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Energy Efficient Routing Protocol for Wireless Sensor Networks

H.Srikanth.Kamath

Abstract

Wireless Sensors are subjected to harsh deployment conditions and have constrained resources. In this paper, we analyse the effectiveness of LEACH protocol in extending the lifetime for energy-constrained wireless sensor networks. Based on LEACH protocol, an improved protocol termed as LEACH-R is proposed. LEACH-R improves the selection of cluster-head by considering the residual energy of the nodes during selection of cluster-head, thereby reducing the possibility of low-energy nodes being selected. Based on both residual energy and distance to base station, relaying node is chosen from clusterheads to become the relay node between base station and other cluster-heads. The simulation results suggest LEACH-R protocol could balance network energy consumption and extend the network life cycle more effectively as compared to LEACH.

Keywords

Wireless sensor networks; LEACH protocol;LEACH-R; lifetime; cluster head

I. Introduction

A wireless sensor network consists of a large number of sensor nodes and a base station as a controller, which interfaces the sensor network to the outside network. Sensor nodes are used to monitor physical or environmental conditions such as temperature, sound, vibration, pressure and motion. Each node is typically equipped with one or more sensors, a radio transceiver, a small microcontroller, and an energy source which in most WSNs is a battery. It iscapable of performing processing, gathering sensory information and communicating with other connected nodes in the network.

WSN nodes are typically provided with constraint processing and storage capabilities and limited energy resources. They are prone to failures due to harsh deployment environments and are easy to be compromised due to typically unattended operations.WSN is characterised by a dynamic topology due to node joining, mobility or failure, thus introducing further security and reliability issues. The difference between the wireless networks and WSN is that sensors are sensitive to energy consumption, therefore, in design of routing protocols for WSN, the energy saving is the crucial issue.

Routing protocol is an indispensable part which ensures the normal operation of Wireless Sensor Network and high efficiency in transmission of information.A cluster based routing protocol groups sensor nodes into clusters where each cluster has a cluster head (CH). Sensed data is sent to the CH rather than the BS, CH performs some aggregation function on data it receives then sends it to the BS where these data is needed.

Routing protocols are classified based on the topological structure of the networks, mainly flat routing and hierarchical routing. Hierarchical routing protocols designed to reduce energy consumption by localizing communication within the cluster and aggregate data to reduce transmissions to the BS. The developments of clustered sensor networks have recently beenshown to decrease system delay, save energy while performing data aggregation and increase system throughput.

LEACH is a hierarchical cluster based routing protocol that has better energy utilisation as compared to other protocols. LEACH uses the mechanism of rotating and random selection of cluster heads, thereby providing each node with an equal chance to perform as a cluster head. By doing so, LEACH balances the energy consumption of the entire network, thus effectively enhancing life cycle of the entire network.It shows significant reduction in the overall network energy over other non-clustering protocol.

II. LEACH protocol

Low Energy Adaptive Clustering Hierarchy (LEACH) partitions the nodes into clusters, in each cluster a dedicated node with extra privileges called Cluster Head (CH) is responsible for creating and manipulating a TDMA (Time division multiple access) schedule and sending aggregated data from nodes to the BS . Remaining nodes are cluster members.This protocol is divided into rounds; each round consists of two phases;
Set-up Phase
(1) Advertisement Phase
(2) Cluster Set-up Phase

Steady Phase
(1) Schedule Creation
(2) Data Transmission

H.Srikanth.Kamath, E&C Department, Manipal University, Manipal, India.

A. Set-up Phase

In the set-up phase, initially the node becomes a cluster- head with a probability P and broadcasts its decision packet. The regular nodes choose their cluster-head based on the least communication energy to reach the cluster-head. The role of the cluster-head keeps on rotating among the nodes of the cluster to enhance the network life time. The selection of cluster-head depends on decision made by the node by generating a random number between 0 and 1. If the number is less than a threshold T (n), the node becomes a cluster-head for the current round. The threshold is set as:

$$T(n)=\begin{cases} \frac{P}{1-P*\left(r mod \frac{1}{P}\right)} & if\ n \in G \\ 0 & if\ n \notin G \end{cases}$$

Where P equals the suggested percentage of cluster-heads, r is the current round, and G is the set of nodes that have not been cluster-heads in the last 1/P rounds. By using this threshold, each node will be a cluster-head at some point within 1/P rounds.

During the first round (r = 0), each node has a probability P of becoming a cluster-head. The nodes that are cluster-heads in round 0 cannot be cluster-heads for the next 1/P rounds. Thus the probability that the remaining nodes are cluster-heads must be increased, since there are fewer nodes that are eligible to become cluster-heads. After 1/ P−1 rounds, T =1 for any nodes that have not yet been cluster- heads, and after 1/P rounds, all nodes are once again eligible to become cluster-heads.

