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Load management scheme for energy holes reduction in wireless sensor networks ☆

Prasenjit Chanak *, Indrajit Banerjee, Hafizur Rahaman

Department of Information Technology, Indian Institute of Engineering Science and Technology, Shibpur, Howrah 711103, West Bengal, India

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ABSTRACT

In a wireless sensor network where sensors are arranged into a flat topology, sensors near the sink consume much more energy than sensors at the boundary of the network. Sensors near the sink relay many packets than far away sensors to the sink. After these sensors expire, energy holes are created near the sink. Therefore, other sensors cannot reach to the sink and the network becomes disconnected. In this paper, we propose some strategies that can balance energy consumption of the deployed sensors and reduce energy holes from the network by balancing the communication load as equally as possible. We performed extensive experiments on the proposed algorithm using various network scenarios and compared it with other existing algorithms. The experimental results verify the effectiveness and feasibility of the proposed work in terms of network lifetime, energy consumption, and other important network parameters.

1. Introduction

Wireless sensor network (WSN) is a collection of low cost, low power, small sensing devices, where sensor nodes are deployed into a monitoring field without a preconfigured infrastructure [1]. After deployment, sensor nodes find neighbour nodes and organize themselves into a network [2,3]. The maximum amount of the energy of a sensor is consumed on two major tasks, viz sensing data from the monitoring environment and transmitting data to a sink or Base Station (BS) [4]. Energy consumption on sensing is dependent only on the sampling rate and does not depend on the network topology or location of the sensors. Therefore, energy consumption on sensing is constant. However, the data routing strategy is the most significant factor that determines the performance of the network [5–7]. In a homogeneous WSN, sensors near the sink consume much more energy compared to the sensors far away from the sink. Since, sensors near the sink relay many packets from sensors at the margin of the network [8], communication load of these sensors is much more compared to the far away sensors and they expire earlier than the far away sensor. After the expiry of these sensors, energy holes or communication gaps are created near the sink [9,10].

Hence, far away sensors cannot transmit data to the sink and then the network becomes disconnected, but still most of the nodes can survive for a long period of time [11–14]. Thus, load distribution among the deployed sensors is one of the most critical problems in the designing of WSNs. It has a profound impact on the network lifetime and performance of

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* Corresponding author. Tel.: +91 9874040413; fax: +91 033 2668 2916.
E-mail address: prasenjit.chanak@gmail.com (P. Chanak).

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the network. Therefore, it is necessary to design and develop a load balancing scheme for WSNs to prolong the network lifetime and performance of the network.

Several cluster-based load management approaches have emerged in the literature review. Most of them have selected cluster head, depending on the remaining energy of the sensor nodes [2,8,15]. Cluster-based data routing strategy is more suitable for energy conservation compared to the direct data transmission. Most of the clustering approaches select cluster head dynamically in each round for better energy management among the sensor nodes. However, each round cluster head selection process imposes extra message overhead or traffic load on these approaches. An on-demand based cluster head selection strategy has selected cluster head depending on the network demand and reduces extra cluster formation overhead from the network. Thus, an on-demand based cluster head selection strategy is perfectly suitable for WSN load management scheme.

In this paper, we propose a new cluster-based load management scheme, referred to as load management scheme for energy holes reduction in wireless sensor networks (LMSEHR) that can balance the energy consumption of the deployed sensor nodes and minimize energy holes creation in the WSN by balancing communication load as equally as possible. For doing this, proposed scheme does not make any assumptions like node distribution, node capacities, and network size. It does not use any location awareness Global Positioning System (GPS) to locate the position of the deployed sensor node. In this paper, we only consider deployed nodes which are varied in their transmission power and are capable of computing their remaining energy. In our proposed scheme, all sensors are organized into distinct clusters and each non-cluster head node belongs to exactly one cluster as a cluster member node. To achieve better energy management, proposed scheme selects CHs on-demand basis. The CHs are selected from the special regional nodes that can reduce extra message overhead and time delay in cluster head selection process. Furthermore, CHs communication load are balanced by the associative cluster heads. The main contributions of this paper can be summarized as follows:

- We propose a new load management strategy for large scale sensor networks where communication load and residual energy of deployed sensors are used for CHs selection.
- We focus on the problem of minimizing energy holes within the network. Then, we mathematically derive an optimal solution based on the load balancing strategies.
- We propose special region based CHs selection mechanisms for energy and time saving.
- We also propose a load balancing data routing strategy for balance energy consumption.
- We carry out extensive simulations. The effectiveness and feasibility of the proposed algorithm are verified by comparing with other existing algorithms.

The rest of the paper is organized as follows. In Section 2, the related work which provides an exhaustive survey about the previous work is discussed. Section 3 states the problem of load-balancing and network model. Section 4 presents the problem formulation and the assumptions made in this paper. The proposed load management scheme is presented in Section 5. Section 6 gives simulation results and some discussions. Finally, Section 7 concludes this paper.

2. Related works

Minimizing load is a major objective in several multi-hop wireless networks. This requirement has become more important for WSNs where sensor nodes are powered by batteries. Numerous studies have been conducted to reduce the load of the sensor nodes and to extend lifetime of the network. Cluster-based data routing strategy is one of the most popular data gathering mechanisms that has been used to maximize WSN lifetime. It also helps to reduce the communication load and data redundancy from the large scale WSNs. Low energy adaptive clustering hierarchy (LEACH) [15] is a well-known dynamic clustering approach where CH load dynamically rotates amongst the non-CH nodes that balance energy dissipation between the non-CH nodes. It works in two phases: (a) setup phase, and (b) steady state phase. In the setup phase, the entire network is divided into different clusters. For cluster formation, each node selects a random number between 0 and 1. If the selected random number is less than the threshold value, the node is selected as a CH. After cluster formation, CHs allocate a time slot to each cluster member node or non-CH node, depending on Time Division Multiple Access (TDMA) approach. In steady state phase, each cluster member transmits sensing information to the CH according to the given time slot. CHs aggregate receiving data and it transmits to BS. The main disadvantages of the LEACH protocol can be summarized as follows.

- The LEACH protocol follows random cluster head selection strategy. Therefore, in this approach message overhead is very high.
- The LEACH protocol selects CHs based on some probability. If any node is detected of low residual energy, it may be selected as a CH for data gathering process. As a result, number of cluster head election process is increased throughout the network lifetime and it potentially degrades the functionality of the network.
- The LEACH protocol does not assure even distribution of the CHs within the network.
- In LEACH protocol, CHs directly transmit aggregated data to the BS by the single-hop communication, which is unrealistic for the large scale WSN. In medium scale WSN, direct data exchange mechanism increases communication load within the CHs and hence it creates high load difference between CHs and cluster member nodes.

In [16], Younis and Fahmy have proposed a hybrid distributed clustering approach known as Hybrid Energy-Efficient Distributed (HEED) clustering. This approach selects CHs by considering residual energy of the sensors and inter-cluster distance. It considers remaining energy of the sensors as a primary parameter and inters cluster communication cost as secondary parameter. HEED usefully minimizes intra-cluster communication cost and effectively distributes CHs throughout the network. However, HEED increases communication overhead during the computation of the communication cost between the nodes. The main drawbacks of the HEED protocol can be summarized as follows.

