

HEEL: A new clustering method to improve wireless sensor network lifetime

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Abstract: In wireless sensor networks, some resources such as memory and energy are limited. In recent years, there has been an increasing interest in improving network lifetime. Node energy plays an important role in the network lifetime. Along with this remarkable growth in wireless sensor networks, however, there is an increasing concern over network lifetime. The principal purpose of this study is to develop an understanding of the effects of other parameters on selecting a cluster head. The methodological approach taken in this study is a mixed methodology typically based on the node's energy. The authors have operated four parameters to select the cluster head: Node energy, the energy of the node's neighbours, number of hops and number of links to neighbours. Each of these parameters has an impact in selecting the cluster head. They accurately observed hop size, energy of each sensor node, average energy of sensor neighbours, links to sensor nodes (HEEL) has better improvements in comparison of Node ranked Low Energy Adaptive Clustering Hierarchy (Nr-LEACH), Modified Low Energy Adaptive Clustering Hierarchy (ModLEACH), Low Energy Adaptive Clustering Hierarchy-B (LEACH-B), Low Energy Adaptive Clustering Hierarchy (LEACH), Power-Efficient Gathering in Sensor Information System (PEGASIS), energy-aware clustering scheme with transmission power control for sensor networks (EACLE) and hybrid energy efficient distributed clustering (HEED) algorithms in possible case of network lifetime and throughput.

1 Introduction

Recent developments in wireless sensor networks (WSNs) have increased the need for energy efficiency. Most of the academic researchers in WSN focused on this potential problem to decrease energy consumption. In a WSN there are interconnected sensitive sensors exchanging information [1]. Today, there has been an increasing interest in the WSN applications in various fields of precision medicine [2], precision agriculture [3, 4], the automotive vehicle industry [5], smart parking system [6], military application [7], E-health [8] and smart cities [9]. With the increasing use of this technology, it is significant to pay attention to its advantages and disadvantages. There are traditionally some key limitations in WSN such as limited memory space and computing power. However, on the other hand, WSN has advantages such as being inexpensive and easy to install. Data transmission tasks such as sending, receiving, processing in WSN are key factors that typically reduce battery level in each sensor node. In a WSN as nodes are deployed randomly, the sensing range for each node can overlap. This causes redundant data. Transmission of redundant data to the base station (BS) can also reduce nodes' energy due to duplicate data transmitted more than once. There are some effective approaches to overcome this fundamental problem.

Sensor nodes process received data and send data to the BS. However, these tasks can reduce residual energy. Data aggregation done at some selected nodes can reduce energy consumption. Another approach to reduce energy consumption is to put some nodes in sleep modes when they are inactive to save energy [10]. However, this approach cannot be applied to all use cases. For example, in target tracking applications each sensor node is necessary to be aware of every local event so they have to be awake all the time. Sensor nodes have limited energy supply.

There are also routing protocols in WSNs developed for increasing the network performance. According to the network structure, there are different categories of routing protocols. In general, there are three types of network structures: flat network architecture, hierarchical networks, and location-based networks.

In the flat network architecture, all of the sensors in the network follow a standard rule in data transmission. In the literature SPIN [11], Directed Diffusion [12], Rumor Routing [13] have been proposed with flat-based networks. A number of authors have proposed the following hierarchical networks: Low Energy Adaptive Clustering Hierarchy (LEACH) [14], Power-Efficient Gathering in Sensor Information System (PEGASIS) [15], TEEN [16], HPAR [17]. In a hierarchical structure, the network is divided into clusters. Each cluster has a cluster head (CH) and cluster members. Unlike networks based on flat architecture, in hierarchical networks CHs directly can communicate with the BS. Cluster members communicate only with corresponding CHs. In hierarchical routing protocols, data aggregation decrease communication between a sensor node and the base station. Data aggregation reduces the transmitted data to base station. Furthermore, authors in GAF [18], GEAR [19], SPAN [20] accurately evaluated the potential effect of geographical coordination of sensor nodes in routing algorithms. In this unique type of network structure, each sensor node gives information about its precise location. Each sensor node is also equipped with a GPS. Radio Signal Strength Indicator (RSSI) is used to calculate the distance between the neighbour nodes. Also, as each node is equipped by GPS more power is needed and sleeping mode scheme is necessary. Network lifetime strongly depends on each node's energy level. In this paper, we focus on increasing network lifetime. There are different CH selection algorithms to increase network lifetime; LEACH [14], MODLEACH [21], HEED [22] and LEACH-B [23]. In this work, we propose a novel clustering method that progressively improves energy efficiency. In our method, we consider residual energy, the distance between a sensor node and the BS and the number of links to neighbours. The remaining part of the paper is structured as follows. Section 2 presents a brief overview of the recent work on CH selection. Section 3 is about network model. Section 4 is concerned with the used protocol for this study. Section 5 analysis the results.

