

Analysis of Setup Energy of LEACH Protocol for Wireless Sensor Networks

Rashmi Jain¹, Manali Kshirsagar², Latesh Malik³

¹ (Dept of Computer Computer Science & Engineering G.H.Raisoni College of Engg. Nagpur, India)

² (Dept of Computer Technology, Yeshwantrao Chavan College of Engg. Nagpur, India)

³ (Dept of Computer Computer Science & Engineering G.H.Raisoni College of Engg. Nagpur, India)

Abstract- In Wireless Sensor Network (WSN) the sensor nodes are very much sensitive to the energy consumption. The reliable operation can be performed in the network (NW) by using hierarchical protocols for communication of data, which can conserve energy of nodes in network. LEACH is the basic protocol developed for the said purpose, in which the operation of network is performed in two steps, namely Setup phase and Steady state phase. Clusters of nodes are formed in setup phase and actual data transfer from network to base station is done in steady state phase. The cluster head (CH) will need more energy for regular communication with cluster members as well as base station so its energy depletes quickly. To balance the energy consumption, CH responsibility is rotated and a new cluster is set up in each round. If the setup phase is to be executed frequently it will cause wastage of energy in the overhead operation. In this paper we analyze the proportion of the energy required in setup phase as well as steady state phase. It is found that the power requirement of both phases is near about same. We propose a new approach so that this overhead energy can be minimized.

*Keywords-*wireless sensor network, dynamic clustering, cluster head, energy efficiency, heterogeneous nodes.

1. INTRODUCTION

Wireless sensor networks has a very important characteristics is that sensor nodes' battery power is quite limited and they are not easy to recharge. All the sensors have to sense the monitored phenomena and convey the data to the base station. Power requirement is more for communication as compared to sensing or some processing at the node. If all the nodes start sending the data separately to the base station then too much energy will be consumed in communication and node's energy will drain soon. Therefore Heinzelman proposed a beneficial strategy, Low Energy Adaptive Clustering Hierarchy (LEACH), for hierarchical organization of nodes. This protocol is more energy efficient as compared to flat routing. Each round of data transmission consists of two phases namely setup phase and steady state phase. Clusters are formed in the first phase. Cluster head and member nodes are selected and a schedule of data transmission is communicated to all members. Actual data gathering and data transmission to base station is done in second phase. All the nodes are having same initial energy and operation of CH is more energy intensive. So to balance the energy consumption dynamic clustering is used. The setup phase energy is an overhead energy and our analysis proves that this energy is on an average 100% of the energy requirement by steady state phase where actual data transmission to sink takes place. The algorithm is implemented in MATLAB with the parameters given in further section. This overhead energy can be reduced if we use a heterogeneous approach. High energy nodes can be deployed to function as CHs so that frequency of setup phase and thereby energy waste in overhead operation is reduced.

2. RELATED WORK

In wireless sensor networks, in case of non-clustering protocols more energy is needed for finding the path from source to sink and follow a multi-hop communication. As the WSN consist of large number of energy constrained nodes more energy is drained in transmitting and receiving the data as compared to other processing. Therefore we can use cluster based (Hierarchical) protocols. Cluster based protocols are used widely in wireless sensor networks,

mobile ad-hoc networks as well as wireless ad-hoc networks. Several clustering techniques have already been introduced for partitioning nodes in these areas. Some of the early clustering techniques include Hierarchical Clustering, Distributed Clustering Algorithm (DCA), Spanning Tree based Clustering, Clustering with On-Demand Routing, Clustering based on Degree or Lowest Identifier Heuristics, Distributed and Energy-Efficient Clustering, Adaptive Power-Aware Clustering. Some of the recently developed clustering techniques are PEGASIS (Power-Efficient Gathering in Sensor Information Systems) [7], Energy Efficient Clustering Routing, PEACH (Power Efficient And Adaptive Clustering Hierarchy), Optimal Energy Aware Clustering, ACE (Algorithm For Cluster Establishment), HEED (Hybrid Energy-Efficient Distributed Clustering), PADCP (Power Aware Dynamic Clustering Protocol), LEACH (Low-Energy Adaptive Clustering Hierarchy) [1], SEP (Stable Election Protocol), and LEACH with Deterministic Cluster Head Selection [17].

