Performance Analysis of Hierarchical Routing Protocol (LEACH) for Wireless Sensor Networks

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***Abstract*—In the wireless sensor networks (WSNs), the sensor nodes are usually scattered in a sensor field - an area in which the sensor nodes are deployed. Sensor nodes in these networks coordinate to produce high-quality information and each of these scattered sensor nodes has the capability to collect and route data back to the base station, which may be fixed or mobile. In WSNs, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the performance of the network in terms of reliability of data sent. The cluster based routing algorithms are more energy efficient as compared to the flat routing algorithms. This paper is based on the analysis of Low Energy Adaptive Clustering Hierarchy (LEACH), a cluster based routing protocol. The LEACH protocol was simulated by varying the number of clusters to observe the effect on sensor network performance in terms of network lifetime, energy dissipation and amount of data reaching at base station.**

Index Terms: LEACH, Hierarchical Routing Algorithms, clustering, wireless sensor networks.

I. INTRODUCTION

Wireless Sensor networks consist of hundreds/thousands of low power multifunctioning sensor nodes, operating in an unattended environment, with limited computation and sensing capabilities. Sensor nodes are equipped with small, often irreplaceable batteries with limited power capacities. They can be deployed manually or be randomly dropped. They are self configuring, containing one or more sensors, with embedded wireless communications and data processing components and a limited energy source. The use of wireless sensor networks is increasing day by day but the problem of energy constraints prevails as there is limited battery life. In order to save energy dissipation caused by communication in wireless sensor networks, it is necessary to schedule the state of the nodes, changing the transmission range between the sensing nodes, use of efficient routing and data routing methods and avoiding the handling of unwanted data [1]. In general, routing in WSNs can be divided into flat, hierarchical, and location based routing depending on the network structure. Flat Routing is the first category of routing protocols where each node typically plays the same role and sensor nodes collaborate to perform the sensing task. The base station(BS) sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. Hierarchical Routing is the well-known technique with special advantages related to scalability and efficient communication. In hierarchical architecture, higher-energy nodes can be used to process and send the information, while low-energy nodes can be used to perform the sensing in the proximity of the target. While in Location-Based Routing Protocols, sensor nodes are addressed by means of their locations. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors.[2]. The Low-Energy Adaptive Clustering Hierarchy (LEACH)is a cluster based routing protocol [3].
This paper is organized as follows: In the next section LEACH protocol is reviewed. In section III simulation of LEACH protocol is discussed. Section IV shows the simulation results by varying the percentage of cluster heads in LEACH protocol and analysis of results about performance of the network in terms of lifetime, energy dissipation and throughput of the network. Last section concludes the paper with few remarks and discussion of certain issues of LEACH protocol.

II. REVIEW OF LEACH PROTOCOL

Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol for sensor networks is proposed by W. R. Heinzelman et.al [3] which minimizes energy dissipation in sensor networks, It is based on a simple clustering mechanism by which energy can be conserved since cluster heads are selected for data transmission instead of other nodes. The operation of LEACH is broken up into rounds, where each round begins with a set-up phase, where the clusters are organized, followed by a steady-state phase, where data transfers to the base station occur. In order to minimize overhead, the steady-state phase is long compared to the set-up phase. **Set-up phase:** During this phase, each node decides whether or not to become a cluster head (CH) for the current round. This decision is based on selection of a random number between 0 and 1. If number is less then a threshold *T(n)*, the node become a cluster head for the current round. The threshold value is set as:

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

where, P = desired percentage of cluster head, r = current round and G is the set of nodes which did not become cluster head in last $\frac{1}{P}$ rounds. Once the cluster head is chosen, it will use the CSMA MAC protocol to advertise its status. Remaining nodes will take the decision about their cluster head for current round based on the received signal strength of the advertisement message. Before steady-state phase starts, certain parameters are considered, such as the network topology and the relative costs of computation versus the communication. A Time Division Multiple Access(TDMA) schedule is applied to all the members of the cluster group to send messages to the CH, and then from the cluster head towards the base station. As soon as a cluster head is selected for a region, steady-state phase starts. Figure 1 shows the flowchart of the this phase.

