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A New Cluster Head Selection Technique based on Remaining Energy of Each Node for Energy Efficiency in WSN

Sagun Subedi[1], Sang-Il Lee[2], Jae-Hee Lee[3]

[1]Ph.D., [2]Professor, [3]Assistant Professor, Department of Electronics and Information Engineering, Mokpo National University, Korea
(sagun434, leesi, jaehee) @mokpo.ac.kr

Abstract

Designing of a hierarchical clustering algorithm is one of the numerous approaches to minimize the energy consumption of the Wireless Sensor Networks (WSNs). In this paper, a homogeneous and randomly deployed sensor nodes is considered. These sensors are energy constrained elements. The nominal selection of the Cluster Head (CH) which falls under the clustering part of the network protocol is studied and compared to Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. CHs in this proposed process is the function of total remaining energy of each node as well as total average energy of the whole arrangement. The algorithm considers initial energy, optimum value of cluster heads to elect the next group of cluster heads for the network as well as residual energy. Total remaining energy of each node is compared to total average energy of the system and if the result is positive, these nodes are eligible to become CH in the very next round. Analysis and numerical simulations quantify the efficiency and Average Energy Ratio (AER) of the proposed system.

Keywords: *Wireless Sensor Network (WSN), Cluster Head (CH) selection, clustering-based protocols, Residual Energy, Routing, Average Energy Ratio (AER)*

1. Introduction

Wireless Sensor Networks consist of small electronic devices known as sensor nodes, generally operating in rural areas. The important challenge in WSN is energy conservation. To exploit, in the highest possible way, what WSN applications have to offer, it is essential to search and apply methods which will sustain as well as elongate the lifetime of network as long as possible. Nodes run on the batteries to cover their energy needs, which limits their lifetime. Reduction of the energy on battery means WSN will stop operating. If WSN is operating in rural area (in many cases which it does), replacement of batteries is unmanageable as nodes are randomly deployed in huge numbers [1].

The first component of WSN is Base Station (BS) which communicates with numerous sensor nodes. The key features of the BS are that BS is never deprived of the energy source and it has greater processing

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Corresponding Author: leesi@mokpo.ac.kr
Tel: +82-61-450-2430
Professor, Department of Electronics and Communication Engineering, Mokpo National University, Korea.

capabilities. If the base station is an energy-constrained node, it would die quickly, as it is being heavily utilized. All the data from the network is accumulated here and final processing of the data takes place. The BS is the network communication point to the user. BS generally resides far from the network. Another component of WSN is Sensor Nodes. Sensor node is little in size with restricted processing power, memory and limited life battery. The number of sensor nodes depends upon the size of the network. These nodes can be deployed randomly (in many cases) or deterministically (in some cases).

In this paper, we will present the basic knowledge needed to understand how a WSN operates, where and when the energy is being consumed. The role of communication protocols in addressing this limited energy issue will also be taken care of. The major energy consuming factors can be addressed by designing energy efficient MAC and Routing protocols. Routing energy efficient protocols focus on methods that minimize the average transmission distance and reduce the amount of data packets that are being sent towards the base station. Whereas, efficient MAC protocol can save energy resources by programming a node's operation time. Elimination of redundant data is important issue in WSN.

A challenge here is the need to find mechanisms that are sufficiently specific to the idiosyncrasies of a given application to support the specific quality of service, lifetime, and maintainability requirements [2]. On the other hand, these mechanisms also have to generalize to wider range of applications lest a complete from scratch development and implementation of a WSN becomes necessary for every individual application- this would likely render WSNs as a technological concept economically infeasible.

2. Background

The first and most extensively used hierarchical routing protocol is LEACH. It provides data fusion through cluster formation. Nodes forward information to the CH, and CH aggregate and compress data then send them directly to the BS [3]. The LEACH protocol was introduced by Heinzelman [4] in 2000. This paper focuses on the hierarchical routing protocol that is based on clustering algorithm especially low energy adaptive clustering hierarchy protocol (LEACH) that expands total network lifetime, and it is the first hierarchal energy adapted protocol. Unexpected node death can be avoided in LEACH protocol by cluster head rotation process which alleviated the power consumption load on a certain node all the time. Data aggregation process aims to combine and summarize the data packets so that the total data transmitted is reduced. Data aggregation process also has been used to accomplish energy productivity and data transfer optimization in several routing protocols.