In clustering, the whole sensor network is divided into small regions known as cluster. In each cluster, one node is elected as Cluster Head (CH). Elected CH is responsible for aggregating sensed data from its cluster member node(s) and propagate/forward it to base station or to the next CH. As CH has to relay the data of all member node(s), and will deplete energy if continuously selected as a CH. So, the phenomenon of CH selection is an important criterion. New CH can be selected randomly or based on the parameters like residual energy, distance from base station, connected nodes, topology etc [4].

S. Lindsey et al. in [7] introduces a near optimal chain-based protocol PEGASIS. Here, each node forms a chain among the sensors and communicates only with a close neighbor. Each sensor in the chain receives data from its neighbor, fuse this data with its own data and thus transmit the data to the base station. Doing so it reduces the amount of energy spent per round. It assumes that positions of all the nodes are known and nodes have global knowledge of the network. To form the chain it employs the greedy algorithm. It maps the problem of having close neighbors for all nodes to the traveling salesman problem. PEGASIS is a greedy chain protocol that is near optimal for a data-gathering problem in sensor networks. Greedy approach considers the physical distance only, ignoring the energy remained and capability of a prospective node on the chain. Hence, a node with a shorter distance but less residual energy may be chosen in the chain and may die quickly.

In [10] a routing algorithm is proposed which combines hierarchical routing and geographical routing. It forwards the packet from the source nodes to the base station consists of two phases—inter-cluster routing and intra-cluster routing. For intra-cluster routing, a simple flooding is used to flood the packet inside the cluster when the number of intra-cluster nodes is less than a predetermined threshold. Otherwise, the recursive geographic forwarding approach is used to disseminate the packet inside target cluster, that is, the cluster head divides the target cluster into some sub-regions, creates the same number of new copies of the query packet, and then disseminates these copies to a central node in each sub region. For inter-cluster routing, a greedy algorithm is adopted to forward packets from the cluster heads of the target regions to the base station. In [9], it uses greedy algorithm based on the distance only but not on the capability or the residual energy. Although it deals with the optimal forwarding approach the criteria to choose the cluster heads optimally is not clearly explained.

PEACH [11] is a cluster formation technique based on overheard information from the sensor nodes. According to this approach, if a cluster head node becomes an intermediate node of a transmission, it first sets the sink node as its next hop. Then it sets a timer to receive and aggregate multiple packets from the nodes in the cluster set for a pre-specified time. It checks whether the distance between this node and the original destination node is shorter than that of between this node and already selected next hop node. If the distance is shorter, this node joins to the cluster of the original destination node and the next hop of this node is changed to the original destination node. PEACH is an adaptive clustering approach for multi-hop inter-cluster communication. However, it suffers from almost the same limitations of PEGASIS due to the choice of physical propinquity.

Optimal energy aware clustering [12] solves the balanced k-clustering problem optimally, where k signifies the number of master nodes that can be in the network. The algorithm is based on the minimum weight matching. It optimizes the sum of spatial distances between the member sensor nodes and the master nodes in the whole network. It effectively distributes the network load on all the masters and reduces the communication overhead and the energy dissipation. However, this research work does not consider of residual energy level while choosing a node as the master. Hence, the choice of the master or cluster head is far away from the optimal energy efficient distribution of the cluster heads. [17]

All the protocols discussed above use the LEACH protocol as a basic idea and propose their work. This protocol outperforms as compared to the earlier flat based routing protocols. Dynamic clustering strategy proposed in it is easily scalable. The following section describes this protocol.

2.1. LEACH [Low-energy adaptive clustering hierarchy]:

LEACH is hierarchical routing approach for sensors networks. The idea proposed in LEACH has been an inspiration for many hierarchical routing protocols, although some protocols have been independently developed [2]. The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Cluster formation is typically based on the energy reserve of sensors and sensor's proximity to the cluster head.

LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network [2]. In LEACH, the cluster head (CH) nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the base station in order to reduce the amount of information that must be transmitted to the base station. LEACH uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions. However, data collection is centralized and is performed periodically. Figure 1 denotes the typical architecture of a network which uses concept of LEACH protocol, consisting of cluster heads and their respective member nodes.

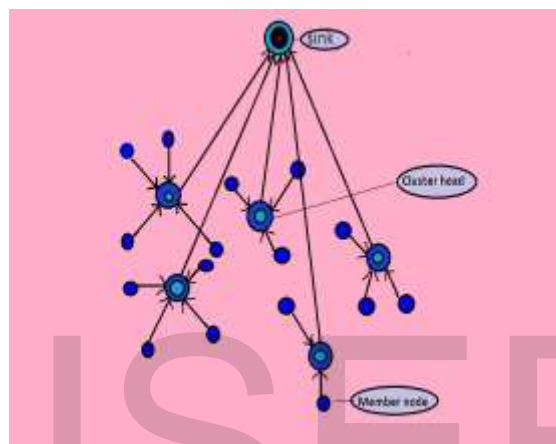


Figure 1: Hierarchical or cluster-based routing

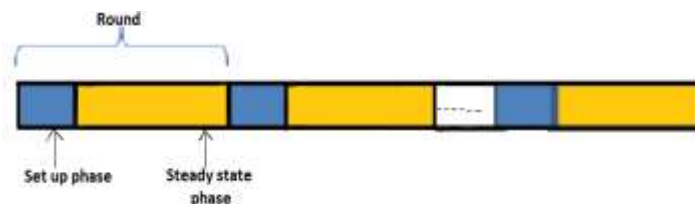


Fig 2: Leach Phases

The operation of LEACH is separated into two phases as shown in the figure 2, the setup phase and the steady state phase[16]. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the base station takes place.

During the setup phase, a predetermined fraction of nodes, P , elect themselves as CHs as follows. A sensor node chooses a random number, r , between 0 and 1. If this random number is less than a threshold value, $T(n)$, the node becomes a cluster head for the current round. The threshold value is calculated based on an equation that incorporates the desired percentage to become a cluster-head, the current round, and the set of nodes that have not been selected as a cluster-head in the last $(1/P)$ rounds, denoted by G . It is given by [16]:

$$T(n) = P / (1 - P(r \bmod (1/P))), \quad \text{if } n \in G$$

Where, G is the set of nodes that are involved in the CH election. Each elected CH broadcast an advertisement message to the rest of the nodes in the network that they are the new cluster-heads.

During the steady state phase, the sensor nodes can begin sensing and transmitting data to the cluster-heads. The cluster head node, receives all the data, aggregates it before sending it to the base-station. The network goes back into the setup phase again and enters another round of selecting new CH.

To analyze the energy consumed in setup phase we develop the protocol in MATLAB and calculate the energy consumption in both the phases. We also propose a heterogeneous approach so that number of setup rounds can be reduced and thereby reduce the overhead energy consumption. The model used is described in the following section.

3. MODEL DESCRIPTION

To develop the LEACH protocol we consider the scenario consisting of the following network model and energy model as proposed by the author:

3.1 Network Architecture

The network model for development of the algorithm for clustering and routing consist of the following:

- 1) In our model we have 100 nodes with equal initial energy The base station is under human observation therefore has unlimited power and the transmit power can be adjusted in an available range.
- 2) The nodes are considered to be immobile and their locations have been known with the help of either GPS or node self-localization algorithms.
- 3) We have single sink node which can be moved. The distance between node in the network and the sink node is known by exchanging information. We can change the positions of sink node for analyzing the best position so that minimum distance and low energy communication will take place.
- 4) CHs can use a single hop to the sink node and need more energy in transmitting the data to the base station and Cluster Member (CM) nodes use single-hop communication with CH as they are closer to the CHs.
- 5) Sensors periodically sense the environment and send the data to the Base Station.