In the following advertisement phase, the CHs inform their neighbourhood with an advertisement packet that they become CHs using CSMA MAC protocol. Non-CH nodes pick the advertisement packet with the strongest received signal strength.In the next cluster setup phase, the member nodes inform the CH that theyhave become a member to that cluster with "join packet" containing their IDs using CSMA. After the cluster-setup sub phase, the CH knows the number of member nodes and their IDs. Based on all messages received within the cluster and the number of regular nodes, the CH creates a TDMA schedule, picks a CSMA code randomly, and broadcasts the TDMA table to cluster members. After that steady-state phase begins.

B. Steady-state phase

After the clusters are created and the TDMA schedule is fixed, data transmission begins. The regular node sends data during their allocated transmission time to the cluster-head according to the TDMA schedule. The radio of each regular node is turned off until the node’s allocated transmission time. The CH will keep its receiver on to receive all the data from the nodes in the cluster. When all the data has been received, the CH performs data fusion functions to compress all the data into a single signal. After that the composite signal is sent to the base station directly by the cluster-head. The base station being far away, this is a high energy transmission. This is the steady-state operation of LEACH networks.

C. Analysis of LEACH

LEACH protocol is difficult to attack as compared to the more conventional multi-hop protocols. In LEACH, the CHs are the only node that directly communicate with the base station as opposed to the conventional multi-hop protocols in which the nodes are around the base station and are more attractive to compromise. In LEACH the location of these CHs can be anywhere in the network irrespective of the base station and the CHs are periodicallyrandomly changed. So spotting these CHs is very difficult for the adversary.Although LEACH protocol acts in a good manner, it suffers from many drawbacks like theCH selection being random, which does not take into account energy consumption.It can't cover a large area.CHs are not uniformly distributed; where CHs can be located at the edges of the cluster.It also assumes all the nodes to have same energy, whichis not the case always in real-time problems. Since LEACH has many drawbacks there is a need to make this protocol perform better.

III. Leach-R Protocol

LEACH-R algorithm is also divided into set-up phase and steady-state phase.In the set-up phase, an improved threshold is used to decide which node would become the CH; the threshold is shown as follow:

$$T_R(n) = \begin{cases} \frac{P}{1-P*\left(r\ mod\ \frac{1}{P}\right)}\left[\delta P + (1-\delta P)\frac{E_{residual}}{E_o}\right] & if\ n \in G \\ 0 & if\ n \notin G \end{cases}$$

Where $E_{residual}$ is the residual energy of node, E_o is the initial energy of node, δ is the number of consecutive rounds during which a node has not been cluster-head by far. When elected as cluster-head, the value of δ for that node is reset to 0. This threshold ensures nodes of higher residual energy have a greater chance of becoming acluster-head, which balances the energy consumption of the network. Since then elected cluster-head will broadcast packet with node’s residual energy and its distance from the base station to notify the regular node, the regular node then choose its cluster to join.

After the formation of clusters, we select R (relay) node from the cluster-head, based on the residual energy and distance from the base station of cluster-head, this decision is made basing on a value λ as follow:

$$\lambda = \frac{E_{residual}}{d_{toBS}}$$

Where d_{toBS} is the distance between current cluster-head and the base station. λ is only calculated for all cluster-heads. The cluster-head having the biggest value λ becomes R node. CHs those are not chosen to be R node will send data to the current R node after the end of data collection through regular nodes, instead of direct communication with BS that is very distant. R node will aggregate the data receiving from cluster-heads and transmit the fusion data to BS. Thus considerable energy will be saved through the communication process with R node.

IV. System Model

For this analysis, LEACH first order radio model assumptions are used and the transmission cost $E_{Tx}(l,d)$ and the receiving cost $E_{Rx}(l)$ are given by the following equations:

$$E_{Tx}(l,d) = \begin{cases} E_{elec} * l + \varepsilon_{amp} * l * d^2 & if\ d < d_o \\ E_{elec} * l + \varepsilon_{amp} * l * d^4 & if\ d \geq d_o \end{cases}$$

Where l is the number of bits and d is the distance between the two nodes.

$$E_{Rx}(l) = E_{elec} * l$$

where E_{elec} is the energy dissipations for transmission and reception. Threshold transmission distance is d_o and depending on it the transmission model is chosen.

$$do = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}}$$

Free-space model is used when d<do, otherwise the two ray model is used.

