

An Energy- efficient Routing Protocol for Homogeneous Wireless Sensor Networks

Abstract: A Wireless Sensor Network (WSN) is composed of sensor nodes spread over the field to sense the data. The sensed data must be gathered & transmitted to Base Station (BS) for end user queries. The used sensor nodes being in- expensive having low computation power & limited energy so are not as much reliable as their expensive macro sensor counter parts but their size and cost enable hundred to thousand of micro sensors to achieve high quality fault tolerant system. In an environment where in each round all sensor nodes have to send data to base station, it is required to effectively utilize energy of sensor nodes so as to increase the life- time of the system. The use of data aggregation & fusion as proposed in LEACH increases system lifetime by a factor of 8 as compared to conventional routing protocols. In this paper along with data aggregation & fusion, we are trying to minimize reduction in system energy by first generating MST between all sensor nodes so as to minimize their transmission energy with in network and after that a node of highest energy among the top tier will transmit the aggregated data of whole network to base station. Keeping network topology same till any node of network dies another highest energy node from top most rank tier is chosen to communicate with BS. This technique achieves much improvement in system life time as compared to LEACH and PEGASIS.

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1. INTRODUCTION

A wide variety of inexpensive sensors are available those are capable of computational task and wireless communication [5, 6]. A sensor network consists of sensors that will collect useful information from environment depending on the application which can be of like measuring temperature, humidity etc.

The main constraint of sensor nodes is very low finite battery energy which limits the lifetime and quality of network, because of this fact the protocols must be designed in a way to efficiently utilize the energy of nodes to prolong the lifetime of the network. Since wireless communication consume significant amount of battery power, sensor nodes should spend as little energy as possible when receiving and transmitting data [7, 8, 9]. Network lifetime can be increased by reducing bandwidth consumption by using local collaboration among nodes & tolerate node failures.

The data generated by nodes in sensor network is too much for end user to process so methods are required to combine them into a small set of meaningful information. A simple way is data aggregation (sum, average, min, max, count) from different nodes and a more elegant approach is data fusion which can be defined as combination of several unreliable data measurements to produce a more accurate signal by enhancing the common signal & reducing uncorrelated noise [1]. The classification performed on the aggregated data might be performed by human operator or manually.

The proposed approach named as Minimum Spanning Multi Tier Protocol (MSMTP) is based on multi hop data transmission nodes to those neighbor nodes which will form minimum spanning tree (MST) for all the nodes of the network and then a node of highest energy among highest rank tier will transmit the whole network aggregated data to base station, we keep on repeating this procedure.

2. BACKGROUND

The earliest and simple approach was direct transmission in which each sensor node will sense & transmit its data to BS individually. Since base station is located far away from sensor nodes resulting higher transmission cost. Because of this high cost transmission the energy of nodes drain off faster and thus having short system lifetime.

In order to solve the problem, clustering based protocols were proposed where a cluster is a group of sensor nodes, with a head node managing all other member nodes. The heads are responsible for coordinating member nodes, gathering data within the clusters, aggregating data and forwarding the aggregated data to the base station.

LEACH [1] is a cluster-based, distributed, autonomous protocol. The algorithm randomly chooses a portion of the sensor nodes as cluster heads, and lets the remaining sensor nodes choose their nearest heads to join. The cluster member's data is transmitted to the head, where the data is aggregated and further forwarded to the base station. The LEACH algorithm reduces the number of nodes that directly communicate with the base station. It also reduces the size of data being transmitted to the base station. Thus, LEACH greatly saves communication energy. Since the protocol randomly chooses cluster heads in each round, the energy consumption is theoretically evenly distributed among all sensor nodes.

TEEN [10] adopts a similar clustering mechanism as LEACH does. It sets two thresholds, a soft threshold and a hard threshold, during the data collecting stage, to further reduce communication traffic [12].

In the PEGASIS protocol [2], a cluster is a chain based on geographical location. The PEGASIS protocol constructs all sensor nodes into a chain with the shortest length. Sensor nodes only communicate with their adjacent nodes so that they can send data at the lowest power level. In each round, the system randomly chooses a sensor node as the cluster head to communicate with the base station. Therefore, communication traffic is reduced.