- HEED protocol follows random CHs selection strategy like LEACH protocol that creates high energy overhead within the network.
- In HEED, every CH communicates with the BS via other CHs. Since CHs close to the BS relay many packets from CHs far away from the BS, it creates unbalanced energy consumption between the CHs. As a result, HEED suffers from the energy holes problem.

In [17], the authors Taheri et al. have proposed an energy-aware distributed dynamic clustering protocol. In this clustering approach, CHs are selected with non-probabilistic fashion. It selects CHs by considering delay times. The CHs selection delay time is inversely proportional to the residual energy. This approach uses fuzzy logic rules in order to choose final CHs from a tentative CH set. It also uses on-demand basis CHs selection mechanism to minimize energy consumption of the deployed sensor nodes. The disadvantages of ECPF protocol are as follows.

- In ECPF protocol, overall energy consumption of the deployed nodes is neither balanced nor minimized.
- In this protocol, CH election process mainly depends on the delay time, but in upper round when residual energy of nodes is less, the delay time is very short. Therefore, in upper rounds CHs are selected in minimum time interval and then high amounts of energy is consumed for CHs selection process.
- In ECPF protocol, fuzzy logic rules are used for effective CHs selection. Hence, limited computing capacity nodes are required more time and energy to selects CHs from tentative CHs set.

In [18], Soro and Heinzelman have proposed a CH selection approach for coverage preservation. It selects CHs by considering network coverage and residual energy of the sensor nodes. On the other hand, this approach also chooses active nodes and router nodes depending on the different coverage-aware cost metrics. It puts extra message overhead within the network. In this approach, overall energy loss of the sensor nodes is neither balanced nor minimized.

In [19], Kim et al. have proposed a CH election mechanism using fuzzy logic in wireless sensor networks (CHEF). Like the approach [17] this approach also uses if-then rules for CHs selection. Here, CH selection occurs in a distributed manner. For CHs selection, two parameters are evaluated by the fuzzy logic if-then rules, one of them is remaining energy and the other is local distance. Local distance is calculated by the sum of distances between the node and the node which is within the average radius of the preferred clusters. The main disadvantages of CHEF approach are as follows.

- The CHEF approach follows random clustering strategy; hence, energy overhead is very high in this approach.
- This approach has not balanced energy consumption between the CHs and cluster member nodes that influence to create energy holes or communication gaps within the network after some initial rounds.

Energy Balance Clustering Approach for Gradient (EBCAG) based data routing is studied in [20]. This approach divides entry network into unequal size of clusters and tries to overcome the hotspots problem in multi-hop WSNs. The main idea behind unequal size cluster formation is to adjust the cluster size with respect to the distance between the CH and the BS. In this approach, each sensor node maintains a gradient value that defines its minimum hop count to the sink. The size of a cluster is determined by the gradient value of its CH. The disadvantages of the unequal clustering approach are as follows.

- In EBCAG approach, each sensor node maintains a gradient value that increases extra energy overhead within the network.
- In this approach, high amount of energy is consumed during different size cluster formation and maintenance.

In [21], the authors Low et al. have proposed an efficient clustering based on load balancing algorithm for wireless sensor network. This approach allocates each sensor nodes to a gateway node in such a way that it distributes the overall network traffic load among the gateway nodes. The authors concede a breadth-first search (BFS) to find out the least load gateway node within the network. The main disadvantages of this load balancing approach can be summarized as follows.

- This approach leads to a large number of message exchanges over the network for efficient allocation of each sensor node to a gateway node. It puts a large overhead and time delay for the large scale WSNs.
- This approach really takes much more amount of memory space for building a BFS tree for individual sensor node.

3. Problem Statement and network model

Assume that N sensors are deployed in $M \times M$ [m^2] monitoring field. Our main goal is to minimize and balance CHs and cluster member's load that can reduce energy holes from the network. Another goal is to propose an on-demand based clustering mechanism that can reduce extra message overhead from the network. Each node v_i, where $1 \leqslant i \leqslant n$ must be communicated to just one CH c_j, where $1 \leqslant j \leqslant k_c$, k_c is the number of clusters ($k_c \leqslant N$). Each CH c_j must be able to communicate with the BS via multi-hop communication. CHs can use a data routing strategy to minimize and balance communication load, as discussed in Section 5. The following requirements must be met by the proposed scheme.

1. Clustering process is completely distributed. Node independently makes decision based on the local information.
2. At the end of the cluster formation time, each node is selected either a CH, or cluster member node and each cluster member node should belong to a single cluster.
3. CHs and cluster members load should be minimized.
4. CHs and cluster members load are distributed in such a way that can reduce energy holes from the network. Energy utilization of each deployed node should be maximized.
5. Clustering and routing mechanisms should be efficient in terms of processing complexity and message overhead.

3.1. Network model

We assume our sensor network model as follows:

(1) We assume all sensor nodes are uniformly deployed in the target area. All deployed sensors become static once they are deployed.
(2) Sensor nodes are powered by non-renewable on board energy source. The initial energy of each sensor is E_{max}.
(3) Sensor nodes sense data at a constant rate and it transmits to the destination node.
(4) We assume there is a perfect Media Access Control (MAC) layer in the network, i.e. transmission scheduling is collision less.
(5) Nodes are location unaware.
(6) The BS is not limited in terms of energy, memory, and computational power.

4. Energy Model and Problem formulation

In this paper, the radio model for energy is adopted from [4,22]. The free space and multipath channels are used depending on the transmission distance between a source node and receiver node. The multipath (mp) model is used when the transmission distance of the source nodes is greater than a threshold value d_0, otherwise the free space (fs) model is considered. Let e_{mp}, and e_{fs} be the energy required by the amplifier for multipath and free space communication respectively. Let e_b be the energy required for transmitter and receiver circuit to transmit and receive one bit data respectively. Then the energy consumed by the source node to transmit β bits data packet to the destination node is given as follows:

$$E_t(\beta, d) = \begin{cases} \beta(e_b + e_{fs}d^2) & \text{if } d \leqslant d_0 \\ \beta(e_b + e_{mp}d^4) & \text{if } d > d_0 \end{cases} \tag{1}$$

The threshold value d_0 is computed as follows $d_0 = \sqrt{e_{fs}/e_{mp}}$. Energy consumption by the receiver circuit for receiving β number of bits includes the cost of aggregation (E_{DA}) is represented by E_r (β) and it calculated as follows

$$E_r(\beta) = \beta e_b + E_{DA} \tag{2}$$

4.1. Problem formulation

In a particular round, communication load or communication energy loss of a sensor node is calculated by the summation of receiving energy loss and transmitting energy loss. In this paper, communication load of a node is referred to as node load (NL). The load of a node is calculated as follows

$$NL = \sum_{i=1}^{R} \beta_i e_b + \sum_{j=1}^{L} \beta(e_b + e_{fs}d^2) \tag{3}$$

where R is the number of messages received by the node and L is the number of messages transmitted by the node. Energy consumption on computing is very low and constant. Hence, it is ignored in the above equation. Let m be the number of nodes in a cluster, then the communication load of a CH i can be written as follows

$$CH_E^i = \sum_{i=1}^{m-1}(\beta_i e_b + E_{DA}) + \delta_i(e_b + e_{mp}d_\epsilon^4) \tag{4}$$

