Modify LEACH Algorithm for Wireless Sensor Network

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Abstract

Research on wireless sensor networks has recently received much attention as they offer an advantage of monitoring various kinds of environment by sensing physical phenomenon. Prolonged network lifetime, scalability, and load balancing are important requirement for many sensor network applications. Clustering sensor nodes is an effective technique for achieving these goals. In this work, we introduce an energy efficient clustering algorithm for sensor networks based on the LEACH protocol. LEACH (Low Energy Adaptive Clustering Hierarchy) is one of popular cluster-based structures, which has been widely proposed in wireless sensor networks. LEACH uses a TDMA based MAC protocol, and In order to maintain a balanced energy consumption. The proposed protocol adds feature to LEACH to reduce the consumption of the network resource in each round. The proposed protocol is simulated and the results show a significant reduction in network energy consumption compared to LEACH.

Keywords: *Wireless sensor networks, hierarchical Clustering , LEACH protocol, network lifetime*

1. Introduction

Microsensor network consist of many spatially distributed sensors, which are used to monitor various kinds of ambient conditions like temperature, humidity, etc and then transform them into electric signal. A sensor is equipped with a radio transceiver, a small microcontroller, and an energy source, usually a battery. Usually sensors are physically small and inexpensive. Small sensors are not as reliable as more expensive macrosensors, but small size and small cost of an individual sensor, allow production and deployment in large numbers. A wireless sensor network contains hundreds or thousands of these sensor devices that have ability to communicate either directly to the Base Station (BS) or among each other. The nodes in WSNs are usually battery operated sensing devices with limited energy resources and replacing or replenishing the batteries is usually not an option. Thus energy efficiency is one of the most important issues and designing power efficient protocols is critical for prolonging the lifetime. Usually, sensor nodes are scattered in the sensing field, being the area where we want to monitor some ambient conditions. Sensor nodes have to coordinate among themselves to get information about the physical environment. The information collected by sensor nodes is routed to the Base Station either directly or through other sensor nodes. The Base Station is a fixed node or mobile node, which is capable to connect the sensor network to an infrastructure networks or to the Internet where users can access and process data.

Routing in WSNs is very challenging due to the specific characteristics that distinguish WSNs from other wireless networks such as wireless ad hoc networks or cellular networks. Many new algorithms have been proposed, taking into consideration the inherent features of WSNs along with the application and architecture requirements.

Based on the network structure adopted, routing protocols for WSNs can be classified into flat network routing, hierarchical network routing, location-based network routing [3].

In flat network routing, all nodes have the same functionality and they work together to perform sensing and routing tasks.

The Sensor Protocols for Information via Negotiation (SPIN) [4] and Directed Diffusion [5] fall into this category. Hierarchical network routing divides the network into clusters to achieve energy-efficient, scalability and one of the famous hierarchical network routing protocol is low-energy adaptive clustering hierarchy (LEACH) [1]. In location-based network routing, location information of nodes is used to compute the routing path. This information can be obtained from global positioning system (GPS) devices attached to each sensor node. Examples of location-based network routing protocols include geography adaptive routing (GAF) [1] and Geographic and Energy-Aware Routing (GEAR) [6].

During the creation of network topology, the process of setting up routes in WSNs is usually influenced by energy considerations. Because the power attenuation of a wireless link is proportional to square or even higher order of the distance between the sender and the receiver, multi-hop routing is assumed to use less energy than direct communication. However, multi-hop routing introduces significant overhead to maintain the network topology and medium access control. In the case that all the sensor nodes are close enough to the BS, direct communication could be the best choice for routing since it reduces network overhead and have a very simple nature. But in most cases, sensor nodes are randomly scattered so multi-hop routing is unquestionably defacto. Many research projects and papers have shown that the hierarchical network routing and specially the clustering mechanisms make significant improvement in WSNs in reducing energy consumption and overhead [7, 8] also have to note that most of clustering protocols proposed for WSNs assume that nodes are stationary. The reason for sensor nodes to be taken as stationary is the assumption of simple network topology. Clustering protocols can reduces signaling overhead since they do not have to manage the mobility pattern or location information of sensor nodes. As a result, it allows nodes saving more energy leading to a longer network life time. However, with some applications such as animal tracking, search and rescue activities this assumption is not very realistic; hence there are raising demands for clustering protocols to support mobile nodes.