The number of cluster- heads is a key factor that affects performance of routing protocols. If the number of cluster-heads is less, each cluster- head need to cover larger region that will lead to some cluster members are far from their cluster-heads and consume much more energy.The excessive number of cluster-heads will increase the energy consumption of the whole network and shorten the network lifetime. Therefore, it is necessary to select optimal cluster-head number to make the energy consumption minimum

Each cluster-head dissipates energy receiving signals from the nodes, aggregating the signals, and transmitting the aggregate signal to the BS. Since the BS is far from the nodes, presumably the energy dissipation follows the two-ray model. Therefore, the energy dissipated in the cluster- head during a single frame E_{CH} is:

$$E_{CH} = l * \frac{N}{k} * (E_{elec} + E_{Da}) + l * \varepsilon_{amp} * d_{toBS}^4$$

E_{DA} is the energy consumption of one byte in data aggregation. Each regular node only needs to transmit its data to the cluster-head once during a frame. It can be assumed that the distance to the cluster-head is small, so the energy dissipation follows the Friss free-space model. Thus, the energy used in each non-cluster-head node is:

$$E_{n-CH} = l * E_{elec} + l * \varepsilon_{fs} * d_{toCH}^2$$

Where d_{toCH} is the is the distance from the cluster-head to the BS.
The energy dissipated in a cluster during the frame is:

$$E_{cluster} = E_{CH} + (\frac{N}{k} - 1)E_{n-CH} \approx E_{CH} + \frac{N}{k}E_{n-CH}$$

and the total energy for the frame is given by E_T=k$E_{cluster}$.
the optimum number of clusters can be found by setting the derivative of E_T with respect to k to zero. Therefore optimal ratio of cluster heads is:

$$P_{opt} = \frac{k_{opt}}{N} = \sqrt{\frac{\varepsilon_{fs}}{2\pi N \varepsilon_{amp}} \frac{M}{d_{toBS}^2}}$$

This P_{opt} P will be used in the threshold $T_R(n)$ to decide which node is eligible to be a cluster-head.

V. Simulation

LEACH and LEACH-R are simulated by Matlab to evaluate their performance. MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. It was developed by Math Worksand it allows matrix manipulations, plotting of functions and data, implementation of algorithms.

A. Network Model

- Nodes are deployed randomly in a square area.
- The base station is constant and localized far from the sensors area.
- All nodes in the sensor network are homogeneous and energy-constrained. No mobility of sensor nodes.
- The communication channel is symmetric.
- All nodes can transmit with enough power to reach the BS if needed and the nodes can use power control to vary the amount of transmit power.

B. Parameters

The proposed algorithm and Low-Energy Adaptive Clustering Hierarchy (LEACH) clustering algorithm for WSN is simulated. The basic parameters used are listed in the following Table

Table 1: Simulation Parameters

Parameter	Value
Number of sensor nodes	100
Network area	200x200
Base station position	(50,175)
Data packet size	500 bits
Initial energy of nodes	1 Joule
E_{elec}	50 nJ/bit
ε_{fs}	10pJ/bit/m2
ε_{amp}	0.0013pJ/bit/m2

C. Simulation results

LEACH algorithm is simulated and cluster-head selection is carried out for 100 rounds. As shown in fig.1 nodes are deployed, then cluster heads are selected and these cluster heads transmit aggregated cluster information to Base Station. Simulation results are shown for few rounds.

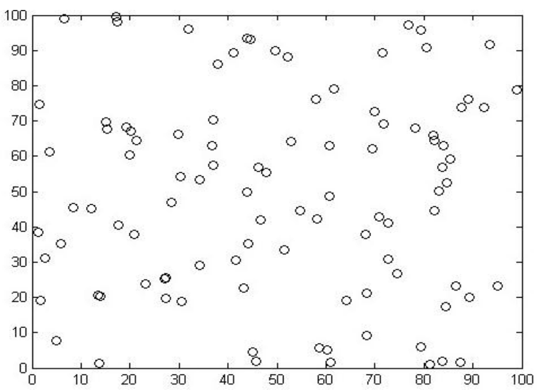

Figure 1: Deployment of nodes in the network area.