The first part of the equation indicates energy consumed in reception of packets from $(m-1)$ nodes in the cluster. The second part indicates the energy consumed by the CH in transmitting messages. Now consider, each cluster member node sends data to CH by multi-hop communication. Therefore, average communication load of a cluster member is represented by CM_E^i [J].

$$CM_E^i = \frac{\sum_{i=1}^{m-1}(\beta_i(e_b + e_{fs}d_i^2) + \sum_{i=1}^{n} e_b\beta_i)}{m-1} \tag{5}$$

where d_i is the distance between cluster member node and the ith CH. Within the cluster, communication distance (d_i) between cluster member node and CH is less compared to d_0 therefore we use 2 in power index. The average load difference between the CH and its cluster members is L_E^i [J] (from Eqs. (4) and (5)) which is calculated as follows

$$L_{Ch}^i = \left| \left(\sum_{i=1}^{m-1}(\beta_i e_b + E_{DA}) + \delta_i\left(e_b + e_{mp}d_\epsilon^4 + e_{da}\right) \right) - \frac{\sum_{i=1}^{m-1}\left(\beta_i\left(e_b + e_{fs}d_i^2\right) + \sum_{i=1}^{n} e_b\beta_i\right)}{m-1} \right| \tag{6}$$

In the above equation, if L_{Ch}^i is increased then energy holes are created very fast within the network. Therefore, our main objective is to minimize L_{Ch}^i during the data routing process that can reduce energy holes from the network.

5. Proposed load management scheme

The proposed load management scheme is divided into two phases, namely clustering and routing. In the clustering phase, deployed sensor nodes are organized into k_c number of clusters. CHs are selected according to the highest energy level and lowest load from the special regional nodes. In the routing phase, CHs select associative cluster heads with respect to its acting load condition. Then associative cluster head selects another sub associative cluster head depending on its present load condition. Associative cluster heads reduce CHs load and balance energy dissipation between the CHs and cluster member nodes. The working procedure of the proposed load managed scheme is shown in Fig. 1. The proposed clustering and data routing strategies are subsequently described in the following sections.

5.1. Clustering algorithm

Here, deployed sensor nodes are divided into δ size of clusters, where total energy loss (E_{total}) of the network is minimized. The cluster size δ is calculated according to [15].

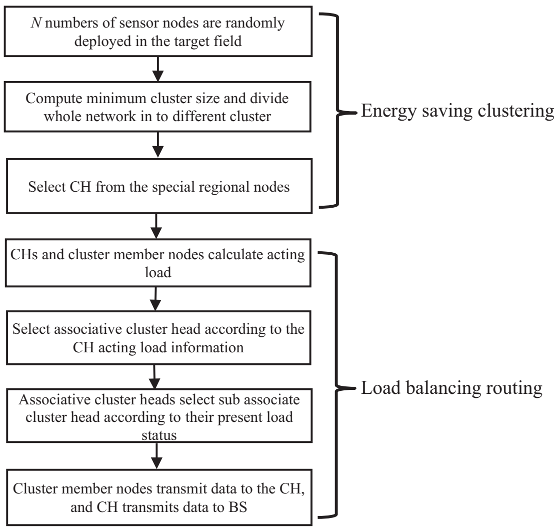

Fig. 1. Step in development of LMSEHR.

$$\delta = N \bigg/ \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{e_{fs}}{e_{mp}}} \frac{M}{d_{\epsilon}^2} \tag{7}$$

CHs are selected on the basis of average load and remaining energy of the special regional nodes. Every CH and cluster member nodes calculate its residual energy ($E_{residual}$) at the end of the data transmission phase. Initially, $E_{residual}$ of the deployed nodes are same. Therefore, CH selects on the basis of *NL* information of the cluster member nodes. After the initial round, CH is selected from the special regional nodes depending on their *NL* and $E_{residual}$ information. Then, minimum numbers of nodes that belong to the special region participate in CH election process. For cluster head selection, acting CH sends beacon messages within the special regional nodes. When special regional nodes receive the beacon message, they are prepared to select new CH. When the new CH election process is triggered between the special regional nodes, then another cluster member node waits for next new CH acknowledgement. For non-demand clustering, each CH sets a timer to start next new CH election process on the basis of its current energy status. Let $T_{CH}(i)$ be the timer of the ith CH which is derived as follows

$$T_{CH}(i) = \frac{1}{\max(\mathrm{CH}_{max}^{i}, E_{max})} \tag{8}$$

The CH selection algorithm is briefly described as follows:

Phase 1. Initially, each CH sets a timer and broadcast beacon message. Let $T(i)$ be the timer of the ith CH that can be derived as follows:

$$T(i) = \frac{\mathrm{CH}_{Max}^{i} - \mathrm{CH}_{Curr}^{i}}{\mathrm{CH}_{max}^{i}} \times T_{SR\_Max} \tag{9}$$

where T_{SR_Max} is the maximum allocated time for special regional nodes selection, CH_{max}^{i} and CH_{Curr}^{i} are the maximum load and acting load of the ith CH respectively. According to above Eq. (9) a special region is selected around the acting CH.

Phase 2. When special regional nodes receive the beacon message, then all special regional nodes send their $E_{residual}$ and *NL* information with their node identification number (*ID*) to the acting CH. Acting CH calculates average residual energy ($AR_{residual}$) and average load (AL_{node}) according to the special regional nodes information and it initially nominates the ith node as new CH from the special regional node set depending on the highest CH_{most} value. The nomination message includes nominated node *ID*, $E_{residual}$, and *NL* information. The $AR_{residual}$, AL_{node}, and CH_{most} are calculated as follows:

$$AR_{residual} = \frac{\sum_{j=1}^{p} E_{residual}}{p}, \qquad AL_{node} = \frac{\sum_{j=1}^{p} NL}{p} \tag{10}$$

$$\mathrm{CH}_{most} = \frac{AR_{residual} - (E_{residual})_i}{AL_{node} - (NL)_i} \tag{11}$$

Phase 3. When a special regional node u receives a new CH nomination message then u compares its own $E_{residual}$, and *NL* information with newly nominated CH $E_{residual}$, and *NL* information for verification of nominated node originality. If $E_{residual}$ of the nominated node is greater than the u and *NL* is less than the u node, u waits for data transitions time slot. Otherwise, an objection message *OBJ_CH* with its new choice is sent to the newly nominated node. If the nominated node receives *OBJ_CH* message from $p/2$ ($1 \leqslant p \leqslant m$) nodes, another choice is elected by reelection process. Otherwise, once the time expires, then nominated node elects as a new CH.

Phase 4. After CH selection, newly selected CH broadcasts a selection message within the δ range. The selection message includes its identification number (*ID*), $E_{residual}$ and CM_{E}^{i} information.

Phase 5. when a non-CH node receives selection message, then it compares own acting *NL* with CM_{E}^{i}. A non-CH node joins the nearest CH head depending on its load difference by broadcasting a join message within the communication rang.

