A Novel Sub-optimum Data Transmission Algorithm for Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) are composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. Energy efficiency and network lifetime are two challenges that most of researchers deal with. In general, base station (BS) used to retrieve data from sensor nodes is far from the sensor field and how to adjust the communication between nodes and BS to achieve energy efficiency and long network lifetime is very important. In this paper, we propose a novel sub-optimum Average Lifetime-oriented Long-distance (ALL) data transmission algorithm. It makes tradeoff between energy cost and residual energy and balances lifetime among all sensor nodes to achieve dramatic lifetime prolongation for network. Simulation results validate that ALL algorithm outperforms traditional protocols or algorithms and prolongs network lifetime dramatically.

Keywords: *Wireless sensor networks, energy efficiency, network lifetime*

1. Introduction

A wireless sensor network consists of a large number of wireless sensor nodes that are densely deployed either inside the phenomenon or very close to it. WSNs have wide applications range like military application, environment monitoring, health-care, smart home etc. [1]. Due to the limited energy of sensor nodes, it is desired the network can work as long as possible.

There are many existing clustering or hierarchical algorithms or protocols aim at extending network lifetime, such as Low-Energy Adaptive Clustering Hierarchy (LEACH) [2], a Hybrid Energy-Efficient Distributed clustering approach (HEED) [3], Geographical adaptive fidelity (GAF) [4], etc. These methods improve energy utilization in data transmission and inter-communication and prolong network lifetime to some extent. To different application scenario, there are different requirement and definition of network lifetime. In general, we always desire to balance energy consumption among all nodes of network and achieve a lifetime extending for entire network [5, 6, 7]. As we known, hotspot phenomenon leads to early dead of many nodes so that those parts of dead nodes are out of monitoring.

In general, clustering methods are more dominant than flat methods, because clustering protocols can use data fusion technique [8]. The procedure of data aggregation is done at cluster heads (CHs). Most of existing clustering protocols have a common point: nodes can only get the topology around them, and the generated schemes is local sub-optimum. In other words, this kind of schemes can only balance energy consumption in local cluster rather than in global network. Nowadays it is not an utopia any more to weigh geographic position via integrating global positioning system (GPS) or using triangulation location [9, 10]. In this way, it is also no longer hard for BS to know the topology of whole network.

In this paper, we propose a novel sub-optimum average lifetime-oriented long-distance (ALL) data transmission algorithm. It makes tradeoff between energy cost and residual energy and balances lifetime among all sensor nodes to achieve dramatic lifetime prolongation for network. In ALL communication protocol, node transmits data to the next node with specified ID. This procedure is quite simple, each node maintains an integer locally which stands for the next-hop node's ID and just transmits data in a fixed radio range to make sure next-hop node can receive. Next-hop ID renews when node receives new ID-updating order from BS.

2. Related work

Many clustering algorithms or protocols are proposed to control the communication between sensor nodes and base station, such as LEACH [2], GAF [4], HEED [3], etc. Because sensor nodes in these algorithms make decisions locally and they are just aware of surrounding information around them, these algorithms have a similar point, namely local-optimum.

One of early famous works is LEACH [2] in which cluster head nodes are elected randomly and clustering distributions change in every round. When cluster heads are selected, they collect data locally and transmit result to the base station directly. In addition, when sensor nodes transmit data to CHs, they also use direct transmission. These direct transmissions are obviously expensive for energy-constrained sensor nodes.

GAF algorithm is proposed in [4], the authors divide one network into several fixed sub-network by their geographic location which is similar to our clustering method, and then rotate cluster head role among nodes in a cluster round by round. GAF protocol is easy to implement and it promotes the communication between inner-cluster nodes by carving up those nodes close to each other into one cluster.

Authors in [11] proposed an advanced inter-cluster routing protocol (ICRP) based on HEED. Its main idea is optimizing transmission between CHs and BS by using multi-hop scheme. The router it found is based on local area's information but not global. At transmission phase, center CHs also using direct transmission approach to transmit packets to BS.

