Performance Analysis of Low Energy Adaptive Clustering Hierarchy (LEACH) Protocol

Vikshant Khanna, Parul Mohindru

Abstract*— Based on the research of LEACH protocol, a low energy-consumption routing protocol LEACH-E is proposed in this paper. The new protocol is characterized by each node will send information about its current location and energy level to the cluster head. The simulated algorithm will determine the clusters for that round. Finally, the experimental results show that LEACH-E performs better than LEACH protocol. It not only extends the lifetime of the network, but also improves the energy efficiency. Therefore LEACH-E protocol is an attempt to overcome the most common issue present in wireless sensor network energy efficiency. It is a popular energy efficient adaptive clustering algorithm that forms node clusters based on the received signal strength and uses these local cluster heads as routers to the base station.

Index Terms*— Cluster, Energy efficiency, LEACH protocol, Network lifetime, Wireless sensor networks.

I. INTRODUCTION

A wireless sensor network consists of a group of sensor nodes that enables the monitoring of a variety of environments for applications that include home security, machine failure diagnosis and environmental monitoring. Gathering sensed information in an energy efficient manner is critical task to operate on sensor network for a long period of time. In wireless sensor networks, data fusion helps to reduce the amount of data transmitted between sensor nodes and the cluster heads. LEACH works in several rounds where each round has two phases, the setup phase and the steady phase. During the setup phase, each node decides whether to become a cluster head or not. Each node chooses a random number p between 0 and 1, which is the probability to elect itself as a cluster head. During the steady phase, the sensor nodes can begin sensing and transmitting data to the cluster heads which aggregate data from the sensor nodes in their cluster and send data to the base station. Hence, LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol is an elegant solution to this data collection problem where a small number of clusters are formed in a self-organized manner. LEACH divides a network into several clusters of sensors as shown in Fig 1, which are constructed by using localized coordination and control not only to reduce the amount of data that are transmitted to the sink but also to make routing and data dissemination more scalable and robust.

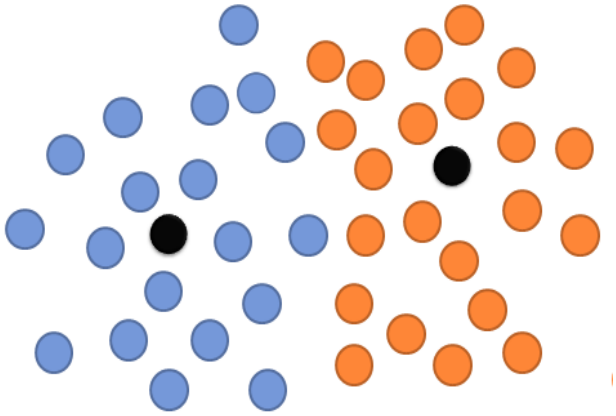

Fig 1: Clustering of sensor nodes

The energy dissipation of the sensors depends on the distance and the data size to be transmitted, LEACH attempts to transmit data over short distances and reduce the number of transmission and reception operations. In LEACH, the cluster heads are not selected in a static manner; otherwise, they will drain their energy and die quickly. LEACH uses a randomized rotation of the high - energy cluster - head position in order to give a chance to all sensors to act as cluster heads and avoid the battery depletion of an individual sensor. Cluster heads use CSMA MAC protocol to advertise their status. Thus, all non cluster-head sensors must keep their receivers on during the setup phase in order to hear the advertisements sent by the cluster heads. These cluster heads are selected with some probability by themselves and broadcast their statuses to the other sensors in the network. The decision for a sensor to become a cluster head is made independently without any negotiation with the other sensors. Specifically, a sensor decides to become a cluster head based on the desired percentage P of cluster heads (determined a priori), the current round, and the set of sensors that have not become cluster heads in the past 1/ P rounds. If the number of cluster heads is <T (n), a sensor n becomes a cluster head for the current round, where T (n) is a threshold. The sensors that are cluster heads in round 0 cannot be a cluster for the next 1/P - 1 round. At round 0, each sensor has probability P to become a cluster head. Among all advertised cluster heads, a sensor selects the closest one that will incur minimum energy communication and then informs its cluster head about its decision to join the cluster using CSMA MAC protocol. Cluster heads should keep their receivers on to hear these join messages. Once the network is divided into clusters, a cluster head computes a TDMA schedule for its sensors specifying when a sensor in the cluster is allowed to send its data. Thus, a sensor will turn its radio on only when it is authorized to transmit according to the schedule established by its cluster head, thus yielding significant energy savings.

