An Energy-Aware Aggregation Tree Scheme in Sensor Networks

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Summary
This paper presents a routing scheme for wireless sensor networks. We use an aggregation tree for sending the data from the sensor node to the base station. For an energy efficient operation of the sensor network in a distributed manner, an aggregation tree is built in order to minimize the total energy required to send data from the individual sensor nodes to the base station. An aggregation tree is a data gathering tree where the base station is the root and each sensor node is either a relaying or a leaf node of the tree. Through simulation, we found that the routing scheme that uses aggregation trees shows longer-lived characteristics when compared with other routing schemes.
Keywords: *sensor network, energy-aware routing, aggregation tree.*

1. Introduction

Recent developments in micro-electronics have enabled sensor nodes which have low-power, low-cost, high-performance processing characteristics, along with sophisticated communication facilities. These devices can gather information about their surrounding environment once they have been deployed in small or large areas. These are generally referred to as Wireless Sensor Networks (WSN) [1][2].

One of the most important constraints in sensor networks is their energy capacity. Usually, a sensor node is deployed in broad areas with a small battery attached to it. Sometimes, the node can receive its power from the environment (such as solar power), but more often, nodes are energy-bound. In such conditions, a more energy efficient sensor network is required that effectively overcomes the energy problem.

Also, as many nodes are deployed in a wide area and many geographical or organic obstacles can be encountered in sensor network environments, flexibility and reliability are particularly important. For instance, the weather can frequently change, a new obstacle can affect the operating status of the node, or any other adverse condition, resulting in the connections between nodes to frequently be on and off. Hence, a highly reliable network and routing technology are paramount requirements so that link or node failures of indefinite duration cannot affect the overall operation.

In this paper, we develop a new routing scheme for sensor networks. It is energy efficient in that it can significantly reduce the energy consumed compared to other implementations. Further, we introduce a scheme to increase the operational lifetime of the most important sensor nodes.

2. Related Works

A sensor node can communicate with the base station directly or through the cluster head, or through other relaying nodes. In a *direct communication scheme*, each node communicates directly with the base station. When the sensor network is large, the energy for communicating with the base station is correspondingly large. Hence, some nodes far apart from the base station will quickly run out of energy.

The other scheme is the *clustering scheme*, where the nodes are grouped into clusters and one node of the cluster is made to carry all data from the nodes in its group to the base station. The LEACH (Low-energy Adaptive Clustering Hierarchy) is a self-organizing and adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensor nodes [3]. In the LEACH scheme, the nodes organize themselves into a local cluster and one node behaves as a local cluster head. LEACH includes a randomized rotation of the high energy cluster head position such that it rotates among the sensors. This feature leads to a balanced distribution of the energy consumption to all nodes and makes it possible to have a longer lifetime for the entire network. Another version of LEACH, called LEACH-C [4], performs cluster formation at the beginning of each round using a centralized algorithm by the base station. This may produce better performance by evenly dispersing the cluster head nodes throughout the network.

Many versions of cluster head selection algorithm have been developed. In [5], Guru *et al.* made some improvement to LEACH by merging multi-hop overlapping clusters. Further, instead of each cluster head directly transmitting data to remote base station, it does so via a cluster head closer to the base station. In [6], Chen elects cluster heads with more residual energy through local radio communication while achieving a good cluster head distribution. Furthermore, it introduced a method to

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balance the load among the cluster heads. A hierarchical clustering scheme selects region nodes from clustering heads, making it possible to reduce the energy and the cost of organizing and managing sensor networks efficiently for large scale WSNs based on the residual battery capacity of nodes [7].

