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Intra-Cluster Multihop Routing in LEACH Based on Shortest Distance

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ABSTRACT

In this paper we propose Intra Cluster Routing Shortest Distance-Low Energy Adaptive Clustering Hierarchy protocol (ICRSD-LEACH) that addresses inefficient energy distribution and dissipation in the Wireless Sensor Networks resulting in reduced network lifetime and communication efficiency. The proposed routing protocol performs intra-cluster multi hope routing to reduce communication cost. However, cluster formation, randomized rotation of cluster heads and data fusion in ICRSD-LEACH is similar to LEACH. Simulation results confirm that the proposed routing protocol reduces the communication cost which improves life time of network through intra cluster multi hoping and signified by prolonged lifetime of nodes which are far away from the base station.
KEY WORDS: Hierarchical clustering, Intra-cluster routing, Energy Efficient communication, Wireless sensor Networks, Algorithm design and analysis.

1. INTRODUCTION

Wireless Sensor network comprises of small light weight wireless nodes which are highly distributed in the area. A Wireless Sensor Network is spatially distributed sensors to monitor conditions at different locations such as temperature, sound, vibration, pressure, motion or pollutants.

Typically, a sensor node consists of sensing, processing capability (CPUs, microcontrollers), RF transceiver, actuators, and power components (batteries and solar cells). One of the benefits of WSNs is their capability to operate in such environment where physical existence of human is either too risky or impossible.

WSNs are widely used to monitor wide range of applications that include Pressure, Humidity, Vehicular movement, Temperature, Noise levels, Mechanical stress levels on attached objects. Typical applications include Agriculture, environmental, surveillance and battle space monitoring by military.

After the initial deployment of nodes, it is desired that nodes should collaborate with one another to obtain current values and report these back to sink. Routing protocols should be designed to manage fault tolerance in case of failure of any node and to ensure minimum energy consumption during data transmission.

In order to scale and increase the life time of the Wireless Sensor Network, nodes are grouped into clusters. There are multiple advantages of clustering like it reduces the size of routing table of each node by localized route set up. Reducing the size of routing table make efficient routing [1].Clustering limits unnecessary exchange of messages among sensor nodes by compression and also confines Inter-cluster communications to Cluster Heads that can in-turn save precious bandwidth [2].

A number of routing protocols designed for wireless sensor communication use clustering at multiple levels to lower energy consumption for improvement in performance and life time of WSN. Usually, energy preservation is guaranteed by means of different approaches [3-5].Such as:

I. Efficient scheduling in sleep and active modes of sensors save energy.
II. Efficient network channel access as well as packet retransmission on the Data Link Layer.
III. An efficient Clustering and routing scheme is used for efficient energy consumption.
IV. Well managed of transmission power to guarantee an optimal exchange between connectivity and energy consumption;
V. Data fusion to eliminate the data redundancy which reduces communication cost.

2. RELATED WORK

Hierarchical Protocols

In WSN, the participatory nodes are grouped together on the basis of residual energy levels, physical/geographical position, power required for transmission and reception of messages etc. Such groups or partitions are termed as clusters [5]. Depending upon information routing criteria and energy optimization certain nodes with in clusters are chosen as cluster head and assigned the task of communicating collected sensor data to the sink. In some networks the collected data is processed, aggregated or passed through a

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mathematical procedure at the cluster head before forwarding to sink [6].

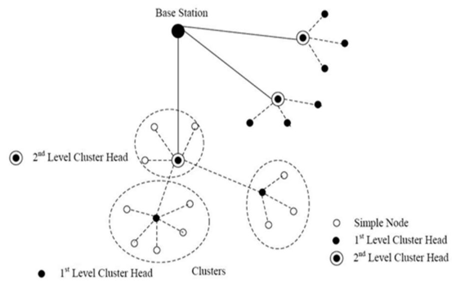

Figure 1: Hierarchical Clustering

Figure1 shows hierarchically partitioned WSN into several cluster layers [6]. Nodes are grouped into clusters at different levels. Simple nodes send their data to cluster head instead of sink/base-station. At level 1, cluster heads aggregate the received data from member nodes and report it to cluster heads of upper layer called 2nd level cluster head.