2 Related work

The clustering method achieves energy efficiency using the hierarchical network structure. Several studies are conducted in this field of study. LEACH is one of the famous protocols that is described by Heinzelman *et al.* in [14]. In addition, most of the new protocols are based on LEACH [11, 21, 23–26]. The main concept of these protocols is to reduce energy consumption by increasing the network lifetime. In the clustering method, the choice of the CH is important. The main role of the hierarchical network is based on CHs. The purpose of the CH is to collect data from the cluster members and send the collected data to a BS. To send data, a protocol should be used. As the role of the BS is to collect the received data from the CHs, it is necessary to get higher precision with a low packet loss. In most of the studies, the data is sent hop by hop. Therefore, the BS must have some information related to the received packets.

LEACH: LEACH stands for Low Energy Adaptive Clustering Hierarchy which is an algorithm developed by Heinzelman *et al.* [14] LEACH algorithm is an example of the hierarchical algorithms. The main goal of this algorithm is to increase network lifetime, control the overhead and data aggregation. The algorithm is based on clustering and CH. In this algorithm, all of the nodes are chosen homogeneously which means that they have the same battery capacity and communication range. The operation of the LEACH is conducted in two stages, that is the setup phase and the steady stage. In the setup phase, cluster and CH selecting. In the steady stage, the data transfer to the BS is implemented. CH and cluster members are selected in the setup phase. In the steady-state, data transfer to the BS is implemented. The CH is selected by using (1). For each node, a random value between 0 and 1 is assigned. If the random value is less than node threshold value $T(n)$ that node is selected as the cluster header

$$T(n) = \begin{cases} \frac{p}{1 - p \times \left(r \bmod \frac{1}{p} \right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Equation (1) is taken from Heinzelman *et al.* works [14]. where n is the given number of nodes, p is the priori probability of a node being elected as a CH, r is a random number between 0 and 1, G is the set of nodes that was not chosen as CHs in the last $1/p$ rounds.

During the steady phase, the selected CH broadcasts the advertisement message. In this stage, the non-cluster node gets a cluster head id. In addition, an RSSI value is used to detect sensor nodes' neighbours. Also, time division medium access (TDMA) schedule avoids collision in inter-cluster communication. CHs aggregate received data and send this data to the BS.

In LEACH algorithm, there is no criteria to limit the G set. G set represents the non-cluster head sensor nodes in each round. Node residual energy, the distance between nodes and neighbours can optimise network lifetime in CH selection. For instance, the distance between the sensor node and a BS can be more than a threshold value, or residual energy of a node can be less than a threshold value. Therefore, it is not efficient to select this node as a CH, i.e. cluster head.

MODLEACH: MODLEACH stands for Modified LEACH algorithm that is introduced by Mahmood *et al.* [21]. This algorithm is another version of the algorithms that are based on the LEACH's algorithm. The goal of this algorithm is to improve throughput and network lifetime. In this algorithm, two methods are proposed to improve the efficiency of the LEACH algorithm. The first method is an efficient CH replacement. The second method is dual transmitting power levels. In the first method, the authors have proposed a threshold value in CH formation in the setup phase. If the existing CH residual energy is more than the threshold value and no more energy is being spent, then it will remain as the same CH for the next round. In addition, in this algorithm, the amplification energy has also been studied. Same energy consumption will be considered for both near and far located nodes and the BS. Data transmission is divided into three modes which are mentioned as follows:

- Intra cluster transmission.
- Inter-cluster transmission.
- Cluster head to base station transmission.