Clustering network is efficient and scalable way to organize WSNs [1, 2]. A cluster head responsible for conveying any information gathered by the nodes in its cluster and may aggregate and compress the data before transmitting it to the sink. However, this added responsibility results in a higher rate of energy drain at the cluster heads. One of the most popular clustering mechanisms, LEACH, addresses this by probabilistically rotating the role of cluster head among all nodes. However, unless each node selects its probability of becoming a cluster head wisely, the performance of the network may be far from optimal. The main focus of this paper is modifying LEACH clustering algorithm. This algorithm fully utilizes the location information of network nodes in routing to reduce the routing cost.

2. Related Work

Clustering is the method by which sensor nodes in a network organize themselves into hierarchical structures. By doing this, sensor nodes can use the scarce network resources such as radio resource, battery power more efficiently. Within a particular cluster, data aggregation and fusion are performed at cluster- head to reduce the amount of data transmitting to the base station. Cluster formation is usually based on remaining energy of sensor nodes and sensor's proximity to cluster-head [1]. Non cluster-head nodes choose their cluster-head right after deployment and transmit data to the cluster-head. The role of cluster-head is to forward these data and its own data to the base station after performing data aggregation and fusion. LEACH is one of the first hierarchical routing protocols for WSNs. The idea proposed in LEACH has inspired many other hierarchical routing protocols [9, 10].

2.1 LEACH and LEACH-C

LEACH (Low-Energy Adaptive Clustering Hierarchy), an energy-conserving routing protocol for wireless sensor network, was proposed by Heinzelman, Chandrakasan and Balakrishnan [1].

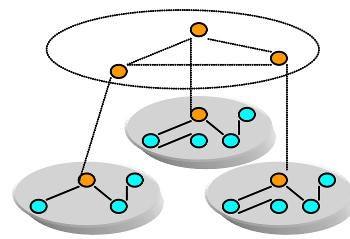

Fig.1 Structure of clustered WSNs.

The idea is to form cluster of sensor nodes based on signal strength and use the cluster-head as a router to forward data of other nodes in cluster to the base station. The data processing is performed at cluster-heads. LEACH is a dynamic clustering mechanism. Time is divided in rounds/intervals with equal length. At the beginning of the round, cluster-heads is generated randomly among the nodes which have remaining energy higher than the average remaining energy of all the nodes.

Each sensor node *n* generates a random number such that 0< random < 1 and compares it to a pre-defined threshold *T (n)*. If random < *T (n)*, the sensor node becomes cluster-head in that round, otherwise it is cluster member.

$$T(n)=\frac{P}{1-P\left(r \bmod \frac{1}{P}\right)} \qquad \forall n \in G \tag{1}$$

In this formula, *p* is the percentage of cluster heads over all nodes in the network, i.e., the probability that a node is selected as a cluster head; r the number of rounds of selection; and G is the set of nodes that are not selected in round 1/p. As we can see here, the selection of cluster heads is totally randomly.

After becoming clusterheads, the nodes broadcast messages to all nodes to inform the status of them. Non cluster-head nodes decide which clusterhead to join based on the receiving signal strength of these messages.

The cluster-heads create schedules and send to all the nodes in the clusters. For the rest of the round, the nodes send data to their respective cluster head nodes, then the cluster-heads aggregate and send the data to the base station.

After each round, clusters-heads are re-generated to form new clusters. The cluster-head rotation allows network to spend energy equally between sensor nodes and hence it can lengthen the sensor network life time.

LEACH-centralized (LEACH-C) [1] is similar to LEACH in operation except cluster formation. In LEACH-C, the cluster head selection is carried out at BS. During the setup phase, BS receives from other nodes information about their current locations and remaining energy levels. BS uses the remaining energy level to determine the candidate set for cluster head node. The average node energy is computed and the node has remaining energy falling below this value will be removed from the candidate set.

Using the candidate set, BS finds clusters using the simulated annealing algorithm [11] to solve the NP-hard problem of finding *k* optimal clusters [12]. This algorithm attempts to minimize the total energy that noncluster head nodes use to transmit their data to cluster head nodes by minimizing the total sum of squared distance between nodes and their cluster head nodes. Once the cluster head nodes are determined, BS broadcast to all nodes the information including cluster head nodes, clusters member node and transmission schedule for each cluster. Nodes use this information to determine its TDMA slot for data transmission.

