

A Comparative Analysis of LEACH and PEGASIS Hierarchical Protocol for Wireless Sensor Networks

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DOI: - <https://doi.org/10.47531/MANTECH/ECC.2021.44>

Abstract

Wireless Sensor Network (WSN) is one of the rising domain in modern times that is regularly improving. WSN is a resource-constrained network in terms of energy consumption. To improve the lifetime of the sensor network, the energy consumption should be as less as possible. An efficient routing routes the sensed data from source to destination with minimum energy dissipation. Hierarchical routings are one of those which routes the data with less energy consumption. Two such popular hierarchical routing protocols are named as LEACH (Low Energy Adaptive Clustering Hierarchy) and PEGASIS (Power-Efficient Gathering in Sensor Information Systems). LEACH is cluster-based, and PEGASIS is a chain-based protocol, where there are leader nodes in both cases which collect the information from the member nodes and forward the aggregated information to the Base Station (BS). In this paper, we have compared both the existing protocols based on network lifetime and discussed the required modifications which made them more efficient.

Keywords: - WSN, Routing Protocols, Clustering, LEACH, Chaining, PEGASIS

INTRODUCTION

Nowadays, sensor networks have gained considerable popularity due to their flexibility in monitoring the physical world that can detect, process, and convey. A wireless sensor network is a group of low power, low cost, multifunctional and small size wireless sensor nodes, and the sensor nodes can communicate among themselves using radio signals. In general, this type of network is deployed to monitor an inaccessible location or the locations which are difficult to access.

A pictorial representation of WSN architecture is shown in Fig. 1. All the sensor nodes in the network are self-configured with a limited power supply having the abilities of data sensing, processing, and sharing through radio connectivity. Sensor nodes should effectively utilize their resources, including CPU power, processing memory, and, more importantly, to enhance the network lifetime and productivity. Increasing the network lifetime by decreasing energy consumption by the sensor nodes has become one of the prior challenges in WSN.

In response to this challenge, over the last few years, several kinds of research are going on how to minimize energy consumption by using different algorithms and techniques in different layers of the WSN. One such layer is the Network layer, where we can implement effective routing techniques for minimizing energy consumption. It is desirable to prolong the system lifetime because we can't access the sensor nodes after deployment. In general, for communication purposes, the sensor node consumes more energy than sensing purposes [7].

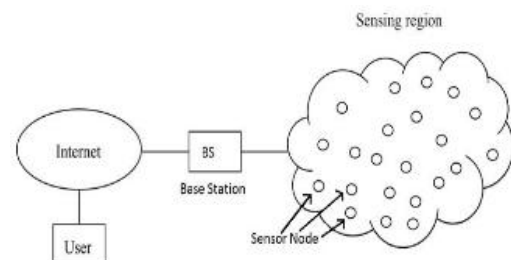


Fig. 1: Architecture of a WSN

In which path or route the sensed data is to be sent to the base station is known by the Routing process. Thus Routing Protocol is required to establish the connection between the sensor nodes

and the base station. In WSN, to manage limited resources adequately, routing protocols need to be energy-aware. Each of the distributed sensor nodes typically has the capability to collect data, analyze them, and route them to a designated point. Depending upon the capabilities of the sensor nodes, the network can be classified into two groups— Homogenous and Heterogeneous. In a homogeneous network, all the nodes are identical, and the routing task is distributed uniformly among the nodes, while in heterogeneous networks, the sensor nodes have different capabilities. So, the highly capable nodes are more responsible for data transmission, and the overall energy consumption can be minimized through optimization in routing techniques. Routing protocols for sensor networks can be classified according to how information is acquired and maintained and how this information is used to compute paths based on the obtained information. In WSN, the Routing Protocols can broadly be classified into three major categories—

- a) Flat Routing Protocols;
- b) Hierarchical Routing Protocols;
- c) Location-based Routing Protocols;

In this paper, we will focus on hierarchical routing, which imposes a structure on the network. In flat routing, also known as data-centric routing, the routes are formed in such regions that have data to transmit [3]. In location-based routing, the location information is needed in order to calculate the distance within two particular nodes so that energy consumption can be estimated.

HIERARCHICAL ROUTING PROTOCOLS

Hierarchical routing protocols impose a structure on the network to achieve energy efficiency, stability, and scalability. In this class of protocols, sensor nodes are organized in clusters in which a node with higher residual energy plays the role of a cluster head, which is responsible for coordinating activities within the cluster and forwarding information between clusters. Clustering has the potential to reduce energy consumption and extend the lifetime of the network. Each cluster will have a cluster head that routes the information to the base station. Hierarchical routing decreases the complexity of network topology, increases routing efficiency, and causes much less congestion because of fewer routing advertisements. The main challenge is to reduce the overhead required to maintain the clusters. A large overhead can easily waste network resources. Due to data aggregation by the cluster heads in each cluster, the message

overhead is reduced, which leads to a significant decrease in energy consumption. Two such popular hierarchical routing protocols are—

LEACH (Low Energy Adaptive Clustering Hierarchy) and PEGASIS (Power-Efficient Gathering in Sensor Information Systems).

