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RESEARCH ARTICLE

COMPARATIVE ANALYSIS OF LEACH AND PEGASIS-ENERGY EFFICIENT ROUTING ALGORITHM FOR WIRELESS SENSOR NETWORKS

[1]NAVEEN RAI, [2]PROFESSOR A KARTHIKEYAN

1. B.TECH,VIT UNIVERISTY, VELLORE, TAMIL NADU
2. NETWORKING DIVISION,VIT UNIVERSITY,VELLORE,TAMIL NADU

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Corresponding Author

NAVEEN RAI

Abstract

Wireless sensor networks consisting of sensor nodes can be deployed for collecting of valuable information from field. They can be used for large number of military operations to gather information from the battlefield or to convey the message to other nodes. Gathering sensed information in an energy efficient manner is critical to operate the sensor network for a long period of time. In this paper, we look at communication protocols, which can have significant impact on the overall energy dissipation of these networks. It is a challenging aim to design an energy efficient routing protocol, which can minimize the energy and thereby extend the lifetime of the network. In this paper we compare the conventional LEACH algorithm with an improvised algorithm, PEGASIS(Power Efficient Gathering In Sensor Systems). Our simulations show that PEGASIS performs better than LEACH by about 100 to 300% when 1%, 20%, 50%, and 100% of nodes die for different network sizes and topologies. PEGASIS shows an even further improvement as the size of the network increases.

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INTRODUCTION

Wireless Sensor Network (WSN) consists of small in size sensor nodes, which form an ad-hoc distributed sensing and data propagation network to collect the context information on the physical environment. WSN is widely used to collect reliable and accurate information in the distance and hazardous environments, and can be used in National Defense Military Affairs, Industrial Control, Environmental Monitor, Traffic Management, Medical Care and Smart Home etc. The sensor whose resources are limited is cheap, and depends on battery to supply electricity, so it's important for Routing to efficiently utilize its power in both military and civilian applications such as target tracking, surveillance and security management. Although WSNs have evolved in many aspects, nodes have limited communications capabilities, due to which a source node can cover only within its maximum transmission range. On the other hand, it causes nodes to relay messages through intermediate nodes to reach their destinations. Due to this reason, routing related tasks become much more complicated in WSNs since there is no predefined physical backbone infrastructure for topology control. This drawback motivates a virtual backbone to be employed in a WSN. Since wireless communications consume significant amounts of battery power, sensor nodes should spend as little energy as possible in the reception and the transmission of the data. Therefore, it is important for communication protocols to minimize the power consumption of the nodes in order to increase their battery life ,efficiently utilize the available bandwidth and prevent node failures.

Finally , the data obtained from each sensor node in the network must be transmitted to a control center or base station, where the end-user can access the data. There are many possible models for these sensor networks. In this work, we consider wireless sensor networks where:

- The BS is fixed at a far distance from the sensor
- The energy cost for transmitting a packet depends on the distance of transmission.

- The sensor nodes are homogeneous and energy constrained with uniform energy.

Sensor nodes consist of several redundant data that needs to be removed since it increases the overload on the node as well as on the base station to which the data is delivered. In addition to helping avoid information overload, data aggregation, also known as data fusion, can combine several unreliable data measurements to produce a more accurate signal by enhancing the common signal and reducing the uncorrelated noise. A simple approach to accomplish this task is for each node to transmit its data directly to the BS. Since the BS is located far away, the cost to transmit to the BS from any node is high and nodes will die very quickly. Therefore, an improved approach is to use as few number of transmissions as possible to the BS and compress the amount of data that must be transmitted to the BS. This will reduce the overload on the BS and allow faster processing of the data thus increasing the efficiency of the sensor networks.

