Weighted Based Energy-Efficient Protocol for Wireless Sensor Networks

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ABSTRACT

Wireless sensor network (WSN) consists of nodes with limited resources. Hence, it is important to design routing protocols which increases energy efficiency. In WSN, cluster-based architectures are one of the most practical solutions in order to cope with the requirements of large scale of sensor networks and make the vital role for the deployment of energy efficient. The Weighted Based Energy-Efficient Protocol (WBEP) is proposed where the improvement is done in cluster-head selection. WBEP selects Cluster Head (CH) by assigning importance (weight) to sensor nodes based on two parameters residual energy and distance to the BS. The node weight mechanism makes the routing protocol energy efficient and improves its performance. Simulation result shows that WBEP can reduce energy consumption and improve the stability period of the network.

Keywords: WSN, Hierarchical routing protocols, LEACH Protocol, WBEP Protocol.

1 Introduction

Wireless sensor networks (WSNs) consist of a large number of low-power multifunctional sensor nodes which can monitor the surrounding environment through sensing, data processing and communication. Recent advances in sensor technology have enabled the development of small, low-cost and low power sensors, that can be connected via a wireless network. Wireless sensor networks densely deployed and can be applicable to a variety of applications that include surveillance, military, national security and chemical or biological detection. Nodes of sensor work on batteries and in many applications, it is impossible to charge or replace the battery. For that purpose, optimal use of node's energy is a key issue in the network. Routing is a significant challenge to extend the lifespan of network. Generally, the routing protocol is a process to select suitable path for the data to travel from source node to the distinction node, also known as Base Station (BS) [1].

Using a conventional routing protocol such as direct communication protocol, in which each sensor sends its data directly to the BS without any intermediate node, if the BS is far away from the nodes, direct communication will require a large amount of transmit power from each node. This will quickly drain the battery of the nodes and reduce the overall lifetime of the network [2].

Hierarchical clustering algorithm is one of the possible solutions to save energy of wireless sensor nodes. Hierarchical algorithms divide nodes into subregions called clusters. One CH is selected from each cluster to allow communication between clusters. CHs are then responsible for the management and transmission of data aggregated inside of the area they supervise. Cluster-based routing generally comprises of two layers of routing: one layer is related to CH selection and the other is related to routing [3]. However. in some applications, network may consist of nodes with different properties, e.g. energy levels, this known as a heterogeneous network. One of these applications could be the re-energization of sensor networks. As the lifetime of sensor networks is limited, there is a need to re-energize the sensor network by adding more nodes. Thus, the newly added nodes will be equipped with more energy than the nodes that are already in use, which makes the heterogeneity in terms of node energy. The other type of the network that consists of identical nodes known as a homogeneous network.

Motivated by the fact that there are a lot of applications that would highly benefit from understanding the impact of such heterogeneity on the network. In this paper a new weighted based energy-efficient protocol is proposed. The proposed routing protocol takes into account the residual energy of nodes and the distance to BS as these parameters have impact on extend the overall longevity of the network.

The overall contributions of this paper are listed as follows:

- To preserve the energy, node weight mechanism based on communication distance to the BS and residual energy is proposed.
- Propose a suitable cluster-based routing algorithm by adapting the proposed weight mechanism of the node to increase the stable period of the network and achieve better energy efficiency.

The rest of this paper is organised as follows: the related work is discussed in section 2. Section 3 describes the novel proposed method. Section 4 presents the simulation tools, experiments and performance metrics that are used in this work to evaluate the performance of the algorithm. The simulation results and discussion are presented in sections 5, followed by the conclusion in section 6.

2 Related Work

Energy being the most important constraint for WSN and many energy efficient routing techniques have been developed. However, based on the network structure, routing in WSNs can be divided into flat based routing, location based routing and hierarchical based routing. In flat based routing, all nodes are typically assigned with equal functionality. In location-based routing, sensor nodes positions are exploited to route data in the network. In hierarchical routing, the network is partitioned into smaller areas called clusters. In each cluster, there is a sensor node selected as a leader known as the cluster head. Within each cluster, each node simply communicates with the CH within a short range. The CHs communicate with each other to transmit their collected data to the BS. In this way, the energy consumption is greatly reduced since the communication range is largely reduced and the sensor nodes within one cluster can be put into sleep state according to a Time Division Multiple Access (TDMA) schedule, which is sent by CH [4].

