 29 Number of dead nodes for 150 nodes

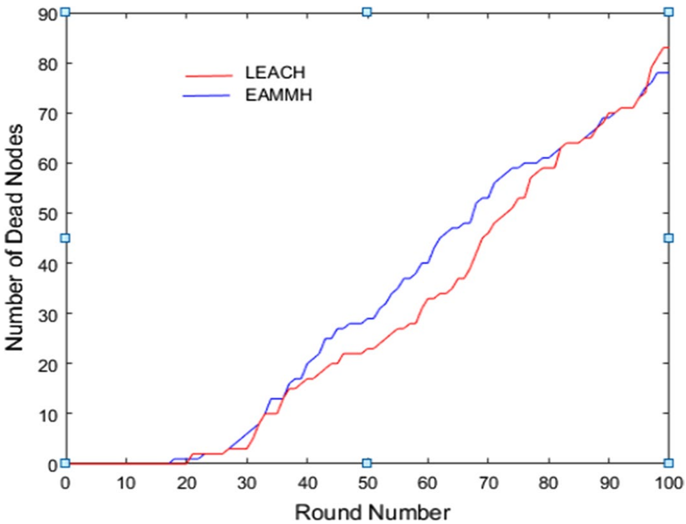


Fig. 30 Number of dead nodes for 200 nodes

A protocol works better for a network when it has fewer dead nodes and high average energy. From the above Tables 2, 3, 4, and 5, it is clear that homogeneous LEACH provides better performance for 50 nodes at 0.05 and 0.2 probabilities. That is, a homogeneous LEACH protocol is applicable for a small network. On the other hand, homogeneous EAMMH is applicable for 50 nodes at 0.1 probability, 100 nodes at 0.2 probability, 150 nodes at 0.05, 0.1 and 0.2 probabilities, and 200 nodes at 0.05, 0.1, 0.2 and 0.4 probabilities. That is, EAMMH is appropriate for large networks.

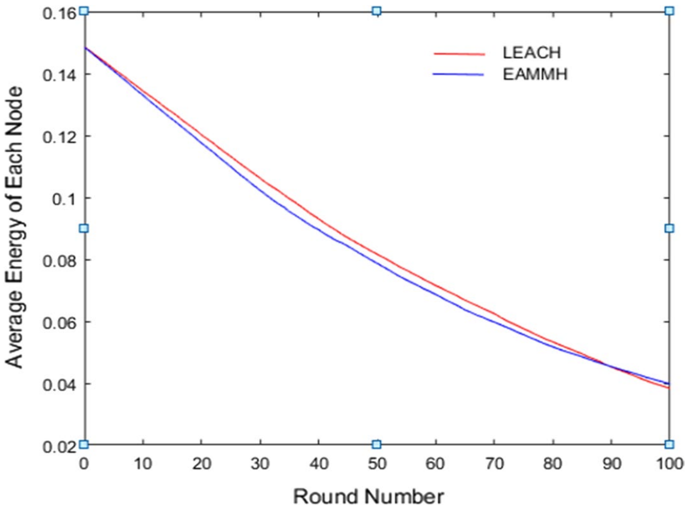


Fig. 31 Average energy for 50 nodes

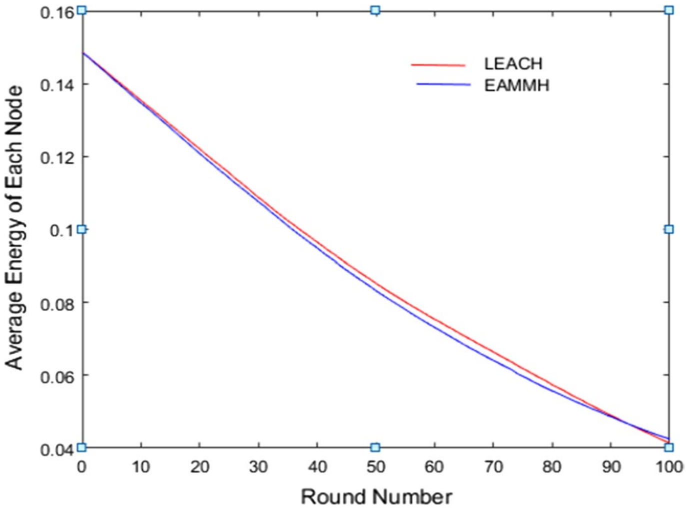


Fig. 32 Average energy for 100 nodes

4.6 Analysis from Excel Sheets Imported into MATLAB

This analysis can also be seen from the excel sheet, which is imported into MATLAB for getting the graphs to understand the performance of these two protocols.