5.2. Routing mechanism for energy holes reduction

We now present the proposed load balancing routing mechanism. Here, CHs select the next hop associative cluster heads for data routing in such a way that associative cluster head must reduce and balance each CH load with respect to their cluster member nodes. In sub associative cluster head selection process, each CH calculates its transmission distance to the BS and it compares with the threshold distance $d_{\in}$. If transmission distance is greater than the threshold distance $d_{\in}$, CH selects a next hop associative cluster head for data transmission to the BS. Otherwise, CH directly transmits data to the BS. The associative cluster head distance $d_\in$ is calculated as follows

$$d_\in = \left| \left(\frac{\sum_{i=1}^{m-1} \beta_i e_{fs} d_i^2 - (m-2)\sum_{i=1}^{m-1} \beta_i e_b - \delta_i (e_b + e_{da})}{e_{mp}\delta_i} \right)^{1/4} \right| \tag{12}$$

Subsequently, if associative cluster head transmission distance is greater than the threshold distance $d_\in^{*^i}$, another sub associative cluster head is selected by the associative cluster head at distance $d_\in^{*^i}$. In the sub associative cluster head distance $d_\in^{*^i}$ is calculated as follows

$$d_\in^{*^i} = \frac{\sum_{i=1}^{m-1} d_i}{m} \tag{13}$$

For associative cluster head selection, each CH transmits *ADV* message composed of 2 tuples (*ID, code*) where code contains associative node selection request. When any node receives *ADV* message from CH, node sends *JOIND* message composed of 2 tuples (*ID, energy level*). Energy level information consists of current $E_{residual}$ energy condition of the node. CH selects highest $E_{residual}$ node as an associative cluster head and transmits data to associative cluster head. Associative cluster head based data transmission process reduces unbalanced CH load from the acting CH set during the data transmission process. Similarly, sub-associative cluster head also reduces and balances associative cluster head load during the data routing process. The detailed description about this load balanced data routing algorithm is summarized in Algorithm 1.

Algorithm 1: Routing

/*Associative CH selection process*/
for each CH i
  Calculated $d_\in$ using Eq. (11);
  if (BS distance $d_i < d_\in$) **then**
    CH i broadcast *ADV* msg. in $d_\in$ range;
  end if
end for
if (non-CH node j receives *ADV* msg.) **then**
  Non-CH node j sends *JOIND* msg. to CH;
end if
for each CH i
  if ($d_i < d_\in$) **then**
    CH i selects highest $E_{residual}$ node as associative CH;
  end if
end for
/*Sub associative CH selection*/
for each associative CH k
  Calculated $d_\in^{*^i}$ using Eq. (12);
  if ($d_k < d_\in^{*^i}$) **then**
    Associative CH k broadcast *ADV* msg. in $d_\in^{*^i}$ range;
  end if
end for
if (non-CH node p receives *ADV* msg.) **then**
  Non-CH node k sends *JOIND* msg. to CH;
end if
for associative CH k
  if ($d_k < d_\in^{*^i}$) **then**
    Associative CH k selects highest $E_{residual}$ node as sub associative CH;
  end if
end for

5.3. Complexity and precision

In the above clustering and data routing scheme, CH load and cluster member node's load are minimized and balanced according to L_{ch}^i within the network by the associate cluster heads and sub associate cluster heads. It reduces energy holes from the network and increases functionality of the network. However, minimized CH_E^i and CM_E^i also increase utilization of the network energy. Since, network waste energy is reduced, the special region based CH election process reduces message overhead and CH election time within the proposed scheme.

Lemma 1. *In LMSEHR scheme, overall energy consumption of the network is balanced and minimized.*

Proof. In LMSEHR scheme, every non-CH node joins with its nearest cluster depending on average cluster member load $\left(CM_E^i\right)$. On the other head, CH also selects associative cluster head for next hop data transmission. Associative cluster head selects within the $d_\in$ distance where $CM_E^i \cong CH_E^i$. Therefore, CHs and the cluster member load are balanced in the LMSEHR scheme. However, if the associative cluster head load is greater than CH_E^i, then another sub associative cluster head is selected to balance energy consummation between the associative cluster head and CH node. Hence, proposed scheme reduces load from all overloaded nodes and balances energy consumption between them. □

Lemma 2. *Message and time complexity of the proposed clustering method is O(1) for each sensor node and O(N) for N sensor nodes in the network.*

Proof. In cluster formation phase, a sensor node either nominates itself as a CH or acts as a cluster member node. Therefore, the message complexity of the proposed clustering scheme is $O(1)$. In the worst case, each sensor needs to process $n-1$ CHs. Therefore the time complexity of the proposed scheme is $O(N)$. □

Lemma 3. The time complexity of the proposed load balancing routing algorithm is O(N) for N sensor nodes in the network.

Proof. In load balancing data routing phase, each CH needs to calculate the residual energy of the node to select an associative cluster head for which it requires checking the residual energy of $N-1$ nodes in the worst case. Therefore, the time complexity of the proposed data routing scheme is $O(N)$. □

6. Performance evaluation

The performance of the proposed scheme is evaluated and compared with the existing EBCAG [20], LECH [15], HEED [16], ECPF [17], and CHEF [19] algorithms in terms of first node dies (FND), half of nodes remain alive (HNA), last node dies (LND), and other important network parameters such as global energy loss by the network, clustering overhead, average energy consumption, number of elected cluster heads. All the algorithms are simulated through MATLAB R2012b and C programing. The simulation parameters used in the simulation are provided in Table 1 [15,20,22–23]. In the simulation, we assume sensor nodes are uniformly deployed in the sensing field. All simulations have been conducted in two scenarios.

Scenario 1. We simulate a WSN with a 500 m by 500 m field and BS is placed at the coordinate (510, 210).

Scenario 2. We simulate a WSN with a 700 m by 700 m field and BS is placed at the coordinate (710, 330).

Table 1
Experimental parameters.

Parameter	Values
Number of node (V)	100–500
Network range	500×500 [m^2] and 700×700 [m^2]
Data Packet Size	800 bit
$\boldsymbol{e_b}$	50 nJ/bit
$\boldsymbol{e_{fs}}$	10 pJ/bit/m^2
$\boldsymbol{e_{mp}}$	0.0013 pJ/bit/m^4
Data aggregation energy $\boldsymbol{E_{DA}}$	5 nJ/bit/signal
BS location	($x = 510$, $y = 210$) and (740, 203)
The duration of each round	20 s
Initial energy of each node (E_o)	0.5 J
Sensing range	10 m
Frame per round	5 frame
Threshold distance (d_0)	75 m

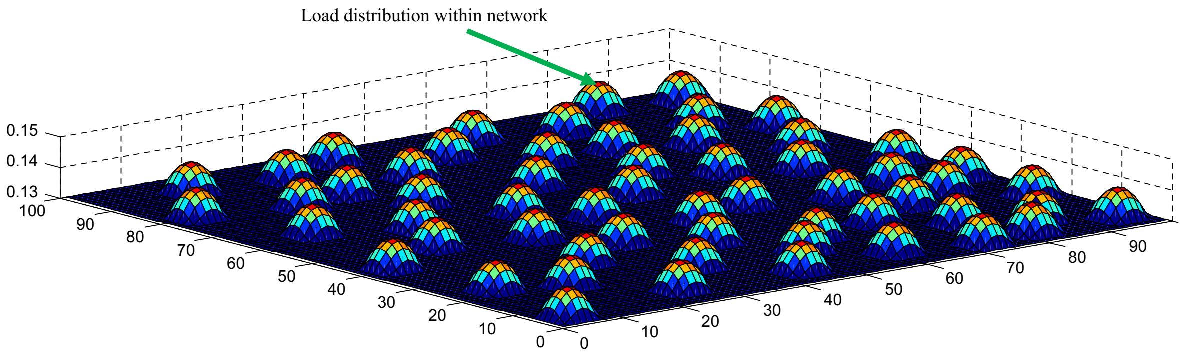

Fig. 2. Load distribution of the sensor nodes.

