Advanced LEACH Protocol in Large scale Wireless Sensor Networks

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ABSTRACT

As the use of wireless sensor networks (WSNs) has grown enormously in the past few decades, the need of scalable & energy efficient routing and data aggregation protocol for large scale deployments has also risen. LEACH is a hierarchical clustering protocol that provides an elegant solution for such protocols. One deficiency that affects the performance of the protocol is existence of very large and very small clusters in the network at the same time. This leads to the decrease in lifetime of WSNs. In this paper, the proposed and analyzed a new energy efficient clustering protocol (Improved FZ-LEACH) that eliminates the above problem by forming Far-Zone. Far-Zone is a group of sensor nodes which are placed at locations where their energies are less than a threshold. The communication between nodes and Sink is based on the energy consumption and the minimum distance. The communicating nodes only will be in active and the remaining nodes will be in sleep mode, to this sleep scheduling algorithm has been used. The simulation results and analysis show that proposed Improved FZ-LEACH algorithm outperforms LEACH in terms of energy consumption and network lifetime.

Keywords – **Cluster formation, Far zone formation, LEACH protocol, Routing protocol,WSN.**

I. INTRODUCTION

A wireless sensor network (WSN) consists of a number of sensor nodes which can communicate wirelessly. A wireless sensor node usually comprises of a microcontroller, a low power radio transceiver, sensors, and a battery power. The purpose of these nodes are to monitor

a given set of environmental conditions, such as temperature, sound, light, or the movement of chemicals or objects or vibrations. WSNs are often installed in very harsh environmental conditions where the human monitoring is very risky,

such as in high alpine environments [1] or on volcanoes [2], forcing them to run unattended for most of the time. These nodes continuously sense the environment, communicate events to each other and route their information to a remote base station. The most important challenge in achieving this goal is the power constraint on these small, low cost sensor nodes. Since energy is the major constrain in WSNs, therefore, to solve the energy constraints problem of WSNs, various energy efficient routing protocols have already been proposed such as LEACH [3], PAMAS [4] and HEED [12].

The main objective of the routing protocols in wireless sensor networks is to find approach for improvement of energy efficiency and reliable transmission of sensed data to the base station. In recent years much research work on power-aware routing has been done [5]. In these protocols the sensor nodes are grouped into clusters. Each cluster has a cluster leader known as cluster head (CH). The CH may be a more powerful node. These CHs collect the information from various sensor nodes and after Aggregation/fusion forward it to the base station thus decrease the number of transmitting packets [6]. Low-Energy Adaptive Clustering Hierarchy (LEACH) is one of the most popular cluster-based routing protocols in wireless sensor networks. The cluster formation process in LEACH is based on the received signal strength. LEACH clustering algorithm is simple but does not guarantee about even distribution of cluster heads over the network. In this protocol it is assumed that each cluster head transmits data to sink over a single hop. LEACH protocol has some deficiencies such as,

1) Some very big clusters and very small clusters may exist in the network at the same time.
2) Unreasonable cluster head selection while the nodes have different energy.
3) Cluster member nodes deplete energy after cluster head was dead.

In this paper the proposed solution of the problem of existence of the large clusters in the sensor networks. For this purpose an improvement in pre-existing LEACH protocol, known as Far-Zone LEACH (FZ-LEACH). A zone is formed within the cluster based on minimum reachability power (MRP), known as Far-Zone. The idea of MRP is borrowed from HEED [12]. MRP can be considered as communication cost from a node to base station (BS). If MRP from a node to BS is greater than the average minimum reachability power (AMRP), then this node will be considered in Far-Zone. Formation of the Far-Zone can be done only after the process of cluster formation is over. Once Far-Zone is formed, nodes within the Far-Zone select a zone head (ZH) of highest energy. ZH role will be rotated in every round. All nodes within the Far-Zone can directly communicate to the ZH rather than CH. ZH collects and aggregates data from all zone members and forwards to the CH. CH then collects sense data from rest of the nodes (nodes within the cluster but not in Far-Zone) and ZH, aggregates it and transmits to the BS. For large real life deployments of WSNs, it may be the situation that there exist large size clusters. This improvement is well suited for such type of scenarios. One point is also worth mentioning that Far-Zone is formed only when nodes have MRP less than AMRP. Rest of the paper is organized as follows. Section II describes the related work. Assumptions and energy model are described in Section III. Proposed FZ-LEACH protocol is described in Section IV. Section V presents the simulation environment and analysis of the proposed work.