Figure 47 shows the dead nodes of LEACH and EAMMH protocols for 100 rounds and 200 nodes at the probabilities of 0.05, 0.1, 0.2 and 0.4. From Fig. 47, it is seen that at every probability, LEACH generates higher dead nodes than EAMMH. As it is a large network with 200 nodes, LEACH does not work well in it. So, EAMMH provides better performance than LEACH.

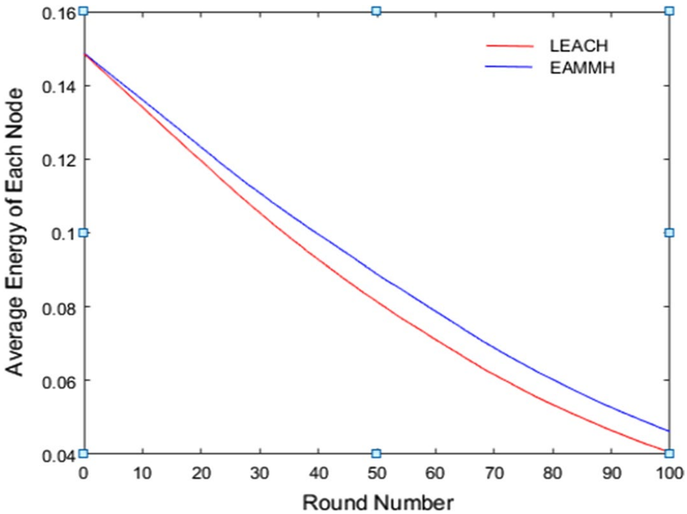


Fig. 33 Average energy for 150 nodes

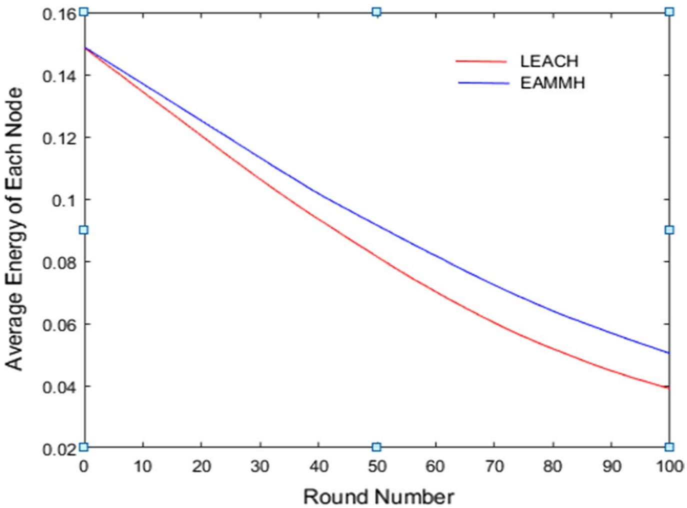


Fig. 34 Average energy for 200 nodes

Figure 48 shows the average energy of LEACH and EAMMH protocols for 100 rounds and 200 nodes with the probabilities of 0.05, 0.1, 0.2 and 0.4. From Fig. 48, it is seen that at every probability, LEACH has lower average energy than EAMMH. EAMMH has a higher average energy for each of the nodes. That is, EAMMH provides better performance than LEACH. Moreover, we also notice that the sensors, which are far away from the sink node or the BS, come out of energy faster than others, which are close to BS. The reason is that the nodes or CHs, which are away from BS, have to spread a large amount of energy for forwarding data to travel long distances.