3.2. Radio Energy Model

We assume two models for the radio hardware energy dissipation: free space and multipath fading where the transmitter consumes energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics. Both the free space (d^2 power loss) and the multipath fading (d^4 power loss) channel models are used in this paper, depending on the distance between the transmitter and receiver. If the distance is less than a threshold d_0 , the free space model is used; otherwise, the multipath model is used.

Thus, to transmit a k bit message a distance d , the radio expends [3]:

$$E_{Tx}(k, d) = \begin{cases} kE_{elec} + k\epsilon_{fs}d^2 & d < d_0 \\ kE_{elec} + k\epsilon_{mp}d^4 & d \geq d_0 \end{cases} \quad (1)$$

To receive this message, the radio expends:

$$E_{Rx}(k) = kE_{elec} \quad (2)$$

4. SETUP PHASE ENERGY ANALYSIS

Where, E_{elec} is the electronics energy; ϵ_{fs} and ϵ_{mp} are the amplifier energy of the free space model and the multipath model.

As discussed in the previous section the operation of leach takes place in two phases. Initially all the nodes have equal probability to become the cluster head. Depending upon the random number selected the nodes themselves decide whether to become the cluster head or not. The nodes eligible to become cluster heads then broadcast its

decision with larger signal strength so as to reach all the member nodes. ϵ_{mp} is the amplification power needed to transmit the signal. The energy dissipated in setup phase can be calculated as follows.

If k numbers of nodes are the CHs then to transmit the l bit message over a distance d each node needs

$$E_{Tx}(l,d) = E_{elec} * l + \epsilon_{mp} * l * d^2$$

To receive this message from each CH the member nodes will need

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

When the nodes hear the cluster head message from the CHs they check for the signal with highest signal strength. The signal from the CH which is closest will have highest signal strength. So the node will join the corresponding head. For joining as member the nodes will send a request to the CH. To transmit the join request the energy dissipated is as follows:

$$E_{Tx}(l,d) = E_{elec} * l + \epsilon_{fs} * l * d^2$$

To receive the join request the CH will need the energy as follows:

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

When all the member nodes join their closest cluster head the cluster formation is completed. CHs then decide the TDMA schedule and send it to all the member nodes.

$$E_{Tx}(l,d) = E_{elec} * l + \epsilon_{fs} * l * d^2$$

The schedule sent by CHs will be received by all the member nodes consuming the energy as follows:

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

Thus the total energy needed by the network in setup phase can be calculated as follows:

Energy dissipated by cluster head:

$$E_{CHsetup} = k * (E_{elec} * l + \epsilon_{mp} * l * d^2) + (n - k) * (E_{elec} * l) + k * (E_{elec} * l + \epsilon_{fs} * l * d^2)$$

$$E_{CHsetup} = (n+k) * E_{elec} * l + k * (\epsilon_{mp} * l * d^2 + \epsilon_{fs} * l * d^2) \tag{3}$$

Energy dissipated by cluster members:

$$E_{nonCHsetup} = k * (n - k) * (E_{elec} * l) + (n - k) * (E_{elec} * l + \epsilon_{fs} * l * d^2) + (n - k) * (E_{elec} * l) \tag{4}$$

Total energy in setup phase is:

$$E_{setup} = E_{CHsetup} + E_{nonCHsetup}$$

$$E_{setup} = (n * (3 + k) - k * (k + 1)) * E_{elec} * l + k * \epsilon_{mp} * l * d^2 + n * \epsilon_{fs} * l * d^2$$

$$E_{setup} = l * ((n * (3 + k) - k * (k + 1)) * E_{elec} + k * \epsilon_{mp} * d^2 + n * \epsilon_{fs} * d^2) \tag{5}$$

We consider the Simulation Parameters mentioned in Table 1 as given by Heinzelman in [16] for implementation of the LEACH protocol and calculate the energy required in setup phase and steady state phase.

4.1 Simulation Parameters

The parameters for simulation and study purpose are as mentioned in Table 1.

