Cost Effective Energy Aware Coverage Preserving Protocol for Wireless Sensor Network

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Abstract— **Wireless sensor networks are formed by small sensor nodes communicating over wireless links without using a fixed network infrastructure. Each of the sensor nodes is capable of sensing, processing, and transmitting environmental information. Since the sensor nodes are equipped with battery having limited energy, energy efficient information processing is of critical importance. The important issues of wireless sensor networks (WSNs includes Coverage-preserving and lifetime-durability. Any coverage hole in a network is not feasible, so to provide full sensing coverage in a security-sensitive area is necessary in many practical applications such as security surveillances or military investigations. The routing protocols were proposed to ensure reliable multi-hop communication, in order to increase lifetime and Quality of Service (QoS) of wireless sensor networks.**

In this paper, to prolong the duration of full sensing coverage, we propose a scheme called an Energy-aware and Coverage-preserving Hierarchical Routing (ECHR) protocol for randomly deployed WSNs. The proposed scheme maximizes the working time of full coverage in a given WSN without taking concern of deployment patterns of the sensor node. It provides energy-balancing and coverage-preserving and selects one Cluster Head (CH) for each round. The cluster head selection mechanism is essential in ECHR protocol. For selecting cluster head, uniform selection mechanism is used. To determine an optimal route for the packet, the power consumption of radio transmission and residual energy over the network are considered. The main idea of this paper is to combine both, the energy-balancing and coverage preserving mechanisms into routing protocols. By the help of proposed scheme we will be seeing the effects of different points of interest (POIs) over the network. MATLAB simulations will be performed to analyze and compare the performance of proposed scheme with other benchmark protocols. The expected output of simulation is up to 80-85% extra lifetime compared to other benchmark protocols.

Keywords-Sensor Network; Cluster Head (CH); Energy-Aware Coverage-Preserving Hierarchical Routing Protocol (ECHR); Points of Interest (POIs)

I. INTRODUCTION

Recent technological advances have led to the emergence of pervasive networks of small, low-power devices which integrates sensors and actuators with limited onboard processing and wireless communication capabilities. These sensor networks open new vistas for many potential applications, such as environmental monitoring (e.g., traffic, habitat, and security), industrial sensing and diagnostics (e.g., factory, appliances), critical infrastructure protection (e.g., power grids, water distribution, waste disposal), and situational awareness for battlefield applications. For these algorithms, the sensor nodes are deployed to cover the monitoring area as much as possible. They collaborate with each other in sensing, monitoring, and tracking events of interests and in transporting acquired data, usually stamped with the time and position information, to one or more sink nodes.

Wireless sensor network [1] have a great deal of research attention due to their wide range of potential applications including environment monitoring, object tracking, scientific observing, traffic control, industrial sensing and diagnostics(e.g., factory, appliances), critical infrastructure protection

(e.g., power grids, water distribution, waste disposal), and situational awareness for battlefield applications.

A typical large-scale WSN generally consists of one or more sinks (or base stations) and thousands of sensor nodes that can be organized into a multi-hop wireless network and deployed either randomly or according to some predefined statistical distribution over a desired geographical region.

Wireless Sensor Networks have become increasingly available for commercial and military applications.

The first step in deploying the wireless sensor networks is to determine, with respect to application-specific performance criteria, (i) in the case that the sensors are static, where to deploy or activate them; and (ii) in the case that (a subset of) the sensors are mobile, how to plan the trajectory of the mobile sensors. These two cases are collectively termed as the coverage problem in wireless sensor networks.

