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IMPROVED LEACH ALGORITHM FOR ENERGY EFFICIENT CLUSTERING OF WIRELESS SENSOR NETWORK (WSN)

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ABSTRACT

The demand for a Wireless Sensor Network (WSN) has increased enormously because of its great ability to supervise the outside world as well as due to its vast range of applications. Since these sensor nodes depend greatly on battery power and being deployed in adverse environments, substituting the battery is a tiresome job. Cluster-based routing techniques are prominent methods to extend the lifetime of wireless sensor networks. In this research, the work on energy efficient clustering approach is considered in two phases. During the cluster head selection phase, cluster heads are chosen which can stabilize the power consumption in sensor networks, by considering both the residual energy and distance of node with respect to sink. Later, during the cluster formation phase, a non-cluster head node will choose a cluster head that lies in close proximity with the center point between the sensor nodes and sink. Also, these non-cluster head nodes should be within the transmission range of the cluster head, as selected by the above method. Initially, the Low Energy Adaptive Clustering Hierarchy (LEACH) which is an eminent protocol for sensor networks is investigated. Furthermore, the same LEACH protocol is enhanced by proposing an effective cluster head election scheme as well as a new cluster formation scheme as mentioned above. Simulation results reveal that the proposed algorithm outperforms the traditional LEACH protocol in prolonging network lifetime.

Keywords: Cluster head election; LEACH protocol; Network lifetime; New cluster formation

1. INTRODUCTION

A Wireless Sensor Network (WSN) has numerous numbers of sensor nodes and base station/sink. The role of sensor nodes is to collect data from the environment using a sensing unit, which is difficult to do with human beings. Thus, collected data is reported to the base station, which is made available to the end user (Akyildiz et al., 2002). Apart from the sensing unit, the sensor node has a processor to process the information, a radio unit for data transmission and a battery for energy. Thus the sensor nodes have the capability of sensing, computation and communication. The typical WSN and its architecture are given in Figure 1. Generally WSNs can be broadly categorized as a homogeneous network and a heterogeneous network. Only the sensor nodes combine to form a homogeneous network; whereas, components/nodes of different capabilities form heterogeneous WSNs (Katiyar et al., 2011). Heterogeneous WSNs include ordinary sensor nodes, super sensor nodes and relay nodes in different combination. Among these, ordinary sensor nodes are resource-constrained nodes and super-nodes are powerful and highly resource rich compared to normal sensor nodes; super

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nodes can have a higher transmission range, better battery power, higher data rate, etc. (Hadi et al., 2014). The super-nodes are also named as master nodes, gateway nodes and micro-servers in the literature.

Typically the sensors are independent devices that are small with many constraints like power management, fault tolerance, bandwidth limitations, coverage, transmission media, data aggregation, quality of service, memory etc. Among these devices, power management is the most important one (Liu et al., 2010).

Hence one of the most important design objectives of the sensor network is to execute an energy efficient way of data communication, while working towards extending the lifetime of the network (Wang et al., 2011). Balancing the power usage of sensor nodes in the sensor network and improving the network lifetime have become salient features of an efficient routing algorithm. One possible way is minimizing the long-distance communication in the sensor network (Vivek et al., 2011). Obviously, the conventional direct communication between sensor nodes to sink is not accepted. Instead, the sensor nodes are arranged properly to form several clusters with one node acting as the Cluster Head (CH) in the respective cluster. The remaining nodes sense and forward the sensor data to the CH and the CH sends the aggregated data to base station (Cheng & Tse, 2011). It is very sure that only the CH takes part in long distance transmission and the other node will do short distance transmission. Consequently, the overall network lifetime is enhanced by reducing the power consumption.