2. FIRST ORDER RADIO MODEL

The first order radio model is the elementary step towards the establishment of wireless sensor networks. The same radio model is adopted for both the LEACH and the PEGASIS. In this radio model the radio dissipates $E_{TX\text{-}Elec}$ = 50 nJ/bit to run the transmitter or receiver circuitry and $E_{TX\text{-}Amp=}$ 100 pJ/bit/m^2 of power for the transmit amplifier to achieve an acceptable Eb/$N_{0.}$(see Figure 1 and Table 1). We also assume an r^2 energy loss due to channel transmission. Thus, to transmit a k-bit message at a distance d using the first order radio model, the total energy spend is:

$E_{TX}(k,d)= E_{TX\text{-}Elec} + E_{TX\text{-}Amp}(k,d)$
$E_{TX}(k,d)= E_{TX\text{-}Elec} * k + E_{TX\text{-}Amp} * k * d^2$ (1)

Similarly for the reception of this message the amount of energy expended by the receiver is :

$E_{RX}(k)= E_{RX\text{-}Elec}(k)$
$E_{RX}(k)= E_{RX\text{-}Elec} * k$ (2)

When we are receiving the information the used algorithm and the protocol should try to minimize the above parameters, otherwise the cost of transmission and reception will be very high. For both the cases it is assumed that the first order radio model is symmetric. That means, the amount of energy required to transmit data from node A to node B will be same as transmitting the data from node B to node A.

3. ROUTING PROTOCOL ANALYSIS

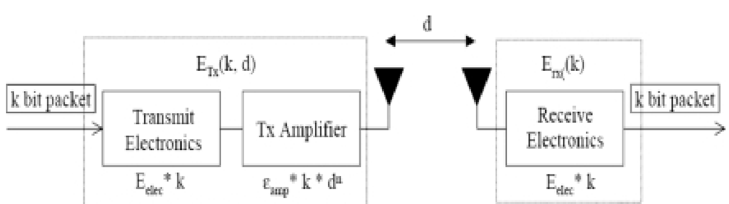

Fig 1:First Order Radio Model

Operation	Energy Dissipated
Transmitter Electronics ($E_{TX\text{-}Elec)}$ Receiver Electronics($E_{RX\text{-}Elec)}$	50nJ/bit
Transmitter Amplifier($E_{TX\text{-}Amp)}$	90pJ/bit/m^2

Table 1:Characteristics of Radio

For wireless sensor networks we have different energy efficient algorithms that have been proposed which can be analyzed. Before comparing the performance of the LEACH and the PEGASIS we analyze the performance of the two basic algorithms that is Direct Transmission in which the data is directly transmitted to the Base Station and the second one is Minimum Transmission Energy(MTE).

In case of Direct Transmission each sensor sends its data directly to the base station. If the base station is far away from the nodes, direct communication will require a large amount of transmit power from each node (since d in Equation 1 is large). This will quickly drain the battery of the nodes and reduce the system lifetime. However, the only receptions in this protocol occur at the base station, so if either the base station is close to the nodes, or the energy required to receive data is large, this may be an acceptable (and possibly optimal) method of communication.
There are various proposed algorithms in which we are trying to optimize the energy requirement of the sensor network by finding routes that connects the node to the BS .All the algorithms try to find out this route by following a different approach. The nodes present en-route to the BS act as routers. Some of these algorithms have only considered the transmitting power while selecting the optimum path for transmission but according to the First Order Radio Model one should also consider the reception power of the receiver electronics circuit($E_{RX\text{-}Elec}$) as well. If node 1 wants to transmit the data to node 3 via some intermediate node 2 then it will only do when the sum of total transmission energy from 1→2 and 2→3 is less than the energy required in case of direct transmission from node 1→3.The following equation governs the condition:

$$E_{TX\text{-}Amp\text{-}12}(k,d) + E_{TX\text{-}Amp23}(k,d) < E_{TX\text{-}Amp13}(k,d) \quad (3)$$

But in case of the Minimum Transmission Energy, instead of transmitting the entire data at once we transmit each data bit by bit. This means that a data will have to go through *n* transmissions and *n* receptions before it reaches the BS. This helps in a way that the node does not need to send the entire block of data at once and helps to minimize the energy at times. Depending on the relative costs of the transmit amplifier and the radio electronics, the total energy expended in the system might actually be greater using MTE routing than direct transmission to the base station.
If we consider a simple linear network of n nodes separated by a distance *r* each as shown in Fig2 where the data is transmitted to the BS then according to the direct transmission algorithm the total energy is:

$$E_{DIRECT}=E_{TX\text{-}Elec}*k + E_{TX\text{-}Amp}*k(nr)^2 \quad (4)$$

In MTE routing, each node sends a message to the closest node on the way to the base station. Thus the node located a distance *nr* from the base station would require *n* transmits a distance *r* and *n- 1* receives and the total energy required for transmission of *k* bit information to the BS will be:

$$\begin{aligned} E_{MTE} &= n*E_{TX}(k,d = r) + (n- 1)* E_{RX}(k) \\ &= n(E_{TX\text{-}Elec}*k + E_{TX\text{-}Amp}* k* r^2) + (n-1)*E_{TX\text{-}ELEC}* k \\ &= k((2n- 1)E_{TX\text{-}Elec} + E_{TX\text{-}Amp}*n*r^2) \quad (5) \end{aligned}$$

