Energy- efficient Routing Protocol for Homogeneous Wireless Sensor Networks

Gaurav Bathla[#1] and Gulista Khan[#2]

[#]Department of Computer Science & Engineering, HEC, Jagadhri, India
[1]gauravbathla86@gmail.com
[2]gulista.khan@gmail.com

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 10x to 20x improvement in system life time as compare to MTP.

KEYWORDS

WSN, energy efficient, data aggregation, routing algorithm, Base station, minimum spanning tree

1. INTRODUCTION

It is possible to build inexpensive wireless micro-sensor nodes with the introduction of low-cost processor, memory, and radio technologies, it becomes. These networks can be used to collect useful information from an area of interest, especially where the corporal environment is so harsh that the macro-sensor complements cannot be deployed. They have a wide range of applications, from military to civil, that may be realized by using different type of sensor devices with different capabilities for poles apart kinds of environments.

The main constraint of sensor nodes is their very low finite battery energy, which limits the lifetime and the quality of the network. For that reason, the protocols running on sensor networks must consume the resources of the nodes efficiently in order to achieve a longer network lifetime. There is an ongoing research on power organization issues in order to reduce the power utilization when the nodes become idle. When power efficient communication is considered, it is important to maximize the nodes' lifetimes, reduce bandwidth requirements by using local collaboration among the nodes, and tolerate node failures, besides delivering the data efficiently. 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 nods 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 network's aggregated data to base station, we keep on repeating this procedure until a node possesses enough energy to transmit data to base station.

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.

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 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 [10] proposed 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 neighbour which are connected in MST structure by multi hop communication. Whole network is divided into three tiers as described in section IV-A. A node from tier1 having highest energy is taken to transmit network's fused data to base station, when it's energy is reduced below threshold then another node from next tier is taken to transmit fused data to BS, in this way load is evenly distributed to all nodes of the sensor network cause increased network lifetime.

3. THE SYSTEM MODEL

3.1 Network Model

The protocol assumes that 100 sensor nodes are distributed randomly in the network of area 100m×100m 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.

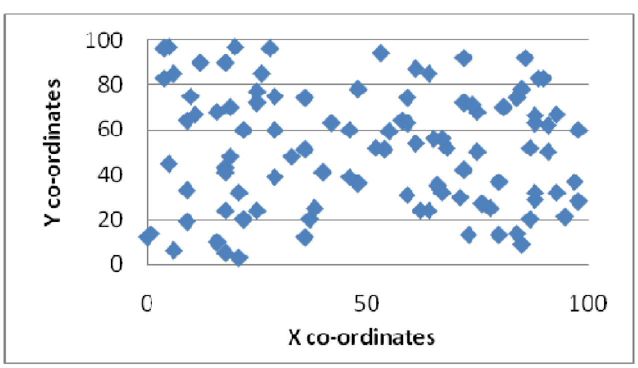

Figure 1. 100 node deployment in 100×100 m^2 area

3.2 Radio Model

We use the same radio model as discussed in [tier]. The radio energy consumption can be calculated using either the free space model or the multipath fading channel models, depending on the distance between the transmitter and receiver [11]. To transmit a *k*-bit message over a distance *d*, the radio expenses 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. The equations used to calculate transmission costs and receiving costs for a *k*-bit message and a distance *d* are shown below:

Transmitting

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

$$= \begin{cases} kE_{elec}+kE_{fr}d^2 & d <= d_0 \\ kE_{elec}+kE_{mp}d^4 & d > d_0 \end{cases}$$

Receiving

ERx(k) = ERx-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. LEACH and PEGASIS use the same constants (Eelec, Eamp, 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 MSMTP protocol achieves even better results than that of LEACH and PEGASIS because of short distance transmissions (except just one to base station). 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).

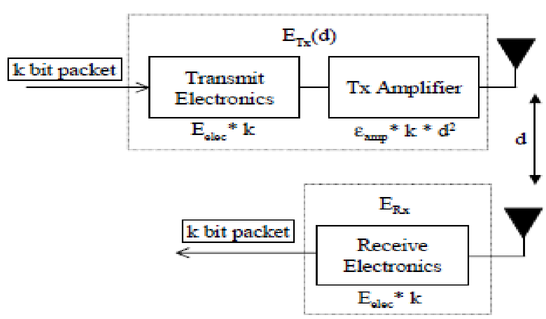

Figure 2. Radio energy dissipation model

3.3 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.