The most popular hierarchical method is Low-Energy Adaptive Clustering Hierarchy (LEACH) which is the first energy-efficient hierarchical clustering algorithm proposed for WSNs by Heinzelman, et.al [1]. LEACH is a classical clustering routing protocol and forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. LEACH arranges the nodes in the network into clusters. All clusters are self-organized, each cluster contains a CH and several non-CH nodes. LEACH allows each node to transmit its data to the CH of its cluster. The CHs aggregate the data received from the non-CH nodes and forward it to the BS. CH node consumes more energy than non-CH nodes. With the purpose of balancing network energy consumption and prolonging the network life cycle, LEACH selects CH randomly and each node has an equal chance to be CH. The cluster structure update constantly in operation, and one updating process is called a round.

LEACH ensures that each node becomes a cluster head only once in 1/p rounds, where p is a desired percentage of CH during each round. The operation of LEACH is divided in to two phases. First one is setup phase where network is organized into clusters, CH advertisement is done and transmission schedule is created. This phase can be further sub-divided into three stages. Advertisement stage, cluster set-up stage and broadcast stage. At advertisement stage, the CH is elected by choosing a random number between (0,1) and then comparing it with the threshold value (Tn), if random number is smaller than the threshold, the node will be the CH in this round. The elected node proclaims itself as a CH by sending a broadcast message to the whole network. The calculation method of threshold value (Tn) is based on the following formula:

$$T(n) = \begin{cases} \frac{P}{1-P*(r mod(\frac{1}{P}))} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

Where: *P* is the percentage of cluster nodes accounting in the total number of nodes, that is the probability of nodes becoming cluster heads.

R is the current number of rounds.

N is the total number of nodes in the network.

G is the set of nodes that did not become cluster heads in the 1/p round.

After the CH is determined and advertises its status, the cluster set-up stage starts and the remaining nodes in the network select their CHs based on the strength of the received signal of the advertisement signals and sends join-request messages to inform the CH node that it will be joint it. In broadcast stage, the CH node receives all the messages for nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the CH node creates a TDMA [1].

In the second phase the steady state phase, the data is aggregated, compressed and then transmitted to the BS. The nodes selected as CH consume more energy due to performing additional functions that results in early death of these nodes. Thus, the stability region, time interval before the death of first node, is low. In order to maintain a stable network, CHs keep on rotating, in every round. So, a node which had become CH may not get an opportunity to become CH again before a set interval of time. However, LEACH assumes all the nodes are equipped with the same amount of energy and does not consider the energy level of a node while electing CHs, as a result, LEACH cannot take full advantage of the presence of node heterogeneity. Many researchers have proposed improved algorithms based on LEACH, such as Stable Election Protocol (SEP) which has operation similar to LEACH, but with the difference that, in SEP sensors have two different level of energy. SEP is a two-level cluster heterogeneous routing protocol in which there are two types of nodes in the network; normal and advanced node. Advanced nodes have more energy than normal nodes. Weighted election probabilities of the nodes are used for the election of CH according to the initial energy of the nodes. To choose the node as CHs, the initial energy of a node is considered as important. As compared to the normal nodes, the energy of advanced nodes is known to be higher therefore, they can be chosen more often as CHs [5]. However, SEP algorithm still has some drawbacks that need improving. In SEP, the election probability is related just to the initial energy of the node and not to the remaining energy. After the network is running for some time, the residual energy of the advanced node may not be higher than the normal node, and the probability of becoming the cluster head is still higher than that of the normal node. This will speed up the death of some advanced nodes and reduces the stability period and overall lifetime network. To provide energy efficiency and prolong network life time, many of the researchers are heading to machine learning algorithms. The enhanced LEACH algorithm, named LEACH-Kmeans is proposed in [6]. The improvement in LEACH-Kmeans is done in cluster-head selection. LEACH-Kmeans utilizes K-means clustering calculation for choosing better cluster heads. However, LEACH-Kmeans proposed with the objective of reducing energy consumption by avoid the poor CH allocation in which some cluster heads located closed to each other which diminish the effectiveness of clustering. Further, LEACH-Kmeans does not considered the remaining energy level of the nodes in the process of selecting cluster heads.

