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Enhancing lifetime of WSN through RA-LEACH (Revised ACO based LEACH algorithm)

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Abstract — *The nodes in a Wireless Sensor Network (WSN) are generally grouped in clusters to improve the longevity and efficiency of the network. Since the nodes have limited power capabilities and finite computation power, it becomes imperative to design algorithms to conserve the limited resources of the WSN in order to enhance the up time of the network.*

In this paper, a revised version of Ant Colony Optimization based LEACH protocol (RA-LEACH) is compared with LEACH protocol [1], with focus on the energy consumption by the nodes. The proposed RA-LEACH protocol while electing Cluster Heads (CHs) takes into consideration the following parameters – the ratio of the residual energy at each node with its original energy and the ratio of the distance of the node from the Base Station (BS) with the distance of the farthest node.

From the simulation results, it is evident that change in the threshold calculations, improves the original design of LEACH algorithm in terms of minimizing energy consumption and improving the network lifetime.

Keywords *- ACO, LEACH, Sensors, RA-LEACH, WSN*

I. INTRODUCTION

Wireless Sensor Networks (WSNs) comprise of sensor nodes that are connected wirelessly. These sensor nodes are small, multi-functional, low cost and have low power. They consist of components that sense data, process it, and share the information by communicating with each other. Hundreds and thousands of such sensor nodes collaborate to form wireless sensor networks.

There are varied applications of these sensor networks including sensing environmental variables like pressure, temperature, etc. Such WSNs may also be deployed in manufacturing units to monitor processes and different parameters associated with these processes. WSNs can also be used to measure gaps/deficiencies in vehicles, structures, infrastructure, etc. Considering the importance of WSNs, a lot of research work is being undertaken in this area. There is still a great scope of improvisation and improvement that can be incorporated in the design and deployment of Wireless Sensor Networks using modern meta-heuristic route optimization techniques. Many such techniques have been inspired by the characteristics and movements of natural swarm.

Marco Dorigo proposed Ant Colony Optimization (ACO) in 1992. ACO is a probabilistic algorithm that is used for solving computational problems that involve finding the shortest path. The objective of the first ACO algorithm was to search for an optimal path in a graph. The basis of the algorithm is the behavior of ants seeking a path between their colony and a source of food. In the real world, ants initially move randomly, and after finding a food source, they return to their colony while laying down chemical pheromone trails. The amount of pheromone deposited depends on the quantity and quality of the food. [12]

Whenever other ants find such a trail, they are likely not to keep travelling at random, but to follow that trail instead, returning and reinforcing it if they eventually find the food. Thus the pheromone amount guides other ants to find the food source. As a result of this phenomenon, the optimal solution derives rapidly. By using this behavior of the ants, optimal cluster head can be selected. This original idea based on movement of real ants, after improvements, can be replicated to solve a wider class of numerical problems.

It again needs to be emphasized that Wireless Sensor Networks find utility in many mission critical applications such as target-tracking in battle-fields and emergency responses. In such crucial applications, the success of the mission is critically dependant on the reliable and timely delivery of sensor data. However, it needs to be kept in mind that the Wireless Sensor Network nodes deployed to gather useful information from the field generally have limited power capabilities, limited computation power and finite battery life.

The proposed algorithm focuses on making the routing in WSNs energy aware so as to maximize the lifetime of the network, thus making it scalable for large number of sensor nodes and tolerant to sensor damage and battery exhaustion. Ant Colony Optimization, swarm intelligence based optimization technique, forms the backbone of this network routing approach. This research paper proposes an algorithm that is decentralized, dynamic and adapts quickly to changes in the network making it a suitable alternative for critical applications.

II. THEORETICAL BACKGROUND

Heinzelman *et al*.[11] has proposed LEACH (Low Energy Adaptive Clustering Hierarchy). LEACH is one of the prominent clustering routing approaches used in WSNs (Wireless Sensor Networks). The primary objective of LEACH is to select Cluster Heads (CHs) from sensor nodes by rotation. Such a strategy ensures sharing of high energy dissipation that is bound to happen in the process of communication of the sensor nodes of the network with the Base Station (BS).

ACO (*Ant colony optimization)* has been adapted and applied in Wireless Sensor Networks, for finding the optimal paths from the source nodes to the base station. Each node of such nework maintains its probabilistic routing table, also called as pheromone tables. On the basis of the death of the first node, ACO is applied on the LEACH protocol in the Wireless Sensor Network (WSN). The proposed algorithm in this paper focuses on enhancing the network lifetime, which in-turn affects the performance of LEACH protocol in terms of energy consumption.