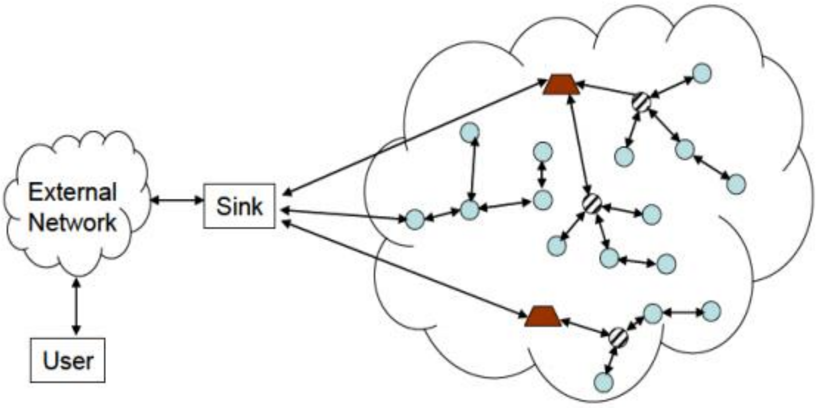

Figure 1 System architecture of WSN

In this research work, an effective clustering algorithm is proposed which can overcome the deficiencies of the LEACH algorithm. The election of cluster heads is primarily based on the residual/current energy of the nodes. Data transmission overhead can be reduced by considering the distance factor between the CH and sink. Thus, those nodes having high residual energy and at the same time having low distance with respect to sink are elected as cluster heads. Also, during the cluster formation phase, a distance-based approach is undertaken for the selection of a CH by a non-cluster head node.

The rest of the research content is organized as follows. Section 2 comprises the related work. Section 3 elaborates the proposed clustering algorithm. Section 4 consists of results and discussions. Section 5 comprises the conclusion and future work.

2. RELATED WORK

Many new algorithms and protocols that deal with energy efficiency have been developed over recent years (Uthra et al., 2012). Low Energy Adaptive Clustering Hierarchy (LEACH) is an intelligent hierarchical protocol that is clustering-based (Heinzelman et al., 2000). It can effectively optimize the energy consumption in sensor network. From LEACH, many protocols have been given birth. The protocol procedures are closely and firmly united and also go well with homogenous and heterogeneous sensor environments. LEACH focuses mainly on the idea of cluster head selection by the cluster members to avoid enormous energy consumption. Despite of this, LEACH still can have certain demerits like 1) uncontrolled use of limited battery power. In the cluster head election phase of the LEACH protocol, there is a probability that some nodes with minimum energy will get elected as the CH for every iteration; 2) overhead due to data transmission; 3) during the cluster formation stage, some non-cluster head nodes may join a cluster, such that the distance between its CH and the BS will be even greater than the distance between that particular sensor node and the Base Station (BS).

PEGASIS (Lindsey & Raghavendra, 2002) is another clustering algorithm in which a chain structure is formed using greedy algorithm. In this scheme only one node (CH) transmits data to BS. The other nodes transmit their data to a neighboring node. It has control over the CH but it is vulnerable to attacks and threats. It also comes with a large amount of communication overhead, which limits its scalability.

The Hybrid Energy Efficient Distributed (HEED) protocol is another clustering algorithm introduced to improve network life (Younis & Fahmy, 2004). The major difference between HEED and LEACH lies in the cluster head election process. LEACH CH election is arbitrary in nature, but it is different in HEED. CH selection in HEED is purely due to the current energy of the node and communication cost within the cluster. HEED works with the assumption that the CH energy is higher than others. The communication method of HEED is the same as LEACH.

The concept of cluster centered routing is exploited for the heterogeneous sensor network in the Energy Efficient Heterogeneous Culstered (EEHC) scheme to enhance the network lifetime (Dilip et al., 2009). In this work, each and every weighted election probability for each node is calculated to decide the success of a node to be CH or not. For a hierarchical WSN, the cluster head selection process is in a distributed way.

Tang et al. (2010) handled the clustering problem of WSN by the chain head selection method. This work is able to achieve better energy saving than the LEACH protocol. LEACH-VF virtual forces protocol is another work used to solve the area problem by overlapping sensing holes upon the sensing coverage (Yassein et al., 2009). But the energy efficiency is slightly compromised, while solving the area problem. In the Threshold sensitive Energy Efficient sensor Network (TEEN) protocol, time-based applications are focused by controlling data transmission (Manjeshwar & Agrawal, 2000).