Therefore, from (4) and (5), when transmission energy is on the same order as receive energy, which occurs when transmission distance is short or the radio electronics energy is high, direct transmission is more energy-efficient on a global scale than MTE routing. Thus the most energy-efficient protocol to use depends on the network topology and radio parameters of the system.

4. LEACH ALGORITHM

LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster-head. If we choose CH on basis of priority then there is a possibility of node and eventually network failure. Thus LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to not drain the battery of a single sensor. In addition, LEACH performs local data fusion to “compress” the amount of data being sent from the clusters to the base station, further reducing energy dissipation and enhancing system lifetime.

Sensors elect themselves to be local cluster-heads at any given time with a certain probability. These cluster- head nodes broadcast their status to the other sensors in the network. Each sensor node determines to which cluster it wants to belong by choosing the cluster-head that requires the minimum communication energy. Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster-head node to be turned off at all times except during its transmit time. Once the cluster-head has all the data from the nodes in its cluster, the cluster-head node aggregates the data and then transmits the compressed data to the base station. Since the base station is far away in the scenario we are examining, this is a high energy transmission. However, since there are only a few cluster-heads, this only affects a small number of nodes. Being a cluster-head drains the battery of that node. In order to spread this energy usage over multiple nodes, the cluster-head nodes are not fixed; rather, this position is self-elected at different time intervals.

4.1 LEACH ALGORITHM DETAILS

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.

4.1.1 ADVERTISEMENT PHASE

During the advertisement 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 the suggested percentage of cluster heads for the network and the number of times the node has been a cluster-head so far. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold T(n), 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. 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. The advertisement that receives the largest signal strength is allocated as the cluster head and if a tie occurs then a random cluster head is elected.

4.1.2 SET-UP PHASE

After the advertisement by the cluster head , the nodes decide he cluster head to which they will transmit and by using a CSMA-MAC protocol the nodes send an acknowledgement to the desired cluster head to include them in their sub-network. 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. Using this TDMA schedule the nodes transmit the data to the cluster head which is then accumulated and transmitted to the Base Station(BS).

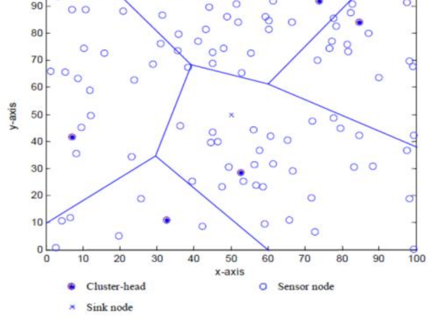

Fig 3:A sample WSN clusters ,the blue circled nodes represents the CH and rest are simple nodes.

5. PEGASIS ALGORITHM

In case of PEGASIS the data is transmitted by each node to the close by node that leads to the BS via the most effective path. Unlike LEACH the data is accumulated at each node individually instead at the cluster head. Each node transmits the data to its nearby node and accumulates the received data with it's own data and then transmits it to the next nearby node that leads to the BS. This approach will distribute the energy load evenly among the sensor nodes in the network. The nodes will be organized to form a chain, which can either be accomplished by the sensor nodes themselves using a greedy algorithm starting from some node.
For analysis a field with 100 random sensor nodes were taken in a 50m x 50m plot, as shown in the Fig.4.It is assumed that the nodes have the global knowledge of the sensor network and the greedy algorithm is applied in case of a node failure. To construct the chain, we start with the farthest node from the BS. We begin with this node in order to make sure that nodes farther from the BS have close neighbors, as in the greedy algorithm the neighbor distances will increase gradually since nodes already on the chain cannot be revisited. Figure 5 shows node A connecting to node B, node B connecting to node C, node C connecting to node D and node D connecting to node E in that order. Whenever a node dies, that means there is a node failure then the chain is reconstructed in the same manner to bypass the dead node.

