An Analysis of Energy-Efficient Data Routing In Wireless Sensor Networks

Jeevan Pinto
Srinivas Institute of PG Studies
Department of MCA
Mangalore, Karnataka

Manjaiah D. H, PhD.
Mangalore University
Department of Computer Science
Mangalore, Karnataka

ABSTRACT

Wireless sensors nodes are made up of small electronic devices which are capable of sensing, computing and transmitting data from harsh physical environments like a surveillance field. These sensor nodes majorly depend on batteries for energy, which get depleted at a faster rate because of the computation and communication operations they have to perform. Communication protocols can be designed to make efficient utilization of energy resources of a sensor node and to obtain real time functionality. In this paper, two classic energy-efficient protocols LEACH (low-Energy Adaptive Clustering Hierarchy) and PEGASIS (Power-Efficient Gathering in Sensor Information Systems) are analyzed, compared and discussed. LEACH introduces clustering based protocol, where sensor nodes are grouped in several clusters and have randomized rotation of cluster-heads that will transmit a data to Base Station (BS). PEGASIS is a chain-based protocol built on top of idea from LEACH, which nodes communicate only to its neighbor and takes turn to be leader to send data back to the BS. We evaluate the performances of these protocols by using C++ programming language.

Keywords

LEACH, PEGASIS, Hierarchical clustering, sensor nodes, wireless sensor network

1. INTRODUCTION

With the advances in micro-electro-mechanical system technologies, embedding system technology and wireless communication with low power consumption, it is now possible to produce micro wireless sensors for sensing, wireless communication and information processing. These inexpensive and power-efficient sensor nodes work together to form a network for monitoring the target region. Through the cooperation of sensor nodes, the WSNs collect and send various kinds of message about the monitored environment (e.g. temperature, humidity, etc.) to the sink node, which processes the information and reports it to the user. Sensor networks have a wide variety of applications and systems with vastly varying requirements and characteristics. The sensor networks can be used in Military environment, Disaster management, Habitat monitoring, Medical and health care, Industrial fields, Home networks, detecting chemical, biological, radiological, nuclear, and explosive material etc. Deployment of a sensor network in these applications can be in random fashion (e.g., dropped from an airplane) or can be planted manually (e.g., fire alarm sensors in a facility). For example, in a disaster management application, a large number of sensors can be dropped from a helicopter. Networking these sensors can assist rescue operations by locating survivors, identifying risky areas, and making the rescue team more aware of the overall situation in the disaster area .

In wireless sensor networks, the sensor node resources are limited in terms of processing capability, wireless bandwidth, battery power and storage space, which distinguishes wireless sensor networks from traditional ad hoc networks. In most applications, each sensor node is usually powered by a battery and expected to work for several months to one year without recharging. Such an expectation cannot be achieved without carefully scheduling the energy utilization, especially when sensors are densely deployed, which causes severe problems such as scalability, redundancy, and radio channel contention. Due to the high density, multiple nodes may generate and transmit redundant data about the same event to the sink node, causing unnecessary energy consumption and hence a significant reduction in network lifetime. For a sensor node, energy consumption includes three parts: data sensing, data processing, and data transmission/reception, amongst which, the energy consumed for communication is the most critical. Reducing the amount of communication by eliminating or aggregating redundant sensed data and using the energy-saving link would save large amount of energy, thus prolonging the lifetime of the WSNs.

Since the entire sensor nodes are battery powered devices, energy consumption of nodes during transmission or reception of packets affects the life-time of the entire network. To make routing, an energy efficient one, number of protocols like LEACH and PEGASIS were developed. Leach is considered as the most popular routing protocol that use cluster based routing in order to minimize the energy consumption.

2. HIERARCHICAL CLUSTERING

The hierarchical cluster based routing is advantageous as the scalability and the power efficiency in the sensor network improves. In this hierarchical based architecture, nodes with higher power levels perform the fusion of data gathered from the other sensor nodes and transmit the aggregated data to the base-station (BS) while the nodes with low power levels only perform the sensing of the environment. They transmit the sensed data to the higher node, known as the cluster-heads (CHs) which are at a lesser distance than the base station. The cluster formation and the assignment of special tasks to the cluster heads (CHs) reduce the power dissipation within a particular cluster, which improves the scalability of the sensor network. Also by aggregating the sensed data, the amount of data to be transmitted to the base-station (BS) is reduced and the lifetime of the overall sensor network is increased. As the data travels from a lower cluster level to a higher cluster level, it covers more distance and the data travels faster to the base-station (BS).