In minimum energy routing scheme, each node communicates with its neighbor node so as to minimize the cost of the total communication. The energy includes the transmission energy and the receiving energy of all the nodes which lie in the path to the base station. Some schemes consider transmitting energy only [8], while others consider both [9]. Often, the direct communication is cheaper than the minimum energy scheme when we consider the transmitting and receiving energy together. In [10], Albert introduces a heuristic-based aggregation tree algorithm that approximates the optimal weighted Steiner tree for a given aggregation efficiency and cost. The power of the node is an important consideration in routing in sensor networks. To maximize the lifetime of sensor networks, [11] proposes a source-initiated routing protocol, [12] proposes a new metric, the drain rate, to be used in conjunction with residual battery capacity to the current traffic conditions.

3. Aggregation Tree and its Routing algorithm

An aggregation tree is a data gathering tree that connects the base node and all sensor nodes of a network. A root node in the tree is a base station in the WSNs to which all nodes should send the data they gather. All nodes in the network are located either at the relaying or a leaf node of the tree. There can be more than one base station. In that case, an independent and separate tree for each base station exists. If each base station uses one virtual address, only one aggregation tree will exist.

3.1 Energy Model

Our energy model of the wireless network is based on the basic first order model of the following:

$$DeliveryEnergy = E_{tx} + E_{rx} \quad (1)$$

$$E_{tx} = k * E_{tp} = k * d^r * E_{rtp} \quad (2)$$

$$E_{rx} = k * E_{rp} \quad (3)$$

E_{tx} is the required transmission energy of a node, E_{rx} is the required receiving energy for a node. E_{tx} is proportional to the length of the message *k*, and to the transmission power E_{tp}. If *d* is the distance between nodes, E_{rtp} is the receiving threshold energy for a required quality, then E_{tx} can be rewritten as (2) with r as 2. E_{rx} is proportional to the length k of the message and the receiving energy E_{rp}.

3.2 Algorithm for the Aggregation Tree

An aggregation tree can be built in several different ways. A *least transmitting power aggregation tree* would select the nearest neighborhood node as a parent at each node. A *shortest path aggregation tree* is made up of the shortest hops from the root to the sensor node. A *least delay aggregation tree* selects the node having the least delay to the base station as a parent of the tree. A *maximum power parent aggregation tree* selects the node having the largest remaining energy as a parent of the tree. The tree that proposed in this paper is a tree that is based on the minimizing aggregated energy required for sending data from each sensor node to the base node.

All tree algorithms have the same structure but have different metrics and cost measures. At first, the root node broadcasts a message including the root node id, sequence number, metric, cost, hop counts, delays, and remaining energy. All nodes receiving this message make the base station as parent. Then the node increases the hop count by one, adds some values to the cost, and replaces the energy values as its own remaining energy value and floods it again. When a node receives many messages from its neighbors, the node chooses the least cost node as its parent. As messages go through, the hop counts, cost, delays are accumulated at each node and remaining energy is replaced by its own remaining energy.

Tree messages are regularly broadcast from the root node and flooded to the child nodes. And, if the cost from the parent is changed, the node floods a new tree messages to the child nodes with newly updated costs. Each node receiving tree messages performs the following algorithm. All nodes are supposed to be able to communicate directly in their neighborhood with more than one node, and are reachable from the root node.

Table 1: Basic Aggregation Tree Algorithm

1. Update received tree message information to the target routing table,
2. If there is no update about smallest cost and parent, just return,
3. If there is a node short of energy, just return,
4. If there is update with the cost but with same parent, flood a new tree message to children node with new costs, and return,
5. If there is an update about the smallest cost with a new parent, establish a new parent relationship and release the parent relationship with current parent. When complete, flood a new tree message with new parent information and cost value, and return.

In a shortest path aggregation tree, every node establishes a parent-children relationship with the farthest node in its neighbor. The cost is the accumulated hop count from the base station. If there are many parents that have the same hop counts, then the node selects one parent from them. In a minimum transmission power aggregation tree, the cost is the transmission power of the node. This makes the node remain in the lowest transmitting energy state. In a lowest delay aggregation tree, the cost is the accumulated delay to the base station, which minimizes the total delay of the delivering data.