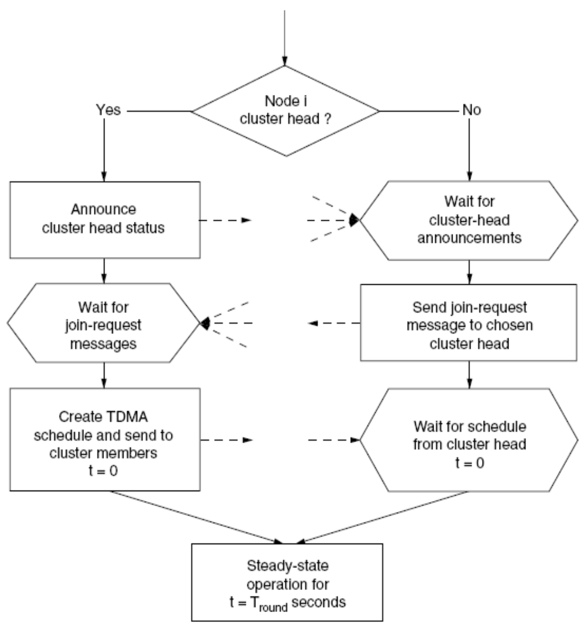

Fig. 1: Flow chart of the Set-up phase of the LEACH protocol

Steady-state phase: Once the clusters are created and the TDMA schedule is fixed, data transmission can begin. Assuming nodes always have data to send, they send it during their allocated transmission time to the cluster head. This transmission uses a minimal amount of energy (chosen based on the received strength of the cluster-head advertisement). The radio of each non-cluster-head node can be turned off until the nodes allocated transmission time, thus minimizing energy dissipation in these nodes. The cluster-head node must keep its receiver on to receive all the data from the nodes in the cluster. When all the data has been received, the cluster head node performs signal processing functions to generate the composite single signal. For example, if the data are audio or seismic signals, the cluster-head node can beamform the individual signals to generate a composite signal. This composite signal is sent to the base station. Since the base station is far away, this is a high-energy transmission. Figure 2 shows the data gathering strategy used by the LEACH protocol. Code Division Multiple Access(CDMA) is utilized between clusters to eliminate the interference from neighboring clusters.

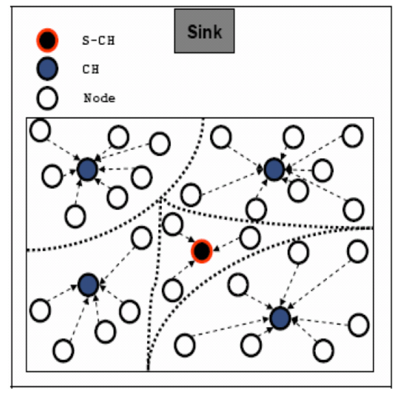

Fig. 2: Data gathering in LEACH protocol.

III. SIMULATION OF LEACH PROTOCOL

To simulate the LEACH protocol, MIT's NS2 extension for LEACH simulator [4][5] is used. The models were used for channel propagation and energy dissipation are as described below:

1) Channel Propagation Model: In the wireless channel, the electromagnetic wave propagation can be modeled as falling off as a power law function of the distance between the transmitter and receiver. Both free space model which considers direct line-of-sight and two-ray ground propagation model which considers ground reflected signal also, were considered depending upon the distance between transmitter and receiver. If the distance is greater than $d_{crossover}$, two-ray ground propagation model is used. The crossover is defined as follows:

$$d_{crossover} = \frac{4 * \pi * \sqrt{L} * h_r * h_t}{\lambda}$$

Where, $L \geq 1$ is system loss factor. h_r is the height of the receiving antenna, h_t is the height of the transmitting antenna and λ is the wavelength of the carrier signal. Now transmit power is attenuated based on following formula:

$$P_r(d) = \begin{cases} \frac{P_t*G_t*G_r*\lambda^2}{(4*\pi*d)^2*L} & \text{if } d < d_{crossover} \\ \frac{P_t*G_t*G_r*h_t^2*h_r^2}{d^4} & \text{if } d \geq d_{crossover} \end{cases}$$

Where, P_r is the received power at distance d, P_t is transmitted power , G_t is the gain of the transmitting antenna and G_r is the gain of the receiving antenna.