3 Weighted Based Energy-Efficient Protocol (WBEP)

Similar to traditional LEACH, WBEP protocol consists of a setup phase and a steady state phase. In the setup phase, every node sends information regarding its current location and its residual energy level to the BS. The BS will then elect the optimal CHs for the network. To elect the optimal CHs, WBEP calculates a weight value (W_i) and assigns it to each sensor. The election of CHs is based on weight allocated to each sensor node. WBEP considers both residual energy and distance to BS for selection process. The selection process is done centrally by the BS.
The weight is calculated using the following equation:

$$W_i = 100E_i \,/ \sum_{i=1}^{n}[E_i/n] + 10d_i \times \sum_{i=1}^{n}[d_i/n] \tag{2}$$

Where: W_i is the weight of node *i*
E_i is the residual energy of node *i*
n is the number of alive nodes in the network
d_i is the distance between node *i* and the BS
The nodes with higher weight (*W*) have more probability to become cluster head. The node weight mechanism has two components to be calculated: residual energy (*E*) and distance to BS. The former is mainly related with sustainable energy consumption. The node with higher residual energy has higher weight which means more probability to be a CH. The latter is related with energy consumption of intra-cluster communication. Selected CH will be node with less distance (*d*) but has

sufficient energy. It is wort noting that unlike LEACH, WBEP does not take into consideration whether or not this sensor was a CH for previous near rounds.
After the weights of each node are calculated, the CHs are selected among nodes in the network by using K-means clustering algorithm and based on weights of nodes and position of nodes.
K-means is the simplest algorithm used for unsupervised clustering. This algorithm partitions the data set into *k* clusters using the Euclidian distance mean, resulting in maximizing intracluster similarity and minimizing intercluster similarity [7]. K-means can be applied to relatively large sets of data. The user specifies the number of clusters to be found and the algorithm then separates the data into clusters by finding a set of cluster centres, assigning each objects to a cluster [6].
The rest of the WBEP is the same as LEACH in which the BS broadcasts an advertisement message to all the other sensor nodes in the network; this message would contain the IDs of the various CHs. Each non-cluster nodes, also known as cluster members, decided which CH to join based on the received signal strength from the cluster head advertisement. After the cluster members join themselves with a CH, the CH assigns a TDMA slot to the members. In the assigned time period, the members only communicate with the assigned CH, and transmit the data they have obtained.
The flow chart of WBEP algorithm is shown in figure 1 and explained in the following steps:

- **Step 1:** Each node sends its ID, residual energy and location to the BS.
- **Step 2:** BS calculates the weight for each node in the network based on equation 2 and runs a centralized cluster formation algorithm based on the weight of nodes (W_i) to determine the cluster heads for the current round.
- **Step 3:** Once the CHs are selected, the BS broadcasts a message that contains the cluster head ID in the network. If a node's ID matches the cluster head ID, the node is a CH and advertises itself to the other nodes in the network. Once the advertisement is done, each non-cluster-head joins a cluster.
- **Step 4:** After the node completes the process of clustering and selecting cluster head the CH divides time into several slots and each cluster member node collects and transmits data to the CH in its own time slot.
- **Step 5:** CH collects data, aggregates it and then sends it to the BS. However, if the distance between the node and its nearest CH greater than the distance between the node and the BS, the node communicates directly to BS rather than CH.
- **Step 6:** In each round, each node sends its own remaining energy to the CH which forwards it to the BS, and the previous steps are iteratively repeated and new nodes are selected as the new CH by the BS.

4 Simulation Setup and Parameters

In this paper, the WSN composed of 100 nodes and one BS. The protocols implemented in a field with dimensions of 100m×100m. The initial energy for nodes is 0.5J. The nodes are randomly distributed over field and the BS is located at the centre of the field (50 ,50) m. The probability of selection of a cluster head is set to be 5% which is the optimal value as proved in [1, 8]. Other simulation parameters are shown in Table 1.