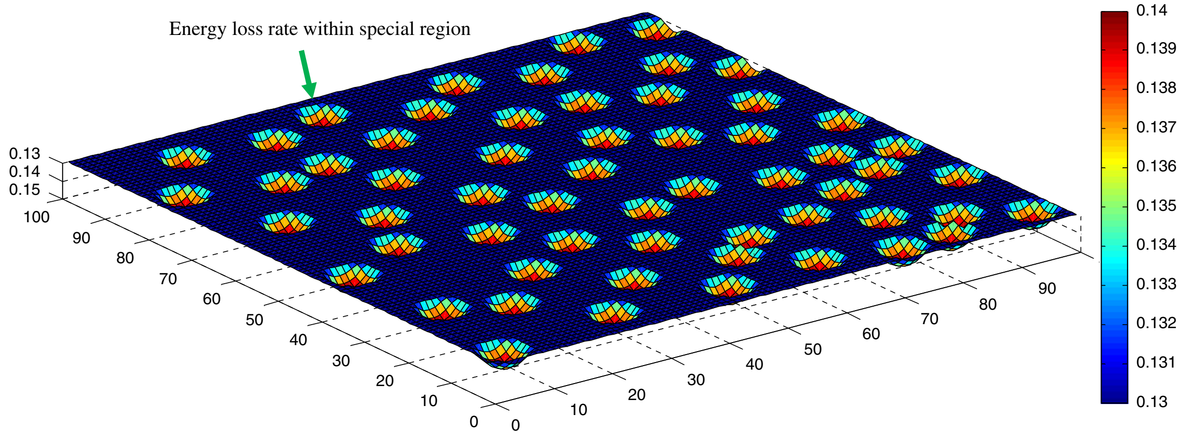

Fig. 3. Unutilized energy of each sensor node in LMSEHR.

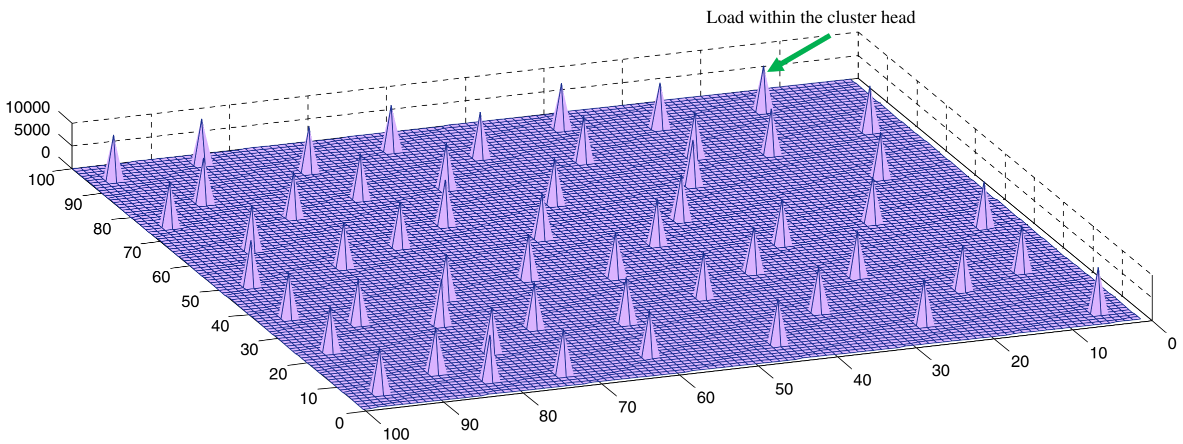

Fig. 4. Cluster head load in LMSEHR scheme.

Fig. 2 shows the load variation of the LMSEHR scheme among the randomly deployed sensor nodes. This is measured with the data receiving energy loss and data transmission energy loss. In LMSEHR, CHs and cluster members load are minimized and balanced in such a way that the load difference between the CHs and cluster members is minimized. On the other hand, energy distribution in LMSEHR can be easily inferred from the Fig. 2.

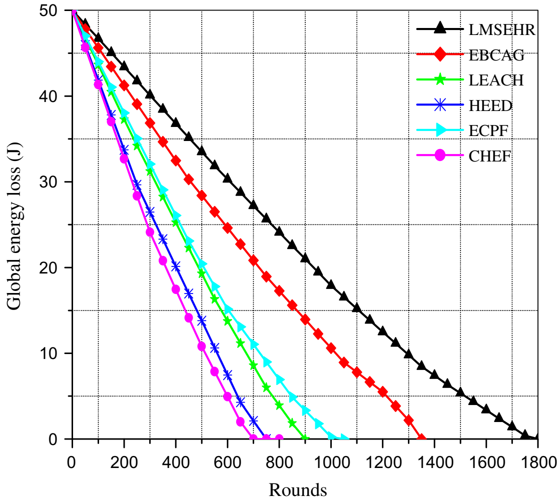

Fig. 5. Global energy loss comparison in Scenario 1 with 100 nodes.

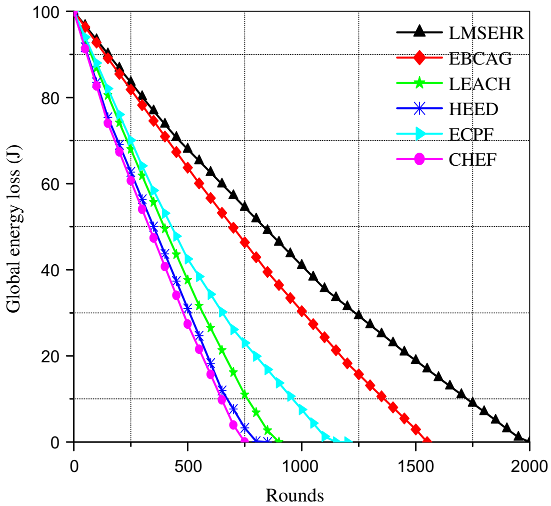

Fig. 6. Global energy loss comparison in Scenario 1 with 200 nodes.

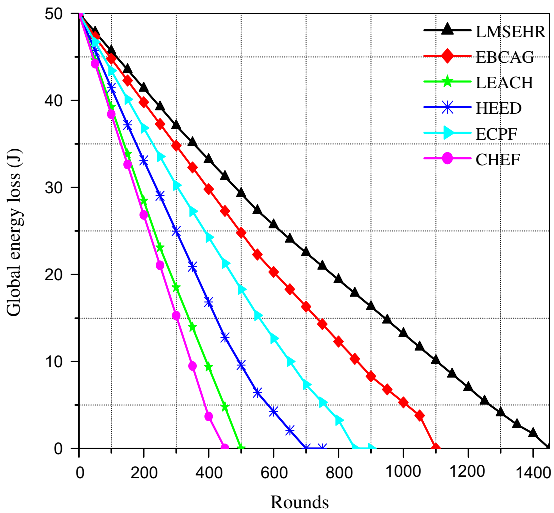

Fig. 7. Global energy loss comparison in Scenario 2 with 100 nodes.