In a maximum power parent aggregation tree, the cost is the remaining energy of the node, which makes the node remain in a longer parent-children relationship state. In an energy-aware aggregation tree, the metric is the required sending energy to the parent. Alternatively, the metric in this scheme can be the square distance to the neighborhood node. The cost of this scheme is the accumulated consuming delivery energy of the message along the path, which allows the network to remain operational for a longer period of time.

3.3 Operation at Energy-Aware Aggregation Tree Algorithm

For a correct operation of this algorithm, each node of the sensor network behaves as follows:

1. Increase the transmission energy until we can find more than one neighbor node.
2. Make a neighborhood relationship with such nodes
3. Process incoming tree message and flood it neighbor node
4. Send a new tree message to the children if the cost changes.

When a sensor node starts operating, the node must find a neighbor node first. When it operates as a leaf node, a single neighbor node could be sufficient. However, if the node operates as a parent node or wants to discover multiple paths to the base station, the node must find more than one neighbor node. Therefore, the node starts to operate from the minimum transmission power to the highest power until it finds more nodes around it. If the node finds neighbor nodes, the setup for the operation of the sensor network is completed.

Now, the target base station broadcasts tree message to all of its neighborhood nodes. All nodes that receive this broadcasting message perform the previously defined aggregation tree algorithm for the specified target.

In our proposed aggregation tree routing scheme, the cost is defined as follows:

$$Cost = \sum_{allpaths}(E_{tx} + E_{rx}) = \sum_{allpaths} k*(d^2 * E_{rtp} + E_{rp}) \quad (4)$$

A target node is a base node that connects the wired network and the sensor network. Through this gateway station, all nodes of the sensor network can be accessed from the node of the application which is currently running. There can be more than one such base station. If there are two or more base stations, each base station uses different node addresses or one virtual address. If the node is different, each sensor node has a different routing target and has a different aggregation tree. If they use the same virtual address, only one routing target exists and there is one virtual aggregation tree in the network.

Forming an aggregation tree is initiated by sending a tree message from the root node. This message is transferred to all neighboring nodes, and flooded again after processing algorithm at each node. There is a target node identifier and a sequence number in the tree message, so duplicated messages are not delivered again to the neighboring node. Other important information in the tree message are metric, accumulated cost, hop counts, energy level, etc. As the tree message is forwarded, the aggregation tree is formed. The root node broadcasts tree messages periodically. If there is any change in the aggregation tree, the node prepares a new tree message and floods it to the children nodes.

If an aggregation tree is formed, the gathering information from the sensor node is sent to the base station through the tree. Every sensor node routes data to the parent node when they receive data from the child node. The aggregation tree information is implemented in the routing table at each sensor node. If a base station needs to send data to a sensor node, it can use broadcast or multicast. If broadcast is used, all neighbor nodes receive it using the same broadcast channel. If multicast is used, the node sends the data using the channel between parent and child nodes. It may use one multicast channel, or use separate channels between parent and child nodes.

3.4 Operation at Energy-Aware Aggregation Tree Algorithm

Usually, a parent node that has many children will run out of energy shortly because it must send much data come from the child nodes. In order to guarantee a reasonable life time for the sensor node, the node must remain as a leaf without actively relaying data. Hence, when the energy of a node is not sufficient, the node participates only as a leaf, sending only the data it gathered on its own. Therefore, the node algorithm of Fig. 1 can be changed as follows:

Table 2: Energy-Aware Aggregation Tree Algorithm

3. Compute $E(n,t) < E_{txA}(n,t) * (T_t - t)$. If true, just return.

Here, $E(n,t)$ is the energy of node *n* at time *t*, $E_{txA}(n,t)$ is the average sending energy used by a node during a unit time, T_t is the target life time for each sensor node. This scheme does not guarantees the exact working time because $E_{txA}(n,t)$ can be increased as time passes. The parent node will stop working as a relaying node when it is low on power. Then, the node should find another node with which to establish a parent relationship. If we change E_{txR} as a required transmitting energy to the root node in a specified time, $E_{txA}(n,t)$, then we can guarantee the life time for that node to be much longer. As a result, $E(n,t) < E_{txA}(n,t) * (T_t - t)$ is the limit of the longest life time, and $E(n,t) < E_{txR} * (T_t - t)$ is the limit of the shortest life time. In our model of the sensor network, the sensor node does not move, and E_{txR} is always constant.