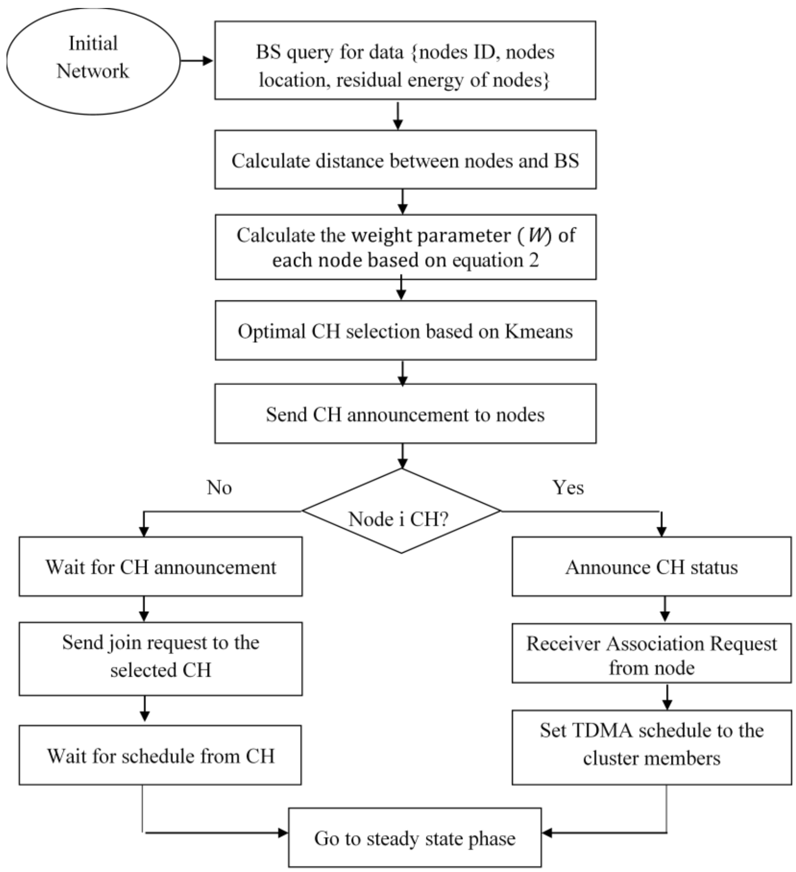

Figure 1 *Flow chart of WBEP protocol*

Table 1. *Simulation parameters*

Parameter	Value
Network Size	100 x 100
Base station location	(50, 50)
Number of sensor nodes	100
Data packet size	4000 bit
Initial energy of sensor	0.5 J

Data aggregation energy (E_{DA})	5 nJ/bit/message
Energy consumed in the electronic ccircuit to transmit or receive the signal (E_{elec})	50 nJ/bit
Energy consumed by the amplifier to transmit at a short distance (ε_{fs}) if $d \leq d_0$	10 pJ/bit/m^2
Energy consumed by the amplifier to transmit for multi path model(ε_{mp}) (if $d > d_0$)	0.0013 pJ/bit/m^2
Reference distance (d_0)	87 m
The probability of cluster heads	5%

However, in the simulation, the BS, and sensor nodes have the following features:

1- BS and all nodes in the network are static and able to connect to the network.
2- Each node can calculate its residual energy and identity of its own.
3- Wireless transmit power of a node is controllable so all nodes can transmit data with great power to reach the BS.
4- The data is always available to be sent to the CHs or the BS in each round.

4.1 Performance Measures

The measures used to evaluate the performance of routing protocols are:

- Stability Period: is the time period measured from the beginning of network operation until the first death of sensor nodes [9].
- Network lifetime: is the time interval from the start of operation until the death of the last alive node [10].
- Number of cluster heads per round: this instantaneous measure reflects the number of nodes that send aggregated data directly to the BS from their cluster members.
- The number of transmitted packets: is defined as number of packets sent over the network. This could be the transmitted packets by CHs to BS, transmitted packets by nodes to CHs or transmitted packets by nodes to BS.
- Average residual energy of network: is the average remaining energy of sensor nodes at the end of each round in the network which impacts strongly the network lifetime. Energy consumption mainly includes circuit energy consumption and power amplifier energy consumption [11, 12].
- The percentage of each node being elected as CH: is the percentage of each node being selected as a CH during the life time period of network.

5 Results and Discussion

Figure 2 shows the initial deployment of 100 nodes in the field of 100 ×100m. The nodes and BS are denoted by the circle and red arrow respectively.

5.1 Network Lifetime and Stability Period

Lifetime of the network is evaluated by following criteria: round time of first node is dead, 30% of nodes in the network are dead, 50% of the nodes are dead, and 70% of the nodes are dead. The round times of first node is dead can represents the stabilization level of the WSN. The performance of the WSN is seriously influenced if half of the nodes died. When %70 of nodes died, the whole network can be regarded as destroyed [13].