Cluster heads at level 2 send data to base station. In this way, Data is transmitted from Lower layer to upper layer in multi hop. Energy consumption becomes efficient by lowering the distance cost. In this section, we shall discuss related work related to routing protocols for hierarchical WSNs.

2.1 Low-energy adaptive clustering hierarchy (LEACH):

A Low Energy Adaptive Clustering Hierarchy communication protocol for WSNs has been presented in [7, 8] and well received in research.

The operation of LEACH is carried out into two phases; setup phase and steady state phase. In the set up phase, cluster-heads are selected randomly based on the following threshold.

$$T(n) = \frac{P}{1 - P \times (r \bmod P^{-1})} \qquad \forall \in G \qquad (1)$$

$$T(n) = 0 \qquad \forall \notin G$$

Where n is a random number between 0 and 1

P is the cluster – head probability and

G is the set of nodes that were not cluster – heads the previous rounds

If n $<$ T (n), then candidate node becomes a cluster – head

Where **P** is probability of desired cluster-head, **r** is current round number and **G** is the set of nodes that will participate for cluster head selection. Once the nodes are selected as cluster heads, they cannot participate for the next **1/P** rounds. After **1/P** rounds, all alive nodes will be members of G set. After clustering, all member nodes inform the cluster head by transmitting a joint request message to cluster head. The node which is closest to cluster head sends the joint route request message to cluster head. After getting all requests from member nodes, cluster head creates and announces a TDMA schedule, assigning time slots to member nodes for transmitting data.

LEACH rotates the cluster heads position among all nodes which distribute energy load. The node which is closest to cluster head sends the join route request message to cluster head. After getting all requests from member nodes, cluster head creates TDMA schedule.

In steady phase, each member node transmits sensed data to cluster head in allocated time slot and finally cluster head sends data to sink/Base station.

LEACH include data fusion/compression feature that reduces the overhead of data redundancy. Also, normal nodes become active only in allotted time slot and remain off as much as possible to conserve energy. LEACH also performs single-hoping instead of direct communication which diminishes the communication cost between sensor nodes and their cluster heads [9]. Despite of low energy consumption, LEACH may not select optimal node as a cluster head. Furthermore, it assumes that all cluster heads directly report data to sink. Nodes which are far away from cluster head will die soon as they consume more energy because of longer distance of transmission.

2.2 Power-Efficient Gathering in Sensor Information Systems (PEGASIS):

PEGASIS [10] is modified and improved variant of LEACH. PEGASIS did not form cluster, it forms chain from sensor nodes by local coordination with neighbour nodes and select one node as a head from the chain. Head node is selected randomly in each round from chain that transmits data to Base station. PEGASIS assumes that all nodes know location of every node. PEGASIS use greedy algorithm to make a chain of sensor nodes starting farthest from the centre. Sensor nodes send data to adjacent node instead of directly to cluster head as occurred in LEACH. Data aggregation is performed after each hop and route for data transfer exists as long as all participatory nodes remain alive. In case of death of any node from chain, data transmission gets stopped and an alternate path/ chain is reconstructed using greedy algorithm.

PEGASIS increases life of WSN two times as compared to LEACH since it purges the overhead of dynamic cluster formation in each round unlike LEACH. Although, PEGASIS is an energy efficient clustering protocol but its drawback is that nodes which are at distant location in chain have excessively delay in transmitting data to base station

2.3 Low-energy adaptive clustering hierarchy –centralized (LEACH-C):

LEACH-C [11] is the extension of LEACH. It comprises of two phases like LEACH, Setup phase and steady phase. In setup phase, each node signifies its location and residual energy to base station. Base station chooses optimal cluster heads based on residual energy and broadcasts information to form cluster using location information of nodes. Main idea behind LEACH is to avoid selection of nodes that have low energy to increase the overall life time of network. In steady phase, data is transmitted from normal nodes to concerned cluster heads and finally cluster heads send aggregated data to base station.

LEACH-C is not suitable for larger networks; nodes face difficulties to send their status to base station which are at distant location to base station. LEACH-C also assumes perfect correlation between nodes and base station.