A number of researchers have already implemented various routing algorithms on Wireless Sensor Network for better performance and longer up-time. Mohammad El-Basioni et al. [10] implemented hierarchical protocols such as EAP protocol – which is essentially LEAP protocol which works around LEACH. Later on, the EAP routing protocol was further improved and named as LLEAP. The author experimented with this protocol and has observed better results as compared to previous routing protocols mentioned earlier in the paper. This routing protocol only improves the other parameters except network lifetime over EAP.

Heinzelman[11] have proposed LEACH which is adaptive clustering protocol for distributing the energy load among the sensor nodes in the network. LEACH protocol uses randomized rotation of the cluster base stations or cluster heads and the corresponding clusters. It is thus able to distribute energy dissipation evenly throughout the sensors in the Wireless Sensor Network, thus increasing the up-time to almost double. The clusters are used for transmitting data to the base station and provide the advantages of smaller transmitting distances for most of the nodes, thus necessitating the need of only a few nodes for transmission of the data from far-off distances to the base station. It further increases the performance of classical clustering algorithms by using adaptive clusters and rotating cluster heads. In addition to the above, the specified protocol is able to perform local computation in each cluster which reduces the amount of data that must be transmitted to the base station. This also helps in achieving a large reduction in the energy dissipation in the WSN.

Zhao et. al.[8] have highlighted that the classical hierarchical protocols such as LEACH and LEACH-C have better performance in saving the energy consumption. However, the selection formula neglects the change of nodes' energy, thus making the nodes act as cluster heads too many times. Such nodes, then, die early owing to the consumption of too much energy. They also remark that the high frequency of re-clustering wastes certain amount of energy. The traditional equation used for selecting cluster heads has thus been improved by considering the dynamic change of nodes' energy in order to distribute the energy more evenly among different nodes. It has also been proposed to establish a vice cluster head for each cluster during the communication process, with the intent to diminish the energy consumption spent on re-clustering and to prolong the time of being in a steady-state phase.

III. VARIOUS FLAVORS OF LEACH

LEACH protocol follows a distributed approach and does not require global information of the network. In literature, various modifications to the LEACH protocol have been suggested, such as TL-LEACH, LEACH-C, V-LEACH, *etc*.
LEACH algorithm has a few drawbacks. The most important being: (1) Random election of CHs causes an imbalance in the energy consumption of the sensor network, and (2) Threshold $T(n)$ is function of only the CH probability, P and the number of the current round, r *(Eqn.1)*. [12]

To overcome these limitations of LEACH, various improvised versions of LEACH have been suggested, including:

- **TL-LEACH:** In TL-LEACH, the CH collects data from other cluster members in the same manner as original LEACH. However, rather than transferring the data directly to the Base Station, TL-LEACH uses one of the CHs that lies between the CH and the BS as a relay station.
- **LEACH-C:** LEACH-C protocol uses a centralized clustering algorithm. The steady-state phase of LEACH-C is same as the same steady-state phase of LEACH. LEACH-C protocol delivers better performance by dispersing the cluster heads throughout the network.

- **V-LEACH:** V-LEACH protocol makes use of a vice-CH in addition to the CH in the cluster. The vice-CH takes the role of the CH when the CH dies.

IV. EXISTING METHODOLOGY

LEACH protocol is one such routing protocol that is grouped in hierarchical routing approaches of WSNs. LEACH is the earliest proposed single-hop cluster routing protocol in Wireless Sensor Networks. It is a self-organizing robust clustering protocol that can significantly conserve network energy. However, the effectiveness of LEACH protocol in cluster head selection is not optimized because of the probability model.

The working of LEACH algorithm can be divided into a number of *rounds*. Each of the round is further broken down into 2 phases: *set-up phase* and *steady-state phase*. In the set-up phase, the clusters are organized, while in the steady-state phase, data is delivered to the Base Station. Further, during the set-up phase, the decision to become a Cluster Head (CH) for the current round is taken by each node. Such a decision is based on the number of times the node has been a Cluster Head (CH) so far and the suggested percentage of Cluster Heads (CHs) for the network. The node chooses a random number between 0-1 to take such a decision. For the current round, the node becomes a Cluster Head (CH) if the number chosen above is less than the following threshold:

$$T(n) = \begin{cases} \frac{P}{1-P\,(r \bmod \frac{1}{P})}, & \text{if } n \in G \\ 0, & \text{Otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots\ (1)$$

where

r : number of the rounds,
P : desired percentage of the cluster head nodes (CHs) in the current round,
G : collections of the nodes that have not yet been elected as Cluster Heads (CHs) in the first 1/P rounds.