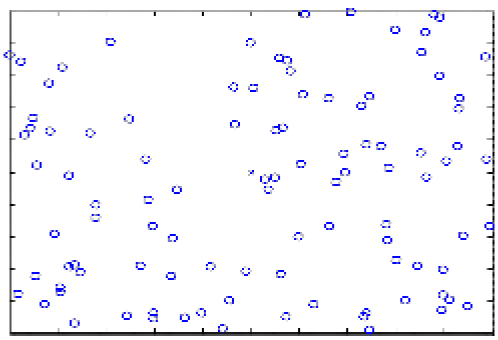

Fig 4:A random WSN with 100 nodes in a 50×50 m field.

A→B→C
↓
D→E

Fig 5:A simple connection of nodes, where a node failure leads to a new topology .

During the time of transmission each node takes the data from the neighboring node that falls in the path leading to the BS and fuses the received data with their own data and similarly the coagulated data is transmitted to the nest node until it reaches the BS. Another important point to be considered is that each node will be at some random position at some time 't'. This is done so that the network can be robust to node failure and a new path or topology can be constructed each time a node failure occurs. Nodes take turns transmitting to the BS, and we will use node number i mod N(N represents the number of nodes) to transmit to the BS in round i. In a given round, we can use a simple control token passing approach initiated by the leader to start the data transmission from the ends of the chain. The cost is very small since the token size is very small. In Figure 6, node B2 is the leader, and it will pass the token along the chain to node B0. Node B0 will pass its data towards node B2. And node B2 receives data from node B1, it will pass the token to node B4, and node B4 will pass its data towards node B2.This concept is known as the *'token approach'* .

B0→B1→B2←B3←B4
↓
BS

Fig 6:Nodes sending data to B2 ,that forwards it to the BS.

Node B2 waits to receive data from both neighbors and then fuses its own data with its neighbors' .After the fusion of data has taken place, the final data is transmitted to the BS in PEGASIS each node will receive and transmit one packet in each round and be the leader once every 100 rounds. There is a possibility that some of the nodes might be having neighboring nodes that are quite far away and in such cases if that node is chosen to be the leader then the energy requirement of the network will increase. Therefore a threshold value for the maximum possible distance needs to be incorporated between the nodes. The effectiveness of PEGASIS over the conventional LEACH can be understood by the following points:

- First, the distance travelled by the data from the individual nodes to the leader is less in case of PEGASIS as compared to that travelled from each nodes to the cluster heads in the LEACH.
- Second, the overload on the leader or decreases as individual nodes perform data fusion in the PEGASIS unlike LEACH where data fusion is performed by the cluster head for each node.
- Apart from this the number of data received by the leader or the cluster head decreases in case of PEGASIS as compared to the LEACH.
- Finally, in PEGASIS there is only one node that transmits to the BS unlike the LEACH where each cluster heads transmit the data to the BS.

6. RESULTS AND DISCUSSIONS

To evaluate the performance of PEGASIS, we simulated PEGASIS and LEACH using several random 100-node networks. We ran the simulations to determine the number of rounds of communication when 1%, 20%, 50% and 100% of the nodes die using LEACH and PEGASIS with each node having the same initial energy and the same radio model adopted for both the algorithms. Once a node dies it is considered dead for the rest of the simulation. We have taken 5 iterations and then taken the average of the obtained values. On performing the simulation of the two algorithms the following results are obtained:

Energy(J)/ Node	Algorithm	1%	20%	50%	100%
0.25J	LEACH	404	482	520	637
	PEGASIS	789	1004	1041	1098
0.5J	LEACH	802	961	1036	1208
	PEGASIS	1575	2011	2082	2194
1.0J	LEACH	1612	1921	2056	2355
	PEGASIS	3158	4023	4165	4379
0.25J	LEACH	166	203	233	308
	PEGASIS	339	624	688	779
0.5J	LEACH	339	408	457	578
	PEGASIS	675	1252	1361	1544
1.0J	LEACH	688	812	911	1072
	PEGASIS	1342	2497	2720	3072

Fig 7:Rounds taken for different algorithms with percentage of dead nodes.