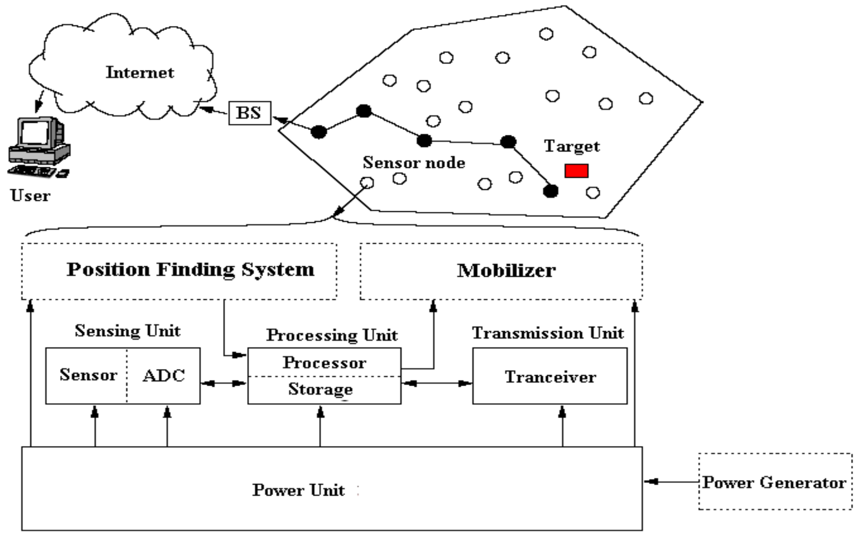

Figure 1. Components of Sensor Network

Figure1 shows the schematic diagram of sensor node components. Basically, each sensor node comprises sensing, processing, transmission, mobilizer, position finding system, and power units (some of these components are optional like the mobilizer). The same figure shows the communication architecture of a WSN. Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment.

Each sensor node bases its decisions on its mission, the information it currently has, and its knowledge of its computing, communication, and energy resources. Each of these scattered sensor nodes has the capability to collect and route data either to other sensors or back to an external base station(s) [2]. A base-station may be a fixed node or a mobile node capable of connecting the sensor network to an existing communications infrastructure or to the Internet where a user can have access to the reported data [3].

There are usually two deployment modes in wireless sensor networks. On the one hand, if the cost of the sensors is high and deployment with a large number of sensors is not feasible, a small number of sensors are deployed in several preselected locations in the area. In this case, the most important issue is *sensor placement* – where to place the sensors in order to fulfill certain performance criteria. On the other hand, if inexpensive sensors with a limited battery life are available, they are usually deployed with high density (up to 20 nodes=m3 [4]). The most important issue in this case is *density control* – how to control the density and relative locations of active sensors at any time so that they properly cover the monitoring area. (Another relevant issue is how to rotate the role of active sensors among all the sensors so as to prolong the network lifetime [5].)

One of the most active research fields in wireless sensor networks is that of coverage. Coverage is usually interpreted as how well a sensor network will monitor a field of interest. It can be thought of as a measure of quality of service.

The coverage usually involves two basic sides

- How to evaluate the coverage performance when sensor nodes are deployed in a monitoring region.
- How to improve the coverage performance when wireless sensor network cannot effectively satisfy application requirements.

The rest of paper is organized as follows: Section 2 includes related work. Section 3 describes the proposed cost effective energy aware coverage preserving routing protocol. Section 4 includes the simulation results and the conclusions are drawn in section 5

II. RELATED WORK

Most of the previous routing protocols that have been proposed were designed to prolong the lifetime of the network [6] and [7]. However, if the network fails to maintain full coverage, there is no use of sensor network.

The routing protocols were proposed to increase lifetime of the network and to enhance the Quality of Service (QoS) [8]. In order to decrease the energy consumption of radio transmission, a Low-Energy Adaptive Clustering Hierarchy (LEACH) routing protocol was proposed by W. R. Heinzelman et al. [9] which minimizes energy dissipation in sensor networks.

LEACH is a very well known hierarchical routing algorithm for sensor networks. It makes clusters of the sensor nodes based on the received signal strength. The 5% of the total number of nodes becomes the cluster head and act as router to the sink. Transmission will only be done by cluster head. Therefore, the energy consumption of sensor node can be highly reduced by preventing it from transmitting the sensing data to the base station (BS) directly.