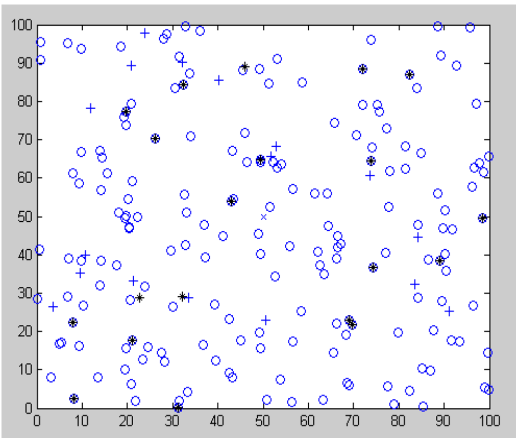

Figure 2: Cluster Head selection in round 20

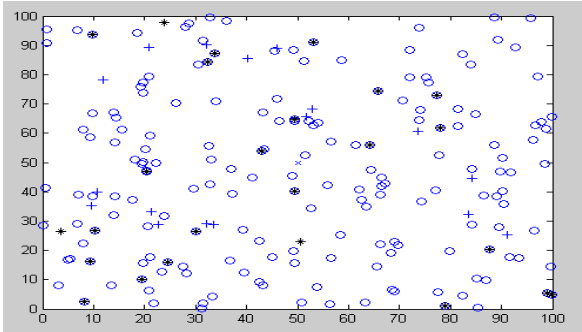

Figure 3: Simulation results for round 60

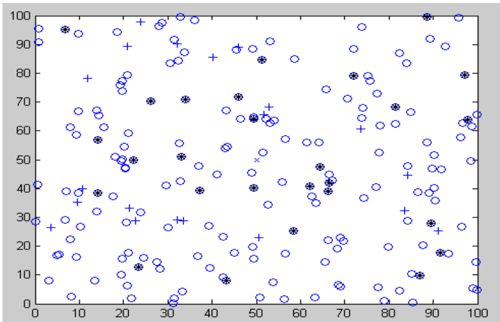

Figure 4: Simulation results for round 80

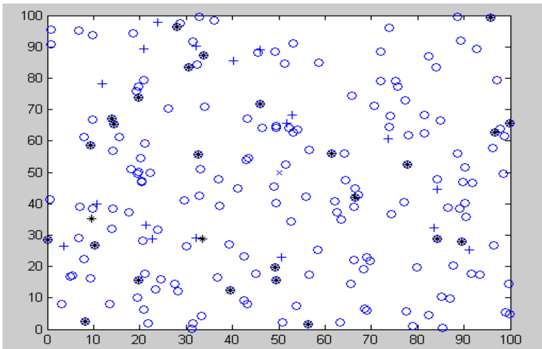

Figure 5: Simulation results for round 100

Simulation results show that the random cluster-head selecting method in LEACH protocol cannot ensure the number of cluster heads completely equal to the anticipant optimal one during the dynamic clustering process, and also that the distances between cluster heads are too close or sensors of some regions are too far from their cluster heads. All above these situations cause the decreasing of LEACH protocol's performance

In LEACH R the nodes are distributed then the cluster heads are chosen according to the threshold T(n) and cluster heads aggregate data and transmissions occur from the cluster heads to the R node which then aggregates the data and sends to the base station.

The transmissions from member nodes to cluster heads is depicted by blue lines. Transmissions from cluster to R node is depicted by green lines and from R node to Base Station by red lines.

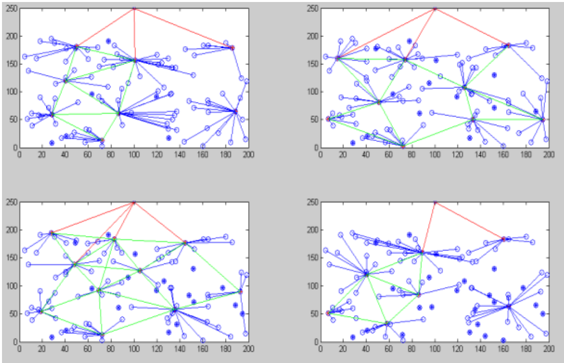

Figure 6: LEACH R simulation results.