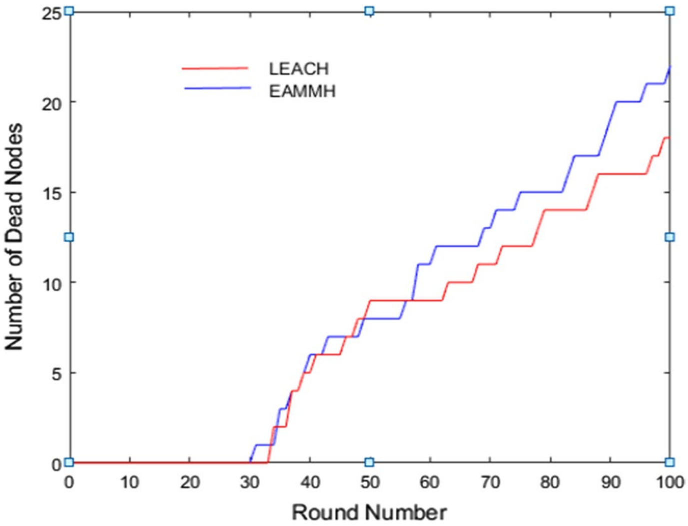


Fig. 35 Number of dead nodes for 50 nodes

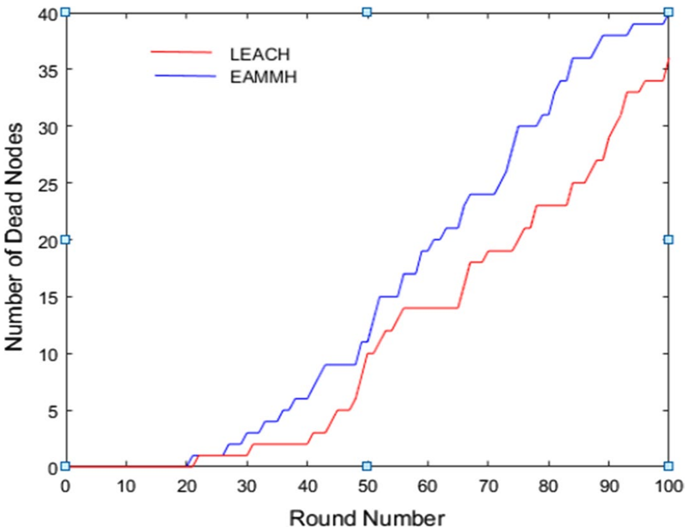
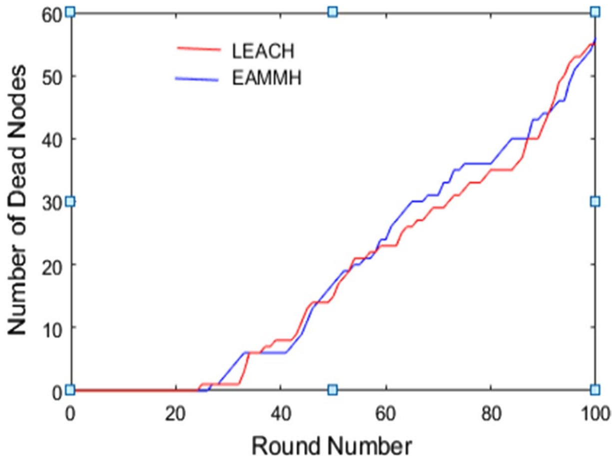


Fig. 36 Number of dead nodes for 100 nodes

5 Conclusion and Future Works

Reduction in energy dissipation without the incorrect interpretation of accuracy of the information transmission is a key principle of wireless sensor networks. For this reason, many methods are needed to manage the network in a proper manner. With these low powered sensors, the main challenge of this network is to increase energy efficiency, increase network life span and minimize the delay of the system to run the network for a longer

Fig. 37 Number of dead nodes for 150 nodes



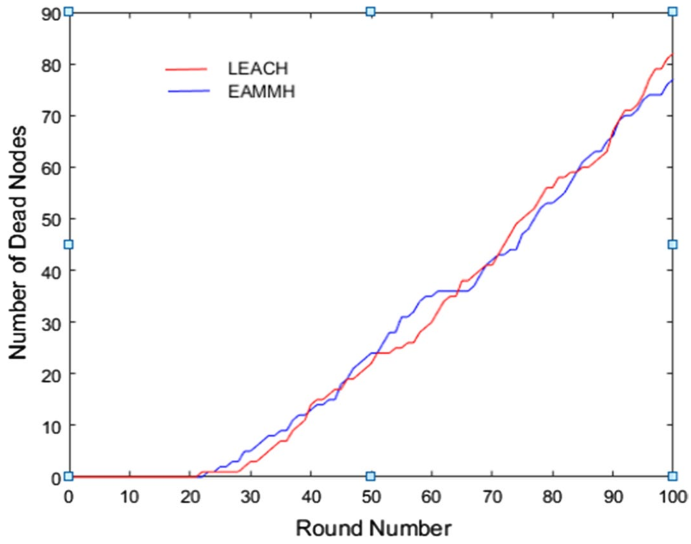
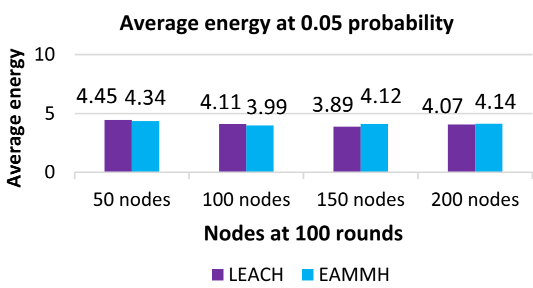