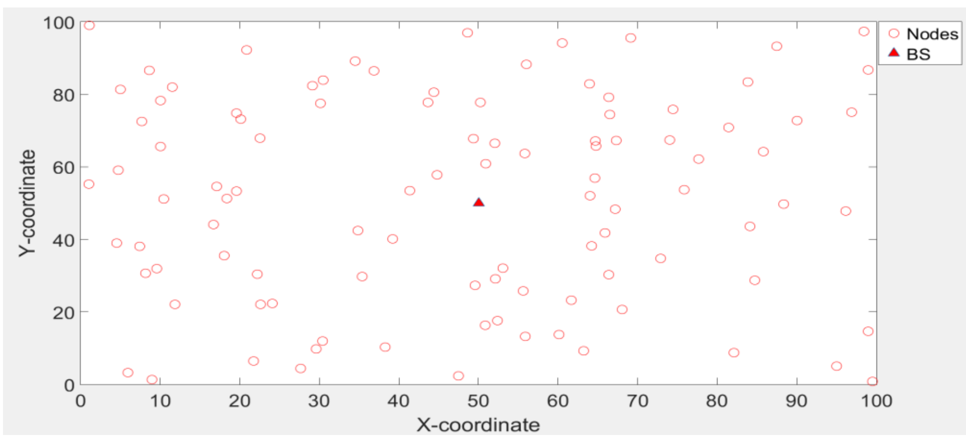

Figure 2 *Topology of the network*

Figure 3 shows the lifetime of network with the LEACH and WBEP protocol. From the figure, it can be seen that in terms of stability period, WBEP is much better than the LEACH protocol. WBEP protocol effectively prolong the time of the first node died by approximately 9.4%, meaning that WBEP is more effective in extending stable period and ensures the completeness and accuracy of information collected.

The number of dead nodes versus the number of rounds is shown in figure 4. It can be observed that the last node dead in WBEP protocol is at round 1518 as compared to 2023 in LEACH protocol. However, even though the network lifetime in LEACH is higher than WBEP, WBEP has higher number of alive nodes until round 1517. In LEACH there is only one node still alive in the network between round 1389 and 2023 and the network during this period becomes useless and regarded as destroyed.