Threshold Equation (1) implies that all the nodes would be able to become Cluster Head (CH) nodes after 1/P rounds. When a node successfully gets elected as Cluster Head (CH), it broadcasts an advertisement message to all the other nodes. Based on the strength of the advertisement of the received signal, other nodes take a decision about the cluster they would join for this round. They, then, send a membership message to its Cluster Head (CH). For the purpose evenly distributing energy load among all the sensor nodes, Cluster Heads' rotation is performed in every round by generating new advertisement phase based on Equation (1).

The sensor nodes sense and transmit data to the Cluster Heads (CHs) during the steady state phase. The Cluster Heads, then, compress the data arriving from nodes that belong to the respective cluster, and further send an aggregated/fused packet to the Base Station (BS) directly. In addition to the above, Low Energy Adaptive Clustering Hierarchy (LEACH) protocol uses a Code Division Multiple Access (CDMA)/TDMA MAC to reduce intra-cluster and inter-cluster collisions. After elapsing of a certain pre-determined time, the network again goes back into the set-up phase and enters another round of Cluster Head (CH) election.

V. PROPOSED MODEL

This paper suggests an improvement in the LEACH clustering algorithm. The proposed revised LEACH would take into account node's residual energy and location information in order to optimize the selection method for electing the cluster head. If, by adopting an improvised approach, the number of cluster heads can be optimized, then the energy consumption of the sensor nodes may be distributed in the WSNs more evenly. It would thus avoid extra energy consumption of a single node and prevent its untimely death, thus directly affecting the network life cycle and up-time.

A numbers of important issues related to development of low power wireless sensor application have consistently been an area of research. Most important of these issues is to use available energy in the most efficient way, without compromising the performance of the sensor nodes. Sensor nodes use batteries as a power source that have quite limited lifetime. Thus efficiency of energy management becomes a key requirement in the wireless sensor network design. Using the concept of ant colony algorithm in WSNs, each node calculates its probability by using the pheromone to be elected as a cluster head. In this section of paper, the basic idea of proposed algorithm is summarized.

RA-LEACH (Revised Ant Colony Optimization based LEACH Algorithm)

As discussed earlier in the paper, wireless sensors devices have limited power capabilities. It necessitates that the Cluster Head (CH) selections be determined not only in terms of probability, but also in terms of the residual power of the node and the distance between node and the base station. For instance, it would be preferable to choose a longer distance node with high energy than a shorter distance node with very low energy.

The proposed algorithm in terms of the behavior of ants suggests that each ant selects its next cluster head on the basis of the initial rule, and then, each ant further elects the optimal cluster head by the use of revised rule as mentioned in Equation (2).

The following sequence of steps explains in detail the design and flow of implementation of the proposed algorithm.

Step 1 Initialize the Wireless Sensor Network. Start from the first node.

Step 2 Move to the next node 'j'

Step 3 Check the energy level of the given node 'j'. If Energy (Node 'j') is greater than 0 that means the node is 'alive'. For 'alive' node, repeat the following steps, else move back to step 2.

Step 4 Select the node as Cluster Head (CH) if it fulfills the conditions of the Threshold function, T(n).

Step 5 Associate member nodes with their nearest Cluster Head (CH) by using RA-LEACH (Revised Ant Colony Optimization based LEACH Algorithm).

Step 6 Remaining energy of each node 'j' is updated.

Step 7 Check if there are any dead nodes? If NO then move back to the step 2, else the number of dead nodes is counted. Network lifetime is calculated.

Step 8 Performance metrics including energy dissipation are calculated. Go back to step 2.

Figure 1 describes the above sequence of steps in a flowchart.

In RA-LEACH, LEACH's stochastic cluster head selection algorithm is extended by adjusting the threshold *T(n)*denoted in equation (1), considering residual energy of the nodes, distance between the nodes and the base station and the number of consecutive rounds in which a node has not been a cluster head as parameters. Therefore,

$$T(n) = \begin{cases} \frac{P}{1-P\left(r \bmod \frac{1}{P}\right)} \text{ x } [E(i)/(1-D(i))], & \text{if } n \in G \\ 0, & \text{Otherwise} \end{cases} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

In Equation (2), residual energy factor is

$$E(i) = (E_{residual}(i)/E_{initial})$$

where $E_{residual}$ is the remaining amount of energy and $E_{initial}$ is the initial energy of node before transmission. Variable i indicates the serial number of nodes.