Fig. 38 Number of dead nodes for 200 nodes

Fig. 39 Average energy for 50, 100, 150 and 200 nodes at 0.05 probability



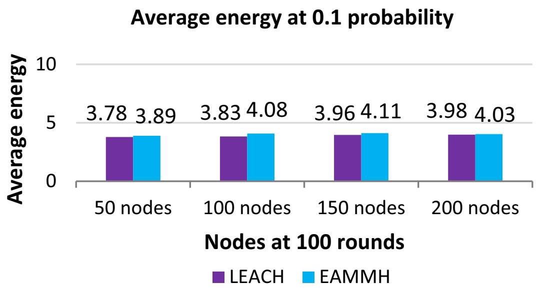


Fig. 40 Average energy for 50, 100, 150 and 200 nodes at 0.1 probability

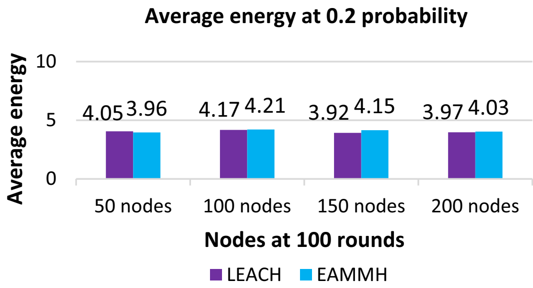


Fig. 41 Average energy for 50, 100, 150 and 200 nodes at 0.2 probability

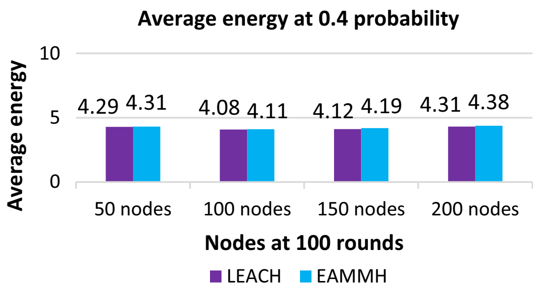


Fig. 42 Average energy for 50, 100, 150 and 200 nodes at 0.4 probability

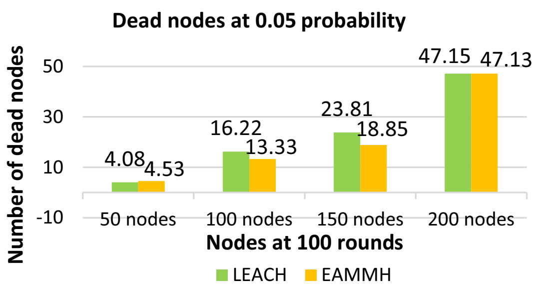


Fig. 43 Number of dead nodes for 50, 100, 150 and 200 nodes at 0.05 probability

Fig. 44 Number of dead nodes for 50, 100, 150 and 200 nodes at 0.1 probability

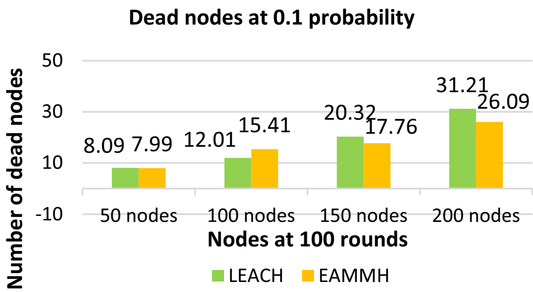


Fig. 45 Number of dead nodes for 50, 100, 150 and 200 nodes at 0.2 probability

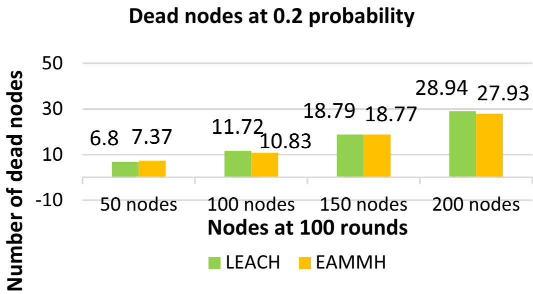
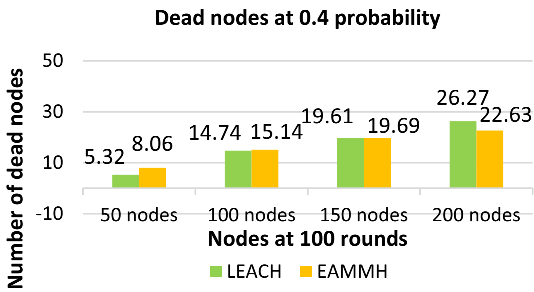


Fig. 46 Number of dead nodes for 50, 100, 150 and 200 nodes at 0.4 probability



time. This paper presents clustering as a method to defeat the difficulties of energy efficiency and provides a brief analysis of homogeneous LEACH and EAMMH routing protocols. It also presents the details about the simulation and its results. It has been observed from the analysis of simulations that LEACH can be applied to small network opportunities where the total number of nodes can be 50 and in this situation, it performs slightly better than EAMMH. EAMMH has better results compared to LEACH because EAMMH has a cross-section routing process that will help keep the network alive for long periods of time. With multi-path and hierarchical routing parameter mechanisms, EAMMH can have better energy efficiency than LEACH where there are large numbers of nodes in the network. In this paper, the analysis between homogeneous LEACH and EAMMH protocols is done by using MATLAB. In the future, we would like to do the analysis of homogeneous and heterogeneous routing protocols using OMNeT++ and compare the simulations