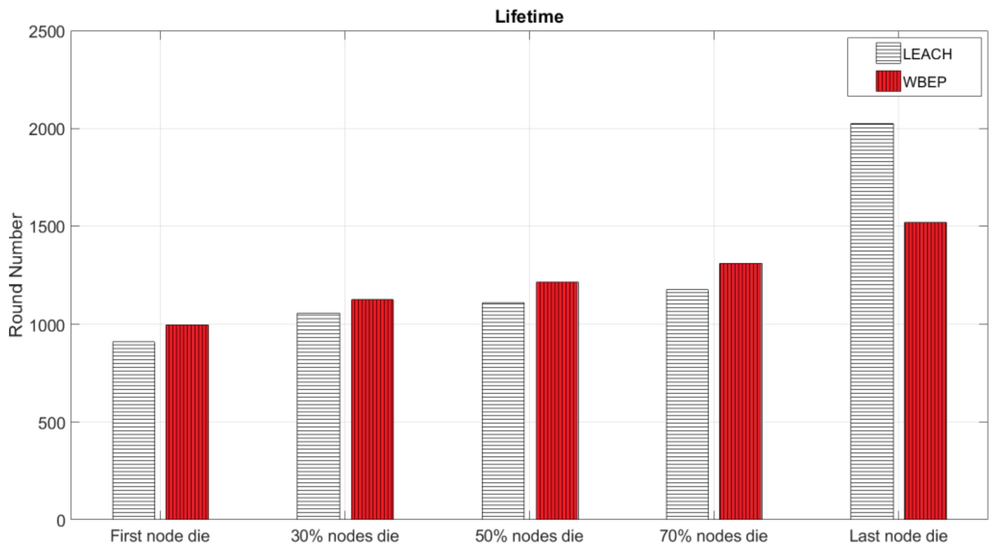

Figure 3 *Comparison of lifetime of LEACH and WEBP protocols*

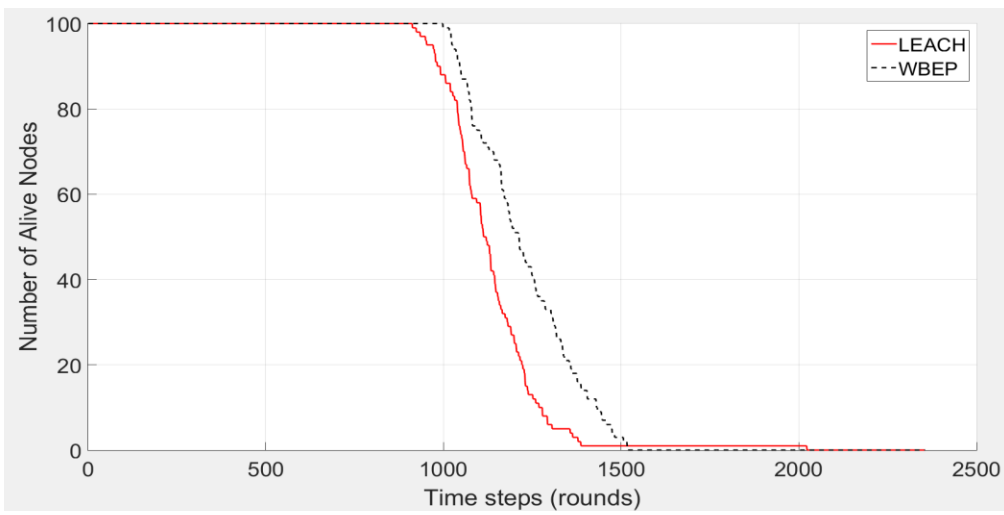

Figure 4 *Network lifetime for LEACH and WBEP routing protocols*

5.2 Average Residual Energy

Figure 5 shows average residual energy versus the number of rounds for both LEACH and WBEP protocol. WBEP reduces energy consumption compared to LEACH. Half of the total energy in the network is consumed at round 559 for LEACH and 619 for WEBP. Better performance of WBEP over LEACH emphasizes the advantage of partition level and weight metric of WBEP over LEACH in term of energy efficiency.

To obtain a more accurate analysis, similar experiments with three different initial energy values of nodes are used. The results from these experiments is shown in Table 2.

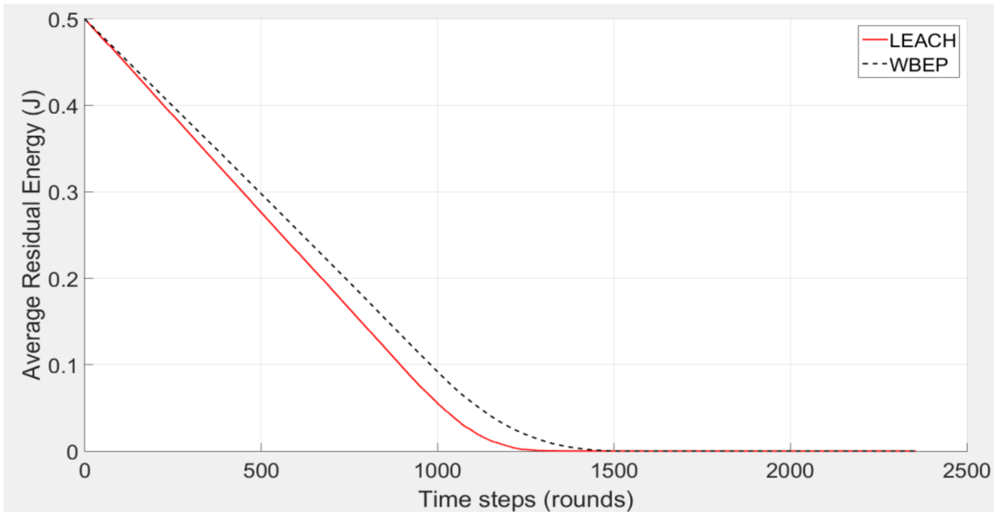

Figure 5 *Average energy of each node in LEACH and WBEP with 0.5J*

Table 2. *Comparison of routing protocol by varying initial energy for sensor*

Energy (J/node)	Protocol	First node die	30% of node die	50% of node die	70% of node die	90% of node die	last node die
0.25	LEACH	458	532	559	590	636	1228
	WBEP	487	555	608	662	728	763
0.5	LEACH	912	1056	1113	1180	1269	2023
	WBEP	998	1129	1212	1309	1431	1518
1	LEACH	1821	2098	2186	2294	2415	3202
	WBEP	1906	2141	2451	2658	2894	2993

5.3 Number of Cluster Head Node

The other performance metric considered in this study is the number of CHs per round. Figure 6 shows the number of CH for both routing versus the number of rounds. As can be seen from the figure, the number of CHs in LEACH fluctuations between 0 and 15. Meanwhile, the number of CHs in WBEP remains constant at 5 clusters between round 0 and 1474 and decreased to reach 0 at round 1518 when there is not any node still alive. This is due to the fact that the cluster-head selection process in LEACH is generated based on the threshold function model, which has great randomness. On the other hand, WBEP finds CH using K-means algorithm based on weight of the node, thereby reducing the randomness of CH counts.