2.4 Low-energy adaptive clustering hierarchy –Fixed (LEACH-F):

LEACH-F [11] forms clusters using the LEACH-C algorithm. Clusters are formed once and remain fixed throughout life time of WSN. After cluster formation, Base station selects optimal nodes as a cluster head from each cluster and broadcast message comprising CH ID for each node. LEACH-F rotates the CH position among nodes in the cluster.

It eliminates the cluster formation overhead at the beginning of each round and decreases the energy dissipation. However, the steady state phase is similar to LEACH protocols.

LEACH-F does not cater for wireless node mobility, is unrealistic for dynamic system, and does not support scalability. It also increases energy dissipation of normal nodes and inter-cluster interference.

2.5 Hybrid, Energy-Efficient Distributed Clustering (HEED):

HEED [12, 13] is the extension of LEACH. HEED elects cluster head periodically using residual energy (primary) and communication cost (secondary) unlike random selection of CH in LEACH. If two candidate nodes of same region have same residual energy then cluster head is elected based on nodes Intra-cluster communication cost. Due to energy based election of CHs, it creates well distributed clusters. HEED requires only local communication which reduces energy load. HEED efficiently distributes the energy consumption that improves the life of network comparative to LEACH. However, it has following shortcomings:

i. Due to periodic cluster head selection, HEED consumes extra energy to rebuild clusters.
ii. Random election of cluster head may cause of communication cost over head between Member nodes and cluster head as well as cluster head and base station.
iii. HEED provides only two level hierarchies but it can be extended to multilevel hierarchy.

2.6 Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN):

TEEN [14, 15] is another hierarchal clustering protocols used for reactive networks that respond immediately to changes in the value of concerned attributes. Nodes that are close to each other make clusters and cluster heads are elected. Nodes within a cluster send their sensed data to the cluster head; cluster head aggregates and forwards data to upper level until it reaches the sink. Energy efficiency is introduced by the cluster head as it broadcasts a threshold (hard or soft) based on value of concerned attribute to its member. In case of hard threshold, member nodes will switch on and transmit data only when sensing value of specified attribute is beyond the absolute value of threshold attribute. In soft threshold attribute, member nodes switch on and transmit data even with a small change in the value of threshold attribute. TEEN is not appropriate for applications that need periodic reports.

2.7 Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN):

APTEEN [16] is an extension of TEEN which overcomes the deficiency of TEEN. APTEEN is hybrid clustering based routing protocol which reacts to time-critical events as well as captures periodic data. APTEEN takes three types of queries: (i) Persistent query monitors an event for a period of time (ii) Historical query is used to analyze past data value (iii) One-time query takes a snapshot of current network view.

APTEEN increases the life time of network and reduces the energy dissipation as compared to LEACH. Disadvantage of TEEN is that it increases complexity and over head dealing with attribute-based naming queries and implementing threshold base functions.

3. Methodology

This paper describes an Intra Cluster Multi-hop Routing based on Shortest Distance criteria in LEACH (ICRSD-LEACH). In this algorithm, cluster heads collect data from the member nodes, aggregate and transmit the data to route node. Route node is selected based on shortest distance between node and cluster head. Finally, route nodes forward received data to base station (BS) as shown in Figure 2.

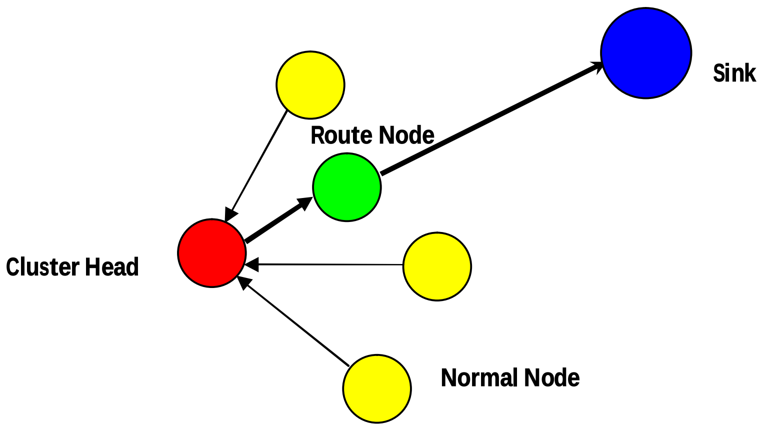

Figure 2: Intra Clusters multi hoping routing with shortest distance

As depicted in Figure 2, normal nodes communicate to cluster head and cluster head have to send data to sink through route node which is closest to cluster head. These elected cluster heads and route node persist for a specific period called round.
The operation of ICRSD-LEACH is separated into two phases:

I. setup phase

a) Cluster head selection
b) Route node Selection

II. Steady state phase.

In the set up phase, the cluster heads and route nodes are selected and clusters are organized. Set up phase for cluster head selection is same as mentioned above in Equation 1 [7].