Table 2 Comparison between homogeneous LEACH and EAMMH protocols for 50 nodes

Probability	Homogeneous LEACH protocol		Homogeneous EAMMH protocol	
	Dead nodes for 100 rounds	Average energy for 100 rounds	Dead nodes for 100 rounds	Average energy for 100 rounds
Probability of 0.05	Less dead nodes	Slightly higher than EAMMH	High dead nodes	Slightly lower than LEACH
Probability of 0.1	Slightly higher than EAMMH	Lower than EAMMH	Slightly lower than LEACH	Higher than LEACH
Probability of 0.2	Less dead nodes	Higher than EAMMH	High dead nodes	Lower than LEACH
Probability of 0.4	Less dead nodes	Slightly lower than EAMMH	High dead nodes	Slightly higher than LEACH

Table 3 Comparison between homogeneous LEACH and EAMMH protocols for 100 nodes

Probability	Homogeneous LEACH protocol		Homogeneous EAMMH protocol	
	Dead nodes for 100 rounds	Average energy for 100 rounds	Dead nodes for 100 rounds	Average energy for 100 rounds
Probability of 0.05	High dead nodes	Higher than EAMMH	Less dead nodes	Lower than LEACH
Probability of 0.1	Less dead nodes	Lower than EAMMH	High dead nodes	Higher than LEACH
Probability of 0.2	High dead nodes	Slightly lower than EAMMH	Less dead nodes	Slightly higher than LEACH
Probability of 0.4	Less dead nodes	Slightly lower than EAMMH	High dead nodes	Slightly higher than LEACH

Table 4 Comparison between homogeneous LEACH and EAMMH protocols for 150 nodes

Probability	Homogeneous LEACH protocol		Homogeneous EAMMH protocol	
	Dead nodes for 100 rounds	Average energy for 100 rounds	Dead nodes for 100 rounds	Average energy for 100 rounds
Probability of 0.05	High dead nodes	Lower than EAMMH	Less dead nodes	Higher than LEACH
Probability of 0.1	High dead nodes	Lower than EAMMH	Less dead nodes	Higher than LEACH
Probability of 0.2	Slightly high dead nodes	Lower than EAMMH	Slightly less dead nodes	Higher than LEACH
Probability of 0.4	Slightly low dead nodes	Lower than EAMMH	Slightly high dead nodes	Higher than LEACH