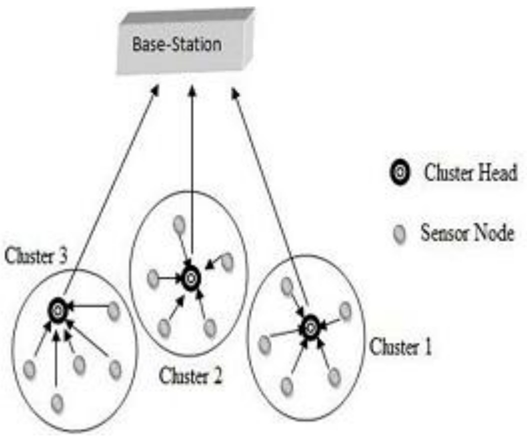

Figure 1: Hierarchical cluster

Figure 1 shows a hierarchical cluster based routing setup in which the sensor nodes transmit the sensed data to the cluster head which in turn transmits the aggregated data to the BS

2.1 Energy analysis of routing protocols

Two conventional routing protocols in wireless network that we will discuss in this section are direct communication and minimum-transmission-energy routing protocol (MTE). In direct communication, each node connects and transmits data directly to the base station. If base station locates far away from sensor nodes, sensor node will deplete its battery quickly and shortens the system lifetime. In minimum-transmission-energy, node routes data to the base station via its neighbors. Each node will act as a router that route a received packet from one neighbor to another. This technique reduces the transmit amplifier energy because distance between node is shorter than the distance between node and the base station. This concept can be expressed mathematically as following:

$E_{Tx}(K, d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2$ ------------------- i

$E_{Rx}(K) = E_{Rx\text{-}elec}(k) = E_{elec} \times k$ --------------------ii

Where E_{elec} is the energy spent in transmitting and receiving data for a sensor; ε_{amp} is the energy spent in amplifying. Therefore, the energy is consumed for a sensor to transmit k-bits data over d meters is defined in (i), and that for receiving data is defined in (ii). Node A will route a packet to C via B if the following equation holds:

$E_{Tx\text{-}amp}(k, d = d_{AB}) + E_{Tx\text{-}amp}(k, d=d_{BC}) < E_{Tx\text{-}amp}(k, d=d_{AC})$

However, we need to take into an account that, in minimum-transmission-energy, each message needs to go through multi-hops and the total energy might ends up greater than direct transmission.

2.2 Related work

2.2.1 LEACH protocol

Heinzelman, et.al introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Cluster Hierarchy – based protocol (LEACH). In LEACH the operation is divided into rounds, during each round a different set of nodes are cluster-heads (CH). Nodes that have been cluster heads cannot become cluster heads again for P rounds. Thereafter, each node has a 1/p probability of becoming a cluster head in each round. At the end of each round, each node that is not a cluster head selects the closest cluster head and joins that cluster to transmit data. The cluster heads aggregate and compress the data and forward it to the base station, thus it extends the lifetime of major nodes. In this algorithm, the energy consumption will distribute almost uniformly among all nodes and the non-head nodes are turning off as much as possible. LEACH assumes that all nodes are in wireless transmission range of the base station which is not the case in many sensor deployments. In each round, LEACH has cluster heads comprising 5% of total nodes. It uses Time Division Multiple Access (TDMA) as a scheduling mechanism which makes it prone to long delays when applied to large sensor networks. Figure 2 shows the communications in LEACH protocol.

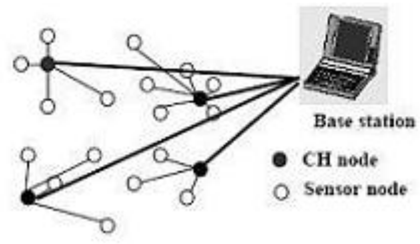

Figure 2: LEACH Routing Setup

Working Principle: The LEACH protocol functions in two different phases. The setup phase and the steady state phase. The formation of clusters and selection of the cluster heads is done during the setup phase and the aggregated data is transmitted to the base-station during the steady state phase which is of greater duration than the setup phase. During the setup phase, a random number r, between 0 and 1, is selected by the sensor nodes. If this random number is less than a threshold value T(n), that sensor node is selected as the cluster head. The threshold value T(n) is calculated as follows