The operation that are carried out in the LEACH protocol are divided into two stages, the setup phase and the steady state phase. The setup phase is just the selection of the CH. All the sensors within a network group themselves into some cluster regions by communicating with each other through short messages. At a point of time one sensor in the network acts as a CH and sends short messages within the network to all the remaining sensors. Every node chooses a random number between 0 and 1, any nodes will be chosen as a CH if this number is less than threshold value T(n) determined by the equation 1, otherwise it turns out to be an ordinary node.

$$T(n) = \begin{cases} \frac{p}{1-p*(r \, mod(\frac{1}{p}))}, & n \in G \\ 0 & Otherwise \end{cases} \tag{1}$$

Here, p is the percentage of the CHs in the network, r is the number of the current round, G is the total number of sensor nodes within the network that have not yet been the CH in the past transmission of data to the BS. The CH can decide the optimal number of cluster members it can handle or requires. Before it enters the steady state phase, network topology and the relative costs of computation versus the communication parameters should be considered.

Energy is spent while transmitting as well as receiving s bits of information. To send s bit information to the remote receiver d units away, the transmitting node consumes energy as

$$E_{tx}(s,d) = \begin{cases} s * E_{elec} + s * E_{fs} * d^2, \ d < d_0 \\ s * E_{elec} + s * E_{mp} * d^4, \ d \geq d_0 \end{cases} \tag{2}$$

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \tag{3}$$

Similarly, to receive s bit of information from the remote transmitter d units away, the receiving node consumes energy as

$$E_{rx}(d,s) = s * E_{elec} \tag{4}$$

After the selection of the CH, all the sensor nodes must communicate with the CH, sharing information of its location and sensed data. The mode of communication is either free space or multi path routing depending upon the distance between them. Similar procedure applies for CHs in order to communicate with BS or with other CHs. The CH transmits this aggregated data in a compressed format to the BS which completes the second phase called the steady state phase.

After the completion of the steady state phase, the whole process comes to an end. It can be said that new setup phase and steady state phase begins with the end of data transmission to the sink. This alternative selection of CHs within the region, which is carried among the sensors in a self-organized way helps in reducing or lowering the energy that is utilized. Since the deployment of the nodes in the network is random, which means there is a possibility that all the sensors might not be close to the CH, so amount of energy that is utilized by the farthest sensor is more than that of the nearest sensor. To minimize the formation of the heterogeneous network after some setup and steady state phase, CH formation or the role of CH is performed by rotation among all the nodes in the network [5]. LEACH minimizes global energy usage by distributing the load of the network to all the nodes or cluster member at different intervals [4].

3. Proposed Algorithm for Cluster Head selection

From Equation 1 it is clear that the CH selected depends upon the probability of the formation of CH (p) and number of rounds (r). It is to be noted that a node beside CH can have low remaining energy than that of CH if the distance between that node and CH is greater than the distance between the CH and BS or another CH. Similarly, if the distance between certain node and CH is lower than the distance between CH and BS, then remaining energy of the CH will be higher than that of certain node.

LEACH clearly defines that no nodes can further become CH if it is already elected as CH in the previous round. This may create conflict in the election of the CH, as the nodes can become CH although it has low energy than the node which already was CH. Initially the network is homogeneous. The CH selection process defined by the Equation 1 may turn the network into heterogeneous. For the remedy of this drawback, it is necessary to modify Equation 1 to elect CH not only depending upon r and p but also depending on the remaining energy of each node.

The network model before describing the LEACH algorithm some assumptions are introduced below.

- All the nodes are deployed randomly in the sensing area, and after the deployment all the nodes and

BS are stationary.

- The location of all the sensor nodes is known clearly after the deployment.
- The transmission power of all the nodes can be changed by nodes themselves depending on the distance to the receiver nodes.
- The system is homogeneous, i.e., all the nodes possess same amount of initial energy.
- BS has infinite processing power and infinite energy.

Table 1 represents different constants which is input for the simulation of LEACH protocol as well as for the simulation of proposed algorithm described in Section 3. These exact values are used by [4] and many other researchers [6, 7] as input for the simulation of their algorithms. Total number of nodes and rounds can be varied according to the demand.