The energy used to transmit n bit by the node is computed by:

$$E_{diss\_Tx} = Energy\ Dissipated\ in\ Transmitting\ nth\ bit$$

The energy used up to receive n bit by the node is computed by:

$$E_{diss\_Rx} = Energy\ Dissipated\ in\ Receiving\ nth\ bit$$

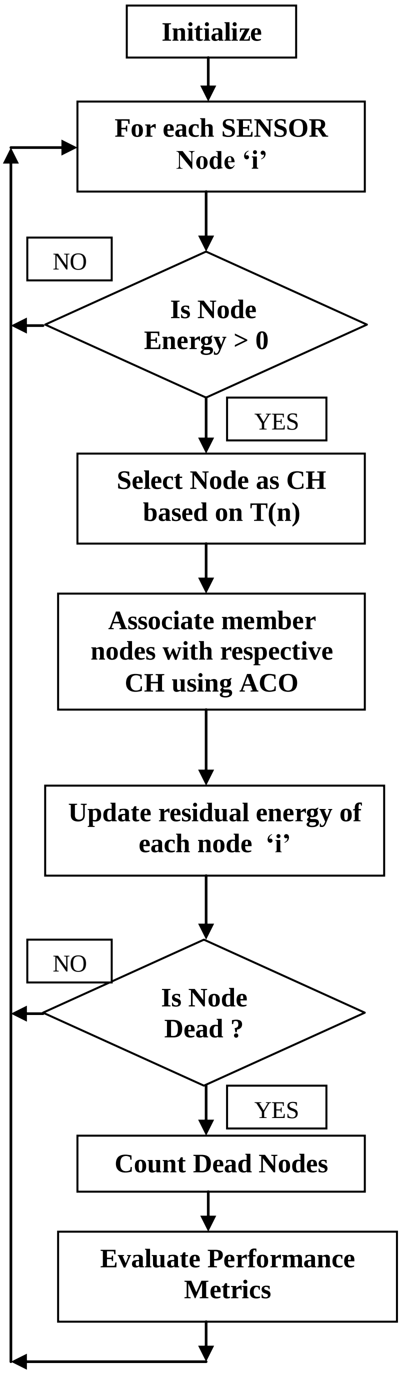

Fig. 1: Proposed Methodology Flowchart

Power consumed for a given time period t is given by:

$$P_{consumed\ (i)} = \frac{E_{diss\_Rx(i)} + E_{diss\_Tx(i)}}{t}$$

The probability of a node to become CH is one with the highest ratio of residual energy, which is computed as:

$$E(i) = \frac{E_{\max(i)} - P_{consumed\ (i)}}{E_{\max(i)}}$$

Where *Emax* is the maximum energy of the battery of the sensor node.

Here, the distance factor is

$$D(i) = \frac{D_{iB}}{D_{Farthest}}$$

where diB is the distance from node i to BS as follows:

$$D_{iB} = \sqrt{(X_{max} - X_{BS})^2 + (X_{max} - X_{BS})^2}$$

and dFarthest is the distance of the farthest node from the Base Station. Here, the coordinates (X_{BS},Y_{BS}) represent the location of the Base Station.

VI. SIMULATION ENVIRONMENT

The proposed revised ACO based LEACH algorithm has been simulated using MATLAB. The simulation has been tested for a random 100 node network which is distributed in a region of 100m X 100m. The location of the base station was selected at (100, 100) in network. Each node has 1 J of initial energy. The packet size is 2k bits, and 0.05 % of the nodes are selected as cluster heads. Table 1 lists the simulation parameters.

Parameter	Value
No. of nodes	100
Network size	100X100 m^2
BS's Location	(100,100)
Cluster Head probability	0.05
Initial energy of node	1 Joule
Node Distribution	Random
Data Packet	2000 bits
Eelec	50 nJ/bit
ε_{mp}	0.0013pJ/bit/m^4
ε_{fs}	10pJ/bit/m^2
$D_{Farthest}$	100m
Energy for data aggregation (EDA)	5nJ/bit/signal