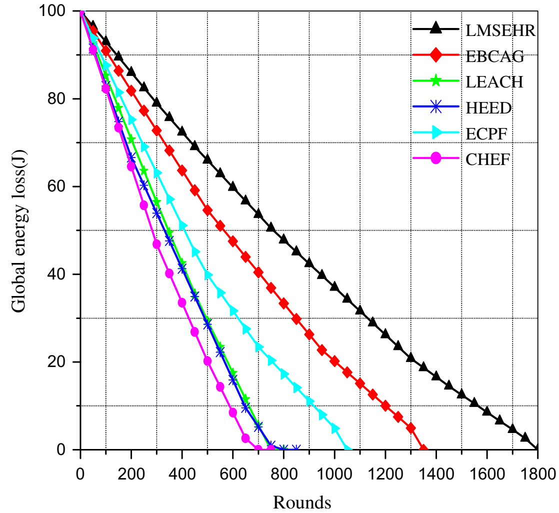

Fig. 8. Global energy loss comparison in Scenario 2 with 200 nodes.

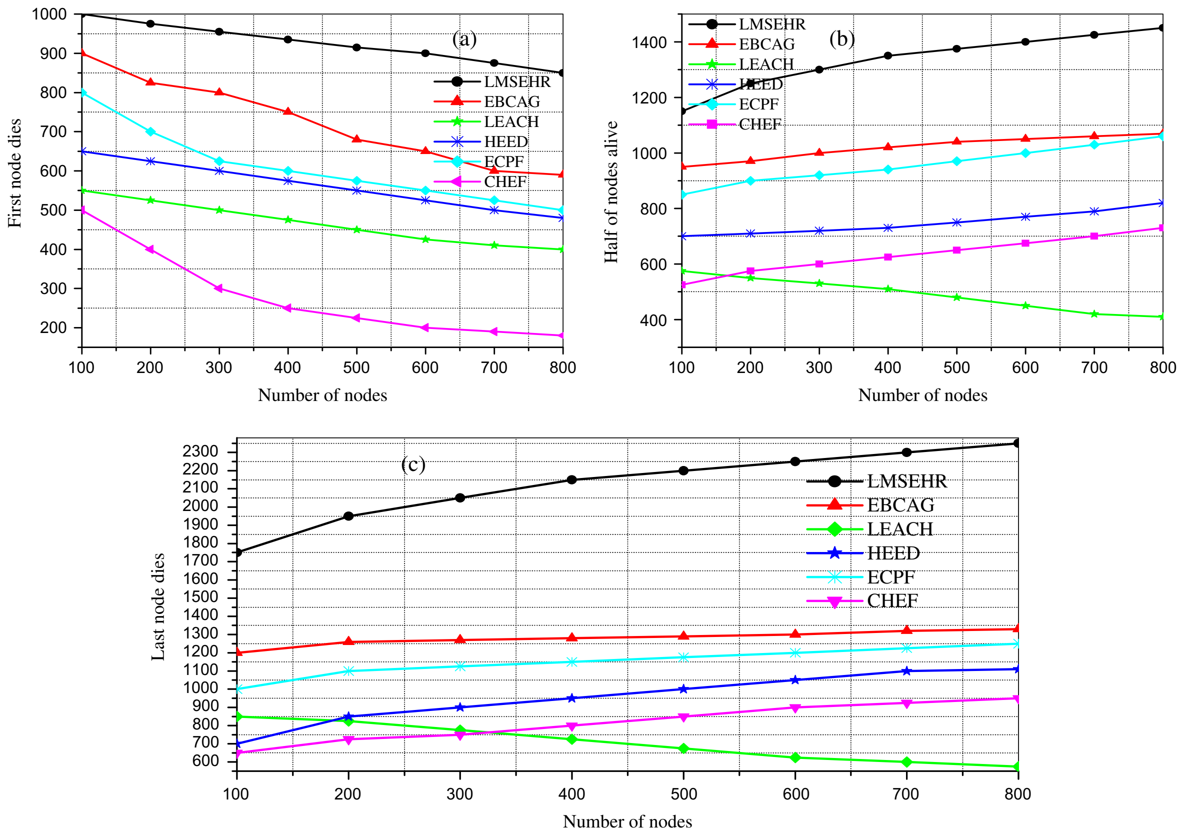

Fig. 9. (a) First node dies (FND) in Scenario 1. (b) Half of nodes alive (HNA) in Scenario 1. (c) Last node dies (LND) in Scenario 1.

Fig. 3 shows the unutilized energy of the deployed sensor nodes in LMSEHR scheme. The unutilized energy is less in our proposed scheme due to proper load balance among the CHs and cluster member nodes. Moreover, in LMSEHR scheme, CH transmission cost is reduced by the associative cluster head. Hence, a node can transmit its data to the BS even with its minimum remaining energy level. Therefore, energy utilization of the proposed scheme is better.