2) Radio Energy Model: The radio energy model describing the radio characteristics, includes energy dissipation in the transmit and receive modes. Transmitter dissipates energy to run the radio electronics and power amplifier whereas receiver dissipates energy to run the radio electronics [3]. Figure 3 shows the energy dissipation model. Using this radio model,

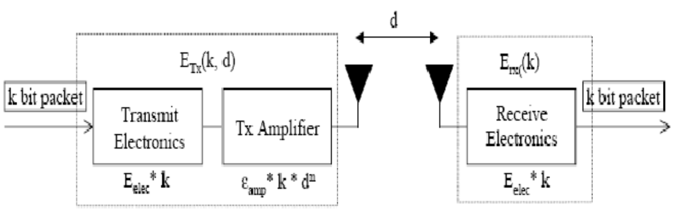

Fig. 3: Radio energy dissipation model.

to transmit k-bit message at distance d the radio expends:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2$$

and to receive this message, the radio expends:

$$E_{Rx}(k) = E_{Rx-elec}(k)$$
$$E_{Rx}(k) = E_{elec} * k.$$

For the simulation experiment, following parameters were used: $G_t = G_r = 1$, $h_t = h_r = 1.5$m, no system loss (L=1), 914MHz radios and $\lambda = \frac{3*10^8}{914*10^6} = 0.328$m. A random test network was used having 100 nodes with base station located at (50, 175) as shown in figure 4.

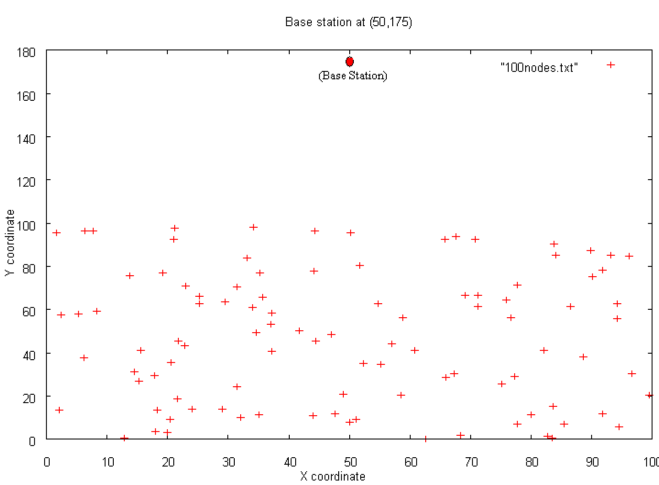

Fig. 4: Sensor network topology.

IV. ANALYSIS OF SIMULATION RESULTS

We simulated LEACH, the cluster based routing protocol using MIT's NS2 extension for LEACH by varying the cluster numbers and evaluated the performance of the network in terms lifetime of the sensor network, throughput achieved and total energy dissipation by the network. For the experiment, percentage of number of cluster heads were changed as 3,4,5,6 and 8 for different readings. Table 1 shows the results while figure 5, 6 and 7 shows the simulation graphs for various cluster head numbers verses lifetime, throughput and average energy dissipation respectively.

TABLE I: Simulation results

No of Clusters	Lifetime (s)	Throughput	Energy (J)
3	285.09	32279	425.00
4	464.10	35897	338.00
5	542.30	52127	292.03
6	464.00	42041	348.64
8	181.39	8301	294.49

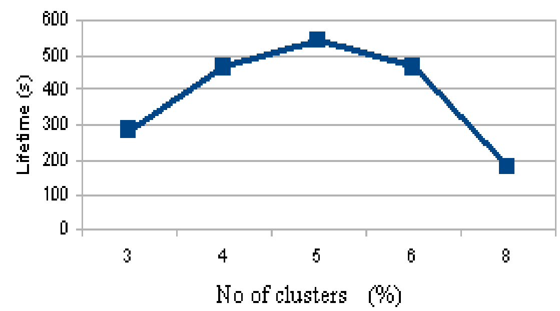

Fig. 5: No of clusters Vs Lifetime of the network.

Fig. 6: No of clusters Vs Throughput of the network.