In addition, Tasi [10] proposed a coverage preserving routing protocol, which was enhanced from LEACH protocol. This protocol is known as LEACH Coverage- U protocol. It calculates the overlap sensing areas of all sensor nodes, and then uses this feature to select cluster head.

Hence, in this study, we present an Energy-aware and Coverage-preserving Hierarchical Routing (referred as ECHR) protocol. This protocol helps to increase the duration of maintaining the full sensing coverage in a WSN. The proposed ECHR protocol will always choose one of the overlapping nodes to be the cluster head in each round. We will also apply the energy-aware hierarchical routing mechanism to find out an optimal route for the data measured by each node.

Comparing with other benchmark protocols, the ECHR protocol can effectively prolong the duration of maintaining full sensing coverage in a WSN.

III. THE PROPOSED COST EFFECTIVE ENERGY-AWARE COVERAGE PRESERVING ALGORITHM

In our work, to prolong the duration of full sensing coverage, we propose an Energy-aware and Coverage-preserving Hierarchical Routing (ECHR) protocol for randomly deployed WSNs. The ECHR protocol will maximize the working time of full coverage in a given WSN without any concern of deployment patterns of the sensor node. The main idea of this project is to combine both, the energy-balancing and coverage preserving mechanisms into routing protocols. In this paper we are seeing the effects of different points of interest (POIs) over the network. MATLAB simulations will be performed to analyze and compare the performance of ECHR with other protocols. The expected output of simulation is up to 80-85% extra lifetime compared to other protocols.

A. Assumptions

In this paper, we assume that there are n sensor nodes randomly deployed in a $L \times L$ sensing field and the sensing field has m points of interest (termed as POI). The definition of POI (denoted as $P1$, $P2$,…, Pm) and the related point coverage problem can be referred to the reference [11].

Some other assumptions made for the network model are:

- Number of nodes in the network are 500.
- The sink node is located far away from the sensing area.
- All the wireless sensor nodes and sink node (sink) are stationary after deployment.
- Nodes are dispersed in a 2-dimensional space and cannot be recharged after deployment.
- All nodes can send the data to the sink node.
- All nodes are of the same specifications.
- All nodes consume same energy for transmission and reception.
- Each node has power control ability which can be adjusted according to the transmission distance.
- Each Sensor node has the same initial power.
- In the first round, each node has a probability p of becoming the cluster head.
- Nodes are uniformly distributed in network.

B. Proposed Algorithm

The proposed algorithm works in rounds. The various models used in the new scheme are:

1) *The Radio Transmission Model:* The first order radio model has been adopted in this study [10].

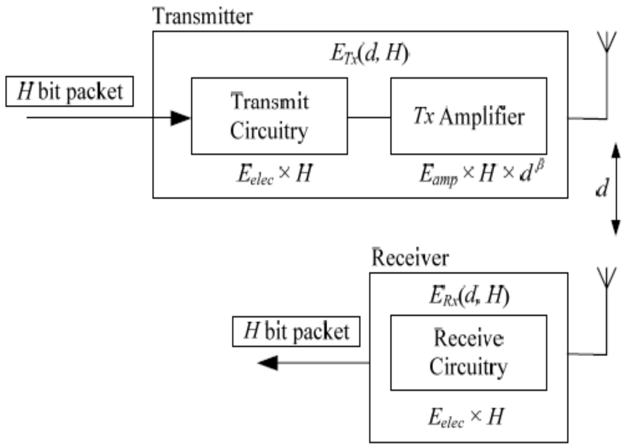

Figure 2. Energy Consumption Model

The two parameters used in this model are, E_{elec} and ϵ_{amp}. Energy dissipation per bit by the transmitter or receiver circuits is given by E_{elec} and is set to 50nJ/bit. Energy dissipations per bit by the transmitter amplifier is given by ϵ_{amp} and is set to 0.1 nJ/bit/m^{β}.