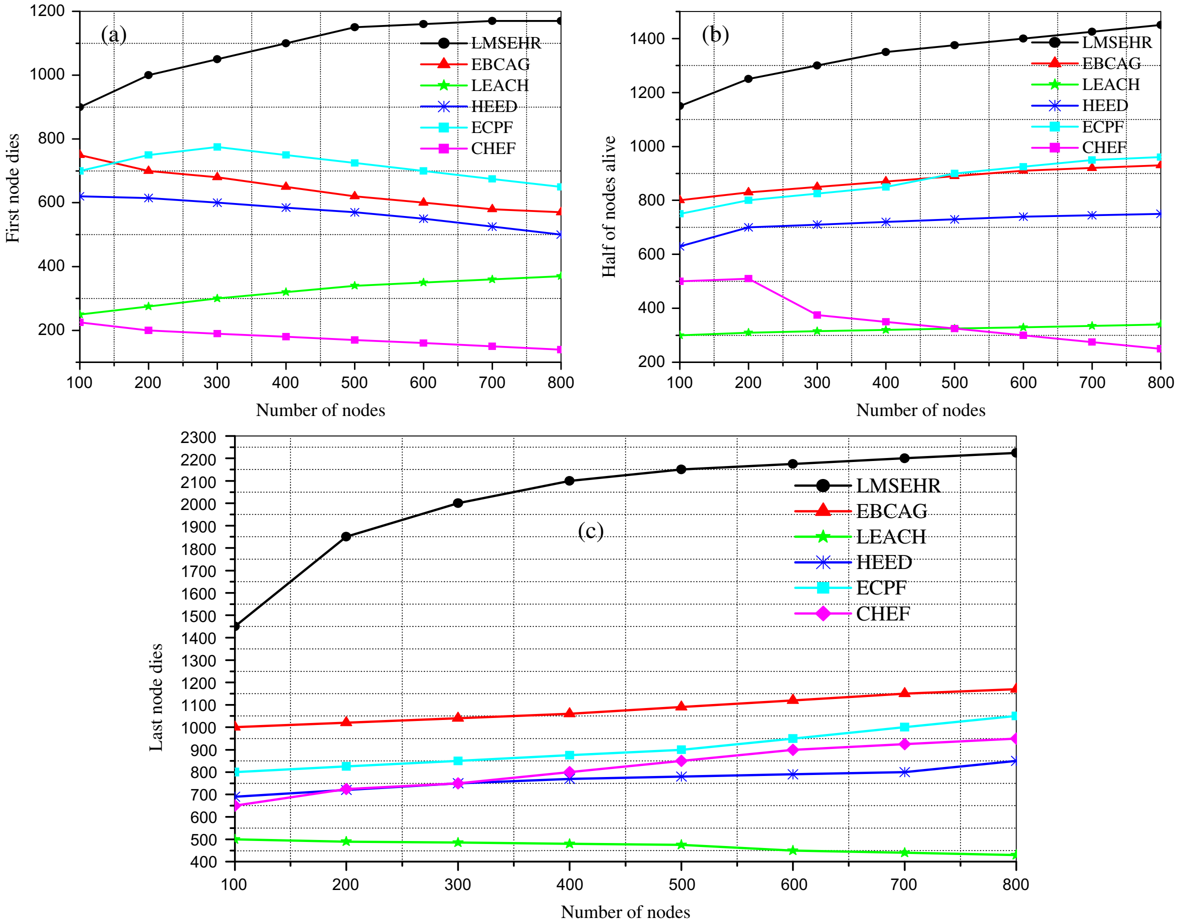

Fig. 10. (a) First node dies (FND) in Scenario 2. (b) Half of nodes alive (HNA) in Scenario 2. (c) Last node dies (LND) in Scenario 2.

Fig. 4 indicates the amount of data transmitted by each CH. This figure also shows the uniform load distribution between the CHs. Uniform load distributions can improve functionality of the network. Since, BS receives data from all clusters throughout the network lifetime. The LMSEHR scheme reduces and distributes data routing load of the deployed sensor nodes through the efficient number of cluster formation within the network that can divide the entire network into effective size of clusters and reduce transmission cost of the deployed sensor nodes. Furthermore, CHs select associative cluster according to their acting load condition and hence associative cluster head also select sub associative cluster head depending on acting load. Therefore, data routing load of the network is uniformly distributed and balanced among all deployed sensor nodes.

6.1. Global energy loss comparison

Fig. 5 shows the global energy of LMSEHR in Scenario 1 with 100 nodes. The global energy loss in LMSEHR scheme is 22.3% less compared to EBCAG, 47.26% less compared to LEACH, 48% less compared to HEED, 40.23% less compared to ECPF, and 51.23% less compared to CHEF scheme. Therefore, the network lifetime of LMSEHR has increased 24% compared to EBCAG technique, 49% compared to LEACH, 55.66% compared to HEED, 47.43% compared to ECPF, and 61% compared to CHEF. This is caused due to the on-demand cluster head election process and load balancing between the cluster members and CHs.

Fig. 6 shows global energy loss in Scenario 1 with 200 nodes. The global energy loss of LMSEHR is less by 23.24% compared to EBCAG technique, 48.12% compared with ECPF, 51% compared with LEACH, 54% compared with HEED, and 58% compared with CHEF respectively. In Fig. 6, it is seen that the network lifetime of LMSEHR has increased as compared to Fig. 5. This is due to the increment of node density in the network and load balancing through the associative cluster head.

Fig. 7 demonstrates global energy loss in Scenario 2 with 100 nodes. In LMSEHR sachem, global energy loss is less by 23% compared to EBCAG, 49% compared to LEACH, 46% compared to HEED, 39% ECPF and 54% CHEF algorithms. Therefore, network lifetime in LMSEHR scheme is increased by 25% compared to EBCAG scheme, 52% compared to LEACH, 49.02% compared with HEED, 44.43% compared with ECPF scheme, and 64% compared with CHEF respectively. If node deployment

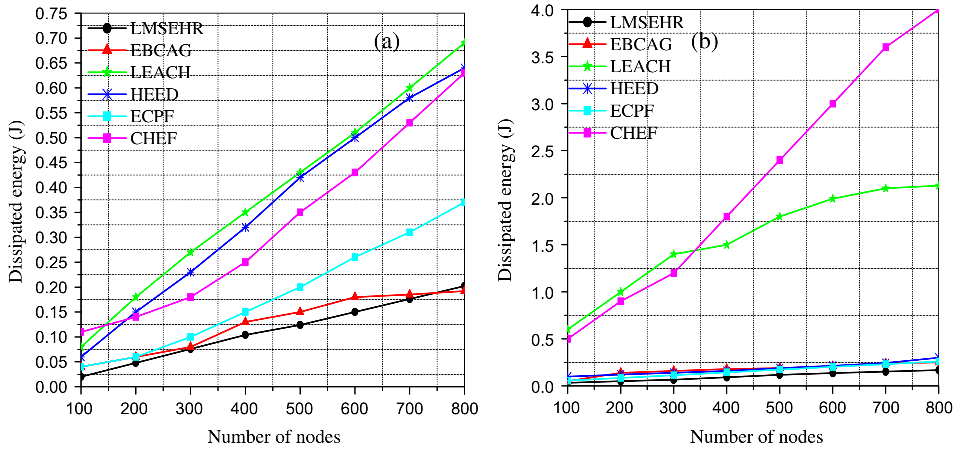

Fig. 11. Average energy consumption of the network. (a) Scenario 1 and (b) Scenario 2.

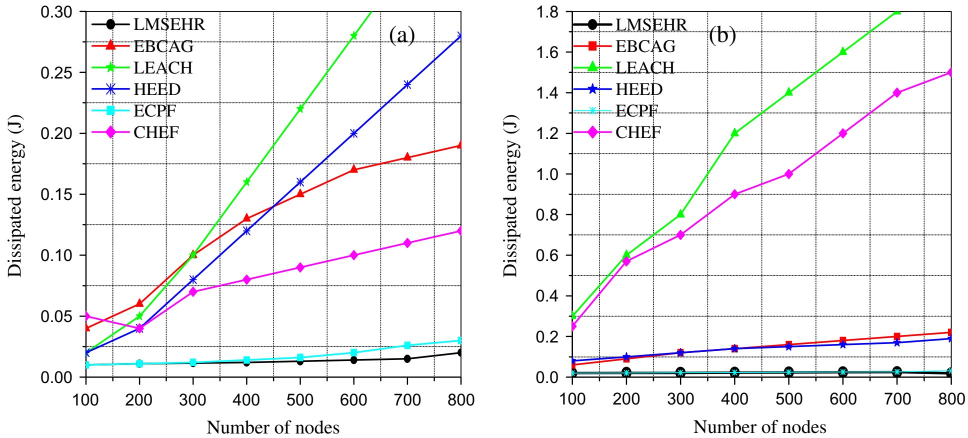

Fig. 12. Average energy consumption of the CHs. (a) Scenario 1 and (b) Scenario 2.

area is increased, global energy loss is also increased due to increment of transmission range of the deployed sensor nodes. Hence, network lifetime is decreased in Fig. 7 compared to Fig. 5.