LEACH-C (Geetha et al., 2012) an extension of LEACH algorithm is based on centralized clustering. In LEACH-C, using a centralized clustering protocol, the steady state stage is quite similar to LEACH. In the set-up phase each and every sensor node sends the current position and the battery level to the BS. Using the global network data the BS selects better clusters that require the minimal power for data transmission. A Global Positioning System (GPS) or the some other location tracking technique is necessary to find the current location. Cost is the considerable factor here. The BS then broadcasts the information to all sensor nodes in the network. Optical-LEACH (O-LEACH) is introduced as an optical, low-energy, adaptive clustering hierachy, which is again an improved form of LEACH protocol (El Khediri et al., 2014). In this paper the node whose current energy is greater than ten percent gets the chance to act as a CH.

Another enhancement of the LEACH algorithm is carried out as a Two-Level Hierarchy-LEACH.TL-LEACH. TL-LEACH has a bi-stage CH selection, which includes primary and secondary stage and this process serves as a single stage in LEACH. The CH elected by the primary stage connects with the secondary CHs, and the consequent secondary CHs get connected with their cluster members. Similar to LEACH, data fusion will also happen here (Loscri et al., 2005). Data transfer from the source node to the BS could be attained in two steps: Initially the secondary CHs accumulate data from their respective cluster members and thus collected data are fused for further processing. Thus fused data are collected by the primary CHs and the second level data fusion is done in the primary cluster head. This in turn reduces the battery consumption, ultimately reducing the total energy usage.

3. PROPOSED WORK

The proposed algorithm has two phases of operation in order to achieve better network lifetime which is well explained in the flowchart shown in Figure 3. The cluster head selection phase involves the selection of the CHs which can stabilize the energy consumption in the sensor networks, by considering both the current energy and the distance of node with respect to the sink. The election of cluster heads is optimized in each and every round by considering the residual energy of the nodes. Data transmission overhead can be reduced by considering the distance between the node and the sink. Thus, those nodes, having high residual energy and at the same time having low distance with respect to the sink, are elected as cluster heads. During the cluster formation phase, a distance-based approach is undertaken for the selection of a CH by a non-cluster head node. It includes choosing the cluster head that is at a close proximity to the center point of the sink and the non-cluster node. The cluster head selected like this and the non-cluster node considered should be within each other's sensing range.

In order for energy efficient selection of cluster heads, features such as residual energy and distance of node with respect to the sink are chosen during the cluster head selection phase. This is possible by using a cost function which incorporates both these criteria, as shown in Equation 1a:

$$Cost(t) = \alpha\left(\frac{E_o - E_i}{E_o}\right) + \beta\left(\frac{DtoBS_i - DtoBS_{\min}}{DtoBS_{\max} - DtoBS_{\min}}\right) \tag{1a}$$

where E_o is the node's initial energy, E_i is the i^{th} node's remaining energy, $DtoBS_i$ is the i^{th} node's distance to BS, $DtoBS_{min}$ is the distance of the closest node to the BS, $DtoBS_{max}$ is the distance of the node, which is at a maximum distance from BS. α and β are weights/free parameters that are assigned to both the factors. Values of α and β are determined through Analytic Hierarchy Process (AHP) method, which should be between 0 and 1. While assigning values for free parameters, more weight is given to the energy criterion free parameter α than β, because the cluster head selected should have the maximum energy level in order to give good results in terms of the first node dead (FND), as shown in Equation 1b.

$$0 \le \alpha \le 1;\ 0 \le \beta \le 1 \tag{1b}$$

It can be inferred from the energy model of sensor network that the energy cost increases with distance. Thus, in order to reduce the power consumption of the WSNs and to enhance the lifetime of the network, a distance-based approach of intelligently selecting the cluster head during the cluster formation phase is followed. If the cluster head chosen is not within the sensing range of the node, then the node will select the next closest cluster head which lies within its range.