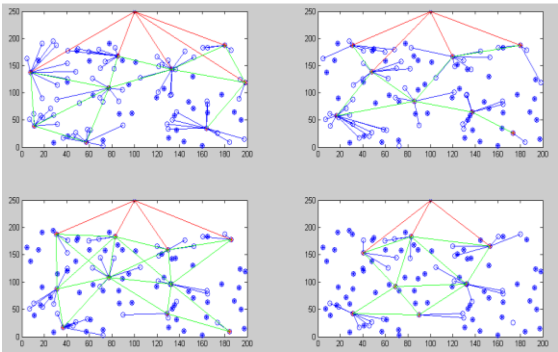

Figure 7: First few rounds of LEACH-R

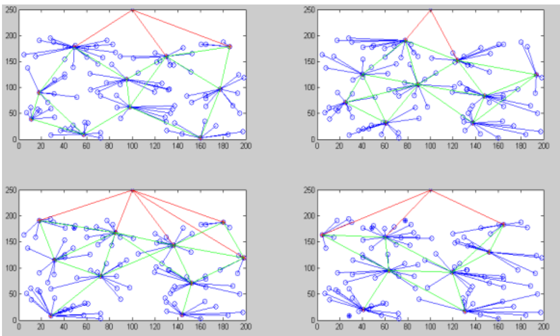

Figure 8: Further rounds of LEACH-R

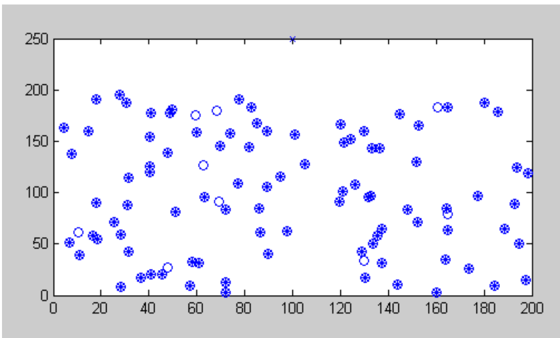

Figure 9: Final Round of LEACH-R.

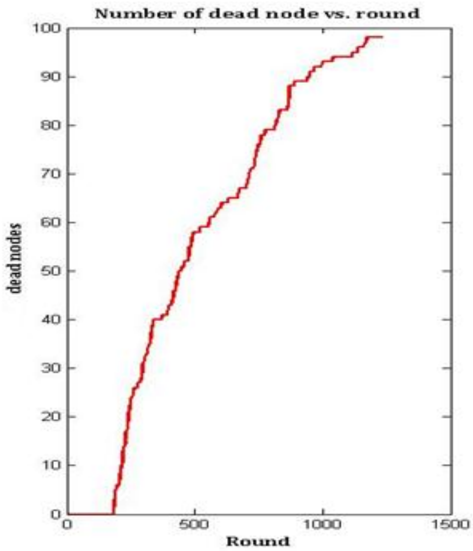

Figure 10: Graphical analysis of LEACH

Majority of nodes are dead, hence no cluster head selected, hence no transmission to base station.

As seen from the simulation results in LEACH R, transmissions to the base station (high energy), takes place only from the R nodes which are selected from amongst the cluster heads, as opposed to LEACH where high energy transmissions to base station takes place from all the cluster heads. Thus LEACH-R reduces the energy consumption considerably as compared to LEACH, hence increasing the network lifetime.

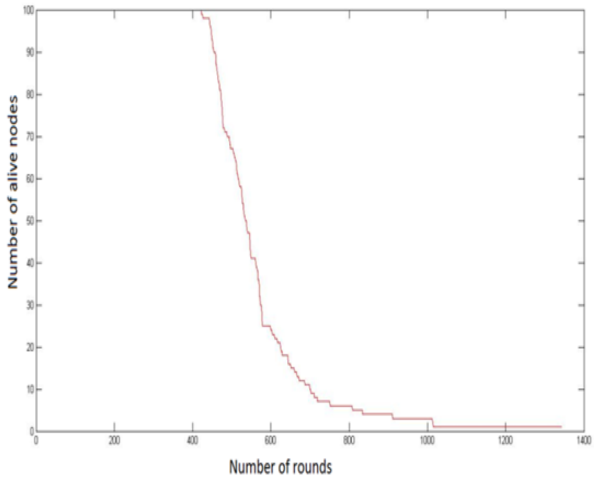

Figure 11: Graphical analysis of LEACH-R

As seen from fig. 10, in LEACH algorithm, the nodes die around the 1200th round. Whereas from fig. 11, it is observed that all the nodes die by 1342th round.Hence it can be concluded that sensor network has a longer lifetime with LEACH-R in comparison to LEACH.

VI. Conclusion

In this paper first LEACH protocol has been explained and then simulated. It has few drawbacks hence an improvement to it has been suggested in the form of LEACH-R protocol.

LEACH-R has been explained and simulated and is found to be more energy efficient as compared to LEACH. Simulation results prove the improvement in the performance of LEACH-R as compared to the original LEACH protocol in terms of energy dissipation rate and network lifetime. This due to the energy saved in transmission by the improvement of cluster-head selection and the R (relay) node.

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H. Srikanth Kamath received the B.E. degree in electronics and communication engineering from M. S. Ramaiah Institute of Technology, Bangalore University, Bengaluru, India, in 1992. He received his M.Tech in electronics and communication engineering (Communication Systems) from Malnad College of Engineering, Mysore University, Hasan, India. His research interest includes Wireless Communication, Wireless Networks and Computer Networks.