After set up phase, all member nodes transmit data to cluster head in assigned TDMA slot. Cluster heads receive, aggregate and forward data to route node. Finally, aggregated data is sent by route node to Base station instead of cluster head. This process is repeated in every round.

Selection of route node depends upon location of cluster head. It may not be optimum choice when route node is farther away from base than cluster head since energy dissipation increases with distance.

Despite of this shortcoming, Simulation result shows that ICRSD LEACH is efficient than conventional LEACH with respect to life time of network and energy distribution.

4. IMPLEMENTATION AND RESULT

4.1 ALGORITHM

The algorithm for the ICRSD LEACH is given below:

Setup phase for Cluster Head:
1. CN=> r
2. If r < T (n) then, CH = CN else, go to step1
3. CH => G : id(CH) , join adv
4. A(i) → CH(j) : id(A(i)) , id(CH(j)) , join req
5. CH(j) → A(i) : id(CH(j)) , < t(i) , id(A(i)) >

Setup phase for Rout Node:
1.A(i) ∈ CH(j) : id(A(i)) , id(CH(j))
2. RN(k) =A(i) : id(A(i)) ,
3. RN(k) → CH(j) id(RN(k),id (CH(j)) , join req route
4. if A(i+1).Distance < RN(k).Distance then RN(k)=A(i+1) : id(A(i)) , id(RN(k)) else, go to step

Steady phase:
1. A(i) → CH(j) : id(A(i)) , id(CH(j)) , info
2. CH → RN: id(CH) , id(RN) , aggr info
3. RN→BS: id (RN), id(RN) , info

The various symbols used here are :
CN: candidate node to become the cluster head.
r: randomvariable(0 < r < 1)
T(n) : threshold value
CH : cluster head
G : all nodes in the network
RN: Route node
id : identification number
join req : advertisement to join the cluster
A : normal node
A.Distance: Distance between normal node and cluster head
R.Distance: Distance between Route node and cluster head
join req: request to join the cluster
join req route: request to join as route node for Cluster.
t : time–slot to send the sensed data
=> : broadcast
→ : unicast
∈ : Belongs to

4.2 NETWORK CONFIGURATION FOR ICRSD

Here we have considered a homogeneous network. A homogeneous network is one in which all the nodes have equal energy. The network configuration for first round of simulations for ICRSD LEACH is as follows:

Table1.System parameters for network configuration

Parameters	**Value**
Network size	**100*100(100 m^2)**
Sensor nodes	**100**
Initial Energy (E_o)	**0.50 Jole**
Data Packet	**4000 bits**
Transmitter Electronics ($E_{Tx-elec}$) **Receiver Electronics ($E_{Rx-elec}$)**	**50 nJ/bit**
Data aggregation(EDA)	**5nJ/bit**
Transmit(E_{fs})	**10 pJ/bit/m^2**
Transmit Amplifier (E_{amp})	**0.0013 pJ/bit/m^2**
d_o	**Sqrt(E_{fs}/E_{amp})**
Location of base station	**(x=0,y=-100)**
Probability of cluster head (p)	**10%**

Only E_o of the above parameters was changed for the further analysis.
The energy required by any transmitter to send a K-bit message over a distance d is,

$$E_T(K,d) = \begin{cases} K.E_{elec} + K.E_{fs.}d^2 & d < d_0 \\ K.E_{elec} + K.E_{amp}d^4 & d > d_0 \end{cases} \quad (2)$$

In equation 2, E_{elec} is the amount of energy dissipated to run the circuit (of receiver or sender) for 1-bit data E_{fs} and E_{amp} are the transmitter constants and depend upon the type of transmitter used and d_o= Sqrt (E_{fs}/E_{mp}).The above network configuration, formulae and values of various parameters were referred to from [11].