This paper compares the performance of both protocols in different aspects. **LEACH** adopts a hierarchical approach to organize the network into a set of clusters where each cluster is managed by an elected cluster head that is responsible for carrying out multiple tasks, including routes the data to the sink. The transmission of the aggregated data is performed in a single hop manner. Data aggregation provides a great saving in energy consumption, as the sensor nodes are no longer needed to send the detected information directly to the sink. **PEGASIS** is another kind of hierarchical routing protocol that follows a chain based approach with the help of the greedy algorithm. Here all the sensor nodes are interconnected to form a chain. Every chain will have a chain leader that is responsible for transmitting the fused data to the sink node. It increases the network lifetime by transmitting data uniformly all over the sensor nodes.

Let us discuss both the LEACH and PEGASIS protocol in detail.

LEACH PROTOCOL

LEACH is one of the fundamental hierarchical protocol. It is a progressive, self-organizing protocol that chooses cluster heads in a rotation manner randomly over time. Each node has an equal probability of becoming a cluster head, and the cluster heads are assumed to maintain single-hop connectivity to the base station. This protocol uses TDMA (Time Division Multiple Access) approaches to allot each node an equal schedule for transferring data to the cluster head. Clustering in LEACH protocol is shown in the following Fig.

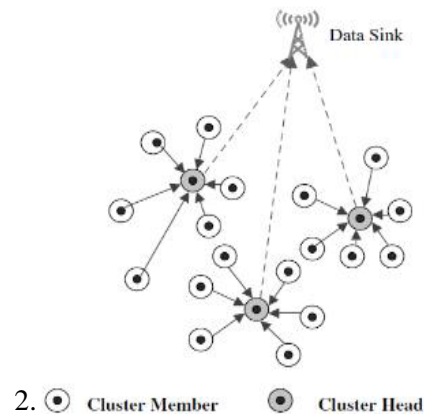


Fig. 2: Clustering in LEACH Protocol

LEACH Operation

The LEACH operation is basically divided into two phases— Set-up Phase and Steady-state Phase.

1. Set-up Phase: The setup phase consists of two steps, cluster head selection and cluster formation. Every sensor node has an equal probability of being a cluster head that is selected randomly. After the selection of cluster heads in each round, every cluster head advertises its new role to the rest of the network for the formation of the cluster [2]. The algorithm for the setup phase is shown in Fig.3.

A. Election of Cluster Heads

The cluster-head selection process ensures that this role rotates among the sensor nodes evenly. The algorithm for selecting cluster heads is randomly distributed over the network. The cluster heads are responsible for controlling the cluster activity, including data transmission. Election of CH depends on threshold value $T(n)$. The formula is as follows [7]:

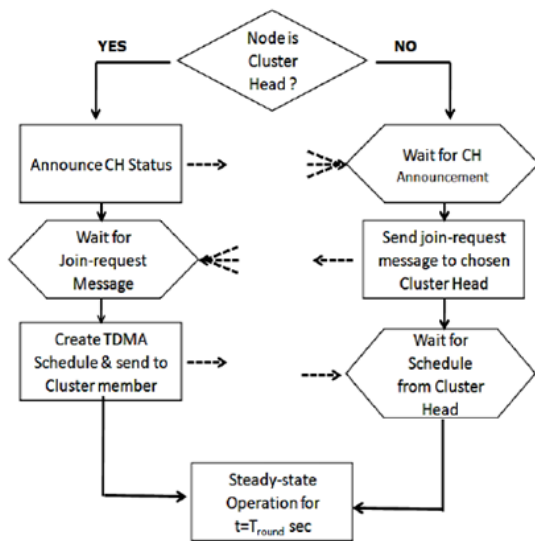


Fig. 3: Setup phase algorithm [2]

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

Where n is a random number between 0 and 1, P is the cluster head probability, r is the total number of rounds, G is the set of nodes that were non-cluster heads in previous $1/P$ rounds [7].

$T(n)$ depends on the desired rate of cluster heads of the network. Each node that wants to be the cluster head selects a value somewhere between 0 and 1. If this random number is less than $T(n)$, then the node turns into the cluster head for that particular round. The nodes that are cluster heads

in the current round cannot become cluster head till the next $1/P^{\text{th}}$ round.

B. Cluster Formation

The cluster heads send an advertisement message to the rest of the member nodes to form a cluster. After receiving the cluster-head advertisements, the remaining node selects a cluster to join based on the received signal strength.