$T(n) = p / [1-p(r \bmod(1/p))]$ if $n \in G$ Where, p is the predetermined number of sensor nodes, r is the random number and G is the set of nodes that are involved in the CH selection that have not been selected as cluster heads in the last (1/p) round. After the selection, the cluster heads sends an advertisement to all the other sensor nodes in the network. The formation of clusters is based upon the signal strength of this advertisement. After the cluster formation, a TDMA schedule is created assigning time slots to the sensor nodes for data transmission. After the cluster formation and the selection of the cluster heads, the network goes into steady state phase where the aggregated data from the sensor nodes is sent to the base-station by the cluster heads. The network again goes back into the setup phase after a predetermined time period to select a new set of cluster heads as to rotate the role of the cluster heads among the nodes of a cluster. The network lifetime is increased as the load of power dissipation is evenly distributed among the nodes in the cluster. Also the amount of data to be transmitted is less which in turn reduces the latency of the network. The LEACH protocol is not suitable for networks deployed in large areas. Also the predetermined cluster heads may not be uniformly distributed. The path taken by the aggregated data to reach the base station is not optimal.

2.2.2 PEGASIS protocol

The Power-Efficient Gathering in Sensor Information Systems (PEGASIS) is an improvement over the LEACH protocol. The protocol is a near optimal chain-based protocol for extending the lifetime of network. In PEGASIS, each node communicates only with the closest neighbour by adjusting its power signal to be only heard by this closest neighbour. Each

Nodes uses signal strength to measure the distance to neighbourhood nodes in order to locate the closest nodes. After chain formation PEGASIS elects a leader from the chain in terms of residual energy every round to be the one who collects data from the neighbours to be transmitted to the base station. As a result, the average energy spent by each node per round is reduced. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the Base station instead of multiple nodes. This approach reduces the overhead and lowers the bandwidth requirements from the BS. Figure 3 shows that only one cluster head leader node forward the data to the BS.

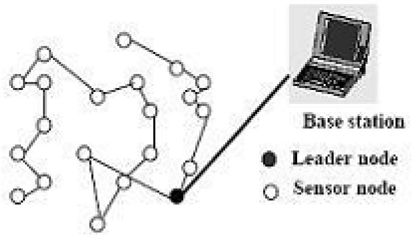

Figure 3: PEGASIS Routing Setup

Working Principle: PEGASIS assumes that all the sensor nodes maintain a database of the location of all the other nodes in the network. Each node determines the distance of its neighboring nodes using the signal strength and adjusts the signal strength only to communicate with the closest node. In PEGASIS, the sensor nodes closest to each other are in the chain and they form a path to transmit the aggregated data to the base-station. The chain is constructed using Greedy algorithms. Each sensor node sends the sensed data to its closest node in the chain. The data is aggregated at each node in the chain and finally only the aggregated data is sent to the base-station. The lifetime of each node is increased as they only have to communicate with their closest node which, as a result increases the network lifetime.

Delay is caused in data transmission from the distant node in the chain. There is significant overhead as the nodes need the know-how about the other node location and the path for transmitting data. To overcome the problem of delay occurrence in transmitting the aggregated data to the base-station (BS) an extension to PEGASIS, called Hierarchical-PEGASIS was introduced in which the transmission of the data was allowed only by the spatially separated sensor nodes. This ensured parallel data transmission and reduced the delay

3. PERFORMANCE COMPARISON AND ANALYSIS

In this paper, we developed the simulation environment for wireless sensor networks using C++ programming language. Some assumption and parameters are described as follows.

3.1 Parameters set up

The simulation variables are set up as follows.

- Sensor field: 100*m* x 100*m*
- Number of sensor nodes: 200 and 400 nodes uniformly deployed
- Initial energy of sensor nodes: 0.25 (*J*)
- The coordinate of base station: (50, 200)
- To evaluate energy consumption, the parameters used are E_{elec}=50nJ/bit,ε_{amp}=100pJ/bit/m^2 , k=2000 bits, and every node consumes 5nJ/bit to complete data fusion.

In this paper, Direct, LEACH, and PEGASIS are implemented and compared. Direct represents each node directly transmits its sensed data to base station. Three evaluation metrics, which are widely-used in data gathering for WSNs, are utilized to evaluate the performance. They are defined as follows.

Round: a round for data gathering stands for all active sensors successfully transmit its sensed data to base station.

Coverage ratio: In some situations, numbers of round is not enough to represent the efficiency of a scheme. Uneven energy consumption, for example, may lead some nodes still having energy to operate, resulting in higher number of rounds, but actually it cannot provide user with sufficient and full information about the sensor field. Therefore, in addition to number of rounds, by observing the coverage ratio, how long the complete information can be provided to end users is known.