2.2 Disadvantages of LEACH

Despite the obvious advantages in using LEACH protocol for cluster organization, few features are still not supported. LEACH assumes a homogeneous distribution of sensor nodes in the given area. This scenario is not very realistic. Let us consider a scenario in which most of the sensor nodes are grouped together around one or two cluster-heads. As being shown in Figure 2, cluster-head a have more nodes close to it's than the other cluster-heads. LEACH's cluster formation algorithm will end up by assigning more cluster member nodes A. This could make cluster head nodes a quickly running out of energy.

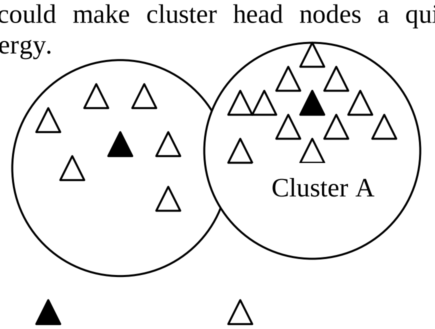

Fig.2 A Sensor Network.

In addition, cluster heads are randomly selected, it is possible the scenario illustrated in Figure 3 occurs, in which two or even more cluster heads are very close to each other.

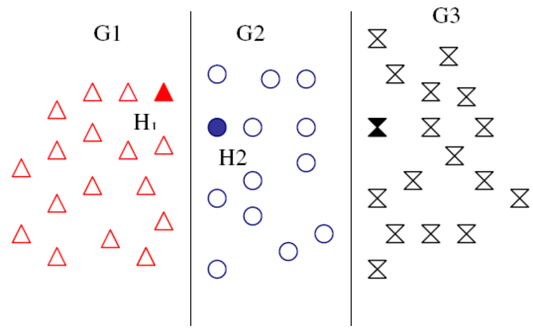

Fig.3 Multiple Cluster-head in small region.

In Figure 3, H1 and H2 are two cluster heads, nodes ▲ and ● are their cluster members, respectively. H1 and H2 are very closely located. According to data communication model, the energy that a cluster head consumes is the sum of that consumed in receiving data and that in sending data.

$$E_{ch} = L\,E_{bit}\,N_{mem} + L\,E\,(N_{mem} + 1) + L\,E_{bit} + L\,m\,d_{to\,Bs} \quad (1)$$

where L is the length of data, m the power consumption of transferring 1 bit of data, E_{bit} the power consumption of processing 1 bit of data, N_{mem} the number of members in a cluster, $d_{to\,Bs}$ the distance between the cluster head and node Sink, $LE_{elec}N_{mem}$ the power that N_{mem} cluster members consume when each of them send out length of l data to the cluster head, and LEN_{mem} the power that the cluster head consumes when it receives data of length l from its cluster members. It follows from (1) that the amount of energy that cluster heads H1 and H2 consume during data transfer is:

$$E_{h1} = LE_{bit}N_{mem1} + LE\,(N_{mem1} + 1) + L\,E_{bit} + L\,m\,d_{h1\,to\,BS} \quad (2)$$
$$E_{h2} = LE_{bit}N_{mem2} + LE\,(N_{mem2} + 1) + L\,E_{bit} + L\,m\,d_{h2\,to\,BS} \quad (3)$$

Where N_{mem1} and N_{mem2} the number of members in clusters H1 and H2, d_{h1toBs} and $d_{h2to\,Bs}$ the distance between the two cluster heads and node Sink, Therefore, the total energy consumed by the two clusters is:

$$E_{h1} + E_{h2} = L\,E_{bit}\,(N_{mem1} + N_{mem2}) + LE\,(N_{mem1} + N_{mem2} + 2) + 2LE_{bit} + L\,m\,(d_{h1toBS} + d_{h2toBS}) \quad (4)$$

When H1 and H2 are very close, we can have

$d_{h1toBS} = d_{h2toBS}$

Then (4) becomes

$$E_{h1} + E_{h2} = LE_{bit}(N_{mem1} + N_{mem2}) + LE(N_{mem1} + N_{mem2} + 2) + 2LE_{bit} + 2Lm\,d_{h1toBS} \quad (5)$$

As we can see, in this case the total energy consumption of two clusters is only $LE_{bit}+Lmd_{h1tobs}$ greater than the case that there is only one cluster head. In addition, because $LE_{bit}+Lmd_{h1tobs}$ is much greater than therefore, the total energy consumption when there are two cluster heads is approximately twice of that when there is only one cluster head.