2. Steady-state Phase: Mainly, the data transportation takes place in the steady-state phase. Each node sends the detected information to their corresponding leaders (CH) using the TDMA schedule assigned by the cluster head [8]. Further, the cluster head sends the aggregated information directly to the base station using single-hop connectivity. The algorithm for the steady-state phase is shown in Fig.4.

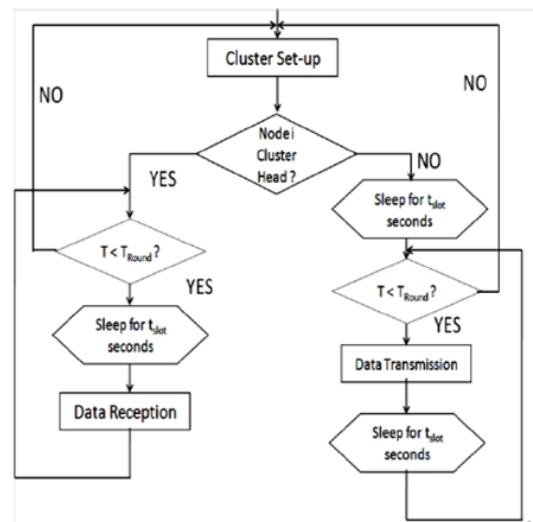


Fig. 4: Steady state algorithm [2]

Advantages of LEACH Protocol

In LEACH, each node has an equal probability of becoming a cluster head due to balanced energy dissipation, and the cluster heads only send the aggregated information to the base station. Such, LEACH is much more energy-efficient than conventional routing protocols. To reduce inter-cluster interference, LEACH uses a code division multiple access based scheme for communication. LEACH uses the TDMA scheme; this prevents cluster heads from any collisions in data transmission.

Limitations of LEACH Protocol

In LEACH, equal chances are given to all the nodes for becoming a cluster head. But, it is not efficient; everytime when the node with less power becomes a cluster head, the network lifetime decreases. Also, there does not exist any inter-cluster communication in the network. Due

to the dynamic clustering, extra overhead occurs at cluster heads.

LEACH-C (Centralized)

It is similar to the LEACH protocol with some modifications. In LEACH-C, the following assumptions are made: each node in the network is capable of calculating its energy level and sending information about its location to the base station directly. LEACH-centralized is so-called because the base station selects the cluster heads based on the energy level of a node and the distance between that node and the base station [4]. In LEACH, the number of cluster heads varies in several rounds, but in LEACH-C, it is an optimal value that is predetermined. Because of that, energy dissipation in LEACH-C is comparatively lesser than LEACH.

PEGASIS PROTOCOL

Power Efficient Gathering in Sensor Information Systems (PEGASIS) is an improved version of the LEACH protocol. Rather than using a tree or star hierarchy as in the LEACH protocol, the PEGASIS routing protocol uses a chain hierarchy to improve the network's lifetime.

Each node transmits its detected information to its closest neighbor, and this continues until the chain leader transmits the combined data to the base station [5]. The PEGASIS routing process can be divided into three steps those are— chain formation (chaining), leader node election, and finally, data transmission.

A. Formation of Chain (Chaining Process)

The formation of the chain starts with the farthest node from the base station. The rest of the nodes in the network are added to the chain progressively using the greedy algorithm [1]. The formation of the chain is shown in the following Fig. 5.

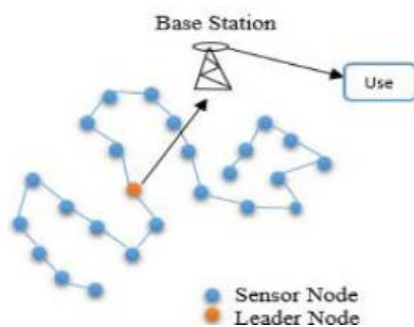


Fig. 5: Chaining in PEGASIS

B. Election of Chain Leader

Initially, a leader node is selected randomly for each round. This selection of the chain leader is

useful as if any leader node dies in a random location that does not make any connection loss or data loss. When the leader node is selected for a particular round, then for collecting data from the chain, a token is traversed through the chain starting from the end node. In each round, a distinct leader node is chosen to balance the energy consumption throughout the network [3].

C. Data Transmission

In the information transmission stage, every node in a chain manages two messages, one it receives and the other one it transmits. We can understand this data forwarding process from Fig.6.



Fig. 6: Data transmission in PEGASIS

Here the chain leader 3 issues a token to the rightmost node telling it to send its sensing information. When the request reaches node 7 it sends the information to node 6 where this one aggregates its information to it in a similar way until the aggregated information reaches node 3. Again node 3 issues the same operation to the leftmost node and, after having all the information from the left and right side, sends the aggregated information to the base station. A better approach would be using parallelism in aggregation to reduce the delay in transmission.