3.4 Sensor Node Information

MSMTP protocol partitions all sensor nodes into different tiers, in 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

X	Y	Tier_id	Node_id	Energy	Threshold	Distance	Transmission energy

Figure 3. Structure of the sensor 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

4.1 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:
Diff= largest distance – 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+diff/3
For **Tier 2,** distance is in range d1+diff/3 & d1+2*diff/3
For **Tier 3,** distance is in range d1+2*diff/3 & d2

4.2 Data Transmission to BS

This protocol is using architecture as proposed in [10], but here we are using network area of 100×100 m^2. Firstly each sensor node forwards its sensed, aggregated data to that neighbour 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. Nodes of tier1 continue to transmit aggregated data to base station until all nodes of tier1 have energy greater than defined threshold level.

When energy level of all nodes of tier1 goes below defined threshold energy then second part of this architecture will come into act; in this part 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. 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.

4.3 Proposed Algorithm

Algorithm for the proposed routing model is as:

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 by1 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 to1.
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

5.1 Platform Configuration

The network lifetime can be measured using three values: the time when the first node dies (FND), the time when the last node dies (LND), and the time when a half of the nodes die (HND). This paper compares the FND and LND values under the MTP and PEGASIS protocols. The simulation is done in C++. The network parameters are configured as follows:

- two network regions, with a size of *100*×*100* m^2 and 200×*200* m^2. The origin (0, 0) locates at the left bottom of the network region.
- sensor nodes are evenly distributed in the regions. There are two levels of node densities, with a total amount of *100* and *200* respectively.
- d_0 is set to be *60* m
- the tier radius is set to be a half of *d0*, *30* m. This is also the cluster radius for LEACH

- the base station is towards the right side of the network. The distance between the base station and the network is adjusted 6 times, with values of *100*, *150*, *200*, *250*, *300*, *350* respectively
- the size of data packet is *512* bytes
- the electronic power is *50* nJ/bit
- free space attenuation coefficient is *12* pJ/bit/m2
- multipath attenuation coefficient is *0.0012* pJ/bit/m4
- node's initial energy is *6.4* J
- the energy threshold is initially set to be *0.256* J. A node is treated as dead when its remaining energy is less than *0.002* J

5.2 Performance analysis

In order to evaluate the performance of MSMTP protocol, we simulated it on 100 node network as shown in figure 1. The BS is located at different locations far from the 100 m×100 m field which is at least 100 meters distant from the nearest node. Also simulations are checked when distance of base station is varied from network area & is checked at the distance of 100, 150, 200, 250, 300, 350 from the nearest node of the network. Previous results are referred from [4]. We run the simulation to get the round in which every node is died. Once energy of a node goes below defined dead energy level it is considered to be dead for the rest of simulation, and our 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 MTP.

Figure 4 and Figure 5 show the relationship between time (rounds of data collecting) and the number of dead nodes. Both use the 100×100 m^2 network region. The base station is located 100 m towards right side of the network. In Figure 4, 100 sensor nodes are randomly placed in the region. The node density of Fig. 5 is twice of Fig. 4.That is, 200 sensor nodes are put in the network region in Figure 5. The result shows that proposed approach achieves 10x to 20x improvement than MTP protocol when 100 nodes are deployed in the network area. Also it is shown that in case of MTP protocol when first node dies, system is going to be dead very soon but in proposed scheme system have much life even after first node is dead.