A few of the nodes in the network were selected as route nodes based on number of clusters. Route node receives data from cluster head and forward to base station. Hence network life time is expected to increase by decreasing the cost of distance.

5. RESULTS

After several rounds of simulation, the following results were gathered. Based upon these results, a detailed analysis is presented as follows

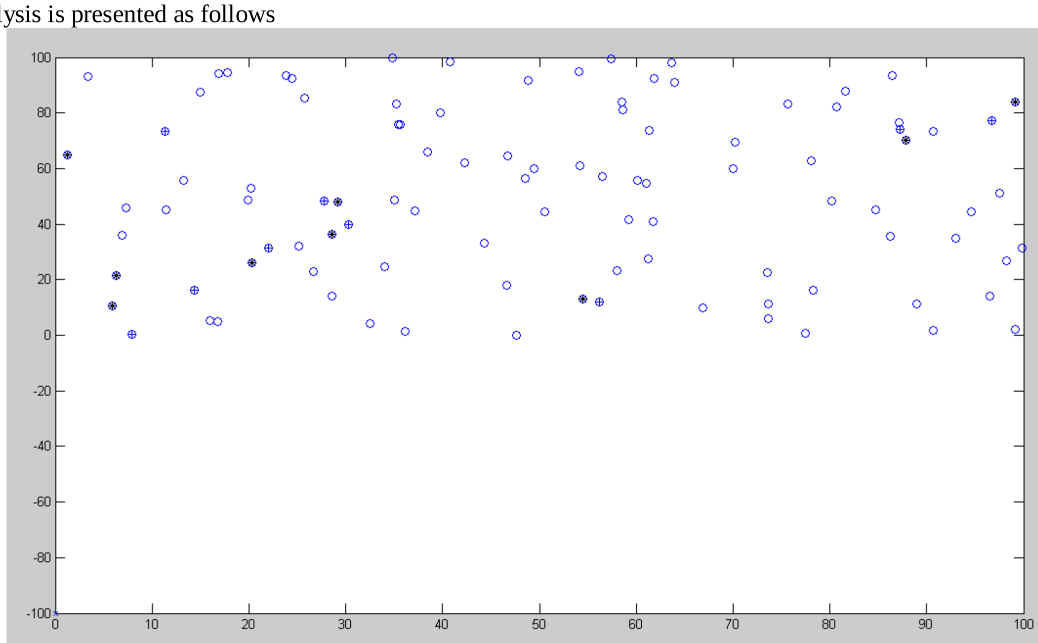

Figure 3: Node deployment and status

Figure 3 shows the initial field distribution of the network, where ICRSD LEACH protocol is implemented. A 100 by 100m field is selected and nodes are randomly placed in it. The sink/base station which is denoted by cross (×), is placed at the far away from Network filed located at (x=0, y= -100).

Here, the Cluster heads are shown by asterisk (*) and route nodes are represented by plus (+) notations while circle (o) signifies a normal node. In Figure 3, all the nodes are alive in deployed network.