- **Table 1. Description of different Notations and its corresponding values.**

Notation	Description	Value
N	Total number of nodes in the system	100
s	Bits of information in one sensor node	400
r	Number of rounds to transmit and/or receive data	100, 500
T(n)	Threshold value to be the CH	Defined by Equation 1
E_{fs}	Free space energy	10 pJ/bit/m^2
E_{mp}	Multipath energy	0.0013 pJ/bit/m^4
E_N	Initial energy of one node	0.5 J
EDA	Data Aggregation Energy	5 nJ/bit
E_{tx}	Energy consumed while transmitting s bits of information	50 nJ/bit
E_{rx}	Energy consumed while receiving s bits of information	10 nJ/bit
E_{elec}	Energy consumed while transmitting or receiving	50 or 10 nJ/bit

For the WSN system with N number of nodes and EN being energy of each node, the total energy of the system can be calculated as

$$E_T = N * E_N$$

(5)

Total transmission energy consumed after the completion of each round is defined as the sum of energy consumed to transmit data from each node to CH and aggregated data transmitted from CH to BS.

$$(E_{tx})_{Total} = \sum_{i=1}^{N(1-p)} E_{tx}(s,d) + \sum_{i=1}^{pN} E_{tx}(s,d) \quad (6)$$

Similarly, total receiving energy is consumed by CH only to receive information from nodes. At the end of each round

$$(E_{rx})_{Total} = \sum_{i=1}^{N(1-p)} E_{rx}(d,s) \quad (7)$$

Now, we can calculate the total remaining energy of the system at the end of each round and is given by

$$(E_{rem})_{Total} = N * E_N - \left\{\sum_{i=1}^{N(1-p)} E_{tx}(s,d) + \sum_{i=1}^{pN} E_{tx}(s,d) + \sum_{i=1}^{N(1-p)} E_{rx}(d,s)\right\} \quad (8)$$

At the end of each round, there remain no CH, all the nodes act as an ordinary node. Each round consists of setup and steady state phase. All the nodes dissipate energy at some level during each round. Calculation of this energy is important because it helps in comparing whether a node which already acted as CH can become Cluster Head or not. If EN1 denotes total initial energy of a particular node, then its remaining energy $(E_{rem})_{N1}$ and the average energy $\left(E_{avg}\right)_N$ of all the nodes can be formulated as

$$(E_{rem})_{N1} = E_{N1} - E_{tx} \quad (9)$$

$$\left(E_{avg}\right)_N = \frac{\sum_{i=1}^{r}(E_{rem})_{Ni}}{N(1-p)} \quad (10)$$

Correspondingly, same principle applies in the case of CH.

$$(E_{rem})_{CH1} = E_{N1} - (E_{tx})_{BS} - (E_{rx})_N \quad (11)$$

$$\left(E_{avg}\right)_{CH} = \frac{\sum_{i=1}^{r}(E_{rem})_{CHi}}{N*p} \quad (12)$$

Last term in the Equation 11 represent the amount of energy required by CH to receive the sensed data from nodes residing within the cluster. In LEACH protocol once any node is elected as CH, it is restricted from being CH in the very next round given by Equation 1. Collectively accepting the possibility of all the nodes to become a CH, we can define new probability function for the selection of CH.

$$T(n) = \begin{cases} \dfrac{p}{1-p*\left(r \bmod\left(\frac{1}{p}\right)\right)}, & n \in G \\ \dfrac{Np}{1-Np\left(r \bmod\left(\frac{1}{Np}\right)\right)}, & (E_{rem})_{CH} \geq \left(E_{avg}\right)_{CH} \; and \; (E_{rem})_{CH} \geq \left(E_{avg}\right)_N \\ 0, & else \end{cases} \quad (13)$$

4. Simulation Results

The most concern in the WSNs is the network lifetime. Handy et al. [8] used the first node dies (FND), half of the nodes alive (HNA) and last node dies (LND) to estimate the network lifetime. However, after more than half of the sensor nodes die, the WSNs almost fails in most cases. Therefore, only FND and HNA metrics are chosen to evaluate the network lifetime. Average energy ratio (AER) is represented as the average energy consumed at each node divided by the total available for simulation time. AER (%) is evaluated as shown.

$$AER = \frac{E_{consumed}}{E_{available}} \times 100 \quad (14)$$

The random selection of CHs don not let all nodes the opportunity to take the position of a CH and perhaps some nodes exhaust their energies earlier than others. In LEACH protocol and some of its derived algorithms [9, 10] the energy of the CH is always supposed to be less than that of normal nodes. Energy is utilized by CH to receive data from its cluster nodes and to transmit data to BS or another CH expending multipath or free space energy. Energy required to transmit data from CH to BS is far more than the transmission between CH to CH or normal nodes to CH. In network system, where the position of each component is known after being deployed, it is necessary to check energy level of each node before the next round starts.