The PEDAP protocol [3] further extended the PEGASIS protocol. In the PEDAP protocol, all sensor nodes are constructed into a minimum spanning tree. PEDAP assumes that the base station knows the location

information of all sensor nodes, and the base station can predict the remaining energy of any node based on some energy dissipation model. After certain rounds, the base station removes dead sensor nodes and re-computes routing information for the network. In the re-setup stage, all sensor nodes only need to receive the routing information broadcasted by the base station. Thus, the PEDAP consumes less energy than the LEACH and PEGASIS protocols in the setup stage.

The Multi-tier Trace-back Protocol (MTP) [4] is an extension to the PEGASIS and PEDAP protocols. Under the MTP protocol, each sensor node calculates its distance to the base station by evaluating the signal strength from the base station. Then, the sensor nodes are partitioned into several tiers based on their distances to the base station. Data is forwarded to adjacent tier nodes that are closer to the base station, which is similar to the PEDAP protocol. Eventually, the MTP protocol chooses a node that is closest to the base station to communicate with the base station, using a mechanism similar to the PEGASIS.

MSMTP protocol proposed in this paper is an extension to the PEDAP and MTP protocols, in this all nodes of the network will transmit the sensed information or aggregated data to their neighbor which are connected in MST structure by multi hop communication. Whole network is divided into three tiers as described in section 4-A. A node of tier1 having highest energy will transmit network's fused data to base station, and similarly a node of highest energy from lowest possible tier id is selected to transmit data to base station & in this way load is evenly distributed to all nodes of the sensor network. This will improve the overall system lifetime.

3. THE SYSTEM MODEL

4. Network Model

The protocol assumes that 100 sensor nodes are distributed randomly in the network of area 50m*50m as shown in figure 1. In addition to data aggregation, each node of the network has the capability to transmit data to other sensor nodes as well as to BS. The aim is to transmit the aggregated data to base station with minimum loss of energy which in fact increase system life time in terms of rounds. In this work we consider sensor network environment where:

- Each node periodically senses its nearby environment & likes to send this data to BS.

- BS is fixed & located far away from sensor nodes.
- Sensor nodes are homogeneous & energy constrained.
- Sensor nodes are stationary & are uniquely identified.
- Data fusion & aggregation is used to reduce the size of message in the network. We assume that combining n packets of size k results in one packet of size k instead of size nk .

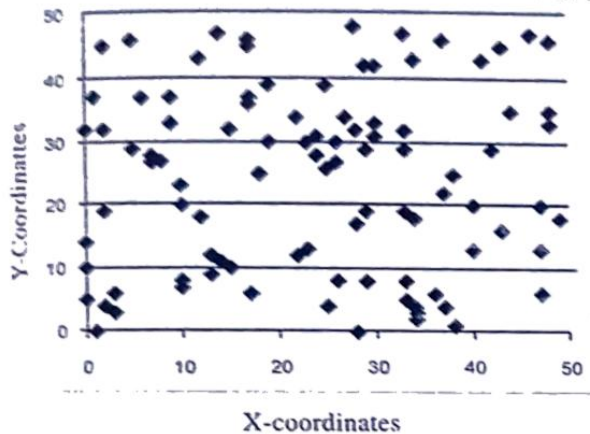


Fig. 1. Random 100-node topology for a 50m x 50m network, BS is located at (25, 150), which is at least 100m from the nearest node.

B. Radio Model

We use the same radio model as discussed in [1] which is the first order radio model. In this model, a radio dissipates $E_{elec} = 50$ nJ/bit to run the transmitter or receiver circuitry and $\hat{I}_{amp} = 100$ pJ/bit/m² for the transmitter amplifier. The radios have power control and can expend the minimum required energy to reach the intended recipients. The radios can be turned off to avoid receiving unintended transmissions. An r^2 energy loss is used due to channel transmission [10, 11]. The equations used to calculate transmission costs and receiving costs for a k -bit message and a distance d are shown below:

Transmitting

$$E_{tr}(k,d) = E_{elec}(k) + E_{amp}(k,d)$$

$$= kE_{elec} + kE_{amp}d^2 \quad \text{with in network}$$

$$= kE_{elec} + kE_{amp}d^4 \quad \text{transmission to BS}$$

Receiving

$$E_{rx}(k) = E_{rx-elec}(k)$$

$$E_{rx}(k) = E_{elec} * k$$

Receiving is also a high cost operation, therefore, the number of receives and transmissions should be minimal. as shown in Fig. 2 LEACH and PEGASIS use the same constants (E_{elec} , \hat{I}_{amp} , and k) for calculating energy costs; therefore the PEGASIS achieves its energy savings by minimizing d and the number of transmissions and receives for each node, and MSMTF protocol achieves even better results than that of LEACH and Y-Coordinates PEGASIS. In our simulations, we used a packet length k of 2000 bits. With these radio parameters, when d is 500, the energy spent in the amplifier part equals the energy spent in the electronics part, and therefore, the cost to transmit a packet will be twice the cost to receive. It is assumed that the radio channel is symmetric so that the energy required to transmit a message from node i to node j is the same as energy required to transmit a message from node j to node i for a given signal to noise ratio (SNR).