Table 1: Simulation Parameters

Parameters	Value
Network size	100m x 100m
Sink coordinates	x = 50; y = 50
E_{elec}	50 nJ/bit
E_{fs}	100 pJ/bit/m ²
E_{mp}	0.0013 pJ/bit/m ⁴
Number of nodes	100
$E_{aggregation}$	5 nJ/bit/signal
Packet size	500 bytes

Initial energy	1J/node
Broadcast range	50

4.2 Results

The network contains 100 nodes in the area of 100 x 100 m². According to standard criteria by Heinzelman 5% of nodes should become the cluster heads. We execute the program of LEACH protocol for 10 rounds each with a setup and a steady state round and obtained the energy dissipations. One of the outputs is given in Table 2. After executing the algorithm many times we observe that near about 100% of Steady state phase is needed during setup phase. Fig 3 shows the energy dissipation in the two phases for 10 rounds.

Table 2: Energy dissipation in setup phase and steady state phase

Round No.	Setup Energy per round	Steady State Energy per round
1	0.0418	0.0412
2	0.0427	0.0407
3	0.0414	0.04
4	0.0456	0.0413
5	0.0425	0.0417
6	0.0424	0.0439
7	0.0415	0.0417
8	0.0421	0.04
9	0.0417	0.0443
10	0.0423	0.0428
Avg	0.0424	0.04176
Percentage Energy in setup phase	101.5326	

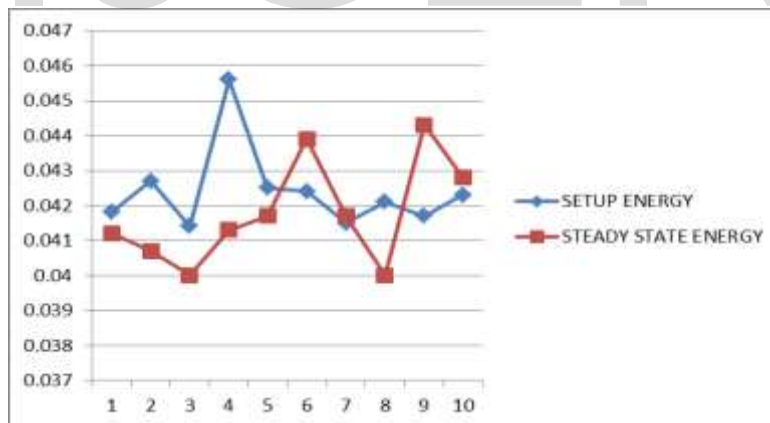


Fig: 3: Energy Dissipation in Setup and Steady State Phase

As the energy consumed in setup phase is an overhead energy, we should find some way to reduce it. We can follow a heterogeneous approach. Some high energy nodes can be used along with the normal nodes so that these high energy nodes can function as CHs for longer time without need of creating clusters in each round. Less number of setup operations will reduce the energy consumption in setup phase and reduce the overhead energy further. This will result in longer lifetime of the network with the same amount of total energy of the network.

5. CONCLUSION

The sensor nodes are very much sensitive to the energy consumption. For large networks hierarchical protocols will be more suitable. Traditional LEACH like protocols use setup and steady state phase for network operation. The energy consumption during setup phase is not considered in these protocols but it is needed. We formulated the energy required in setup phase. Using the parameters as given by Heinzelman we designed the program to calculate the energy dissipated in both the phases of the protocol for a randomly deployed network. We found that about 100% of energy of steady state phase is consumed in the setup phase which can be reduced further by assigning heterogeneous energy levels to the nodes.