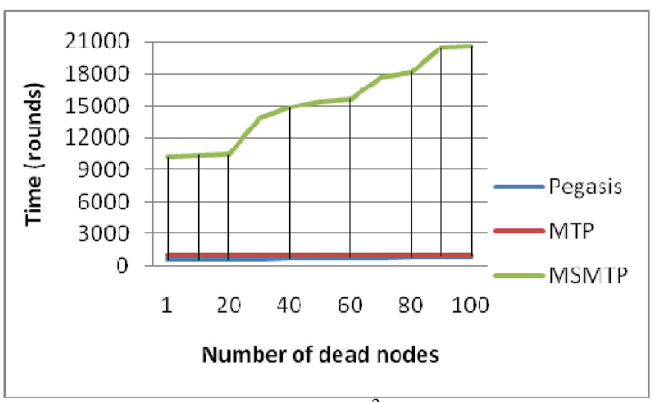

Figure 4. 100×100m^2, 100 nodes

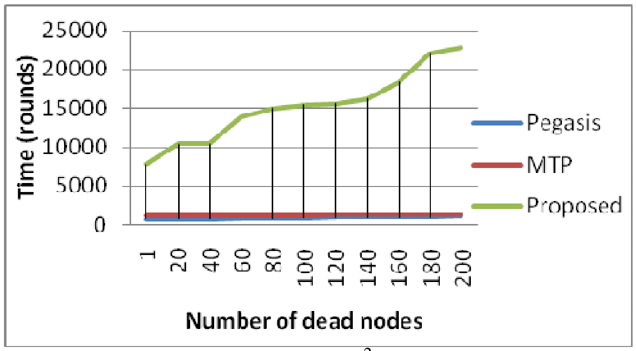

Figure 5. 100×100m^2, 200 nodes

Figure 6 and 7 shows the relationship between the network lifetime and the distance of the base station. When the base station is located far away from the network, the lifetime reduces under all protocols. Our paper is based on MTP but because of generation of minimum spanning tree for communication among nodes of the network; we got better results than previous protocols. Major advantage of proposed protocol is increased network stable life time i.e. the time when all nodes of the system are alive, also the overall life of proposed solution is better than existing protocols.

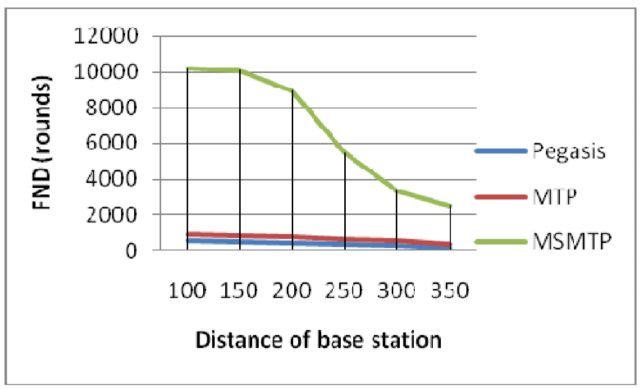

Figure 6. FND vs. Distance of base station

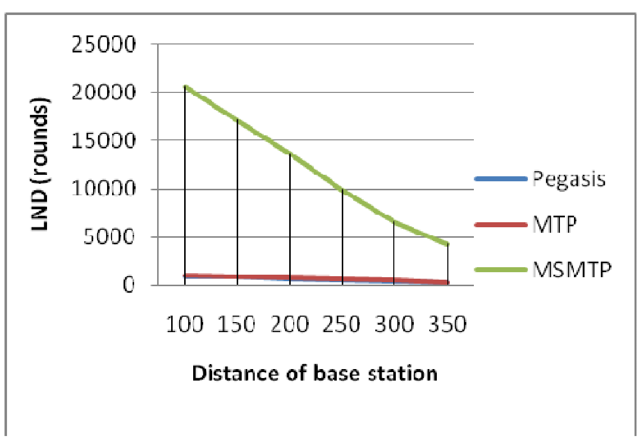

Figure 7. LND vs. Distance of base station

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 better than MTP which was near to optimal routing protocol. In each round of communication generation 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. Also we have taken homogeneous WSN which is randomly deployed, and remains static after deployment. Proposed algorithm assumes that sensor nodes are randomly placed in the network, and the network has good connectivity. So some nodes will become the key nodes to connect multiple components in the network. If those key nodes die, other nodes have to increase their amplifier power level to gain the connectivity. Our future research is to find those key nodes and prolong their lifetimes also we can think about heterogeneous WSN and mobility as well.

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Authors

Gaurav Bathla born in yamunanagar in India, on August, 19, 1986. He completed his B. Tech. from JMIT, Radaur in 2007. He completed Post Graduation (M. Tech.) from MMEC, Mullana in 2010. Presently he is working as Lecture in the Department of Computer Science and Engineering at Haryana Engineering College, Jagadhri, Haryana (India). His fields of interest lie in Wireless Sensor Networks.

Gulista Khan born in India, on September, 30, 1985. She completed his B. Tech. from Shri Krishan Institute of Engineering And Technology, Kurukshetra in 2006. She completed Post Graduation (M. Tech.) from MMEC,Mullana in 2009. Presently she is working as an Lecturer in Haryana Engineering College,Jagadhri, Haryana (India).