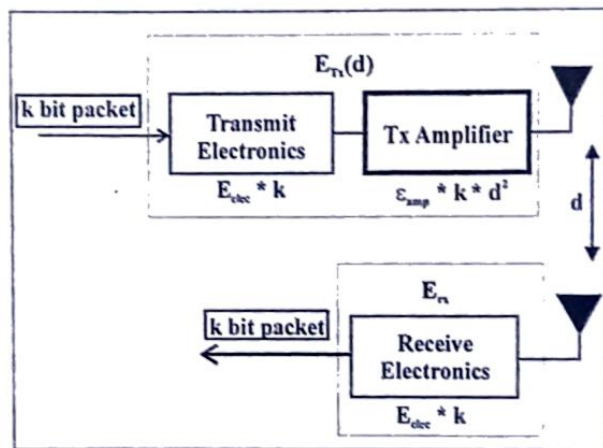


Fig. 2: Radio energy dissipation model

C. Problem Statement

In this work, our main consideration is wireless sensor networks where the sensors are randomly distributed over an area of interest. The locations of sensors are fixed and the base station knows them all a priori. The sensors are in direct communication range of each other and can transmit to and receive from the base station. The nodes periodically sense the environment and have always data to send in each round of communication. The nodes fuse or aggregate the data they receive from the others with their own data, and produce only one packet regardless of how many packets they receive.

The problem is to find a routing scheme to deliver data packets collected from sensor nodes to the base

station, which maximizes the lifetime of the sensor network under the system model given above. However, the definition of the lifetime is not clear unless the kind of service the sensor network provides is given. In applications where the time that all the nodes operate together is important, – since the quality of the system will be dramatically decreased after first node death – lifetime is defined as the number of rounds until the first sensor is drained of its energy. In another case, where the nodes are densely deployed, the quality of the system is not affected until a significant amount of nodes die, since adjacent nodes record identical or related data. In this case, the lifetime of the network is the time elapsed until half of the nodes or some specified portion of the nodes die. In general, the time in rounds where the last node depletes all of its energy defines the lifetime of the overall sensor network. Taking these different possible requirements under consideration, our work gives timings of all deaths for all algorithms in detail and leaves the decision which one to choose to system designers.

D. Sensor Node Information

MSMTP protocol partitions all sensor nodes into different tiers, according to the distance towards the base station. The system assigns a tier ID to each node during the initialization stage. Those sensor nodes having the same tier ID are treated to be in the same tier. They approximately have the same distance towards the base station, and they consume approximately the same energy to communicate with the base station. Nodes closer to the base station are assigned lower tier IDs. Section IV-A describes the details how tier ID are assigned. For a sensor node in the proposed system, adjacent nodes with lower tier IDs are called its upper tier nodes (closer to the base station), while adjacent nodes with higher tier IDs are called down tier nodes (farther off the base station), nodes with the same tier ID are called peer nodes (approximately the same distance to the base station). Data trace-back will forward a node's data to its upper tier nodes, where the data is aggregated and further forwarded to even upper nodes. Basic information of a sensor node includes location of node, node ID, tier ID, energy contained by that node, energy threshold defined, distance of node from base station & energy required by the node to transmit data to BS, which is represented in the figure 3.

X	Y	Tier_id	Node_id	Energy	Threshold	Distance	Transmission energy
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Figure 3. Structure of the node

Where X, Y represents the location of the node in the network, node ID is globally assigned and is unique; the tier ID represents the distance towards the base station, and it is determined during the system initialization; energy of node records current remaining energy of the node; the energy threshold is used to decide whether or not the node has enough energy to communicate with the base station, distance contains distance of node from base station, and transmission energy contains amount of energy required to transmit data to BS. Some factors like location of node, node ID and the tier ID, distance, transmission energy are static, remaining unchanged during the lifetime of the sensor node. The remaining energy will change during its lifetime. The energy threshold is dynamically set by the base station, which is least energy required by a node to transmit data to BS and is redefined time to time and is half of its previous value.