Advantages of PEGASIS protocol over LEACH

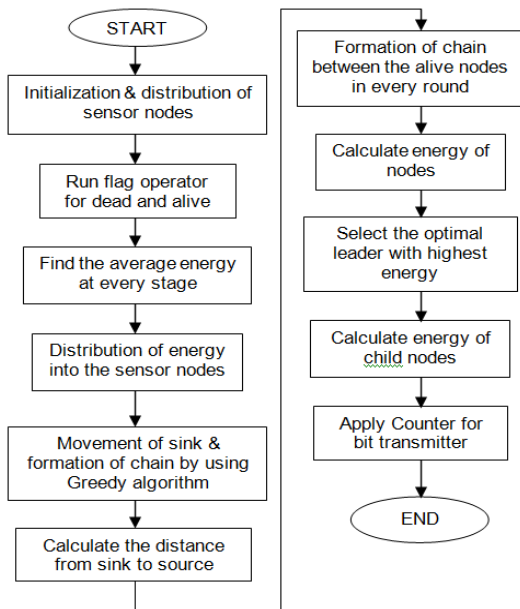
- 1) In PEGASIS, the distance between the chain leader and the base station is less compared to LEACH; because of that, the amount of energy dissipated in PEGASIS is lesser than LEACH.
- 2) Provides better network lifetime due to less energy consumption.
- 3) Minimization of data traffic occurs as the last node (head node) in a chain only sends the fused data as a single message to the base station, whereas in LEACH, more than one message from different nodes at the same time is received by the base station.
- 4) PEGASIS is more reliable than LEACH because in PEGASIS, if any node dies in between, then the chain is reconstructed to bypass the dead node to maintain the continuity in data transmission.

RADIO ENERGY MODEL

Each routing protocol has a particular mechanism for communicating and transmitting information between the nodes connected in a network. Almost

each of these protocols depends on the first order radio energy model for transferring data more effectively [3]. Maximum energy is consumed for data transmitting and data receiving in a data aggregation process.

PEGASIS protocol flowchart



Therefore, we use the following radio energy model as mentioned in [6], “to define the energy consumption for the network. The amount of energy a radio expends to transmit a k-bit message to a distance d is given by,

$$E_T(k, d) = E_{Tx_elec}(k) + E_{Tx_amp}(k) = E_{elec} \times k + \epsilon_{amp} \times k \times d^2 \quad (1)$$

where, E_{elec} and ϵ_{amp} are the energy consumed by transmit electronics and amplifier respectively to transmit one bit of data” [6]. The amount of energy a radio expends to receive the same message is given by,

$$E_T(k, d) = E_{Rx_elec}(k) = E_{elec} \times k \quad (2)$$

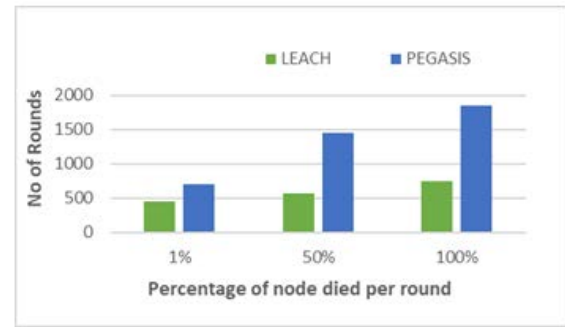
SIMULATION AND RESULTS

In this section, the performance of the proposed work has been evaluated by using simulations in MATLAB. Let us consider a randomly distributed network with 100 sensor nodes having an area of 100*100m.sq, with an initial energy of 0.5 J per node.

Table 1: Comparison between LEACH and PEGASIS protocol on the basis of Network Lifetime

Parameter (Rounds)	LEACH	PEGASIS
1% Node Dead	450	700
50% Node Dead	575	1460
100% Node Dead	750	1850

The performance can be analyzed more specifically from the following chart.



CONCLUSIONS AND FUTURE WORK

In this paper, we have compared the LEACH and PEGASIS protocol in terms of energy consumption and network lifetime. From the research analysis, we can observe that PEGASIS outperforms LEACH in terms of network lifetime, communication overhead, and the percentage of alive nodes. The number of alive nodes decreases with the increasing number of rounds due to limited energy resources. The result shows that PEGASIS provides a longer network lifetime as compared to LEACH.

PEGASIS is efficient in terms of energy, but transmission delay is very large due to long-distance communication between the nodes and leader nodes. Modification in PEGASIS can be done by selecting the sink reachable to all the leader nodes and also provide a short distance between the nodes and leader nodes so that the transmission delay can be minimized.

The routing algorithm can be chosen for a specific application depending upon its requirements. For instance, if an application can tolerate delay in data transmission then, we can use PEGASIS as it gives a higher system lifetime when contrasted with LEACH.

Future work in designing efficient routing protocols for wireless sensor networks can be based on a trade-off between energy consumption and delay in data transmission.

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