Table 5 Comparison between homogeneous LEACH and EAMMH Protocols for 200 Nodes

Probability	Homogeneous LEACH protocol		Homogeneous EAMMH protocol	
	Dead nodes for 100 rounds	Average energy for 100 rounds	Dead nodes for 100 rounds	Average energy for 100 rounds
Probability of 0.05	Slightly high dead nodes	Lower than EAMMH	Slightly less dead nodes	Higher than LEACH
Probability of 0.1	High dead nodes	Slightly lower than EAMMH	Less dead nodes	Slightly higher than LEACH
Probability of 0.2	High dead nodes	Lower than EAMMH	Less dead nodes	Higher than LEACH
Probability of 0.4	High dead nodes	Lower than EAMMH	Less dead nodes	Higher than LEACH

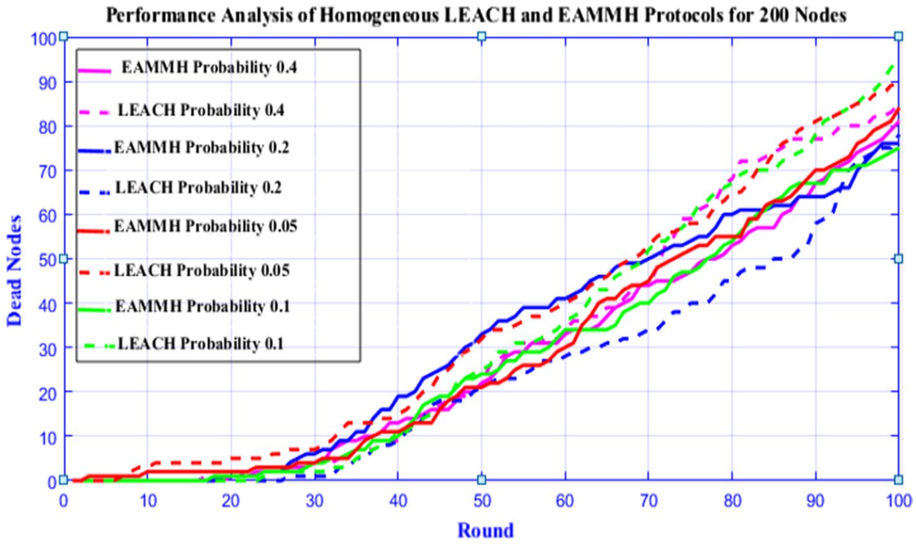


Fig. 47 Performance analysis of homogeneous LEACH and EAMMH protocols for 200 nodes at 0.05, 0.1, 0.2 and 0.4 probabilities (for dead nodes)

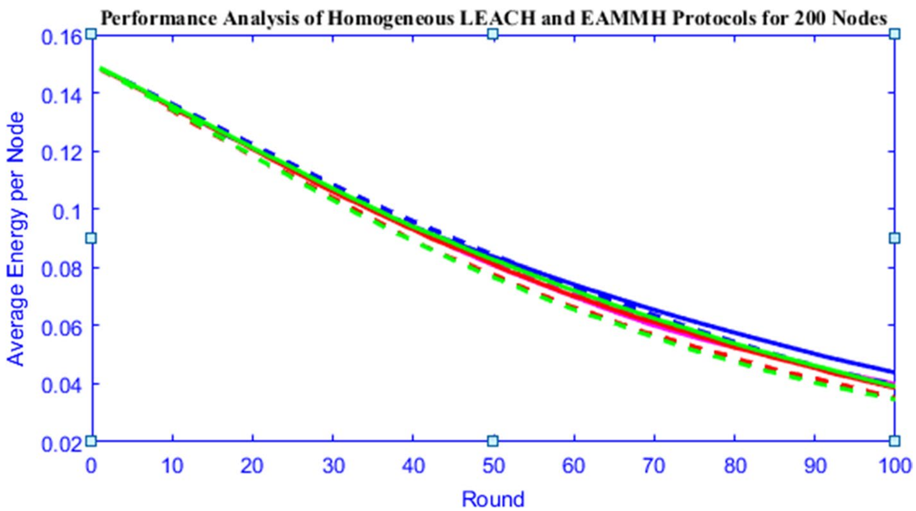


Fig. 48 Performance analysis of homogeneous LEACH and EAMMH protocols for 200 nodes at 0.05, 0.1, 0.2 and 0.4 probabilities (for average energy)

between MATLAB and OMNeT++. Moreover, we would like to propose a new model for better outcomes compared to the existing models.

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Compliance with Ethical Standards

Availability of Data and Materials All the data and materials are available to the author.

Conflict of interest Authors declare that they do not have any competing interests.

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