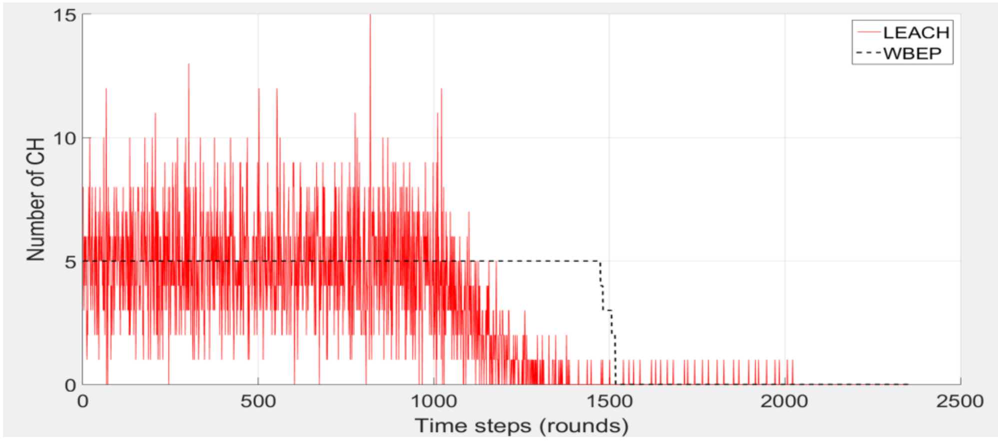

Figure 6 *Number of cluster head per round*

5.4 Number of Transmitted Packets

Figure 7 shows the number of packets received by CHs for LEACH and WBEP. It can be observed that LEACH has slightly higher number of packets received by CHs than WBEP in the stable region and for some of the unstable region up to round 1000. In LEACH, the number of CHs is slightly higher than WBEP between round 1 and 1000. Therefore, there are more packets per round received by CHs in LEACH than WBEP. On the other hand, figure 8 shows the number packets received by BS. It is clear from the figure that the transmitted packet to BS in WBEP is higher than LEACH. In this sense, better packet delivery has provided by the proposed protocol than LEACH.