Fig. 8, shows that LMSEHR has lesser global energy loss of 21%, 52%, 47%, 40.13%, and 56% as compared to EBCAG, LEACH, HEED, ECPF, and CHEF in Scenario 2. It is due to efficient load balancing between CH and cluster member nodes, where CH loads are reduced by the associative cluster head.

6.2. Network life comparisons

Fig. 9a shows the comparison results in terms of Fast Node Dies (FND) at Scenario 1. It is seen that in LMSEHR scheme FND occurs after more than 12.3% rounds compared to EBCAG, 14.28% rounds as compared to ECPF, 73.91% rounds as compared to HEED, and 78.02% rounds as compared to LEACH respectively. From Fig. 9a, it can be observed that if number of nodes is increased, FND time decreases very slowly in LMSHR as compared with EBCAG, LEACH, HEED, ECPF, and CHPF schemes. Fig. 9b shows the comparison results in terms of the Half of Nodes Alive (HNA). From this figure, it can be observed that LMSEHR performs better than the EBCAG, LEACH, HEED, ECPF and CHEF when considering the HNA metric. This causes due to the elimination of extra load from the cluster heads and cluster member nodes. Fig. 9c shows the comparison results in terms of Last Node Dies (LND) at Scenario 1. As can be seen from the figure that LMSHR scheme performs 25% better than EBCAG, 50% better than ECPF, 62.11% better than HEED, 64% better than LECH, and 74% better than CHEF when considering the LND metric. Fig. 9a–c show that LMSEHR scheme performs better than EBCAG, LEACH, HEED, ECPF, and CHEF schemes in terms of FND, HNA and LND. Hence, it can be observed that LMSEHR scheme successfully reduces energy holes from the network.

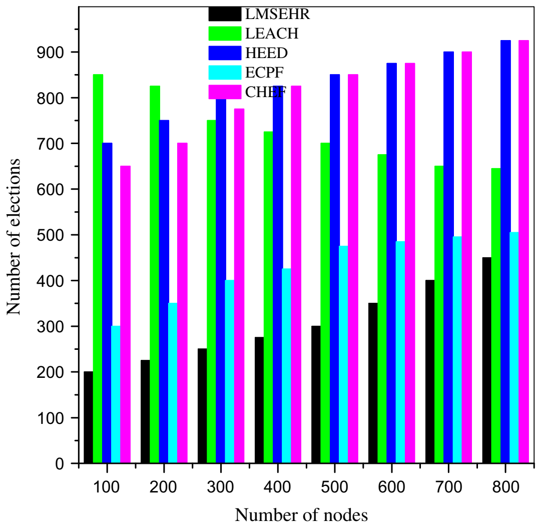

Fig. 13. Number of cluster head election in Scenario 1.

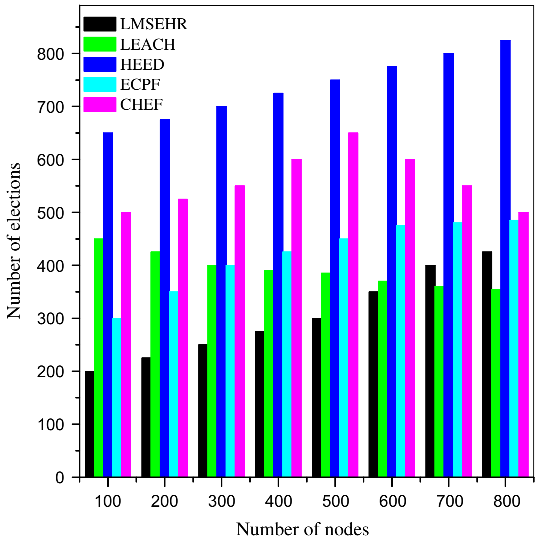

Fig. 14. Number of cluster head election in Scenario 2.

Fig. 10a–c show the comparison results in terms of FND, HNA and LND at Scenario 2. From these figures, it can be observed that in large scale WSN, LMSEHR also performs better than the EBCAG, LEACH, HEED, ECPF, and CHEF when considering FND, HNA, LND metrics.

Fig. 11 shows the average energy consumption comparison in Scenarios 1 and 2. This is the measure of the ratio between the sums of energy consumption of all deployed nodes to the total number of deployed nodes. Average energy consumption rate of LMSEHR is less as compared with EBCAG, LEACH, HEED, ECPF, and CHEF. This is caused due to the elimination of message overhead from cluster formation phase.

6.3. Competition of number of cluster head elections

Fig. 12a–b show average energy commotion of the CHs. The average energy consumption of the CHs in LMSEHR is less as compared to EBCAG, LEACH, HEED, ECFP and CHEF due to minimization of CH_E^i load. In the proposed scheme, CH loads are minimized through the associative cluster head and associative cluster head loads are reduced by the sub associative cluster heads. Therefore, average energy consumption in LMSEHR scheme is less compared to the other load management schemes.

Figs. 13 and 14 show details of the number of CHs election process in Scenarios 1 and 2. It is seen that LMSEHR has less number of CHs election process as compared with LEACH, HEED, and CHEF. It is due to minimum load distribution among the CHs and cluster member nodes. However, on demand clustering process mainly reduces the number of CH election process from the network.

7. Conclusions

In this paper, we have proposed a new energy efficient load management scheme for wireless sensor network which is not only energy efficient but also able to balance load. In the proposed scheme, cluster heads have been selected in non-probabilistic fashion based on the residual energy and communication load of the nodes. It has been shown that the proposed clustering algorithm has required $O(N)$ time complexity for N sensor nodes. We have developed associative cluster head based simple but elegant data routing strategy that balances energy differences between the CHs and cluster member nodes. The proposed scheme has been simulated extensively using two different scenarios of WSN. Simulation results have been compared with five existing algorithms. The proposed scheme has been shown to outperform all these algorithms in terms of FND, LND, HNA including global energy loss, energy utilization in both the scenarios. In the future, this work deserves to be considered for being applied to some real-life applications such as agricultural crop monitoring or livestock monitoring.

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Prasenjit Chanak received M. Tech degree in Information Technology from Bengal Engineering and Science University, Shibpur, Howrah, India in 2011. Currently he is a Ph.D. student in the Department of Information Technology, Indian Institute of Engineering Science and Technology, Shibpur, Howrah, India. He is a recipient of the Senior Research Fellowship from CSIR, Government of India. His main research interest is wireless sensor networks.

Indrajit Banerjee is an assistant professor in the Information Technology Department at Indian Institute of Engineering Science and Technology, Shibpur, Howrah, India. He has received his M.Tech in Information Technology from Bengal Engineering and Science University in 2004. He has received his Ph.D. in Information Technology from Indian Institute of Engineering Science and Technology in 2014. His research interests include wireless sensor network and cellular automata.

Hafizur Rahaman received the M.E. degree in Electrical Engineering and Ph.D. degree in Computer Science and Engineering from Jadavpur University, Calcutta, in 1988 and 2003, respectively. He is a professor in the Information Technology Department at Indian Institute of Engineering Science and Technology, Shibpur, India. His research interests include logic synthesis and testing of VLSI circuits, fault-tolerant computing, and quantum computing.