The arrangement of network is 100*100 units, 100 randomly deployed nodes operating for 100 and 500 rounds. For data transmission, receiving and aggregation, 0.5 J of energy is allotted for each node. This energy is spent by the nodes for the given number of rounds. We then evaluate the performance mainly according to the following metrics using MATLAB.

- Average energy ratio
- Network Life Time
- FND and HNA
- Alive Nodes

Figure 1 corresponds to the energy level (for both alive and dead nodes) available after the completion of 100 and 500 rounds. When nodes are subjected for a greater number of rounds, more energy will disperse. This can be noted when node is subjected to 500 rounds.

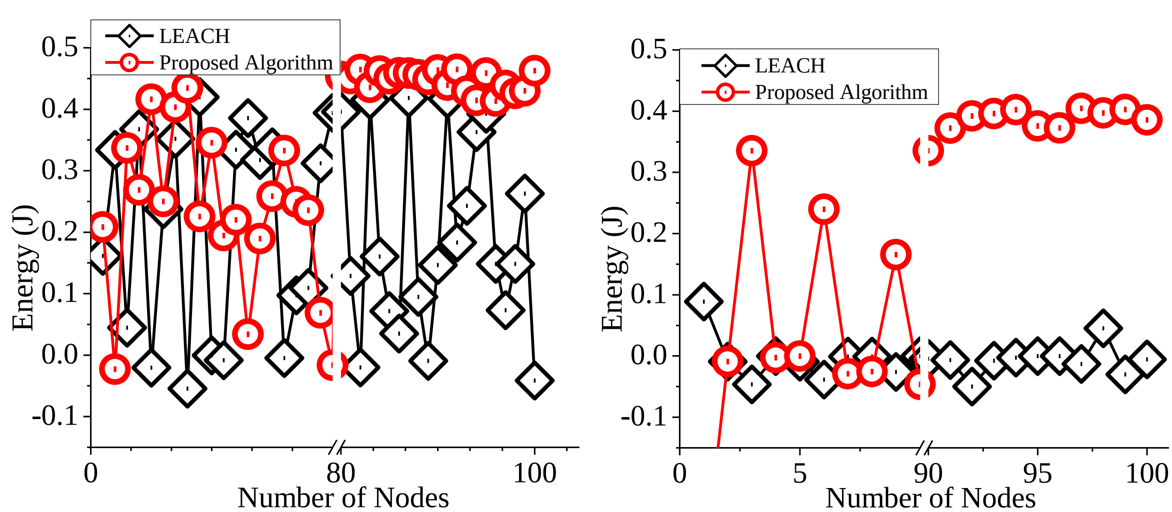

Figure 1. Total remaining energy of the nodes for 100 (a) and 500 (b) rounds

Figure 2 (a) and 2 (b) shows remaining energy in each node for proposed algorithm and LEACH. From energy level diagram proposed algorithm surpass LEACH. Under investigation, majority number of nodes are alive and reside in the upper chain of the energy level of proposed algorithm.