We assume a first order radio model, which is similar to the basic LEACH protocol. In order to transmit a *m-bit* message over a distance *d* (between the transmitter and the receiver of sensor nodes) the transmission energy required is calculated in Equation 2:

$$\begin{aligned} E_{TX(m,d)} &= E_{TX-elec(m)} + E_{TX-amp(m,d)} \\ &= mE_{elec} + mE_{fs}d^2 \end{aligned} \tag{2}$$

E_{elec} is the energy dissipated per bit from the transmitter circuit, E_{amp} is the energy dissipated per bit from the transmitter amplifier and E_{fs} is the energy lost per bit.

Energy cost with respect to reception is shown in Equation 3:

$$\begin{aligned} E_{RX\,(m)} &= E_{RX-elec\,(m)} \\ &= mE_{elec} \end{aligned} \tag{3}$$

Thus, the overall energy cost for a network will be as calculated in Equation 4:

$$E_{overall} = E_{TX} + E_{RX} + E_{idle} + E_{s} \tag{4}$$

The main goal is to minimize the total energy spent, i.e. $min(E_{overall})$.

E_{idle} is the cost of energy dissipated during the idle state and E_s is the cost of energy during sensing. Here, apart from the transmission cost, every other cost is constant for a node. Therefore, it is only E_{TX} that is required to be minimized.

It can be inferred from Equation 2 that the energy cost due to transmission depends greatly on the distance d with all the other variables being constant. Thus, it is must to optimize $min(d^2)$. Here, the distance that we consider includes both the distance among the CH and the non-cluster head *(distNtoCH)* as well as the distance between the CH and the sink *(distCHtoSink)* as shown in Figure 2. Further, we can simplify the goal of minimizing d^2 as $min(distNtoCH^2 + distCHtoSink^2)$. Figure 2 shows a triangle NCS, which features the position of a non-cluster head node *(N)*, cluster head *(C)* and the sink *(S)* respectively. Distance between the sink and the non-cluster head node is taken as *distNtoSink = w*, *distNtoCH = u* and *distCHtoSink = v*.

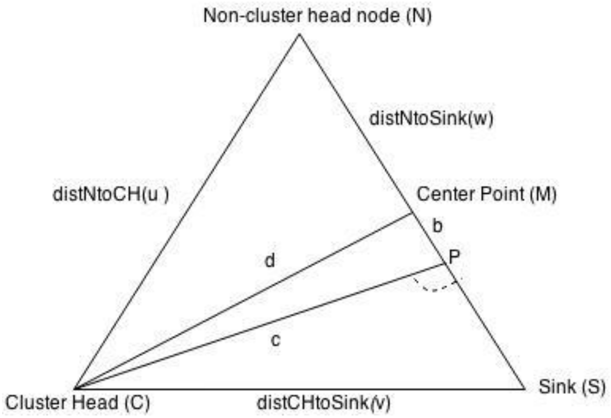

Figure 2 Concept of center-point

From point C at the Cluster Head (CH) onto the line NS a perpendicular is drawn at point P and c is the length of this perpendicular. Center point of N and S is depicted by Point M. d represents the distance between the cluster head and the center point between the non-cluster head node and the sink. Hence, $PM = b$, $CP = c$, $MC = d$.

On applying Pythagoras's theorem,
In ΔSPC shown in Equation 5:

$$\begin{gathered} distCHtoSink^{\,2} = CP^{\,2} + (distNtoSink/2 - b)^{\,2} \\ v^{\,2} = c^{\,2} + (w/2 - b)^{\,2} \end{gathered} \tag{5}$$

In ΔNPC shown in Equation 6:

$$\begin{gathered} distNtoCH^{2} = CP^{2} + (distNtoSink/2 + b)^{2} \\ u^{2} = c^{2} + (w/2 + b)^{2} \end{gathered} \tag{6}$$

Equations 5 and 6 are combined as shown in Equation 7 to obtain:

$$\begin{aligned} v^{2} + u^{2} &= c^{2} + (w/2 - b)^{2} + c^{2} + (w/2 + b)^{2} \\ &= 2\,c^{2} + w^{2}/2 + 2\,b^{2} \end{aligned} \tag{7}$$