4. PROTOCOL DESCRIPTION

A. Tier Partitioning

The system partition the whole network into three tiers based on the distance from the base station. The least possible distance $d1$ (from middle of that side which is towards base station) & largest distance $d2$ (from that corner of the network which is on other side of base station) is calculated, and after their difference is calculated as:

$$\text{Diff} = \text{largest distance} - \text{least distance}$$

Now the nodes are assigned tier id based on their distance from base station as:

For **Tier 1**, distance is in range $d1$ & $d1 + \text{diff}/3$

For **Tier 2**, distance is in range $d1 + \text{diff}/3$ & $d1 + 2 * \text{diff}/3$

For **Tier 3**, distance is in range $d1 + 2 * \text{diff}/3$ & $d2$

B Data Transmission to BS

In this protocol, each sensor node forwards its sensed, aggregated data to that neighbor node which is connected to it in MST structure. Then a node of top most rank will transmit the aggregated data of all nodes of the network to the base station as shown in figure 4 below:

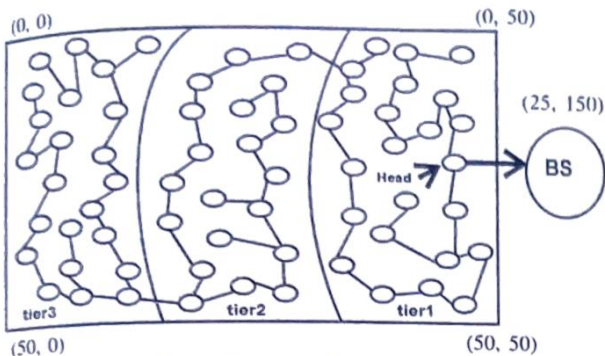


Fig. 4: Proposed Architecture when transmission is through tier1 node

Nodes of tier1 continues to transmit aggregated data to base station until all nodes of tier1 have energy greater than defined threshold level, when all nodes of tier1 have energy below threshold energy then nodes of tier2 will transmit data to base station and same procedure will be shifted to nodes of tier3. This procedure is known as TOP TIER SHIFTING as depicted in figure 5. When all nodes of tier3 have energy below threshold energy then a new threshold is defined. This procedure is continued until threshold goes below dead energy, at that moment all nodes of network are dead so the network is assumed to be dead.

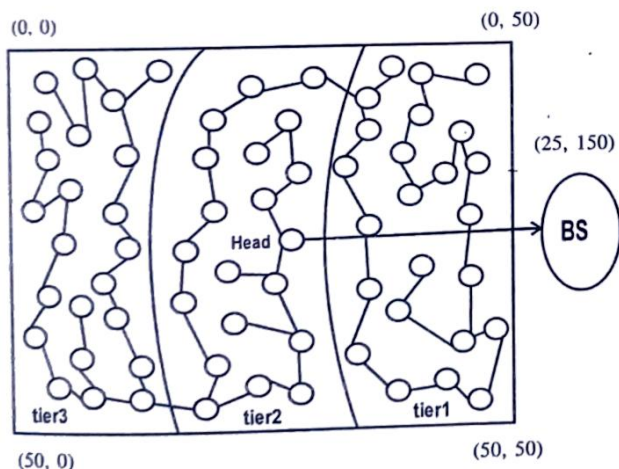


Fig. 5. Proposed Architecture in top tier shifting approach

C. Proposed Algorithm

Algorithm for the proposed routing model is as below:

- i. Distribute energy in network area keeping track of their location used to assign tier-id to them with a node closest to BS in tier1 and farthest in tier3, assign initial energy to them & calculate energy required to transmit data to BS and to nodes within network.

- ii. Generate MST of nodes arranged in form of graph to communicate data within network.
- iii. Select a Head node among tier1 of highest energy which will transmit network aggregated data to BS, having energy more than transmission energy.
- iv. Transmit data to BS and deduct energy of Head node, if energy of node is below dead energy then discard that node from network area.
- v. If no node is available in tier1 having energy more than transmission energy then increment tier id by 1 and chose a node from tier2 to transmit data to BS.
- vi. Repeat the procedure to transmit data to BS by incrementing tier-id till and when it reaches to 4 a new threshold is defined and tier-id is set to 1.
- vii. This new threshold is defined to the level until it goes beyond dead energy of a node, after this value network is considered to be dead.