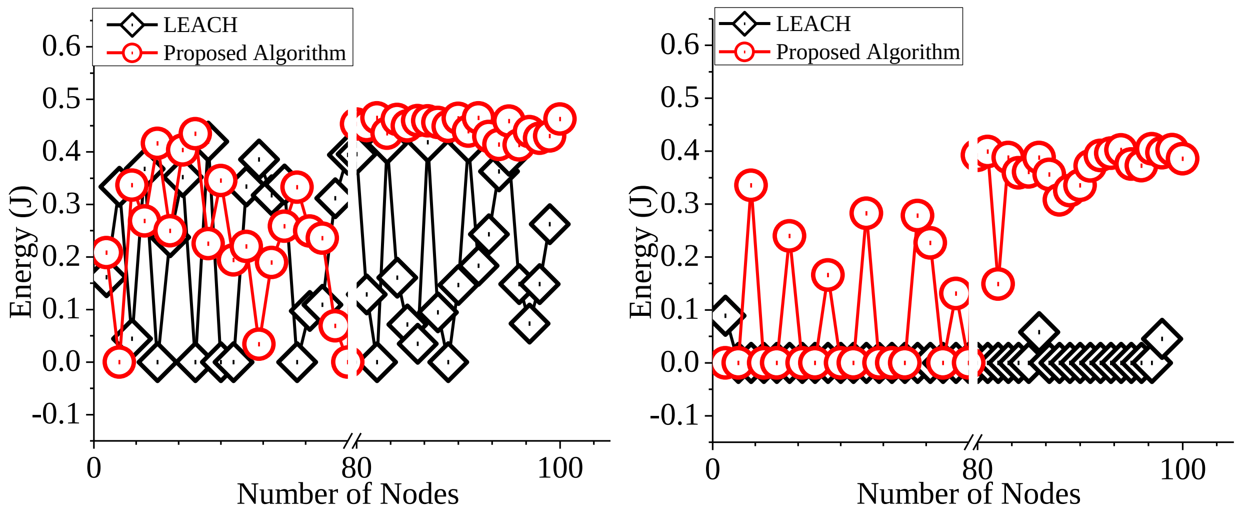

Figure 2. Remaining energy of the alive nodes for 100 (a) and 500 (b) rounds

Figure 3 (a) and 3 (b) shows the energy consumed by the dead nodes. It indicates the number of nodes which utilize energy more than assigned. These are called dead nodes. Figure 3 (a) shows that only 2 nodes in the case of proposed algorithm utilize energy more than assigned, i.e., 0.5 J.

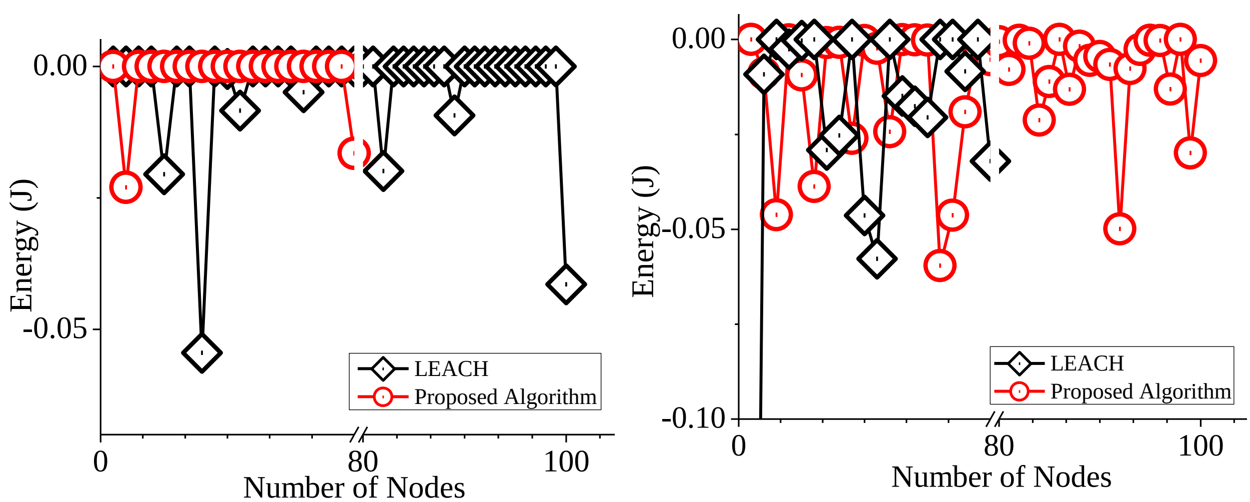

Figure 3. Exceed energy used by nodes for 100 (a) and 500 (b) rounds

Different variables for LEACH and proposed algorithm for 100 and 500 rounds are shown in the Table 2. On the basis of these available data, we can calculate AER metric. The value of AER is found to be 2.5653% and 0.0995% for LEACH and proposed algorithm respectively for 100 rounds. Similarly, the value of AER of the system operating for 500 rounds is found to be 125% and 3.8786%. Total energy of the system is given by Equation 5. Since we are using 100 nodes, hence total energy of the system is 50 J. Each node consumes energy, which is defined by the Equation 6 and 7. Total residual energy of the system is given by Equation 8.

Table 2. Comparison of LEACH and proposed protocol under different conditions

Number of rounds	100	500
Alive Nodes (LEACH)	77	11
Alive Nodes (Proposed algorithm)	98	71
Dead Nodes (LEACH)	23	89
Dead Nodes (Proposed algorithm)	2	29
Residual energy of LEACH (J)	23.341404916	0.818007148
Residual energy of the Proposed algorithm (J)	39.73854799	20.78306276
Exceeded energy of LEACH (J)	0.547469798	1.026981506
Exceeded energy of the Proposed algorithm (J)	0.547469798	1.026981506

Figure 4 shows the number of alive nodes for 100 (a) and 500 (b) rounds of data exchange in two different kinds of algorithm. Number of alive nodes which is directly proportional to the network lifetime is more in proposed algorithm for both 100 and 500 rounds.