It is clear now that when multiple cluster heads are randomly selected within a small area, a big extra energy loss occurs. The amount of lost energy is approximately proportional to the number of cluster heads in the area. Of course, there is a precondition on this conclusion, that is, cluster heads are very closely located and the distance between them becomes negligible.

3. PROTOCOL PERFORMANCE

LEACH protocol is suitable for the WSNs under the following assumptions:

1. All senor nodes are identical and charged with the same amount of initial energy. All nodes consume energy at the same rate and are able to know their residual energy and control transmission power and distance. Every node has the capability to support different MAC protocol and data processing. All communication channels are identical. The energy consumption of transferring data from node A to node B is the same as that of transferring the same amount of date from node B to node A.

2. Every node can directly communicate with every other node, including the sink node.

3. The Sink node is fixed and far away from the wireless network. Thus we can ignore the energy consumed by the sink node. We assume that it always has sufficient energy to operate.

4. Every node has data to transfer in every time frame. The data transferred by sobering nodes are related and can be fused.

5. Sensor nods are static.

WSNs are autonomous networks. Sensor nodes are independent with each other. The coordination between nodes is done through wireless communication, which costs much. This is one of the major reasons that the LEACH protocol selects cluster heads randomly. As we discussed before, this approach may cause the waste of energy because of unbalanced cluster head distribution. To solve this problem, we propose a new approach to selecting cluster heads. We assume that:
1. The network satisfies the pre-conditions of applying LEACH protocol.
2. After deployment, sensors are able to know their positions through GPS, or before deployment, their positions are accurately decided.
3. All nodes are able to adjust data transmission power. If necessary they can communicate with the base stations to acquire the initial setting information of the network.

If we modify the procedure of the calculation of $T(n)$ during the cluster head generation such that cluster heads are produced progressively, then a node could decide if it is suitable to be a new cluster head based on the locations of existing cluster heads and its own location. More specifically, if the node is very close to any existing cluster head, then this node will give up the attempt to be a cluster head.

As shown in Figure 4, the network is divided into three parts. Nodes in region G1 will compete for being a cluster head. When a node is selected as a cluster head, it will broadcast the information to nodes nearby. Nodes in region G2 will receive the message. Thus, when nodes in this region compete for being cluster head, the location information of the cluster head in region G1 will taken into consideration. If a node in G2 is close to the cluster head in G1, the node will be discarded. The cluster heads in all other regions will be generated in the same way.

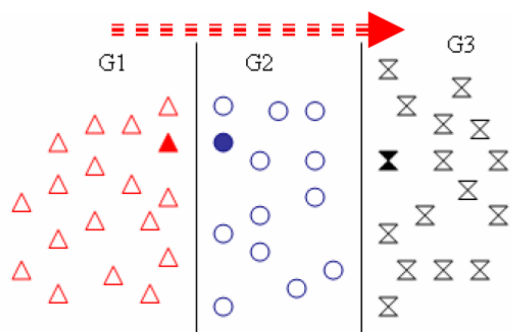

Fig.4 Selecting Cluster-heads.

The cluster heads generated with this approach will not be close to each other. However, because some nodes quit the competition for cluster head, the total number of cluster heads can be reduced, which is not good for saving the network energy. Our approach to solving this problem is when a node is excluded in the cluster head selection, a message is broadcast to other nodes and *T* (*n*) will be modified to increase the probability of others nodes being selected as cluster heads. The modified *T* (*n*) is:

$$T(n) = \begin{cases} \dfrac{P}{1 - P(r \bmod (1/p)) - pk} & n \in G \\ 0 & \text{others} \end{cases}$$

K is the number of nodes that are excluded from the cluster head selection due to the location reason, with an initial value of 0. When *k* increases, *T* (*n*) increases as well, which will ensure sufficient number of cluster heads will be generated by the progressive algorithm.