The energy consumption for transmitting/receiving *H*-bit data message for a given distance *d* is formulated by:

$$E_{Tx}\,(d,H) = k\,(E_{elec} + \epsilon_{amp}\; d^{\beta}\,)$$

(1)

$$E_{Rx}\,(d,H) = HE_{elec}$$

Where E_{Tx} represents energy consumption for transmitting data, E_{Rx} denotes the energy dissipation by receiving data and β is the pass loss exponent. The pass loss exponent α is set to 2 for the transmission from each node, and β is set to 2.5 for the transmission from a cluster head to BS.

2) Coverage Model: Each sensor node has sensing range r_s and location $\{x_i, y_i\}$, $i \in [1, n]$. The location of each POI is given by $\{x_j, y_j\}$, $j \in [1, m]$. We also denote a coverage set of a sensor node S_i by CS_i. The set of POIs that are covered by multiple CS_i can be determined by the following equation:

$$PO_i = CS_i \cap (CS_1 \cup CS_2 \cup \dots \cup CS_{i-1}$$

(2)

$$\cup\, CS_{i+1} \cup \dots \cup CS_n)$$

Where PO_i is the set of POIs that are covered by multiple sensor nodes.

The coverage ratio *CR* of the network can be defined as:

$$CR = \frac{||CS_1 \cup CS_2 \cup \dots \cup CS_{n-1} \cup CS_n||}{m} \qquad (3)$$

If a node *S*1 runs out of energy, CS_1 in equation (3) will become an empty set.

C. Flowchart of Proposed Algorithm

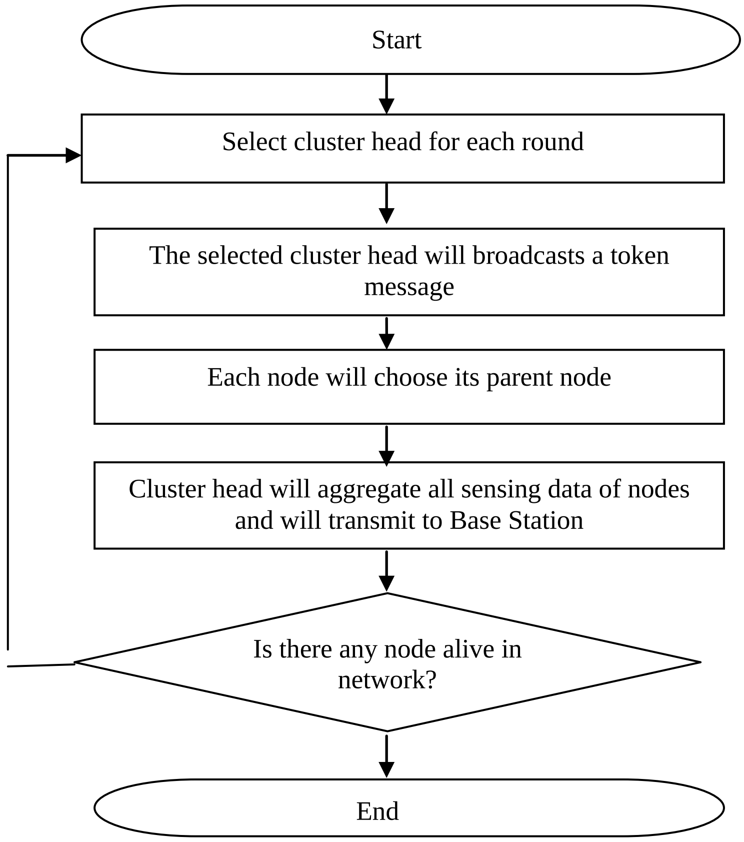

Figure 3. Flowchart of Proposed Algorithm

IV. SIMULATION SETUP AND PERFORMANCE EVALUATION

All simulations have been implemented using MATLAB. We have assumed that 500 nodes are randomly distributed in field of 200x200 and the sink is located about 50m away from the field edge. The simulation parameters are given in Table 1. The performance of the proposed protocol is compared with that of the LEACH protocol. The points of interest have been chosen randomly and fixed to 500.