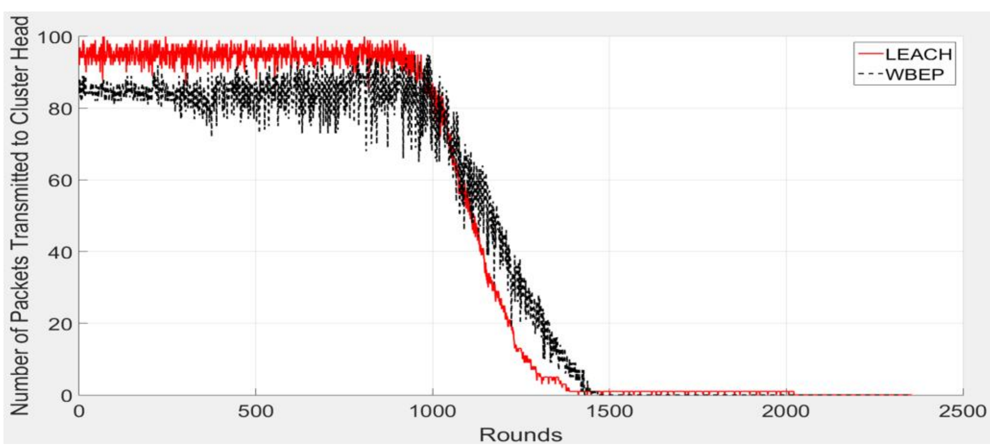

Figure 7 *Number of packets sent to the cluster heads per round*

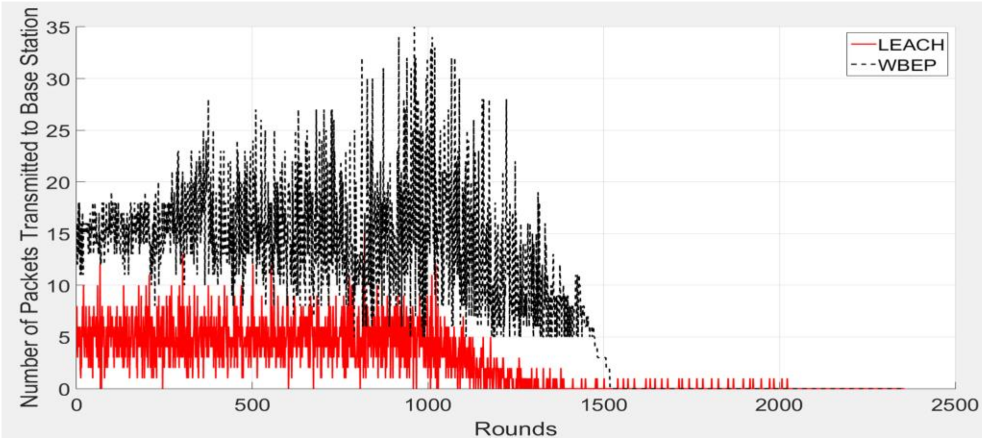

Figure 8 *Number of packets sent to the base station per round*

5.5 Percentage of Each Node Being Elected as a Cluster Head

Figures 9 and 10 show the percentage of each node that elected as CH for LEACH and WBEP respectively. In LEACH protocol, the CH is randomly selected, and does not take into account the residential energy of the node. However, in WBEP protocol, the priority of selection CHs is given to the nodes with the high energy and does not take into consideration whether or not the sensor was a CH for previous near rounds. This causes nodes with high residual energy have been selected as cluster more often than other nodes. However, in LEACH the probability of each node to be elected as CH is same. It is worth noting that node ID 95 in LEACH has been selected as CH more than others because it was the only alive node in the network from round 1389 to 2023 and considered as a CH because it communicates directly to the BS.

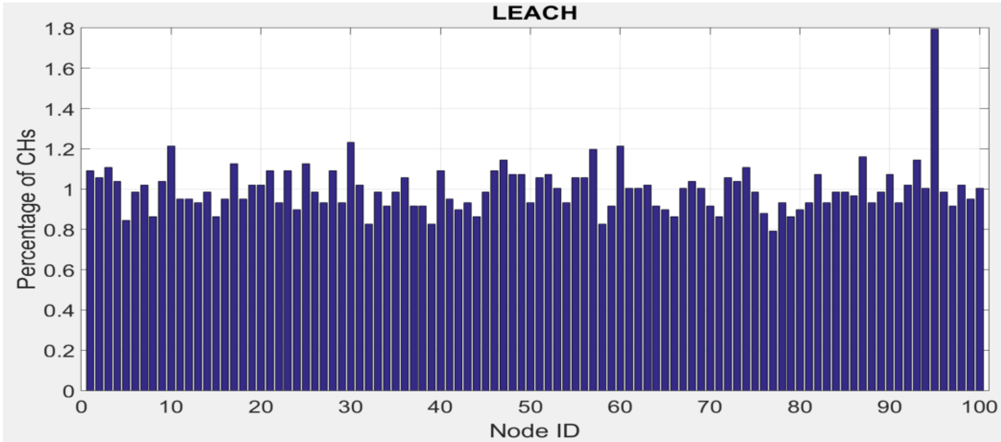

Figure 9 *Percentage of becoming cluster head at LEACH protocol*

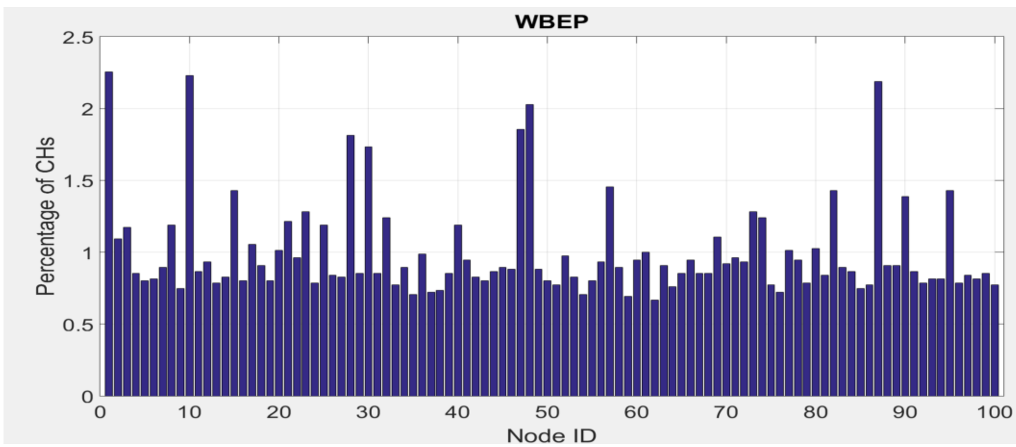

Figure 10 *Percentage of becoming cluster head at WBEP protocol*

6 Conclusion

Energy saving is an important issue in WSNs. To enhance energy efficiency and extend the service life of sensor nodes. CH selection is an essential step in cluster formation that affects network performance. In this paper, WBEP is proposed for energy efficiency applications. WBEP takes into account the residuary energy of the nodes in the network and their distance to the BS. With the help of MATLAB, the proposed algorithm is evaluated and compared with LEACH protocol under various performance metrics. The simulation results show that WBEP algorithm makes the energy distribution more balanced and outperforms LEACH protocol in terms of most performance metrics, e.g. stability region, energy consumption and fair election of nodes as CHs based on their available resources.

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