Therefore, for the parts of the communication within a cluster, i.e. cluster members and CH, intra cluster transmission is proposed. In addition to that, inter-cluster transmission is proposed for the transmission between two CHs. So, the required energy for the three modes is different. High energy amplification used for CHs to communicate with other CHs. Low energy amplification is used for cluster members communication and CH.

HEED: HEED stands for Hybrid Energy Efficient Distributed Clustering which is one of the clustering algorithms that are described in [22]. In this algorithm, all nodes are again homogeneous. In HEED, different CHs will be selected based on the residual energy and the density of nodes. In HEED, links between the nodes are symmetric. Non-uniform energy consumption can occur for all nodes due to the nodes' responsibilities, processing and communication capability. Prolonging network lifetime, controlling the overhead and making compact well-distributed clusters are the goals of the HEED algorithm. In this algorithm, CH selection is a hybrid of residual energy and communication cost. Average minimum reach-ability power (AMRP) is the mean of the minimum power levels. This value is required by all M nodes within the cluster range to reach u

$$\text{AMRP} = \frac{\sum_{i=1}^M \text{MinPwr}_i}{M} \quad (2)$$

Here, (2) and (3) are originally referenced in Younis and Fahmy's work [22]. For (2), MinPwr_i is the minimum power level required by a node v_i to communicate with a CH u such that $1 \leq i \leq M$. For every step, a probability is set in such a way that it describes the initial percentage of CHs among all n nodes as C_{prob} . The residual energy of node as E_{residual} and maximum energy of supplied battery as E_{max} are arguments of the cluster probability that are calculated for every node as follows:

$$\text{CH}_{\text{prob}} = C_{\text{prob}} \times \frac{E_{\text{residual}}}{E_{\text{max}}} \quad (3)$$

CH sends a message to its neighbours with the following format: [Nodeid, selection-status, Cost]. The selection status consists of two values, $\text{Tentative}_{\text{CH}}$ or Final_{CH} . Here, $\text{Tentative}_{\text{CH}}$ means that at each epoch the node needs to be the CH. If CH_{prob} has reached the value 1, this will be changed to Final_{CH} mode, and until CH_{prob} becomes <1 the node selection status will be kept as $\text{Tentative}_{\text{CH}}$. $\text{Tentative}_{\text{CH}}$ node can become a regular node at a later iteration, if it finds a lower cost CH.

A node is considered as 'covered', if it heard a message as $\text{Tentative}_{\text{CH}}$ or Final_{CH} . If it did not hear any messages, then the node is considered as 'uncovered', and it announces a message with the selection status Final_{CH} . By considering the explanations mentioned above, low cost and high residual energy are important factors for the selection of the CH in HEED algorithm. Yet, HEED algorithm has some limitations. For instance, at each round, selecting the CH causes more overhead in the network. Consequently, energy dissipation increases and decreases during the lifetime of the network. Also, in HEED algorithm, a node can be considered as uncovered status and its status may change from $\text{Tentative}_{\text{CH}}$ to Final_{CH} . In this case, more clusters with only one cluster member will be created.

NR-LEACH: Authors in this algorithm [11] improved LEACH algorithm to increase network lifetime. Node ranked LEACH (NR-LEACH) algorithm is a new clustering method for hierarchical network structure. NR-LEACH is based on two parameters to choose CH: path cost and a number of links between nodes. Authors claimed that NR-LEACH algorithm has good performance in a large-scale network. The first parameter in NR-LEACH is path cost, that calculates received signal strength and residual energy for each node. NR-leach also focuses on node's residual energy similar

to other leach algorithms. NR-LEACH select CH from each nodes ranking. Nodes rank will be obtained according to its position, residual energy, and connection links. The rank function selects a node with the highest rank. Equation (4) is a node rank function:

$$NR(n_i) = PO(n_i) \times \alpha \times \sum_0^i NR(n_j) \frac{1/d_{out}^{ji}}{\sum_{k \in NH} d_{out}^{jk}} + (1 - \alpha) \quad (4)$$

In (4), NH is the set of neighbours for the k , d_{out}^{ji} is the distance from node j to node i , $PO(n_i)$ is the current energy of node i and α is damping factor. Authors in [11] considered damping value equal to 0.85. Initial rank of each node considered is one. NR-LEACH algorithm repeat this function to each node until reach convergence score. This algorithm avoids random selecting of CH.