Figure 7 shows how many rounds are taken for 1%, 20%,50%, 100% nodes of the network to die for a 50m x 50m network and similarly Figure8 conveys about the number of rounds taken for same parameters but for a l00m x l00m network. It comes out to be that PEGASIS gives an efficiency of almost 2 times as compared to the LEACH algorithm. The energy value of the nodes is 0.5J in Figure 7 and 1.0 J in Figure 8. As the energy level doubles the number of rounds also doubles for all cases. For a l00m x l00m network, PEGASIS performs almost 3 times better than the LEACH.

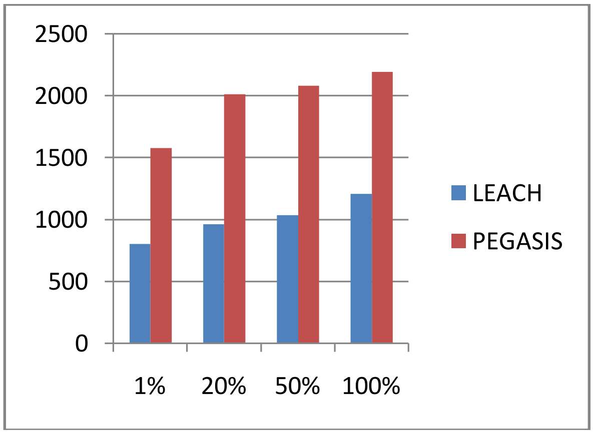

Fig 7:The number of rounds with initial node energy as 0.5J for 50m×50m field.

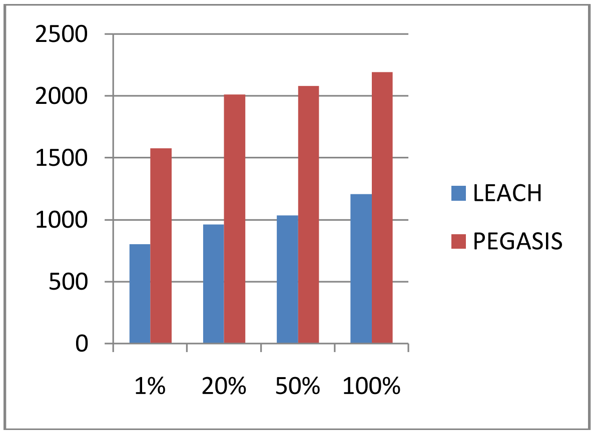

Fig 8: The number of rounds with initial node energy as 1.0J for 100m×100m field.

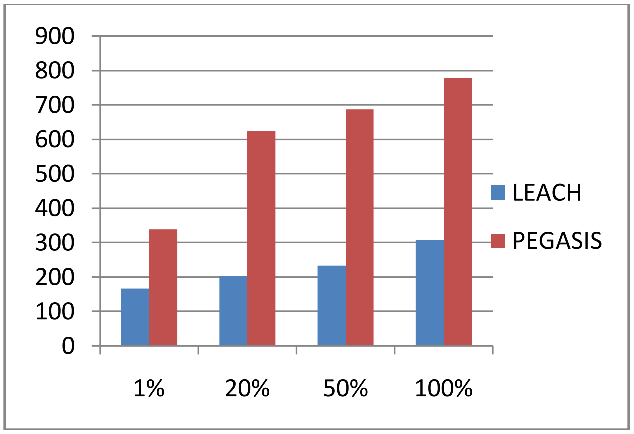

Fig 9: The number of rounds with initial node energy as 0.25J for 100m×100m field.

7. CONCLUSION

In this paper, we have compared the performance of the improvised PEGASIS with the conventional LEACH algorithm. PEGASIS outperforms the LEACH on the basis of reducing the number of transmissions from the leader to the BS and also it also reduces the load of compressing the data by the cluster head. Moreover, the number of transmissions to the BS decreases as only there is a single leader instead of multiple cluster heads. By assigning the job of data compression to each individual node the overall lifetime of the network increases ,thus leading to energy optimization. The simulation on MATLAB shows that PEGASIS performs better than LEACH by roughly 100 to 300% when 1%, 20%, 50%, and 100% of nodes die in the network. As we increase the size of the network the performance of the PEGASIS further improves.

For future work we would try to improvise on the existing LEACH-C(Centralized) by considering the queuing algorithm for the selection of the leader by analyzing the data arrival and the data processing rate of the nodes.

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