2. RELATED WORK

The main objective of cluster-based routing protocol is to enhance the WSN life by efficiently maintaining the energy consumption of sensor nodes. These objectives may be achieved by multi-hop communication within a cluster and by performing data aggregation and fusion to decrease the number of transmitted messages to sink and communication distance of sensor nodes. Low-Energy Adaptive Clustering Hierarchy (LEACH) [3] is the most popular cluster-based routing protocols in wireless sensor networks. In LEACH the cluster heads are randomly selected and when the cluster head die then another node will be selected as cluster head. Therefore, the cluster head role keeps on rotating to balance the energy dissipation of the sensor nodes in the networks. The function of cluster head nodes are to fuse and collect data arriving from cluster members and forward the aggregated data to the sink in order to reduce the amount of data and transmission of the duplicated data. The data collection is performed periodically. In LEACH protocol, initially the node becomes a cluster head with a probability *p* and broadcasts its decision. The nodes choose their cluster head based on the least communication energy to reach the cluster head. The role of the CH keeps on rotating among the nodes of the cluster to enhance the network life time. A node becomes a cluster head for the current rotation round if the number is less than the following threshold:

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

Where *p* is desired percentage of cluster head nodes, *r* is the current round number and *G* is the set of nodes that have not been cluster head in the last 1/*p* rounds.

The decision to change the cluster head is probabilistic; it is possible that the node with low energy may be selected as cluster head. When this low energy node dies the whole cluster becomes dysfunctional. It is assumed that the cluster head has a long communication range so that the data can reach the base station directly. But this assumption is not always true because the network is deployed in large region and therefore all the cluster heads may not communicate directly.

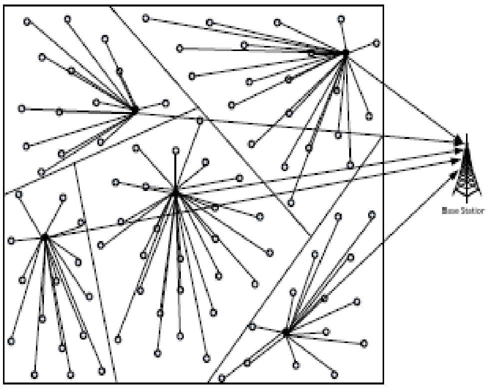


Fig .1.Cluster formation in LEACH.

Keeping in view the aforementioned problem of LEACH, various modifications have been made to the LEACH protocol. Some of these are E-LEACH [7], TL-LEACH [8], M-LEACH [9], LEACH-C [10] and V-LEACH [11].

In Energy LEACH (E-LEACH) protocol the cluster head selection is based on the residual energy level of the nodes. The residual energy level decides that whether the node will become a cluster head or not after the first round [7]. In this protocol all nodes have equal probability to become the cluster head in the first round. The residual energy level in the second round is different for each node because of the first round communication. In this protocol the nodes that have a more energy level will become the cluster head rather than the nodes with low energy level. Therefore, this protocol improves the cluster head selection procedure.

The function of the cluster heads in LEACH protocol is the collection and fusions of data received from member sensor nodes and forward the information directly to the base station. But the problem in LEACH protocol may occur if the cluster head is far away from the base station. The cluster head which is far away from base station require more energy to transfer the information to the base station and therefore it will die soon. Therefore to solve this problem Two-level LEACH (TLLEACH) protocol [8] was designed. In this protocol, the cluster head is responsible for collection and fusion of data like LEACH protocol from respective cluster members, but the cluster heads will not directly forward the data to the base station. It uses one of the cluster head that lies between cluster head and base station as a relay station.

In LEACH protocol all the cluster heads transmit the data collected from the sensor nodes directly to the base station. But if the cluster head is far away from base station then it require large amount of energy to transmit the data to base station. Multihop-LEACH (M-LEACH) protocol [9] solves this problem by changing the transmission mode between cluster heads and base station from single hop to multihop. This protocol chooses the best possible path between the cluster head and base station by using the other cluster heads as relay stations to send data to base station. In LEACH protocol the cluster heads are not uniformly distributed. They may be located at any place in the cluster. LEACH-C [10] is an improvement over the LEACH protocol. This protocol uses the centralized clustering algorithm, and the steady-state phase that is used by LEACH. In LEACH-C each node sends their current location information and residual energy level to the sink. The sink will calculate the average node energy and find out that which nodes energy level is below the average.