LEACH-B: LEACH balanced algorithm is proposed by Tong and Tang [23]. That algorithm is another version of the LEACH algorithm. Also, the main aim of LEACH-B is to improve the network lifetime.

ERPLBC-CS: This algorithm proposes an efficient load-balanced clustered routing protocol. Authors in [27] combine new clustering strategy with compressive sensing (CS) theory. CS theory is one of signal processing techniques for transferring sufficient information with low power consumption. CH election in this algorithm is based on residual energy and concentration degree of sensor nodes. Concentration degree of any node is the number of sensor nodes that can sense during the same round. BS broadcast E^t is the average residual energy of network, if residual energy of each node is bigger than E^t that specific node's calculated weight from residual energy and concentration degree. After this, that node sends that weight with own ID to BS. BS decides to which sensor node will be selected as CH by choosing the maximum weight. Then, a sensor node that is selected as CH will broadcast to its neighbouring nodes to inform them. In this method, the authors claimed that the proposed algorithm can produce and balance energy consumption in addition to a prolonged lifetime of the network.

There are several other algorithms which are the modified versions of the LEACH algorithm. TL-LEACH [26] is another algorithm that is proposed with a two step hierarchy:

- a top cluster head as primary cluster head (CH_i);
- a second cluster head as secondary cluster head (CH_{ij});
- and simple node as SN.

In this method, CHs do not send the data directly to the BS. There exists two data aggregation methods. At first, SNs send data to (CH_{ij} s), then (CH_i) collect the aggregated data from (CH_{ij}). In TL-LEACH, two step CH selection causes extra overhead.

PEGASIS: Lindsey and Raghavendra [15] This algorithm is one of the cluster-based algorithms but PEGASIS is done in chain system, the main goals of PEGASIS energy efficiency and data aggregation and extend network lifetime [15]. Reduce the delay of data on the way of sink is another goal of PEGASIS. In this, algorithm nodes have good knowledge about every node positions, because PEGASIS transfer data to BS by chain system. The network has one leader nodes, from the last node in the right side section of network transferring data start to the leader from the left side too. The leader node gets two side data aggregate and sends to the BS. RSSI measures the distance to all its neighbours.

EACLE: Authors in [28] proposed a new energy-aware clustering method. In this method, control transmission power to improve the network lifetime. EACLE tries to build a tree scheme by sink node and sensor nodes. In EACLE there are two power transmission modes 'power low' and 'power high'. Power low is used for packet transmission inside of cluster between CM and CH. Power high is used between CHs transmission. Authors in EACLE noted that there is not any other information about the distance between nodes in data packets. The connection between CHs is a mesh network connecting. In the routing step, only CHs have routing information, so the connecting tree makes fast between CHs.

In MELEACH-L [24] authors had improved the energy efficiency and the network lifetime by selecting the CH based on the residual energy of the network. According to these studies, we have proposed our method in the next section. We used some parameters that have more effect on the CH selection.

Let us consider a network in which node is deployed randomly. For instance, let us consider a node n_i , where $1 \leq i \leq n$ that is located far away from the BS. Also, let us assume that the BS is located at the centre of the network. For this specific case, transferring the collected data to the BS requires more energy and increases the cost. If the node n_i does not have enough energy to transfer data to BS, in this way the data transfer is unsuccessful. When n_i is selected as the CH, it will not have enough energy for the transmission with respect to the BS. Under these assumptions, we have proposed a new method to select the CH.

3 Network model and assumptions

Our motivation for this work is to develop a new clustering method. Our network model will be based on the hierarchical network model that contains clusters, cluster members, CHs and a BS. The succeeding text enumerates the description of our architecture:

- **Cluster:** Consist a set of sensor nodes that have transmission with each other.
- **Cluster member:** In each cluster, there are sensor nodes that have the duty of gathering data and acting with respect to the events.
- **Cluster head:** Each cluster has one CH that is responsible for collecting data from cluster members, aggregating the data and transmitting it to the BS or to the higher level CH.
- **Base station:** It is located at the centre of the network on top of the network hierarchy. It collects data from the CHs. Also, it has an unlimited energy supply.