From ΔMPCs shown in Equation 8:

$$d^{2} = b^{2} + c^{2} \text{ or } b^{2} = d^{2} - c^{2} \tag{8}$$

On substituting the value of b^2 in Equation 7 we get the result calculated in Equation 9:

$$d^{2} = b^{2} + c^{2} \text{ or } b^{2} = d^{2} - c^{2} \tag{9}$$

From Equation 9, we can derive that the value of w *(distNtoSink)* is constant. Therefore, $v^2 + u^2$ are related only to d^2. This means that $min(distCHtoSink^2 + distNtoCH^2)$ is similar to $min(d^2)$. Therefore, if a non-cluster head node chooses a CH which is in close proximity to the center point of that particular node and the sink, the square of their communication distance, i.e. $(distCHtoSink^2 + distNtoCH^2)$ minimizes. This in turn will minimize the distance (d) between the CH and the center point of the non-cluster head node and the sink such that the distance between the sink and the node is constant. Thus, non-cluster nodes choses a cluster head as its node for communication if it is nearest to the center point between that sensor node and the sink and this process is described in the flowchart shown below in Figure 3.

3.1. Pseudocode of Proposed Algorithm

3.1.1. Initialization phase

The size of the sensor network area and the sink location are predefined. Deployment of the sensor nodes is done randomly. These sensor nodes include both normal and advanced nodes. Advanced nodes will be involved having twice the energy of the normal nodes. For the **symbol** ‘o’ represents normal nodes whereas ‘+’ symbol represents advanced nodes.

3.1.2. Cluster head selection phase

Cluster Heads are selected using the cost function which incorporates two criteria such as remaining power and distance to the sink. Thus, high energy nodes with less distance to sink are selected as cluster heads.

```
For Round 1:rmax
    for each node ‘i’
        Assign a random number
        Calculate cost value using cost function (1)
        Calculate Threshold = (P / (1 – P * (round % 1/P)) * cost(i))
        if (random number (i) < threshold value)
            Node selected as Cluster head
            Count for cluster head gets incremented
        Or Else go to the next node
Stop
```

Clusters are ready to be generated after the cluster heads are selected for a round.