In LEACH protocol the cluster head is responsible for receiving data from cluster members, fusion of received data and then send it to the base station. If base station may be far away from cluster head then cluster head will die soon as compare to other nodes because the energy will dissipate in receiving and forwarding of the data. If the cluster head dies then the data collected by the cluster head will never reach to the base station and therefore the cluster will become useless. V-LEACH [11] protocol solves this problem by introducing the vice-cluster head. In V-LEACH protocol a cluster contains a cluster head, vice-cluster head and cluster nodes. In this protocol if the cluster head dies then vice-cluster head will start working as cluster head and the cluster head data will reach to the base station. There is no need to elect the new cluster head, so it will save the energy and enhance the network life time.

3. SYSTEM MODEL

3.1 Assumptions

This paper considers a WSN deployed for real life applications. The following assumptions are made about the sensor nodes and the network model:

1. The base station (i.e. sink node) is located inside the sensing field.
2. Nodes are location-unaware, i.e. not equipped with GPS capable antennae.
3. Communication within the square area is not subjected to multipath fading.
4. The communication channel is symmetric.
5. Data gathered can be aggregated into single packet by cluster heads (CH).
6. Nodes are left unattended after deployment. Therefore, battery re-charge is not possible.

3.2. Energy Model

The same energy dissipation model as in [3] is used here. To achieve an acceptable signal-to-noise ratio (SNR) in transmitting *k* bit message over a distance *d*, the energy cost of transmission (E_{Tx}) and reception (E_{Rx}) are given by:

$$E_{Tx}(k,d) = \begin{cases} k * E_{elect} + k * \varepsilon_{fs} * d^2 & if\, d \le d0 \\ k * E_{elect} + k * \varepsilon_{mp} * d^4 & if\, d \ge d0 \end{cases}$$

Where *E elect* = 50 *nJ*, is the energy being used to run transmitter and receiver circuit. For *d0* = *d* we can calculate the distance threshold, *fs mp d* = ε ε 0. To receive a *k* bit message, the radio expends $E_{Rx} = k * E_{elect} \cdot E_F$ is the energy of fusion per bit.

4. FZ-LEACH PROTOCOL

In this section I present an improvement in pre-existing, well known clustering protocol LEACH, proposed by Heilzemen *et al.* [3]. One major drawback of this protocol is that size of the cluster is not limited; clusters in LEACH may be very small or very large in size. In large clusters sensor nodes deplete energy faster because of the transmission distance. Here the solution to this problem by introducing the concept of Far-Zone. The working of algorithm can be divided into two phases.

4.1 Cluster-head Selection and Cluster Formation Algorithm

In the proposed algorithm, cluster head selection and cluster formation is done in same manner as LEACH. The operation of FZ-LEACH is generally divided into two phases, the set-up phase and the steady-state phase. In the set-up phase, cluster heads are selected and clusters are organized. In the steady-state phase, the actual data transmissions to the sink take place.

In the proposed FZ-LEACH algorithm, few nodes are randomly selected as CHs. This role is rotated to all nodes to balance the energy dissipation of the sensor nodes in the networks. Cluster formation for the algorithm is shown in the figure 2.

During the set-up phase, 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 a predetermined fraction of nodes and the threshold T(s) given by following equation.

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & if\, n \in G \\ 0 & otherwise \end{cases}$$

Where *Popt* is the predetermined percentage of cluster heads (e.g., *Popt* = 0.05), r is the current round, and G is the set of nodes that have not been cluster heads in the last 1/ *Popt* rounds.

Using this threshold, each node will be a cluster head at some round within 1/ *Popt* rounds. After 1/ *Popt* rounds, all nodes are once again eligible to become cluster heads. In FZLEACH, the optimal number of cluster heads is estimated to be about 5% of the total number of nodes.

Each node that has elected itself cluster head for the current round broadcasts an advertisement message to the rest of the nodes in the network. All the non-cluster head nodes, after receiving this advertisement message, decide on the cluster to which they will belong for this round.

This decision is based on the received signal strength of the advertisement messages. In this way after cluster head receives all the messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the cluster head creates a TDMA schedule and assigns each node a time slot when it can transmit.

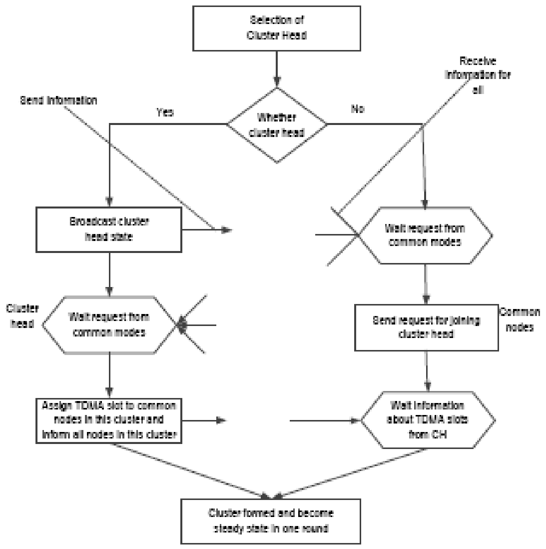


Fig - 2. Flow chart of cluster head selection and cluster formation in FZ-LEACH.