We assume that 100 number of sensors are dispersed on 100×100 m² operational area. Below are properties in our network:

- The nodes are deployed randomly in a specified area.
- BS is located at a fixed point in the centre of the network.
- Whole network divided into 16 clusters.
- Each cluster will have one CH.
- All nodes are homogeneous, initial energy is fixed in each node.
- Each node can send data directly to the BS.
- All nodes have the same transmission range.
- All nodes have a unique identification number.
- Nodes are not mobile.

The network range size in metres is 100×100 , the BS is in the centre of the network at 50×50 m² coordinates. Initial energy of all nodes is fixed at the beginning of the network and it is set to 0.5 J. Assuming that all nodes are homogeneous, data packet size per round is 4000 bytes. We suppose that all of the sensor nodes have at least one neighbour. The power model used is similar to the LEACH algorithm [14]. Equations (5) and (6) calculate the amount of energy consumed during the transmission and receiving, respectively. Power dissipated while sending k bits of data can be calculated as:

$$E_{tx}(k, d) = \begin{cases} E_{elec} \times k + e_{fs} \times k \times d^2, & d < d_0 \\ E_{elec} \times k + e_{mp} \times k \times d^4, & d \geq d_0 \end{cases} \quad (5)$$

And to receive k bits of data radio expends:

$$E_{rx}(k) = k \times E_{elec} \quad (6)$$

where E_{elec} is the amount of energy consumption in the transmitter t or receive r, e_{mp} is multi-path fading energy consumption, e_{fs} is

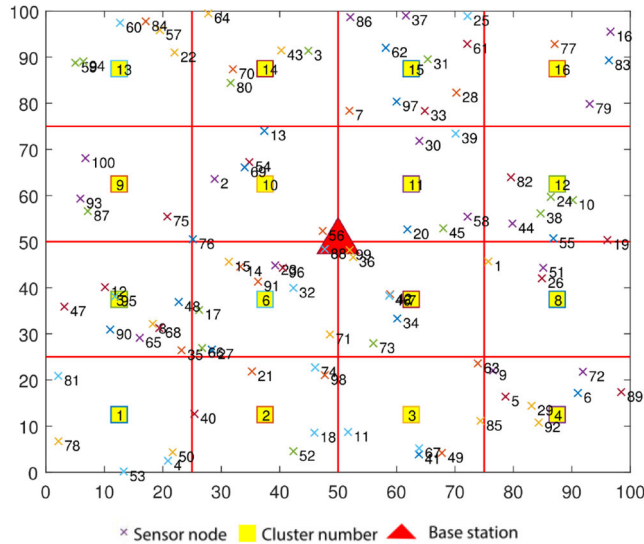


Fig. 1 Network structure

Table 1 Neighbour table

Node ID	Node Energy	Energy of node's neighbours	Number of hops	Number of links to neighbours	Cluster ID
i	$E(i)$	$Es(i)$	$H(i)$	$L(i)$	$Cl(i)$

Request Packet:

Source Address	Get Node Energy	CRC
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Answer Packet:

Source Address	Destination Address	Node Energy	CRC
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Fig. 2 The transmission data packets

free space energy consumption and d is distance between the node s .

4 Our method

The proposed network structure is presented in Fig. 1. HEEL is based on clustering and cluster selection in WSNs. This algorithm uses application layer of WSN. The purpose of the invention is to reduce the number of dead nodes, and increase the lifetime of the network. Also, another goal of this algorithm is to optimise the energy consumption throughout the entire network. As LEACH algorithm is based on clustering, it has some problems in selecting cluster header. In this paper, we propose a different method for choosing a CH. For each node, we propose four parameters that each of these parameters saved in a table named neighbouring table in each node. The neighbouring table is shown in Table 1.

- (i) Node energy.
- (ii) Energy of node's neighbours.
- (iii) Number of hops.
- (iv) Number of links to neighbours.
- (v) Cluster ID.

After nodes deployment, a neighbouring table will be created for each node in their memory. In this step, each node broadcasts a packet to aggregate data from neighbours and save it in the table. Each node broadcasts a packet as shown in Fig. 2 to get neighbour node energy and find neighbours in the step is based on the received signal strength indicator (RSSI). After this neighbour node broadcasts a message as shown in Fig. 2 to the source node. In this situation, node i updates its own neighbour table. Calculate the number of links and sum of neighbour nodes energy. In the neighbour table, the number of hops to the BS gets by the message

that is broadcasted by the BS to each node. Also each node will define its own cluster and then save that cluster ID in the neighboring table.