To facilitate the explanation of our improved algorithm, we introduce the following notations:

Bs The base station or node *Sink*
S_i The *i*-th sensor node
H_j The *j*-th cluster head
Mem (C_j) Members of the *j*-th cluster
Mem $(C_j)_I$ The *i*-th members of the *j*-th cluster
Loc (S_i) Location of the *i*-th sensor node
Delay (S_i) Time delay that the *i*-th sensor node start to compete for a cluster head
Num(Giveup) Number of discarded cluster heads
|| Operation of concatenation

3.1 cluster head selection

After the deployment of sensor nodes, we first acquire all nodes' location information (through GPS technology or known prior to its deployment) and report it to the base station. The base station decides Delay (S_i) for every node based on the geographic distribution of all sensor nodes.

Delay (S_i) = 0 for those in the region to start first. As illustrated in Figure 4, nodes in G1 start to compete for cluster heads at time 0, then nodes in G2 start with a delay, and then nodes in G3 start with a delay after nodes in G2 are finished, and so on. During the process, nodes need to send their location information to the base station:

S_i → BS: Loc (S_i)

The base station needs to send the delay information to each node:

Bs → S_i: Delay (S_i)

Set Num (Giveup) to 0. Start with the nodes in G1. If a cluster head is generated from G1, broadcast a *Hello* package and Num (Giveup).

H_j → broadcast: Hello, Num (Giveup)

When nodes in G1 are finished, consider nodes in G2. Now the cluster heads generated in G1 are reference points. The distance between a node in G2 and any cluster head in G1 is a factor in selecting the node as a cluster head, as well as the random value of T (n). If all conditions are satisfied, then broadcast the Hello message and Num (Giveup).

Hj → broadcast: Giveup, Num (Giveup)

Otherwise, only broadcast Num (Giveup). When nodes in other region receives this message, they will increment Num (Giveup) by 1, and then modify T (n) to increase the probability of being selected as cluster head.
Repeat the above process until all nodes in the network are considered.

4. Simulations

In this section, we evaluate the performance of My LEACH protocol implemented with NS2.

100 sensor nodes are randomly distributed in an area of 100 m x 100 m. BS is put at the location with *x* = 175, *y* = 50. The bandwidth of data channel is set to 1 Mbps, the length of data messages is 500 bytes and packet header for each type of packet was 25 bytes. The number round is set to 500s. When a node uses energy down to its energy threshold, it can no longer send data and is considered as a dead node.

E_{bit} = 50nJ/bit
E = 5nJ/bit/report
E_0 = 0.5 J

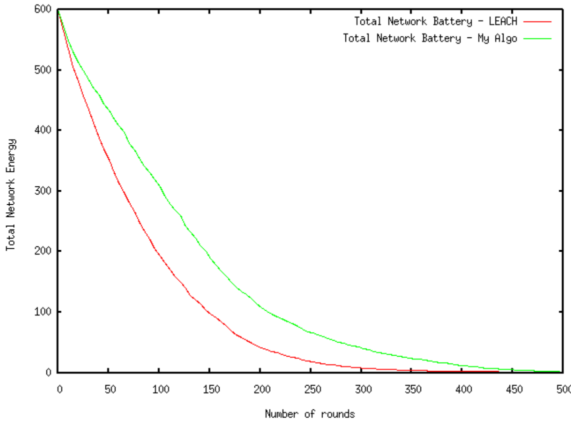

Fig.5 Compare Total Network Energy LEACH and My Algo.

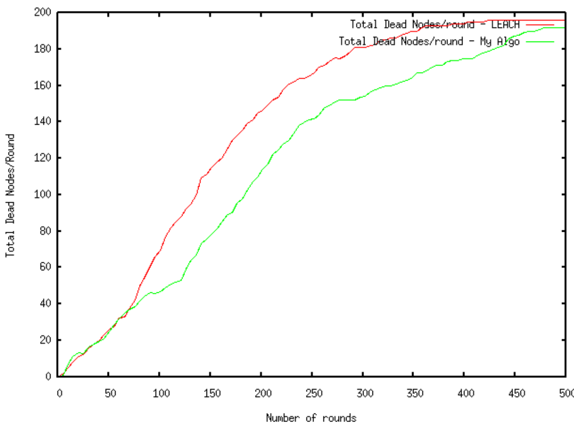

Fig.6 Compare Total Dead Nodes LEACH and My Algo

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