A. Cluster Head selection mechanism

To prolong the lifetime of the network with full sensing coverage, a cluster head selection mechanism was developed which was based on energy-balancing and coverage-preserving. This mechanism is used in the ECHR protocol. We also apply the energy-aware hierarchy routing mechanism in order to determine an optimal route for packets generated by each node.

According to the radio model described above, the transmission between a cluster head and the BS could consume huge amount of energy. In the ECHR protocol, the cluster head selection is based on uniform distribution. Therefore, the cluster head selection mechanism is essential. Clustering provides resource utilization and minimizes energy consumption in WSNs by reducing the number of sensor nodes that take part in long distance transmission [12] and [13].

Cluster based operation consists of several rounds. These involve cluster heads selection, cluster formation, and transmission of data to the base station.

In our mechanism of cluster head selection the representative nodes will be selected as cluster heads based on the following equation:

$$P\text{ (k successes in n rounds)} = \binom{n}{k} p^k\, q^{n-k} \qquad (4)$$

Where n= no. of rounds

k= no. of success

n-k = no. of failures

p = probability of success in one round

q = (1-p) = probability of failure in one round

B. The Energy-Aware Hierarchy Routing Mechanism

In order to reduce the power consumption of data transmission, we adjust communication range of each node. Thus, all sensing data of sensor nodes will be transmitted by multi-hop mechanism. Each node uses the hop count of received information in a neighbor table. Thus, each sensor node knows which nodes are closer to the cluster head, and these nodes could be its parent node. However, a node *Si* might have multiple parent nodes available for choosing.

Therefore, we calculate the parent node factor P_k for the parent node S_k by:

$$P_k = (1/d_k) \times RE_k \qquad (5)$$

Where d_k is distance between the node S_i and the parent node S_k . According to equation (5), each node will calculate the parent node factor according to its parent nodes and all the values saved in the neighbor table. After calculating the parent node factor, each node will transmit sensing data to its parent node.

C. Simulation Parameters

Table 1 shows the various simulation parameters that are used in the proposed algorithm.

TABLE 1: Simulation Parameters

Parameters	**Values**
Simulation Round	2000
Network size	200*200
Number of Nodes	500
Node distribution	Nodes are uniformly distributed
Control Packet size	500bits
Data Packet size	2000bits
Distance between BS and Sensor field	100-100m
Initial energy of node	0.05 joule
Point of interest	500
Compression coefficient	0.05
Energy dissipation	10*0.000000000001 Joule
Energy for Transmission	50*0.000000000001 Joule
Energy for Reception	50*0.000000000001 Joule
Energy for data aggregation	5*0.000000000001 Joule

D. Simulation Results

The nodes were deployed uniformly in the proposed algorithm. Figure 4 shows the node deployment in wireless sensor network.

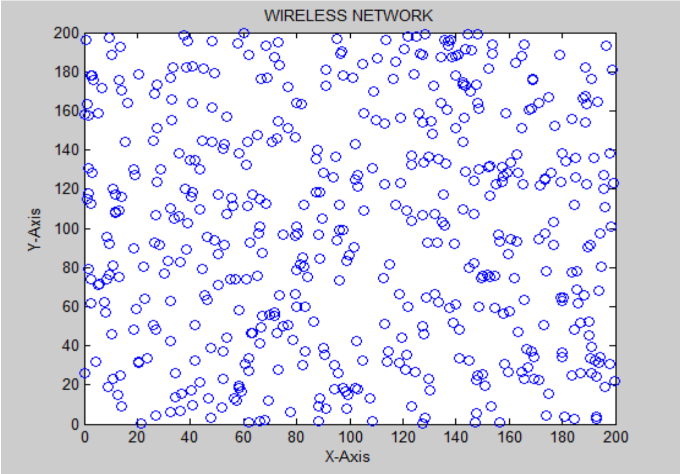

Figure 4. Nodes randomly deployed in the network

1) *Cluster Head formation*

The transmission between a cluster head and the BS could consume huge amount of energy. Therefore, the cluster head selection mechanism is essential. Clustering provides resource utilization and minimizes energy consumption in WSNs by reducing the number of sensor nodes that take part in long distance transmission [12] and [13].