4.2. Far-Zone Formation Algorithm

Most of the percentage of nodes energy is consumed in long distance transmissions. One of the solutions to efficiently utilize the energy in LEACH protocol is formation of Far-Zone in large clusters formed by LEACH protocol.

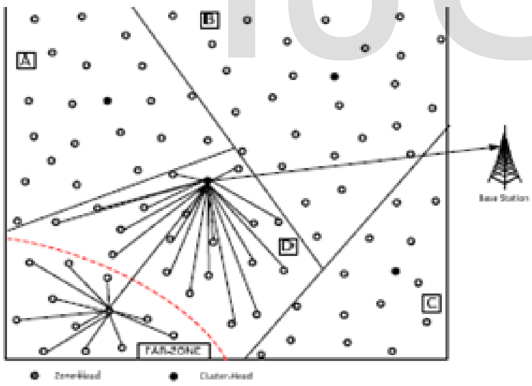


Fig 3. Communication within and from Far-Zone.

Once the cluster head formation is complete, proposed algorithm searches for eligible clusters to form Far-Zone. For formation of Far-Zone each node of the cluster sends its power level to CH. The idea of power levels is borrowed from HEED [12]. Based on the power levels, CH selects the members for Far-Zone as shown in Figure 3.

There are four clusters (A, B, C and D) as shown. In cluster D, nodes residing at distant locations form Far-Zone.

Here consider the case of intra-cluster communication. Let *MinPwri* denote the minimum power level required by a node *vi*,, $1 \leq i \leq N$ to communicate with a cluster head *u*, where *N* is the number of nodes within the cluster range.

All cluster members send their *MinPwri* to the CH. CH now computes *average minimum reachability power* (AMRP) with *MinPwri* values of all sensor nodes. AMRP can be defined as the mean of the minimum power levels required by all *N* nodes within the cluster range to reach *u*, i.e.

Use the AMRP as estimate of the communication cost. The AMRP of a node is a measure of the expected intracluster communication energy consumption for communication to the cluster head. Using AMRP as communication cost, It can find out Far-Zone members.

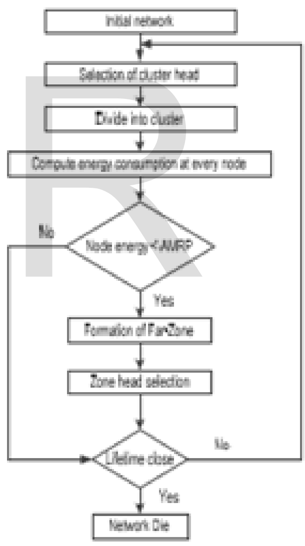


Fig 4. Block diagram of Far-Zone formation in FZ-LEACH.

$$AMRP = \frac{\sum_{i=1}^{N} MinPwr_i}{N}.$$

The nodes power levels below the AMRP are considered in Far- Zone. When Far-Zone is formed, any member of the zone is selected as ZH in pure random basis only for that round may be one with the highest energy.

The ZH create TDMA schedule as LEACH and assign time slots to zone members to transmit the sense data to the ZH. ZH then transmit data to the BS. In this way one round is completed.

4.2 Energy Analysis

Far-Zone within a cluster can be considered as level-2 cluster. In this sub-section analyzed the energy consumption for the proposed model. The energy analysis presented in this section is based upon analysis presented by F. Comeau *et al.* [13]. To compute the energy consumption in two-level hierarchical sensor network with sensor nodes, here the following top-down approach. *k1* is the number of the CHs and *k2* is the number of ZHs. Sensor nodes send sense data to *k2* ZHs. They collect data, aggregate it and transmit to the *k1* CHs. Energy consumption at each level can be calculated as follows. Expected energy expended to process *l*-bits of data at *zone level* includes the energy of sensing data by nodes and receiving data by *k2* CHs.

$$E_2 = l * [2 * (N - k_2) * E_{elect} + \frac{\varepsilon_{fs} M^2}{\pi}\left(\frac{N}{k_2} - 1\right) + N * E_p]$$

Selection of ZHs is done randomly depends upon the energies transmitted to the *k1* CHs. To compute the energy consumption, only (*k2 – k1)* nodes will participate. Expected energy expended by CHs, includes the energy of receiving data from *k2* ZHs, energy expended in aggregation and transmission to *k1* CHs.