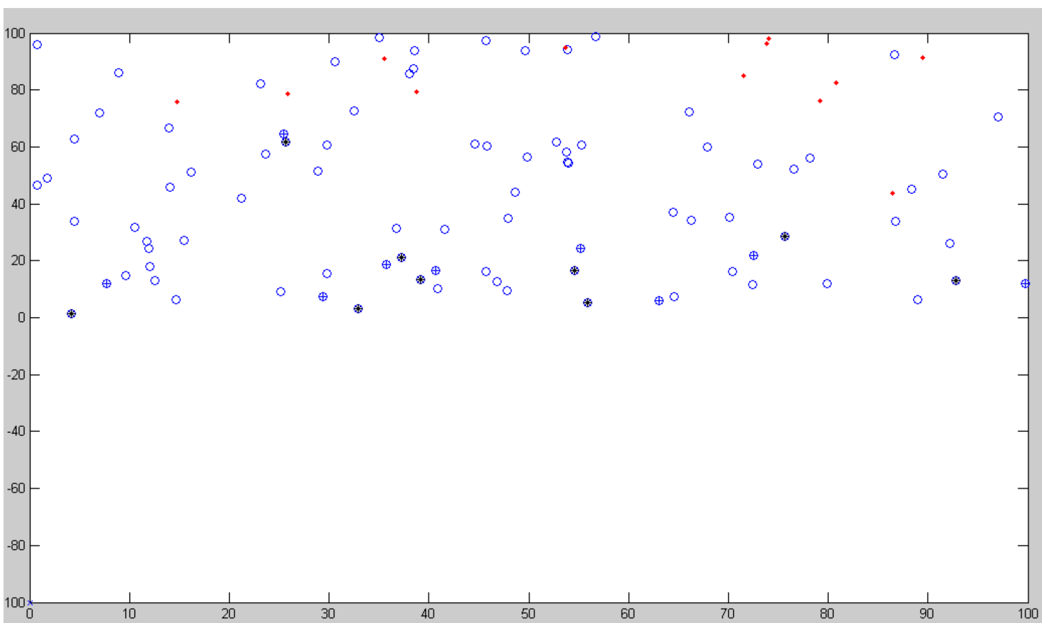

Figure 4: Field distribution after few rounds

In Figure 4: after a few rounds, a few of the nodes drains out all their energy. Such dead nodes are shown by the dot symbol (•). The reason why some of the nodes drain out their energy before the others is because their respective distance cost and probability to become route node is higher than other normal nodes. In ICRSD, normal nodes send data to cluster heads and cluster heads have to aggregate the data and send it to the route node; route node finally sends the data to base station. Route nodes utilize more energy than the cluster heads and normal nodes.

Since the node which is located at (x=1, y=100) has lowest probability to become route node because cluster head selects other member node as route node based on shortest distance. Despite of being located farthest away from base station, it does not drain its energy contrary to LEACH. Nodes die randomly in ICRSD depending upon the location of neighbour nodes and base station.

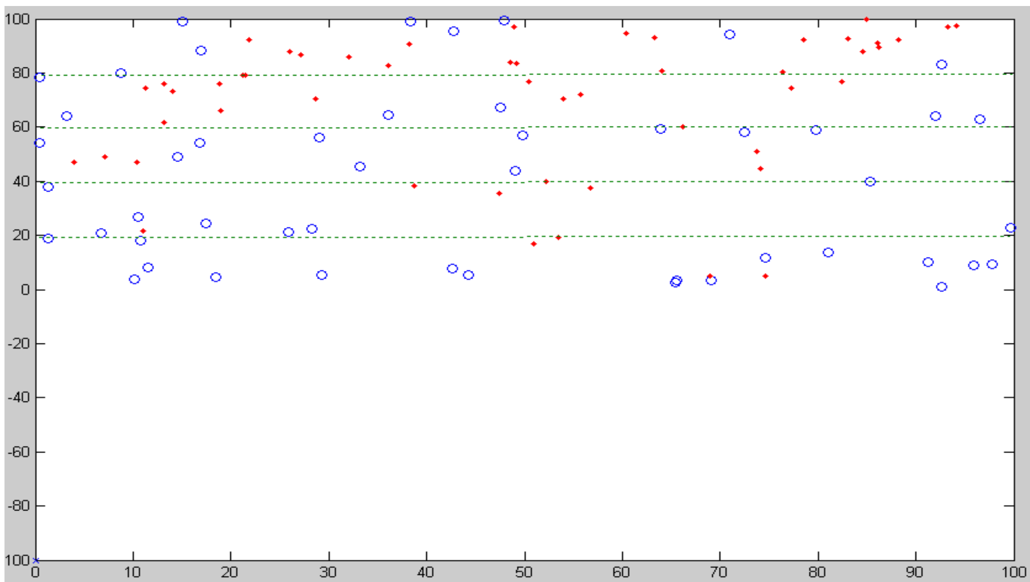

Figure 5: Field distribution with half dead network

Figure 5 shows that 50% nodes in the network are alive. Network field is divided into five equal areas marked by doted lines. It also shows that some nodes are alive in each area of network and these may transfer data to sink. Nodes which are far away from base station are still alive while in LEACH protocol the nodes which are far away from base station will die soon as they consume more energy because of longer distance cost. Simulations show that ICRSD-LEACH distributes Energy in network better than LEACH because of random death of nodes in all parts of network area.