Node Energy: Energy of a node is a crucial element in WSNs. Residual energy of the node can help us while choosing the CH; therefore, it is very effective. If the residual energy of a node is less than the required energy for the transmission of the data, choosing these nodes for a cluster is useless. One of the important tasks of the cluster is to collect information from cluster members. CH sends aggregated data to the BS. If the residual energy is less than a threshold value, then the node will not be selected as the CH. The residual energy of a node varies per round depending on the task of the cluster member or CH.

Energy of Node's Neighbours: For the selection of CH, we also consider the energy of the node's neighbours. The energy of the neighbour of the candidate CH must be more than the amount of necessary energy for data transmission. Otherwise, the selection of this CH will not be useful. In this case, neighbours will be dying and the data will not be transmitted. In addition, the distance between the CH and the BS will affect the selection of the cluster. Each node counts the number of neighbours from the received message packet (Fig. 2).

Number of Hops: Consumption energy of a node is also important in CH selection. It is related to the distance between each of the nodes. The candidate CH is not located far from the BS, because the dissipation energy for each distance will be different. HEEL tries to select a node that is closer to the BS, as it will save more energy. So, we consider the number of hops to the BS in selection CH method. In this step, BS sent a packet to each sensor node to calculate the distance between BS and sensor nodes.

Number of Links to Neighbours: The next one is the number of links to neighbours, in other words, the number of paths between a node and the other nodes. Here, for each node, a path table is

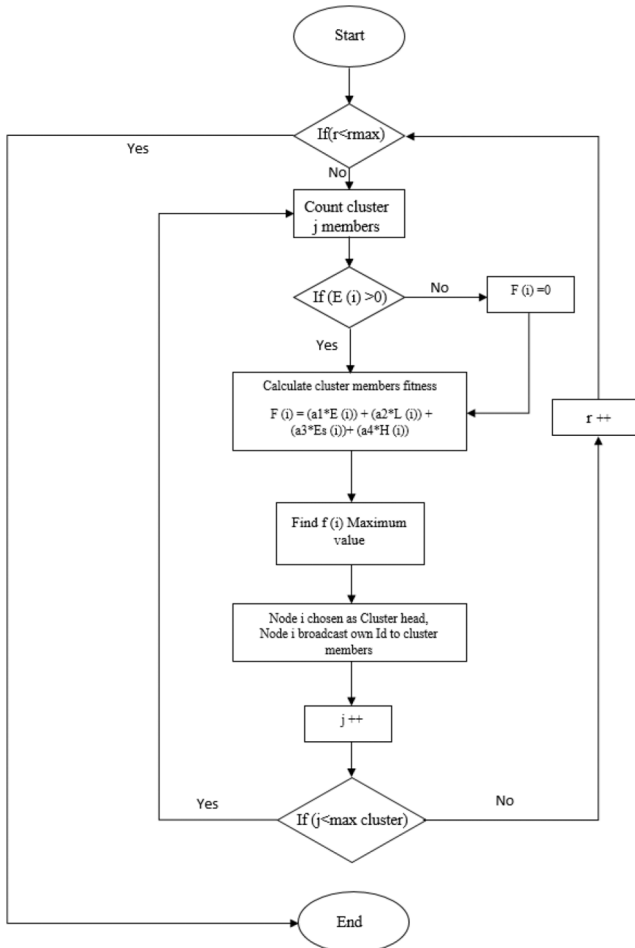


Fig. 3 HEEL algorithm flowchart

Input: All of nodes in each round
Output: Selected cluster head

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1: N=Total Number of nodes
2: J=Max cluster numbers
3: E(i)=Node energy
4: Es(i)=Energy of node's neighbors
5: L(i)=Number of links to neighbors
6: H(i)=Number of hops to base station
7: Rmax= Maximum round number
8: for r=1 : Rmax do
9:   if j <= J then
10:    j= cluster members size
11:    for i=1 : j do
12:      if E(i) > 0 then
13:        Fitness(i) = (a1 * E(i)) + (a2 * L(i)) +
(a3 * Es(i)) + (a4 * H(i))
14:      else
15:        Fitness(i) = 0;
16:      end
17:    find max Fitness
18:    Broadcast selected CH-id to Members
19:    State(i)=CH
20:    Update(E(i))    ▷ Calculate Dissipation Energy
21:  end
22:  j ++
23: end
24: r ++
25: end
26: end