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Vikshant Khanna, Department of CSE & IT, Lovely Professional University, India.

Parul Mohindru, Department of CSE, Punjab Technical University, India.

LEACH enables data fusion in each cluster by aggregating the data in order to reduce the total amount of data before sending them to the sink. In another words, once a cluster head gathers all the data from its sensors, it aggregates them and transmits the aggregated data to the sink [1]. LEACH–E is the enhanced version of LEACH protocol here every sensor node sends its energy level and current location to cluster head. It not only extends the lifetime of the network, but also improves the energy efficiency.

II. LITERATURE REVIEW

In [2] authors proposed LEACH protocol as a solution to static clustering as LEACH may not be optimal for sensor networks which is a clustering-based protocol. It uses randomized rotation of local cluster base stations (cluster-heads) to evenly distribute the energy load among the sensors in the network. LEACH uses localized coordination to enable scalability and robustness for dynamic networks, and incorporates data fusion into the routing protocol to reduce the amount of information that must be transmitted to the base station. LEACH is completely distributed, requiring no control information from the base station, and the nodes do not require knowledge of the global network in order for LEACH to operate. LEACH reduces communication energy.

In [3] authors presented a new version of LEACH protocol called VLEACH which aims to reduce energy consumption within the wireless network that performs better than LEACH protocol. In V-LEACH cluster contains Cluster Head (CH) (responsible only for sending data that is received from the cluster members to the BS), vice-CH (the node that will become a CH of the cluster in case of CH dies), cluster nodes (gathering data from environment and send it to the CH). In the original leach, the CH is always on receiving data from cluster members, aggregate these data and then send it to the BS that might be located far away from it. The CH will die earlier than the other nodes in the cluster because of its operation of receiving, sending and overhearing. When the CH die, the cluster will become useless because the data gathered by cluster nodes will never reach the base station. In proposed V-LEACH protocol, besides having a CH in the cluster, there is a vice-CH that takes the role of the CH when the CH dies.

In [4], clustering techniques are used to distribute the energy consumption among nodes in each cluster and extend the network lifetime. LEACH (Low-Energy Adaptive Clustering Hierarchy), a clustering-based protocol that utilizes randomized rotation of Cluster-Heads (CHs) to evenly distribute the energy among the sensors in the network. But LEACH cannot select CHs uniformly throughout the network. Therefore there is the possibility that the elected CHs will be concentrated in certain area of the network. Hence, some nodes will not have any CHs in their vicinity. They proposed U-LEACH to address this problem. It describes a Uniform Distribution Technique (UDT) for selecting CHs and their corresponding clusters. This approach build such a wireless sensor network in which each sensor node remains inside the transmission range of CHs and therefore, the lifetime of the network is prolonged.

In [5] authors focused on how to set the time length of each round, to prolong the lifetime of the network and increase throughput, which is denoted as the amount of data packs sent to the sink node. The functions of lifetime and throughput related to the time length of each round are deduced. These functions can be used to enhance the performance of cluster-based wireless sensor networks in terms of lifetime and throughput. The advantage of LEACH is that each node has the equal probability to be a cluster head, which makes the energy dissipation of each node be relatively balanced. In LEACH protocol, time is divided into many rounds. In each round, all the nodes contend to be cluster head according to a predefined criterion. The analysis of performance of LEACH-based wireless sensor networks is done in terms of lifetime and throughput. The reasonable number of frames in a LEACH round is deduced to prolong the lifetime and increase the throughput.

In [6] authors ensured that if the system operates at a minimum energy for each quality point, the system can achieve both flexibility and energy efficiency, allowing the end-user to maximize system lifetime. Simulation results show that the proposed adaptive clustering protocol effectively produces optimal energy consumption for the wireless sensor networks, and resulting in an extension of life time for the network. The preparation phase is performed only once before the set-up phase of the first round. The processes of following set-up and steady-state phases in every round are the same as LEACH. The results showed that LEACH outperformed all the conventional protocols in terms of energy efficiency. Therefore LEACH is able to distribute energy dissipation evenly throughout the sensors, doubling the useful system lifetime.

III. MATLAB SIMULATION OF LEACH-E

The operation of LEACH is broken up into rounds, where each round begins with a set-up phase, when the clusters are organized, followed by a steady-state phase, when data transfers to the base station occur. In order to minimize overhead, the steady-state phase is long compared to the set-up phase as shown in Fig 2.