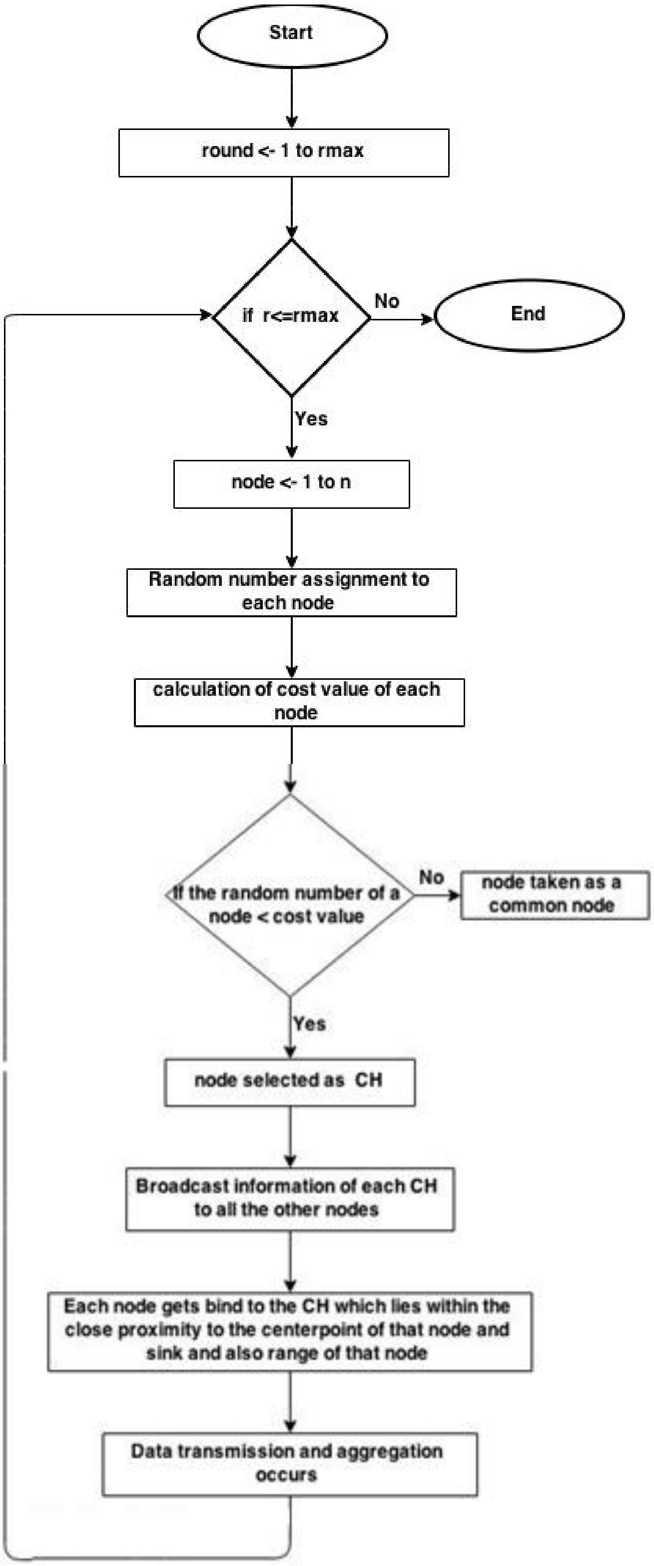

Figure 3 Flowchart of the proposed algorithm

3.1.3. Cluster formation phase

From the cluster heads that have already been chosen, non-cluster head nodes will select those cluster heads which is having least distance to the center point of that node and the sink. If that node and the cluster head selected by this way doesn't come under each other's range, next cluster head which is having lesser distance to the center point is selected.

```
For each node
   if node is a not a CH
        compute the center point between node and sink
   for each cluster head
        find the distance between center point and CH
        find the least distance
      if sensor node is within the range of least distant CH
         Node binds to that corresponding CH
           That CH id is allocated to that node
find what elses is the next closest CH within that node's range
Stop
```

4. RESULTS AND DISCUSSION

Matlab is used for simulation and to compare the proposed algorithm with the traditional LEACH protocol. Table-1 below gives the details of the simulation environment.

Table 1 List of parameters and their values

Simulation area	100×100 m^2
Simulation time	300 rounds
Number of nodes	100
Nodes Distribution	random deployment
Initial Energy of Node	1 J
CH Probability	0.2
Transmission energy	50×0.000000001 J
Reception energy	50×0.000000001 J
Transmitter Amplifier energy dissipation free Space	10×0.000000000001 J
Transmitter Amplifier energy dissipation multiPath	0.0013×0.000000000001 J
Data Aggregation Energy EDA	5×0.000000001 J
Base Station location	located at 150×50

4.1. Initial Heterogeneous Sensor Network

A WSN with heterogeneous sensor nodes is randomly distributed in 100×100 network field. In a heterogeneous sensor network, there are two kinds of sensor nodes, namely, the normal nodes and the advanced nodes, wherein the advanced nodes will be considered, for example, with two times of energy than the normal nodes. After considering the network assumptions, the simulated environment involves nodes that are describing their energy level as shown in Figure 4. '+' describes the sensor nodes having energy level as “1”, 'o' indicates the energy = 0 in the network and 'O' describes the base station in the simulated environment. Then, to measure the performance of the protocols, a set of simulation runs were carried out. The performance analysis of the improved LEACH scheme is done based on various metrics, like the number of dead and alive nodes, remaining energy, first node dead, half node dead, etc.