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Fig. 4 HEEL pseudocode

considered. After finding the number of neighbours of a node, the information of each node is stored in the neighbour table. The purpose of finding the number of links to neighbours is to select a

node that has a greater number of neighbours because it covers a large number of nodes. This will cause the selection of a node as a CH that has a maximum number of neighbours. In this case, data aggregation will be done and there will be no clusters without the nodes. As mentioned above, we consider four parameters to select the CH in each cluster. A specific value is calculated for each node by using the following formula to select a CH:

$$\text{fitness}(i) = (a_1 * E(i)) + (a_2 * L(i)) + (a_3 * Es(i)) + (a_4 * H(i)) \quad (7)$$

where $E(i)$ is residual energy of node i , $L(i)$ is number of links of node i to its neighbours, $Es(i)$ is energy of node i 's neighbours, and $H(i)$ is number of node i 's hops to the BS.

Number of hops to the BS and number of links to the neighbours have constant values during the lifetime of the network. So, we have used fixed coefficients in (7). In addition, node's energy and energy of node's neighbours have different and more effective coefficients. Here, a_1 , a_2 , a_3 and a_4 are weights that are assigned to each of the parameters. These weights are related to the usage of the application and purpose of the network. For example, if in the network our goal is to have a greater energy efficiency, it is necessary to use a_1 and a_3 with a higher value. As another example, if the distance is the most important component for the network, a_4 must have a higher value to use low power energy. In (7), $a_1 + a_2 + a_3 + a_4 = 1$, where $a_i \in (0,1)$.

The obtained value from (7) for each sensor node of a cluster is compared to other sensor node's value. A sensor node will be selected as CH that has the maximum value in that cluster. CH broadcasts a package that contains the cluster head's ID. After all, in each round the network has 16 CHs. CH in the neighbour table has own neighbours, so in the broadcasting package, the ID of the neighbouring sensor node is shared. So cluster members aware of their cluster head id and communicate with the cluster heads. Same as LEACH algorithm, HEEL algorithm is used TDMA schedule for inter-cluster communication to avoid the collision. Intra CH communication is done in low energy amplification. CH's aggregate collected data from cluster members, so they must forward data to BS. HEEL algorithm followed a hierarchical structure, so each CH must forward data to an up-warding layer near to BS. In HEEL we have four parameters to calculate fitness value for each node. The first step is to deploy nodes randomly. In (7) all of the parameters are in between 1 and 100. For instance, at first step initial energy of nodes are 100. On the other hand, the node that has a minimum distance to the BS, that is the minimum number of hops, gets the higher corresponding value in (7). The maximum value of the hop size gets the minimum value in (6). We consider the fact that if the number of links to the neighbours in a node is maximum, the corresponding value is maximum or 100. According to these, the fitness value is computed for each node. The HEEL algorithm flowchart and pseudocode is presented in the Figs. 3 and 4 respectively.

5 Performance evaluation

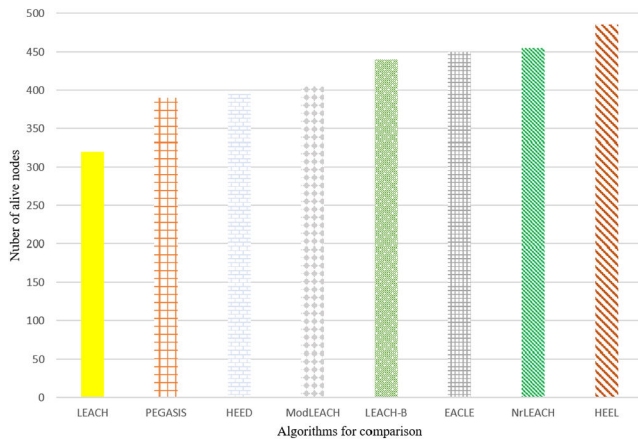
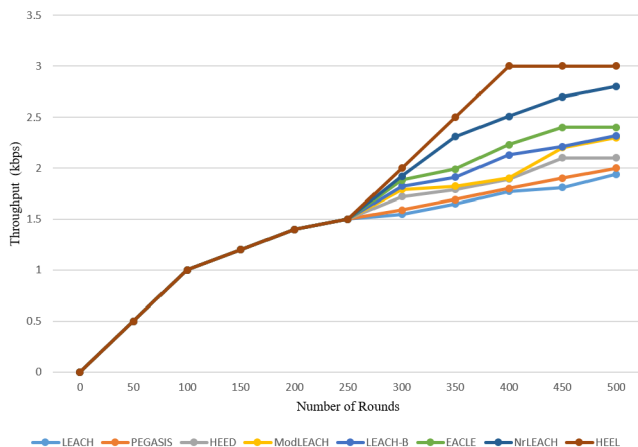
This section compares HEEL with NR-LEACH, MODLEACH, LEACH-B, LEACH, PEGASIS, EACLE and HEED algorithms. The parameters such as the throughput, total residual energy and the number of alive nodes are compared between the presented algorithms. Furthermore, in the following part simulation results are shown. In this network, we assume a_1 is 0.4, a_2 is 0.15, a_3 is 0.3 and a_4 is 0.15. Simulation parameters are shown in Table 2.