Cluster based operation consists of several rounds. These involve cluster heads selection, cluster formation, and transmission of data to the base station. The Cluster Heads were generated using the uniform distribution mechanism.

Figure 5 shows the cluster head formation in ECHR. The cluster heads are selected using the uniform distribution method.

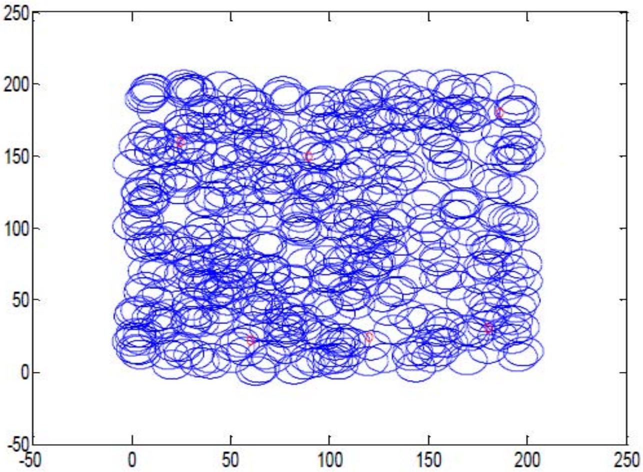

Figure 5. Cluster head formation in ECHR

2) *Network Life Time*

When a node is dead in the network, it is no longer the part of the network. It shows that if a dead node occurs in early rounds of the algorithm, this may affect the life time of the network which may lead to early dead of all nodes. Table 2 shows the simulation results of the two schemes.

Figure 6 shows the conclusion that in the proposed algorithm, the first node dies later in the network

TABLE 2: Network Lifetime (First node dead)

No. of Rounds	Round number when first node dies	
	LEACH	Proposed Algorithm
500	375	0
1000	355	678
1500	337	731
2000	348	713

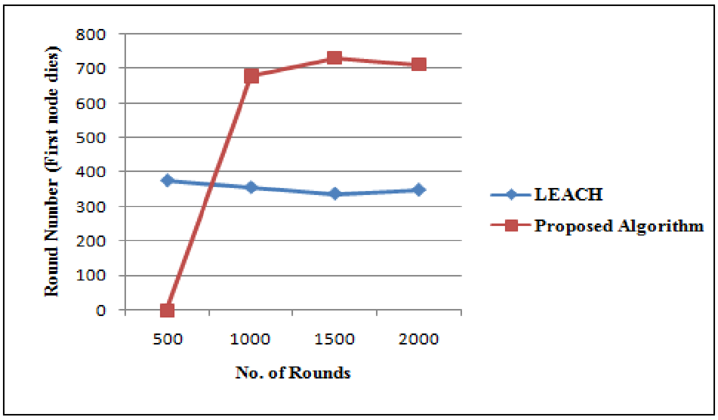

Figure 6. Network Lifetime(First node dead) v/s No. of Rounds

3) *Network Lifetime with Number of Nodes dead*

The increase in number of nodes that are alive contributes to the increase in network life time. Table 3 and Figure 7 show the number of nodes that are dead with the increase in number of rounds. The lifetime of WSN in the proposed scheme is better compared to LEACH Protocol.