V. REFERENCES

1. "A review on wireless sensor networks routing protocol: Challenge in energy perspective" Ismail Ahmedy, Md. Asri Ngadi, Syaril Nizam Omar and Junaid Chaudhry, Scientific Research and Essays Vol. 6(26), pp. 5628-5649, 9 November, 2011.
2. "Compression of Various Routing Protocol in Wireless Sensor Network", Parul Kansal, Deepali Kansal, Arun Balodi, International Journal of Computer Applications (0975 – 8887) Volume 5– No.11, August 2010.
3. "A Dynamic Clustering Protocol for Wireless Sensor Networks", Zhi-kun Liu, Zhong Liu, 2011 International Conference on Computational and Information Sciences , 978-0-7695-4501-1/11 , 2011 IEEE.
4. "Energy efficient and secure pattern based data aggregation for wireless sensor networks", P.Nair ,H.Cam, S.Ozdemir and D. M Espda, IEEE Conference on cations IEEE Sensors, Volume: 2,2003,pp732-736.
5. "A survey on clustering algorithms for wireless sensor networks", Ameer Ahmed Abbasi, Mohamed Younis, Computer Communications 30 (2007) 2826–2841.
6. "Energy Efficient Multi Hierarchy Clustering Protocol for Wireless Sensor Network", Babar Nazir, Halabi Hasbullah, 2010 International Conference on Intelligence and Information Technology (ICIIT 2010).
7. "PEGASIS: Power-Efficient in Sensor Information Systems", S. Lindsay and C. Raghavendra, Proc. on the 2002 IEEE Aerospace Conf. Mar. 2003, pp. 1-6
8. "Energy Aware Intra Cluster Routing for Wireless Sensor Networks", Adeel Akhtar, Abid Ali Minhas, and Sohail Jabbar, International Journal of Hybrid Information Technology Vol.3, No.1, January, 2010.
9. "Wireless Ad Hoc Networks: Basic Concepts", High Frequency Electronics, March 2007.
10. "Density Based Protocol For Head Selection In Wireless Sensor Networks", Priti Narwal, S.S. Tyagi, International Journal of Soft Computing and Engineering (IJSC) ISSN: 2231-2307, Volume-1, Issue-3, July 2011.
11. "A Study of Dynamic Clustering Method to Extend the Lifetime of Wireless Sensor Network", Wernhuar Tarnng, Kun-Jie Huang, Li-Zhong Deng, Kun-Rong Hsie and Mingteh Chen, World Academy of Science, Engineering and Technology 61 2010.
12. "A Dynamic Clustering and Energy Efficient Routing Technique for Sensor Networks" Ming Yu, Senior Member, IEEE, Kin K. Leung, Fellow, IEEE, and Aniket Malvankar, Student Member, IEEE, IEEE transactions on wireless communications, vol. 6, no. 8, August 2007.
13. "An Adaptive Clustering Protocol for Medium-Scale Wireless Sensor Networks", Xu Zhezhuang, Zhang Shiqing, Zhang Xiliang, Bao Binghao, Li Peng, 1-4244-1312-5/07© 2007 IEEE.
14. "Energy efficient clustering and routing scheme for Wireless Sensor Networks", Wenjun Liu, Jiguo Yu, 978-1-4244-4738-1/09, 2009 IEEE.
15. "Energy Efficient Hierarchical Clustering For Sensor Networks", S.V.Manisekaran, Dr.R.Venkatesan, 2010 Second International conference on Computing, Communication and Networking Technologies 978-1-4244-6589-7/102010 IEEE.
16. "Energy-Efficient Communication Protocol for Wireless Microsensor Networks", Wendi Heinzelman, Anantha Chandrakasan, Hari Balakrishnan, 33rd Hawaii International Conference 2000 IEEE.
17. "Stable Sensor Network (SSN): A Dynamic Clustering Technique for Maximizing Stability in Wireless Sensor Networks", A. B. M. Alim Al Islam, Chowdhury Sayeed Hyder, Humayun Kabir, Mahmuda Naznin, Scientific Research jornal on Wireless Sensor Network, 2010, 2, 538-554
18. "Wireless Sensor Networks, Technology, Protocols, and Applications", Kazem Sohraby, Daniel Minoli, Taieb Znati, John Wiley & Sons Publication, 2007.
19. "Energy Saving in Heterogeneous Wireless Sensor Networks", Rashmi Jain, Manali Kshirsagar International Journal of Scientific and Engineering Research (IJSER), Volume 4, Issue8, January 2013

IJSER