Total energy consumption per round: the sum of every sensor's energy consumption in one round data gathering. An efficient data gathering scheme should have lowered total energy consumption per round. Here, the equation used to compute this value is

Avg. total energy per round = (total energy consumption of a system before the first node dies) /(Number of rounds a system has run before the first node dies)

3.2 Simulation assumption

In our simulation environment, we assume that all nodes always have data to send and sensor devices are not with mobility, same initial energy, and capable of transmission range adjustment. No multiple access interference problems when sensors broadcast and data can be correctly transmitted and received. Furthermore, for correctness of simulation, initially base station provides address localization for each sensor.

Table 1 lists some of the network parameters and their definitions, which are used in a Wireless Sensor Network.

Parameter	Definition	Unit
[X, Y]	Network range	m^2
N	Total number of nodes	
n_i	The ith node	($1 \le i \le N$)
R	Transmission range of each node	m
d_{ij}	Distance from n_i to n_j	m
E_I	Initial energy for all nodes	J
e_i	Remaining energy of n_i	J

Table 1: Network parameters

3.3 Simulation results and discussion

Number of nodes : 200

Energy J/Node	Protocol	1%	20%	50%	100%
0.25	Direct	29	36	52	116
0.25	LEACH	144	246	319	491
0.25	PEGASIS	270	925	945	963

Table 2: Node death percentage VS. number of rounds

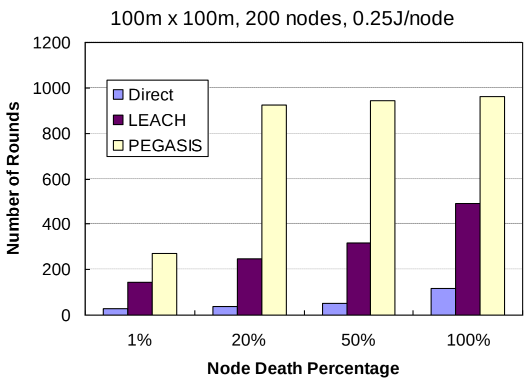

Figure 4: Node death percentage VS. number of rounds

Number of nodes: 400

Energy J/Node	Protocol	1%	20%	50%	100%
0.25	Direct	29	36	51	118
0.25	LEACH	109	273	356	557
0.25	PEGASIS	265	1006	1007	1010

Table 3: Node death percentage VS. number of Rounds

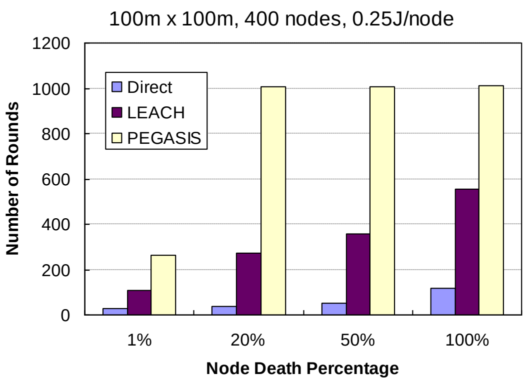

Figure 5: Node death percentage VS. number of Rounds

In figure 4 and figure 5, X axis represents node death percentage (percentage of nodes with no power) and Y axis represents number of round. From the simulation results, it can be noticed that direct scheme has worst performance because all sensor consume more energy to transmit data directly to base station, resulting in shorter network lifetime whereas LEACH utilizes the advantage of clustering, only a few cluster-heads take the responsibility to send data and every sensor takes turn to be the cluster-head, causing the energy consumption distribute to other sensors so that higher network lifetime can be achieved. However, PEGASIS outperforms LEACH in three ways. First, the distance between neighbors in a chain is much shorter than the distance between a node in a cluster and its head, so each sensor won't take that much energy. Furthermore, only one node transmits a data packet to BS per transmission round instead of several cluster heads in LEACH. Finally, the amount of data that the leader will receive in PEGASIS is two rather than from all cluster nodes in LEACH. As we can see in Figure 4, it is approximately almost 3 times better than LEACH.

4. CONCLUSIONS

The flexibility, fault tolerance, high sensing fidelity, low cost and rapid deployment characteristics of WSN create many new application areas for remote sensing which would make senor networks an integral part of our lives in recent future. In this paper we analyzed and compared energy efficient LEACH and PEGASIS routing protocols which can be used in the real time applications to enhance the life time of the network. The simulation results show that PEGASIS can greatly prolong sensor network's lifetime. Here we have restricted the simulation for 200 and 400 nodes. Further we have to analyze the performance of these two energy efficient routing protocols for larger number of nodes say more than 500.

5. ACKNOWLEDGMENT

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