Even if we are not choosing a specific target time to the sensor node, we can control the lifetime of the specific sensor node by setting the node remains as only in a leaf state. This is done by setting some specified energy amount or specified percentage of the total initial level. If the remaining energy of the sensor node remains under that level, the node changes its state to that of leaf node. Then, the lifetime of the node can be increased.

4. Simulation Results

We used a stand alone Java simulation program for the simulation of the proposed scheme for the sensor node. Our sensor network consists of 100 nodes with a single base station. The nodes are randomly dispersed in a grid form of 10x10 square fields. Our cost is a total consuming energy for delivery the gathered data to the base station. We do not consider data aggregation at sensor node as in LEACH. The gathered data is simply delivered to the base station one-by-one. The initial node energy is 0.5J and the simulation time is 2,000,000 unit times. We compared our proposed aggregation scheme (AGGTREE) with a 3-LEVEL hierarchical scheme and the centralized LEACH scheme (LEACH-C).

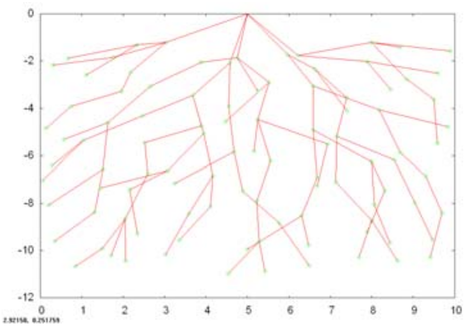

Fig. 1 Aggregation Tree Deployment

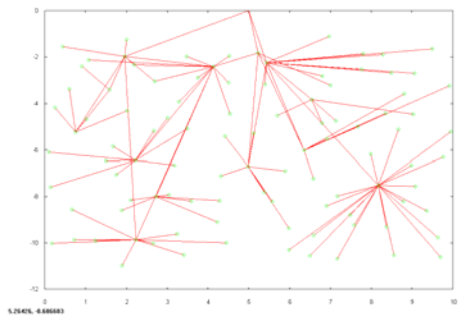

Fig. 2 3-LEVEL Scheme Deployment

Fig. 1 is the initial shape of the aggregation tree in the proposed scheme. The root node is the base station and 5 nodes are the children node of the root node in the figure. With time, the energy level of some nodes are decreased and they stop relaying the data coming from other node and remain only in the leaf state. If there is no relaying node around it, the sensor node attemps to increase the transmit power and search for more nodes. Fig. 2 is the deployment shape obtained with 3-LEVEL hierarchical scheme that we compared with our scheme. In 3-LEVEL hierarchical scheme, there is a region node between base station and cluster head node. A region node aggregates some cluster head data and sends to the base station. In LEACH-C scheme, each cluster node selected by a base station aggregates data of the neighbor sensor node and sends to the base station.