$$E_1 = l * [2 * (k_2 - k_1) * E_{elect} + \frac{\varepsilon_{fs} M^2}{\pi}\left(\frac{k_2}{k_1} - 1\right) + k_2 * E_p]$$

Finally CHs transmits to the BS. The energy consumed is

$$E_0 = l * k_1 * \left[E_{elect} + \frac{\varepsilon_{fs} M^2}{\pi}\right]$$

The total energy expended in each round to transmit *l*-bits for such system is sum of *E2*, *E1* and *E0*.

$$\begin{aligned} E_{total,2} &= E_2 + E_1 + E_0 \\ &= l * [(2N - k_1) * E_{elect} + \frac{\varepsilon_{fs} M^2}{\pi}\left(\frac{N}{k_2} + \frac{k_2}{k_1} + k_1 - 2\right) \\ &+ E_p * (N + k_2)] \end{aligned}$$

Lifetime of the network in terms of number of rounds can be calculated from the above discussion. Number of rounds can be calculated by dividing total network energy by energy expended in one round.

5. SIMULATION AND ANALYSIS

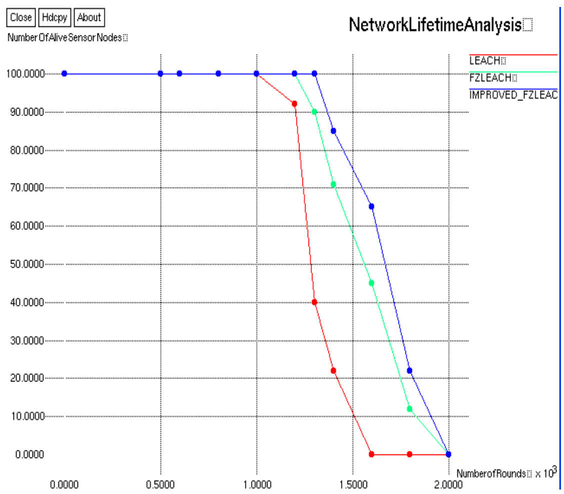
This section compares the performance of proposed algorithm with LEACH protocol. The performance evaluation includes two parts: network lifetime and energy consumption. The sensors are simulated to deploy over a square sized area of 100m x 100m with variable communication range.

Simulation is performed using ns-2 [14], a discrete event network simulator. I have compared the performance of FZLEACH with LEACH. The basic parameters used are listed in Table-I.

TABLE I. SIMULATION PARAMETERS

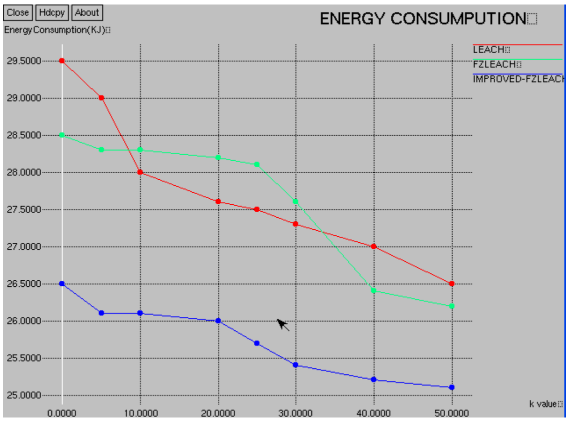
Parameter	Value
Number of nodes	100
Network grid	100 100 m
Base station position	50 X 175 m
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_{elect}	50 nJ/bit
Size of data packet	500 bits
Initial energy of normal nodes	1 J

Figure 5 illustrates the performance comparison of FZLEACH and LEACH in terms of energy dissipation. As shown in Figure 5, energy consumption of FZ-LEACH is less than LEACH protocol in all cases thus it is energy-efficient and has optimum performance with comparing to LEACH.



Above Figure illustrates the performance of our algorithm comparing to LEACH algorithm in terms of network lifetime.

As it is clear from Figure that sensor network performs longer with FZ-LEACH in comparison to LEACH. This is due to energy saving in transmission by the sensor nodes in Far-Zone.



Energy consumption analysis

6. CONCLUSION

In this paper the proposed concept, an improvement in LEACH protocol to overcome the shortcoming in this well known and widely used protocol for clustering in wireless sensor networks. The proposed FZ-LEACH algorithm, which is based on the original protocol and considers a Far-Zone inside a large cluster. Simulation results prove the improvement in the performance in the original LEACH protocol in terms of energy dissipation rate and network lifetime. It is found that FZ-LEACH protocol saves around 30% energy of sensor network in comparison to LEACH.

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