Table 1: Simulation Parameters

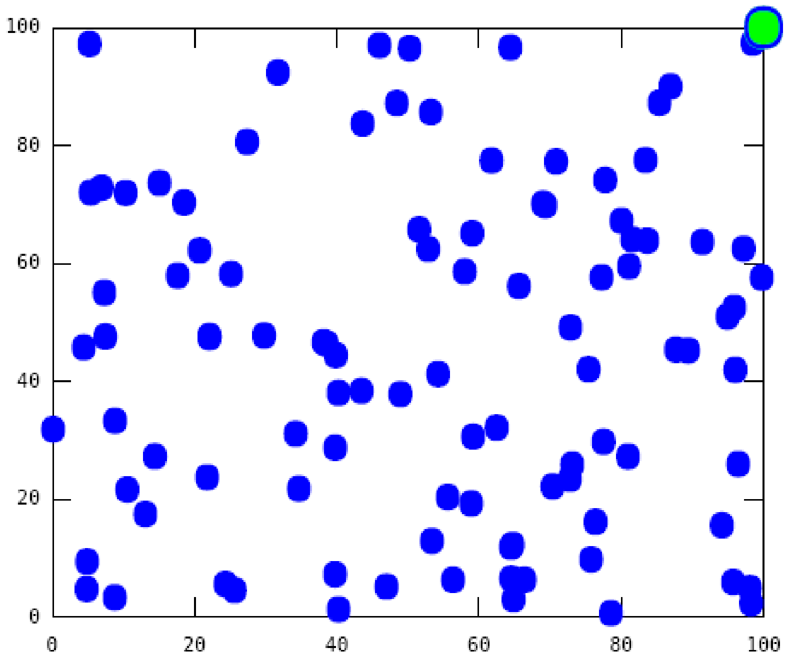

Fig. 2: Node deployment in 100m X 100m

Figure 2 shows the randomly distributed 100 sensor nodes in a 100m X 100m area with the Base Station (BS) located at the coordinates (100,100).

VII. SIMULATION RESULTS

The simulation results of the proposed algorithm have been compared with revised ACO based LEACH Algorithm (RA-LEACH). Fig. 3 and Fig. 4 display the results of simulation with respect to the system lifetime and energy consumption as a function of the number of rounds. Further, Table 2 displays the comparison of lifetime of LEACH and RA-LEACH Algorithms for initial energy as 1J/node. Table 3 shows the comparison of energy consumption by LEACH and RA-LEACH with respect to different amount of initial energy. The respective plots have been drawn in Fig. 3 and Fig. 4.

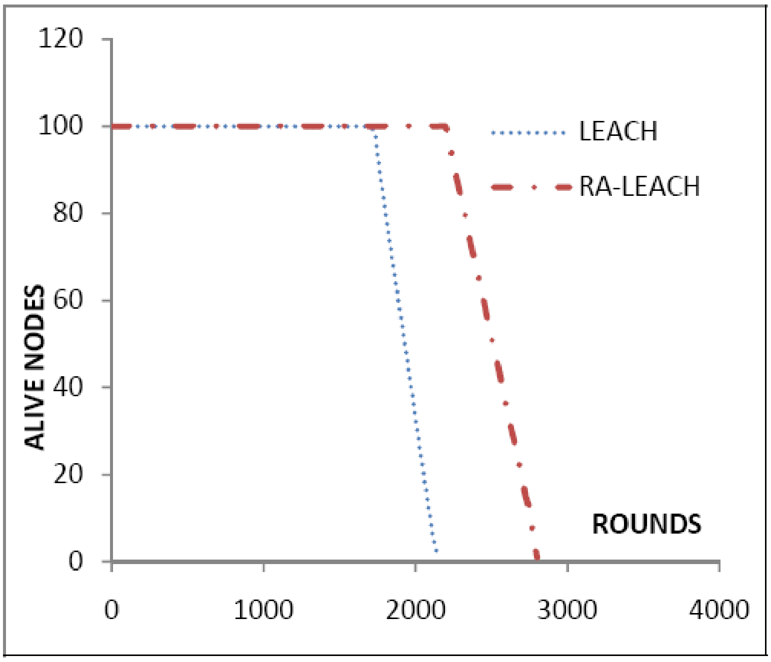

Fig. 3: Comparison between LEACH and RA-LEACH

Figure 3 shows the plot of number of alive nodes in the network versus number of rounds, for LEACH and the proposed RA-LEACH protocol. From the plot it is evident that, RA-LEACH shows better performance than LEACH. Figure 4 displays the amount of Energy consumption of LEACH and RA-LEACH based on the number of rounds. RA-LEACH betters the performance of LEACH as is evident in the graph.