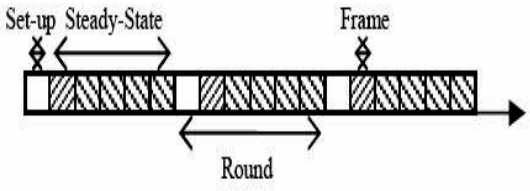

Fig 2: Phases of LEACH Protocol

A. Advertisement Phase

Initially, when clusters are being created, each node decides whether or not to become a cluster-head for the current round. This decision is based on the suggested percentage of cluster heads for the network (determined a priori) and the number of times the node has been a cluster-head so far. This decision is made by the node choosing a random number between 0 and 1. If the number is less than a threshold, the node becomes a cluster-head for the current round. Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. For this "cluster-head-advertisement" phase, the cluster-heads use a CSMA MAC protocol, and all cluster-heads transmit their advertisement using the same transmit energy.

The non-cluster-head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement. Assuming symmetric propagation channels, the cluster-head advertisement heard with the largest signal strength is the cluster-head to whom the minimum amount of transmitted. The MATLAB simulation is as shown in Fig 3.

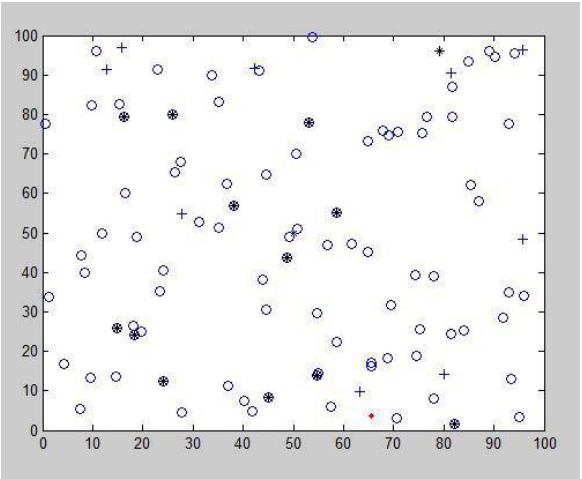

Fig 3: Advertisement Phase

B. Cluster Set Up Phase

After each node has decided to which cluster it belongs, it must inform the cluster-head node that it will be a member of the cluster. Each node transmits this information back to the cluster-head again using a CSMA MAC protocol. During this phase, all cluster-head nodes must keep their receivers on.

C. Schedule Creation

The cluster-head node receives all the messages for nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster.

D. Data Transmission

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 node's 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 compress the data into a 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. This is the steady-state operation of LEACH networks. After a certain time, which is determined a priori, the next round begins with each node determining if it should be a cluster-head for this round and advertising this information.

E. Multiple Clusters

The preceding discussion describes how the individual clusters communicate among nodes in that cluster. However, radio is inherently a broadcast medium. As such, transmission in one cluster will affect (and hence degrade) communication in a nearby cluster.

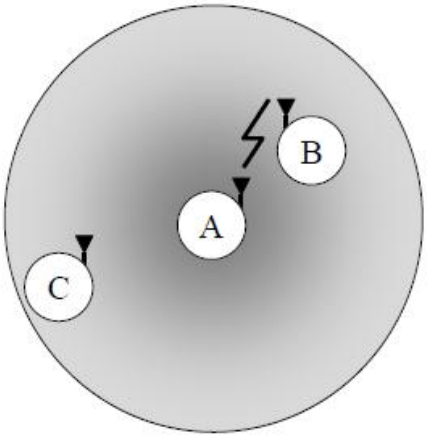

Fig 4:Radio Interference

For example, Fig. 4 shows the range of communication for a radio. Node A's transmission, while intended for Node B, corrupts any transmission to Node C. To reduce this type of interference, each cluster communicates using different CDMA codes. Thus, when a node decides to become a cluster-head, it chooses randomly from a list of spreading codes. It informs all the nodes in the cluster to transmit using this spreading code. The cluster-head then filters all received energy using the given spreading code. Thus neighbouring clusters' radio signals will be filtered out and not corrupt the transmission of nodes in the cluster. Efficient channel assignment is a difficult problem, even when there is a central control centre that can perform the necessary algorithms. Using CDMA codes, while not necessarily the most bandwidth efficient solution does solves the problem of multiple-access in a distributed manner.

F. Hierarchical Clustering

The LEACH described in this paper can be extended to form hierarchical clusters. In this scenario, the cluster-head nodes would communicate with "super-clusterhead" nodes and so on until the top layer of the hierarchy, at which point the data would be sent to the base station. For larger networks, this hierarchy could save a tremendous amount of energy. In future studies, we will explore the details of implementing this protocol without using any support from the base station, and determine, via simulation, exactly how much energy can be saved.