TABLE 3: Network Lifetime with number of nodes dead

No. of Rounds	No. of dead nodes	
	LEACH	Proposed Algorithm
500	351	0
1000	412	52
1500	500	492
2000	500	497

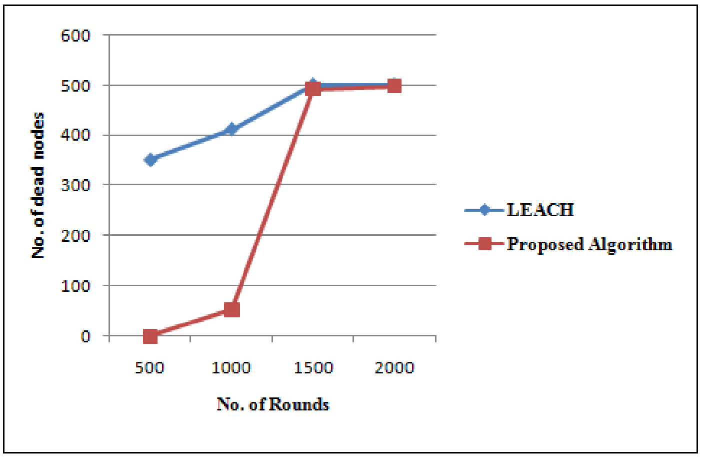

Figure7. Network Lifetime (dead nodes) v/s Number of Rounds

4) Residual Energy Comparison

We calculated the residual energy for the proposed scheme and compared it with LEACH protocol. Table 4 shows the values of residual energy for both the protocols and Figure 8 concludes that the residual energy of LEACH protocol decreases faster as compared to ECHR

TABLE 4: Maximum Residual Energy

No. of Rounds	Residual Energy	
	LEACH	Proposed Algorithm
500	0.04295	0.37531
1000	0.04143	0.18025
1500	0.03591	0.06895
2000	0.03310	0.02512

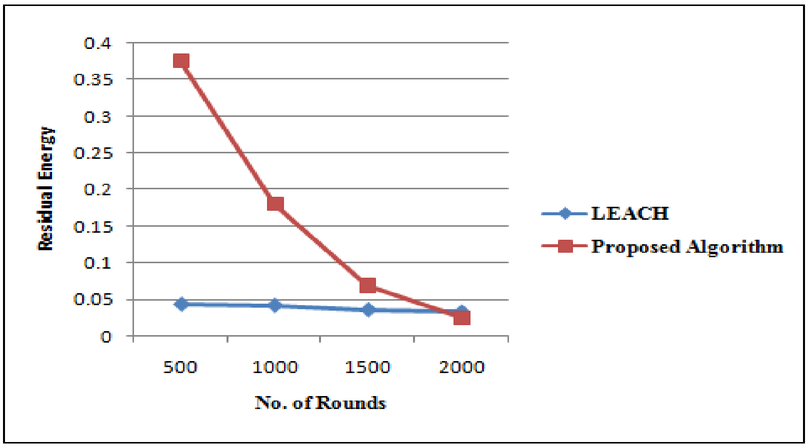

Figure8. Residual Energy v/s Number of Rounds

5) Coverage Ratio of Proposed Scheme

Table 5 shows the values of coverage ratio for LEACH protocol and the proposed algorithm. Figure 9 concludes the results.

TABLE 5: Coverage Ratio

No. of Rounds	Coverage Ratio (%)	
	LEACH	Proposed Algorithm
500	100	100
1000	95	100
1500	30	60
2000	0	0