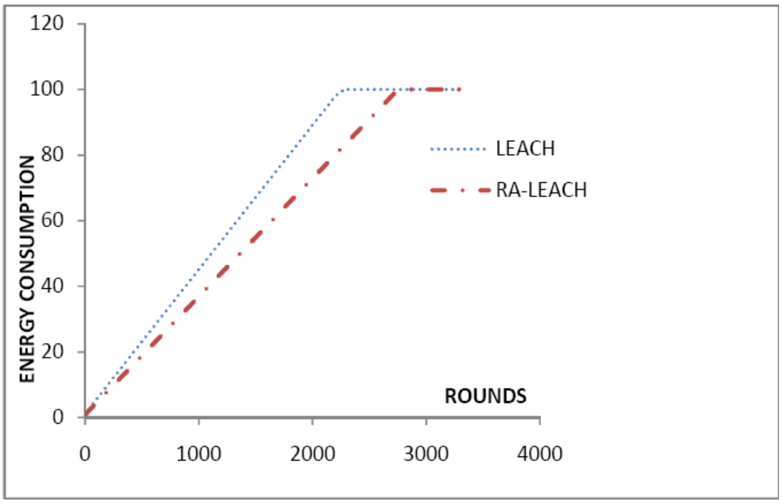

Fig. 4 Plot for energy consumption

Table 2 shows the comparison of network lifetime with respect to the parameters FND and LND for LEACH and RA-LEACH. Figure 5 shows a bar graph representation of the network lifetime. As indicated in the graph, the network lifetime is prolonged in RA-LEACH when compared to LEACH protocol.

Protocol (initial energy= 1J/node)	**Round First Node Dies (FND)**	**Round Last Node Dies (LND)**
LEACH	1757	2296
RA-LEACH	2205	2788

Table 2 Comparison of Network Lifetime with respect to FND and LND

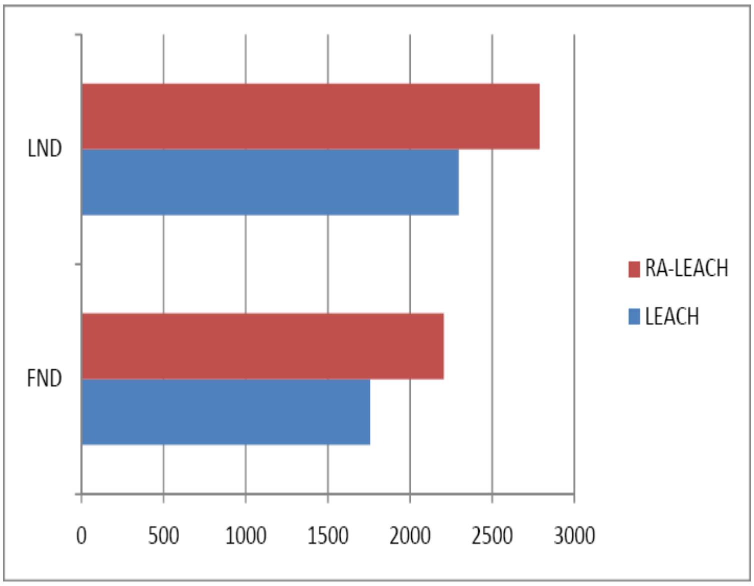

Fig. 5 Comparison of Network Lifetime (initial energy= 1J/node)

Initial Energy (J/node)	**Protocol**	**Round First Node Dies (FND)**	**Round Last Node Dies (LND)**
0.5	LEACH	883	1146
	RA-LEACH	980	1397
1	LEACH	1757	2296
	RA-LEACH	2205	2788

Table 3: Comparison of Network Lifetime with respect to different amount of initial energy

The above simulation provides a comparison between LEACH and the improved version of LEACH (RA-LEACH). In RA-LEACH, selection of the CH differs from that in LEACH in the set-up phase. The steady-state phase in RA-LEACH is same as in LEACH. The CH selection in RA-LEACH considers residual energy of the node and the distance of the node from the BS. It results in the minimization of energy consumption in the Wireless Sensor Network (WSN). This is because RA-LEACH improves LEACH protocol by improving the CH selection algorithm.

Simulation results show that RA-LEACH exhibits better performance than LEACH with respect to the number of alive nodes and energy consumption. Number of rounds is taken as the reference. Analysis shows that RA-LEACH is 25.5% better than LEACH with respect to the parameter First Node Dies (FND). And, RA-LEACH is 21.4% better than LEACH with respect to the parameter Last Node Dies (LND). Thus, the above simulation results prove that revised algorithm slows down the energy consumption of the network and increases the lifetime of the network.

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