IV. RESULTS

Simulation results shows that after no. of rounds the power of sensor nodes will reduce and starts changing its state from alive to dead state as shown in Fig. 5.

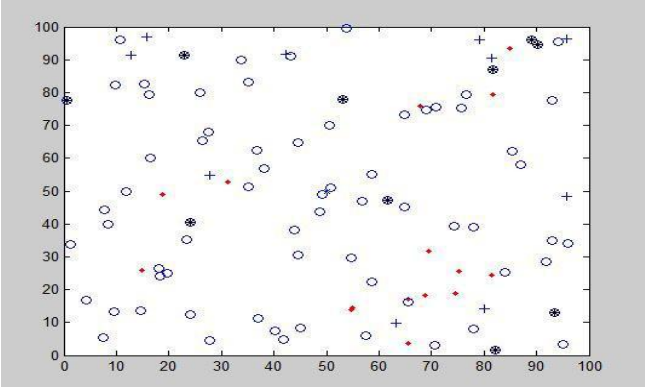

Fig 5: Alive and dead nodes

As the number of rounds increases, number of alive nodes decreases due to power consumption that are shown in Fig. 6.

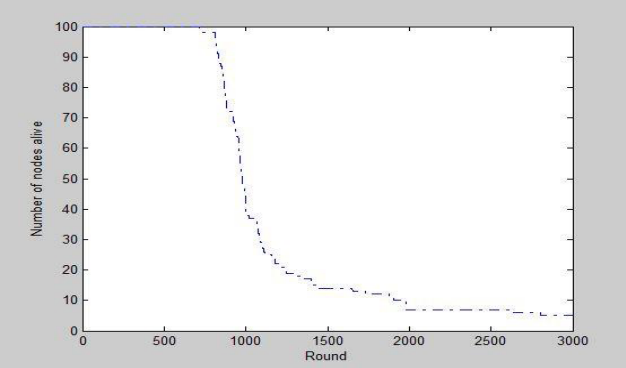

Fig 6: No. of nodes alive/round vs. no. of rounds

Fig. 7 shows the relationship among number of rounds and cluster head/round. Energy efficiency of LEACH-E protocol is also shown in the graph.

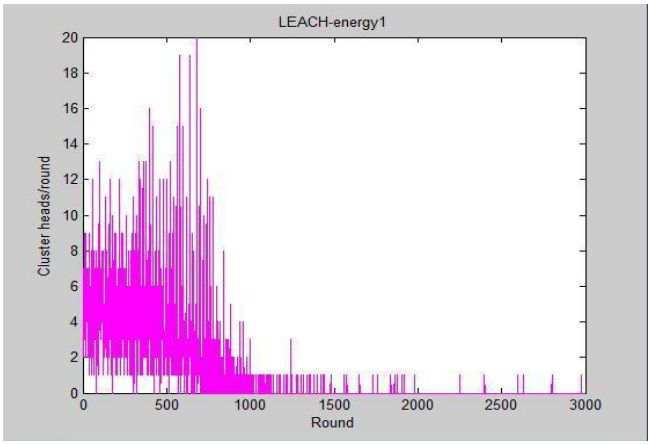

Fig 7: Energy efficiency graph with respect to cluster heads/round vs. no. of rounds

Following observations are made on basis of this graph:

1. When number of rounds are between 0 to 500, the number of cluster head/round varies between 6 to 16.
2. When number of rounds are between 500 to 1000, the number of cluster head/round varies between 12 to 20.
3. When number of rounds are between 1000 to 3000, the number of cluster head/round varies between 0 to 1.

Hence we concluded that with increase in number of rounds, cluster head/ round first increases. After few rounds it starts decreasing as the number of dead nodes increases.

V. CONCLUSION

The LEACH is a well-known routing protocol for cluster based wireless sensor networks. This paper analyses the performance of LEACH-based wireless sensor networks in terms of lifetime and energy efficiency. The selection of cluster head is done in more efficient manner. The new protocol is characterized by each node will send information about its current location and energy level to the cluster head. The simulated algorithm will determine the clusters for that round. Finally, the experimental results show that LEACH-E performs better than LEACH protocol. It not only extends the lifetime of the network, but also improves the energy efficiency. Therefore LEACH-E protocol is an attempt to overcome the most common issue present in wireless sensor network energy efficiency.

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