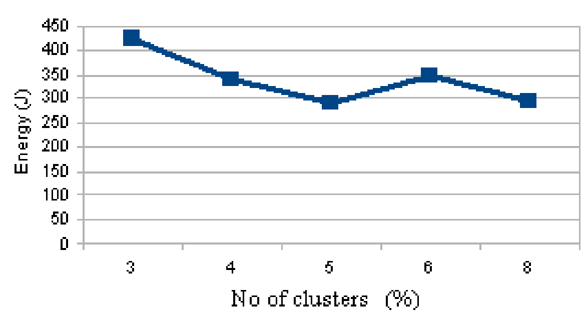

Fig. 7: No of clusters Vs energy dissipation of the network.

Despite the significant overall energy savings, however, the various assumptions made by LEACH[3] protocol raise a number of issues: 1) LEACH assumes that all nodes begin with the same amount of energy and that the amount of energy a CH consumes is more than that of a noncluster node. It also assumes that the amount of energy consumed by clusterheads in every cluster round is constant. This assumption is however not realistic. 2) LEACH assumes that all nodes can communicate with each other and are able to reach the sink. Therefore, it is only suitable for small size networks. 3) LEACH requires that all nodes are continuously listening. This is not realistic in a random distribution of the sensor nodes, for example, where cluster-heads would be located at the edge of the network. 4) LEACH assumes that all nodes have data to send and so assign a time slot for a node even though some nodes might not have data to transmit. 5) LEACH assumes that all nearby nodes have correlated data which is not always true. 6) Finally, there is no mechanism to ensure that the elected cluster-heads will be uniformly distributed over the network. Hence, there is the possibility that all cluster-heads will be concentrated in one part of the network.

LEACH doesn't consider data rate generation from a region while selecting cluster-heads. Hence non CH nodes that belong to the regions that have a higher data rate generation, which are expected to transmit frequently, dissipate more energy in transmitting data to a remote CH located far. This leads to uneven energy dissipation over the network thereby reducing the network lifetime. Secondly, LEACH assumes that every time a node becomes a CH, it dissipates an equal amount of energy. This is incorrect, as cluster-heads located far from the base station spend more energy in transmitting data those located near to the base station. To ensure an even energy load distribution over the whole network, additional parameters including the residual energy level of candidates relative to the network and their data rate generation value should be considered to optimize the process of CH selection.

Another improvement over LEACH is to prevent energy depletion by selecting one or more nodes are chosen as CH backup node(s) which substitute the CH in some failure/energy depletion of current CH to avoid a complete cluster set-up phase. The "number-of-hops" metric can be introduced, which indicates how far the CH is from the sensing node. This allows nodes to: 1) Select the nearest CH node, which saves energy and reduces messaging needed to bridge the distance between the CH and the sensor node. 2) Allows a node to learn the shortest path to the selected CH. Some other proposals are: 1) The sensor nodes can send the information regarding their energy level and location to the base station (BS) so that BS can later on decide which nodes will be elected as cluster heads. This is better as only the nodes with the required energy level and location are needed to be considered for cluster head formation. 2) The clusters need not be formed every time and the clusters with ample energy be retained. This eliminates another overhead.

V. Conclusions and Future Work

The LEACH routing protocol is energy efficient cluster based routing protocol for the sensor network. By selecting the various number of clusters size , performance of the network in terms of lifetime, throughput and average energy dissipation is changed. From above simulation results, we concluded that the network perform better when cluster size is 5 percent of the sensor nodes. There are certain optimizations possible in the protocol as discussed earlier which may be integrated in the basic LEACH algorithm.

References

[1] Mohammad Ilyas and Imad Mahgoub, "Handbook of sensor networks : compact wireless and wired sensing systems", *Chapter 1 & 6 CRC Press, 2005.*

[2] Jamal N. Al-Karaki,Ahmed E. Kamal, "Routing Techniques In Wireless Sensor Networks: A Survey", *IEEE Wireless Communications,December 2004*

[3] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy Efficient Communication Protocol for Wireless Micro Sensor Networks," *Proceedings of IEEE HICSS, Jan 2000.*

[4] Massachusetts Institute of Technology, Cambridge "The MIT uAMPS ns Code Extensions, Version 1.0" *August, 2000*

[5] A Website http://www.isi.edu/nsnam/dist/ns-allinone-2.27.tar.gz