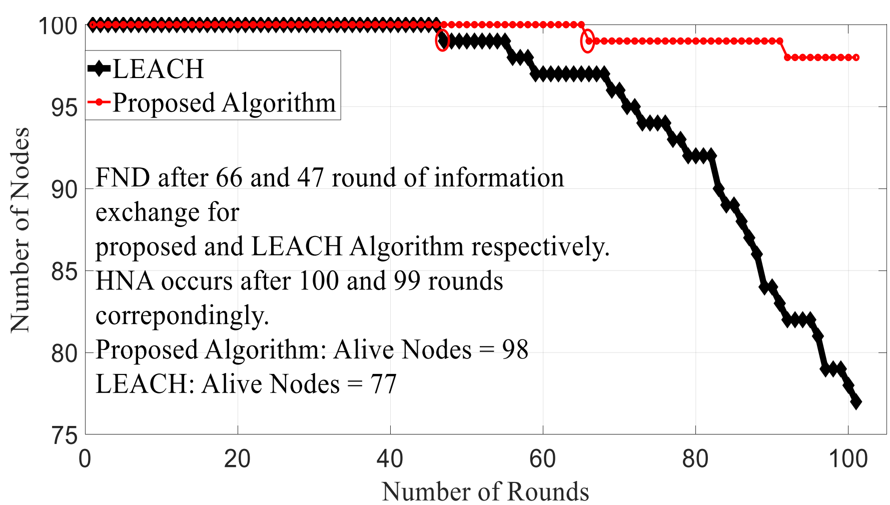

Figure 4 (a). Network lifetime for 100 rounds

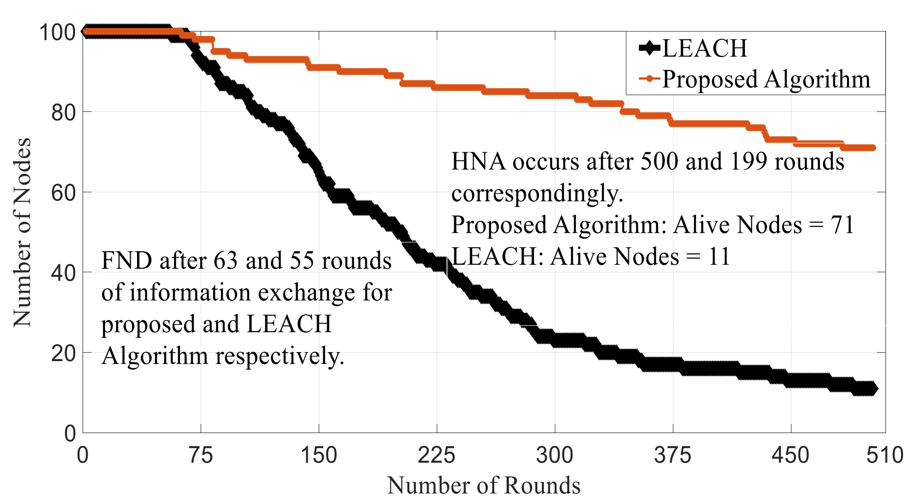

Figure 4 (b). Network lifetime for 500 rounds

5. Conclusion

A new algorithm for the selection of CH is proposed, which aims to balance the workload among all the sensors. When a node loses its energy rapidly than other nodes, the network becomes unstable. Here we try to maintain the equality among the nodes in terms of energy usage. This equality is maintained by selecting the CH in view of important parameters like the initial energy and remaining energy of individual node. After each round of the data transmission, the residual energy of all the nodes including ordinary and CH node is checked. This operation is performed through the Equation 9 and 11. Nodes with the higher energy level in comparison to others has higher probability to be the CH in the upcoming round. Composition of network in this form enhance network lifetime by avoiding nodes to die too early. The results obtained through simulation on MATLAB shows that our algorithm is suitable for large as well as small network system. Estimation of performance metrics such as AER, Network lifetime, FND, HNA and Alive nodes shows notable difference than that of LEACH protocol.

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