5. RESULTS

In order to evaluate the performance of MSMTTP protocol, it is simulated on 100 node network as shown in figure 1. The simulations are done in c++. The BS is located at (25,150) in a 50 m*50 m field. We run the simulation to determine the round in which every node is dead. These are same parameters as used in PEGASIS protocol. Once a node dies it is considered dead for the rest of simulation, and the results shows near to optimal solution because it balances energy dissipation among sensor nodes to have full use of complete sensor network & achieves better results than PEGASIS.

Table 1. Number of rounds when 1%, 20%, 50%, 100% nodes die in the area of 50m*50m network

Energy J/Node	Protocol	1%	20%	50%	100%
0.25	Direct	54	62	76	117
	Leach	402	480	523	635
	Pegasis	788	1004	1041	1096
	MSMTTP	833	1126	1360	1406
	Direct	108	124	152	235
0.5	Leach	803	962	1036	1208
	Pegasis	1578	2011	2082	2192
	MSMTTP	1596	2510	2922	2974
	Direct	215	248	304	471
1.0	Leach	1610	1921	2055	2351
	Pegasis	3159	4023	4165	4379
	MSMTTP	3363	3853	5523	5657

Table 1 summarizes the results with initial energy per node of 0.25J, 0.5J, 1.0J for 50m * 50m network; data of previous protocols shown in table is referred from [2].

Figure 6 shows the comparison graph between various protocols when deployed with initial energy of nodes as 0.5J when 1%, 20%, 50% & 100% of nodes are dead which is represented by 1, 2, 3, and 4 respectively on horizontal axis.

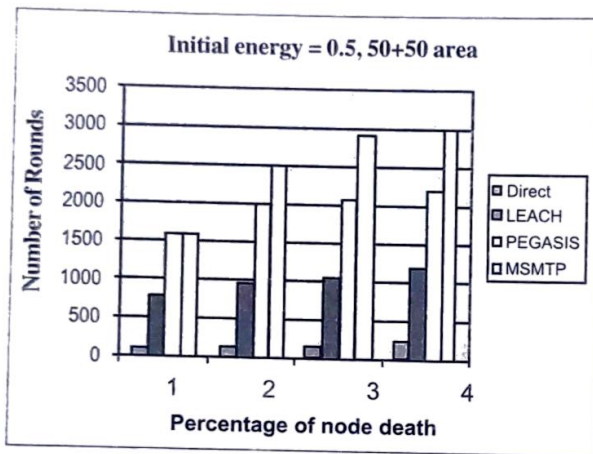


Fig. 6: Performance results for a 50m*50m network with initial energy 0.5J/node

Figure 7 compares the results of the various protocols when graph is plotted between number of rounds and corresponding dead nodes & shows that MSMTTP provides much better network lifetime at every state of network as compared to rest protocols. In this figure vertical axis shows number of rounds & horizontal axis represents number of dead nodes.

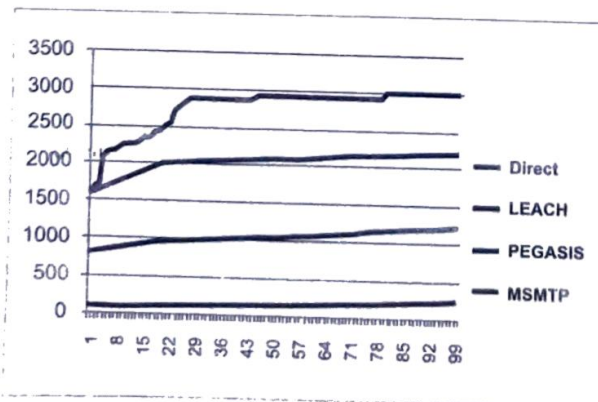


Fig. 7: Round for node death in network of size 50m * 50m

6. CONCLUSION AND FUTURE SCOPE

In this paper a routing strategy based on minimum spanning tree and tier formation of nodes is proposed, and through simulation the results are proved to be better than PEGASIS which was near to optimal routing protocol. In each round of communication construction of minimum spanning tree tries to balance the load among the nodes. The distribution of load evenly to all nodes has a great impact on system lifetime.

In the presented work homogeneous WSN has been taken which is randomly deployed, and remains static after deployment. As a future work one can think of heterogeneous WSN and incorporate mobility as well.

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