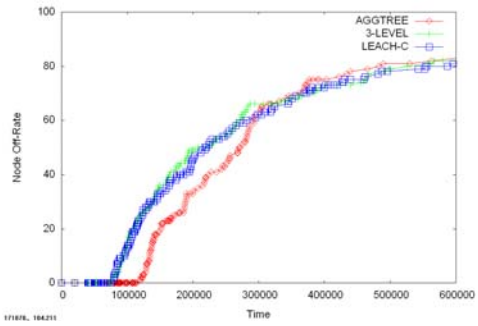

Fig. 3 Node Off-Rate of the Network

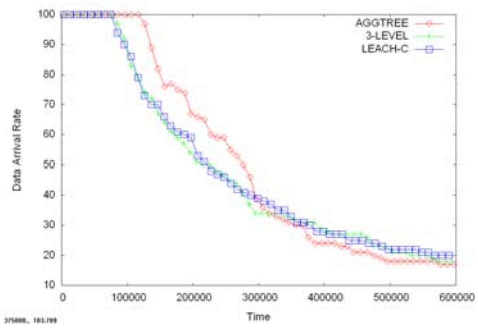

Fig. 4 Data Arrival Rate from Nodes

Fig. 3 shows how many sensor nodes stop working with time. After 60,000 units of time, the sensor node of the LAECH-C and 3-LEVEL scheme stops working. The results of the LEACH-C and 3-LEVEL are similar. We can see from this figure with more than 1.5 times longer than the sensor node of the AGGRTREE scheme stops working. We can see similar results from the Fig. 4. It is the counts of the receiving data from all the sensor nodes. All sensor nodes periodically send data to the base station at predetermined intervals. They continued to sending data until they stop working. So, the receiving data rate represents the number of working and connected nodes to the base station at that time.

In the LEACH-C scheme, the node far from the base station stops working first. In the AGGTREE scheme, the node near the base station stops working first if there is no energy guaranteeing strategy. The energy level of the LEACH-C scheme decreased fast in some nodes with time. In AGTREE scheme, they operated one and half times longer than the node of the LEACH-C scheme.

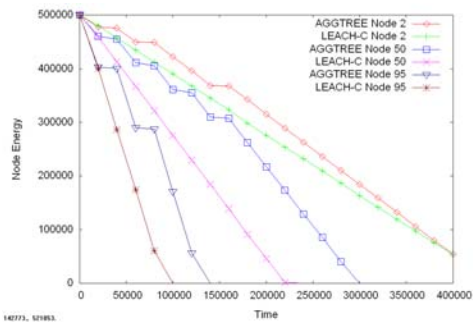

Fig. 5 Node Energy Comparison

The AGGTREE scheme shows an improvement of about 50% in node energy over than in the LEACH-C mode when we check the time of the first stopping node. From Fig. 5, node 95 stops working at 100,000 units of time in the LEACH scheme while the node are still working until in the 150,000 in AGGTREE scheme.

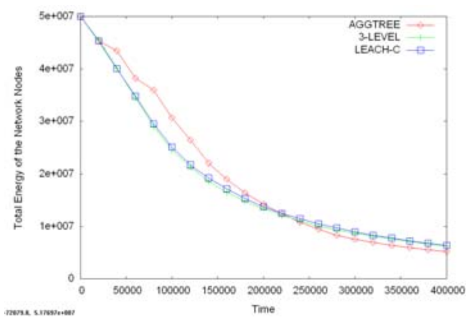

Fig. 6 Total Energy of network Nodes

In Fig. 6, we can see that there is more remaining energy in the total node energy in the AGGTTEE scheme from time between 500,000 to 1,000,000 units of times. After the 2,000,000 units of time, the total energy of all sensor nodes is under the LEACH-C and 3-LEVEL scheme. However, the most important region is in the middle range of the deployment duration. We can see from Fig. 3 and Fig. 4 that all nodes are working until the middle range of the deployment duration in the AGTREE scheme whilst some nodes are start to stop working in the LAECH-C and the 3-LEVEL scheme.

5. Conclusions

In this paper, we proposed a routing scheme for the sensor networks. We observed some energy improvement when the network use the aggregation tree routing algorithm compared to the LEACH-C and 3-LEVEL hierarchical scheme. This improvement is comes from the energy model of the sensor networks.

The LEACH scheme is a simple and good scheme for gathering the data from the sensor networks. However, it has some limitations with the size of the sensor networks. The aggregation Tree scheme would be a good solution for large sensor networks. Further, if we control the operating state of each sensor node, we can manage the lifetime of sensor nodes efficiently for the gathering of environmental data effectively.

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