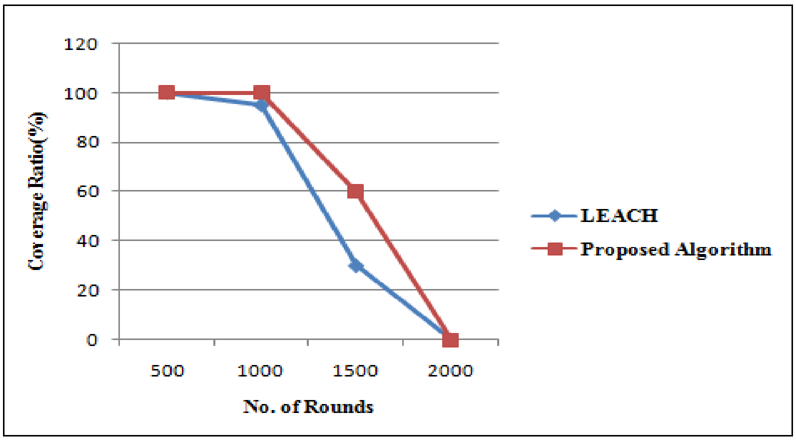

Figure9. Coverage Ratio v/s No. of Rounds

The proposed algorithm is able to maintain 100% coverage ratio till 1690th round whereas LEACH protocol lose full coverage ratio at 900th round. Figure 9 concludes that the proposed algorithm provides about 80-85% extra life time compared to LEACH protocol.

6) Cost Metric

A cost metric has been defined for the network to show that the proposed scenario has less costing as compared to LEACH. We have computed the cost of the network in terms of energy.

The total energy of 500 nodes consumed in each round in the network has been calculated which gives the average energy of the network consumed in each round until any node dies.

Mathematically, it is formulated as:

$$Avg.Cost = \sum_{i=1}^{500} S(i).Eres(r) - \sum_{i=1}^{500} S(i).Eres(r+1)$$

Here, i is the total number of nodes in the network. r is the round number. Eres is the residual energy of any node. S is the array of 500 nodes in simulation. S(i).Eres is the residual energy of the i th node.

Table 6 and Figure 10 conclude that the cost of network is more in LEACH as compared to the proposed algorithm

TABLE 6: Cost Metric

Simulation Run	LEACH	Proposed Algorithm
1	0.21415	0.16713
2	0.20102	0.16674
3	0.20857	0.1701
4	0.21369	0.16334
5	0.19219	0.1666
6	0.19659	0.1626
7	0.19649	0.16993
8	0.19854	0.16504
9	0.20842	0.16883

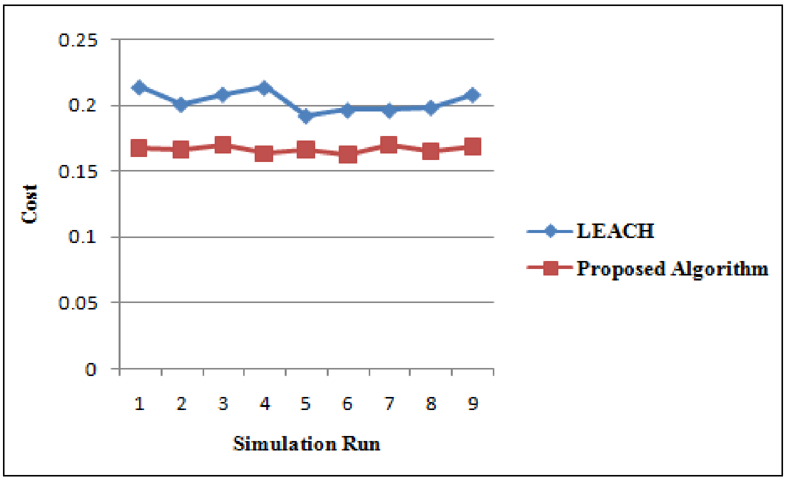

Figure10. Cost v/s Simulation run

V. CONCLUSION

The main issue in wireless sensor network is to preserve the coverage. In this paper, we have proposed a cost effective energy-aware and coverage-presenting hierarchy routing protocol to increase the lifetime of network. The aim of this study is to prolong the duration for maintaining full sensing coverage. The main idea is to combine energy balancing and coverage-presenting mechanisms into routing protocol. Simulation results show that the proposed ECHR protocol is able to prolong the duration of the network with 100% coverage ratio, which provides 80-85% extra lifetime comparing with LEACH protocol. We have also calculated the cost and concluded that the cost of network is more in LEACH as compared to the proposed algorithm.

The proposed protocol is for the homogeneous network and we propose to extend our work for heterogeneous network in future. We will also try to evaluate the performance of the proposed system in aspects of transmission delay and throughput in future and compare our algorithm with other benchmark protocols

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