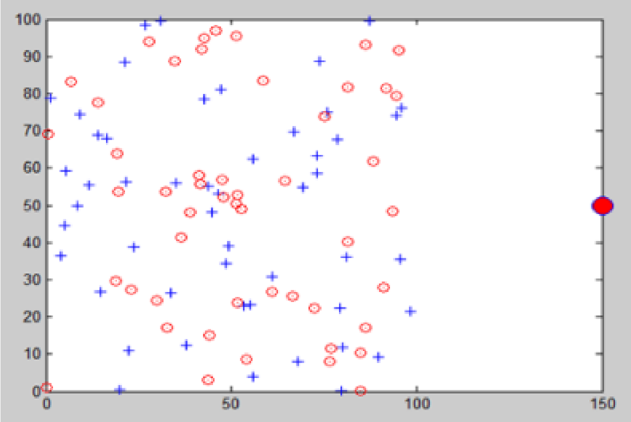

Figure 4 Initial heterogenous sensor network

4.2. The Number of Alive Sensor Nodes

This parameter gives the number of sensor nodes that are alive in the network with the increase in the number of rounds. A comparison of the number of nodes alive in LEACH as well as in improved LEACH is done as shown below in Figure 5. Results shows that the number of alive nodes have increased, in case of the Improved LEACH.

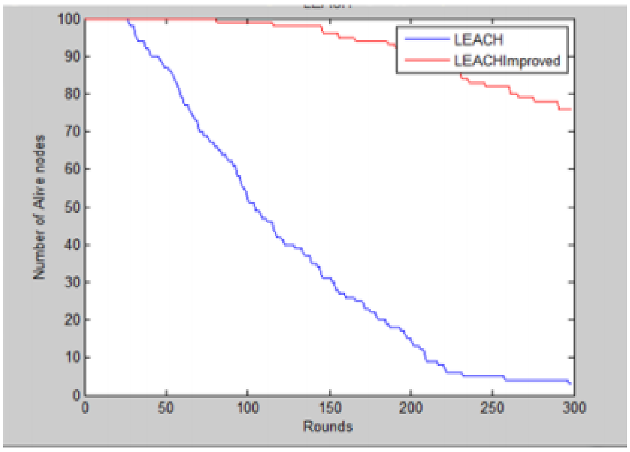

Figure 5 Number of alive sensor nodes

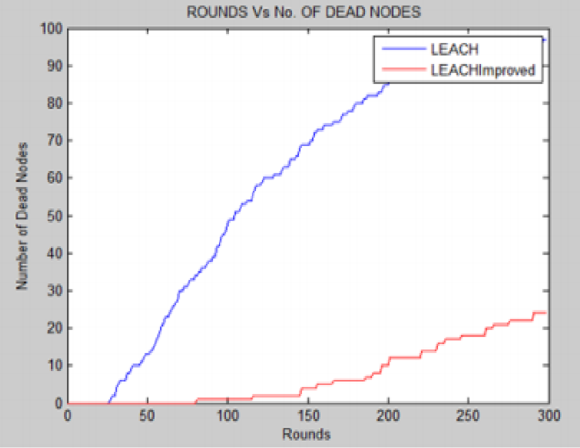

Figure 6 Number of dead nodes

4.3. The number of Dead Nodes

Figure 6 gives the number of sensor nodes that are dead in the network with the increase in the number of rounds. A comparison of the number of nodes alive in LEACH as well as in improved LEACH is done as shown below in Figure 6. Results show that in the case of improved LEACH, the number of dead nodes has been decreased. It is seen from Figure 6 that the network lifetime was prolonged for the improved LEACH. Network lifetime is well-defined as the round at which the First Node Death (FND) happens.

5. CONCLUSION

In this research work, a new approach for centralized clustering for Wireless Sensor Networks (WSNs) is presented. The main purpose is to reduce the power consumption of the network and thereby to improve the sensor network lifetime. In the LEACH protocol, since the CH selection is random, network lifetime will not always be stable. But in the enhanced version of LEACH, the sensor node with the maximum residual energy and with optimized distance to the sink node will become a CH in the initial cluster formation stage. At this stage, the non-cluster head nodes will select those cluster heads which are having the least distance to the center point of that node and the sink. The simulation results of both the LEACH and enhanced LEACH algorithms are presented. From the results, it is observed that proposed LEACH is preferable over the basic LEACH protocol as it improves the network lifetime over several other rounds. The next improvement can be possible by considering sink mobility to ensure successful delivery of data.

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