We have simulated our method on MATLAB. Throughput is the number of data per unit that is sent by the sensors to the BS or CHs. Fig. 5 shows throughput results on HEEL, NR-LEACH, MODLEACH, LEACH-B, LEACH, PEGASIS, EACLE and HEED algorithms. HEEL is observed to be performing better results compared to other algorithms.

The number of alive nodes in WSNs describes the whole network lifetime. Fig. 6 shows how the HEEL algorithm improves the network lifetime with respect to the other algorithms. The first dead node in HEEL algorithm is observed in the earlier rounds, but

Table 2 Configuration parameters

Parameters	Values
network size	100×100 m ²
node size	100
BS location	50×50 m ²
data packet size	4000 bytes
e_0	0.1 J
e_{fs}	10 pJ/bit/m ²
e_{mp}	0.0013 pJ/bit/m ⁴
e_{elec}	50 n J/bit

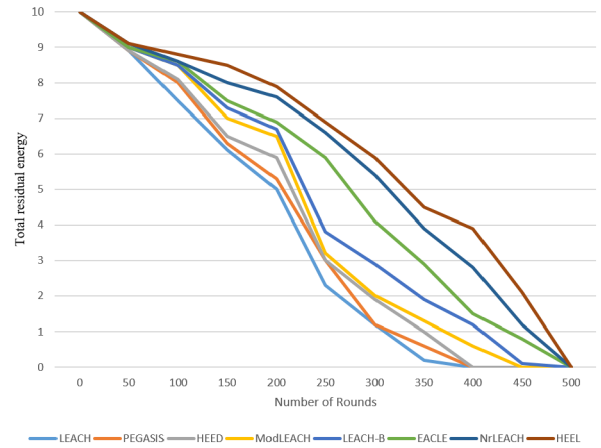
**Fig. 5** Number of alive nodes**Fig. 6** Throughput value in every round

the overall amount of alive nodes of HEEL algorithm is found to be better compared to the others.

The residual energy of the whole network is also another factor which is important for the network lifetime. Fig. 7 shows the results that are obtained from the preliminary analysis of the HEEL. There was a significant improvement between HEEL, NR-LEACH, MODLEACH, LEACH-B, LEACH, PEGASIS, EACLE and HEED algorithms.

6 Conclusion and future work

The purpose of this study was to determine several parameters that have a positive impact on the CH selection. This paper proposes a new method for selecting a CH that improves the network lifetime and throughput. HEEL is based on the node's energy and the location of the node. Node energy, the energy of the node's neighbours, number of hops, number of links to neighbours are parameters that have important effects on the CH selection. The results show that HEEL provides energy efficiency in WSNs. It can be used in various case studies. For example, in different applications of WSNs such as healthcare, monitoring and

**Fig. 7** Total residual energy of whole network

agriculture. Moreover, it is a good suggestion for Internet of Things-based projects. In this method, the life of the system is long as well as efficient and balanced use of resources is another advantage. As a future work, it is planned that the parameters in the presented function will be obtained by a meta-heuristic algorithm [29] and machine learning methods, not by classical simulation and experimental methods.

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8 References

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