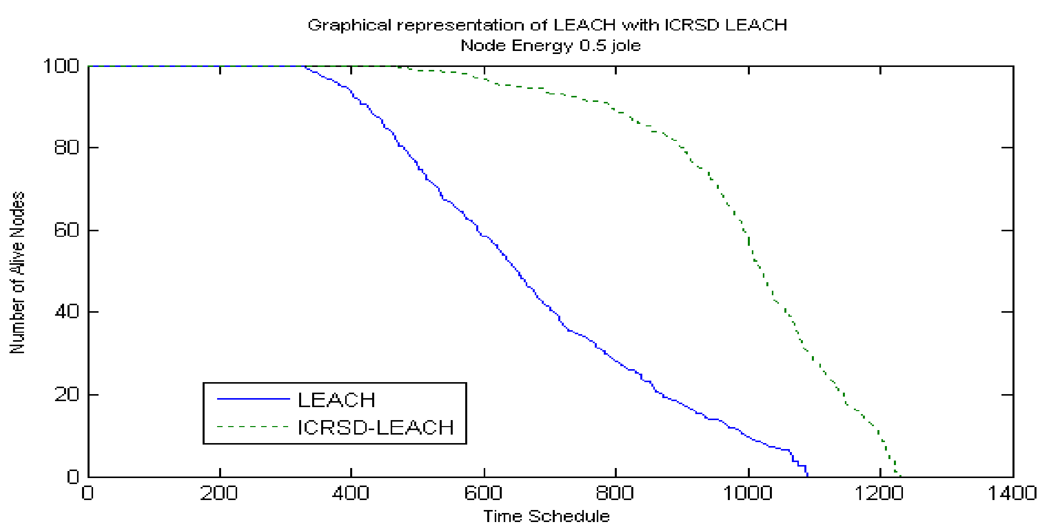

Figure 6: Network Life Time

Figure 6 shows the lifetime for the 100m*100m sensor network with 100 nodes having 0.5 Joule initial energy o f each node and the comparison between lifetime of LEACH and ICRSD LEACH. In LEACH protocols network, first node drain out approximately 337 rounds while in ICRDS LEACH, first node died in 429 rounds. All the nodes drain out their whole energy in LEACH and ICRSD LEACH after 1093 and 1224 rounds respectively. It is observed that life time network is increased in ICRSD LEACH. Experimental results show that ICRSD takes approximately 1.28 times longer for the first node to die and 1.12 times longer for the last node to die. There is not much improvement in the network life time but it reduces the shortcoming of LEACH where cluster head located far away from the sink dies earlier because it must consume large energy to transmit data packets. But in ICRSD protocol cluster head which is far away from the cluster head use route node to transmit the aggregated data and save energy consumption. In ICRSD-LEACH energy consumption depends upon the neighbour node's location instead of distance from Cluster head to base station.

Table 2. Comparison between ICRSD and LEACH with different initial value of energy

Energy (J/node)	Protocol	Round first Node dies	Round last Node dies
0.25	LEACH	165	528.6
	ICRSD-LEACH	227	614
0.5	LEACH	337	1093
	ICRSD-LEACH	429	1224
1	LEACH	667	2173
	ICRSD-LEACH	1072	2441

The results presented in Table 2 are average values calculated after 50 simulation runs. In some cases, it is possible that first node death of ICRSD LEACH occurs before LEACH depending upon the physical location of route node. A far away specific node selected as a route node in consecutive rounds for different Cluster Heads may die before other nodes. However, network life time and energy distribution in WSN employing proposed scheme is always better than LEACH protocol.

6. CONCLUSIONS AND FUTURE WORK

In this paper we described ICRSD-LEACH routing protocol which utilizes less energy to transmit data from source nodes to base station than conventional LEACH. During each round, cluster head aggregates received sensor's data and chooses route node which is closest to it for sending processed data to sink. Our simulations show that ICRSD-LEACH increases about 11% network life time comparatively to conventional LEACH. First node death occurs over 1.28 times later than the first node death in LEACH and last node death in ICRSD occurs over 1.12 times later than the last death of LEACH. ICRSD-LEACH also distributed the energy more effectively in network. Future extension of work include optimized selection of route node based on node energy which will be help full to increase network sustainability.

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