The literature [12] proposes an optimization design based on GAF named ERGAF. It makes a tradeoff between transmission distance and residual energy which is obviously not exact. Firstly, energy cost in transmission contains two parts, namely running circuit and running radio amplifier. Secondly, energy cost of second part is proportional to distance2, not distance alone.

3. Our proposed ALL algorithm

3.1. Assumptions

Our work is based on the following assumptions:

1) The base station is aware of locations of all nodes;
2) Sensor nodes are deployed in a square area;
3) Each node has its own fixed ID;
4) The wireless sensor network is based on query.

3.2. Main Idea of ALL Algorithm

Our ALL algorithm tries to find the best path for each transmission, and this selection is conducted by the weight (W). We use weight-evaluation (W) function to compute weight for each path as shown in below equation (1). In equation (1), "EC" stands for the total energy consumption of node i in transmission phase and "RE" stands for the rest energy of node i. Before using them, we need to normalize them to reduce the error caused by their different value ranges.

$$W(i) = \frac{Normalized\ EC}{Normalized\ RE} \qquad (1)$$

3.3. Network Communication Principle

In our ALL algorithm, BS plays a central role. It not only maintains the global information of network but also controls every communication among nodes. Nodes in this network are blind to the procedure of generating the best scheme. Our ALL algorithm contains two parts, namely clustering part and working part. Clustering part is performed when all the sensor nodes are deployed, and clustering algorithm used in ALL is quite simple, namely dividing the sensor field into 9 clusters according to their positions as show in Fig. 1. Each sub-square has same edge length.

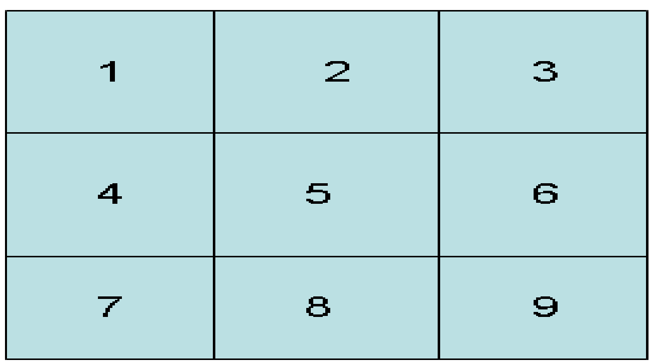

Figure 1. Clustering Method of Sensor Network

Working part can be broken into rounds, and there are three phases for BS to receive data from all nodes in each round. They are scheme generating, order Broadcast and data transmission.

(1) Scheme generating phase

This phase is done at the BS. It considers the current state of network and generates the best scheme. We assume that there are n+1 nodes in the network and the (n+1)th node is the base station. Some related variables are shown in Table 1.

Table 1. Relevant Variables

Variables	Subject to	Illustration
$Flag(i)$	$1 \le i \le n$	If Flag(i)=1, it stands for this node has found its best path.
$A(i)$	$1 \le i \le n$	It can be computed by equation 1. Initially, $A(i) = \frac{SBC(i)}{SRE(i)}$
$AN(i, j)$	$1 \le i \le n$ $1 \le j \le n$	Weight of node j to node i. $AN(i, j) = \frac{SCost(i, j)}{SRE(j)}$
$Next(i)$	$1 \le i \le n$	Next node's ID which node i forward packets to in the best path.

Following are pseudo codes of the scheme generating algorithm.

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Step 1. Find k subject to:
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$$A(k) = Min\{A(i) \mid Flag(i) = 0\}$$

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        Then set Flag(k)=1;
        If k can't be found, go to Step 4. (Each node has found
        its best path)
Step 2. Update A(j) while Flag(j)=0
            For i=1 to n, step by 1
               If Flag(i)=0
                      If A(k)+AN(k,i) < A(i)
                           A(i)= A(k)+AN(k,i);
                           Next(i)=k;
                      End If
               End If
            End For
Step 3. Go to Step 1;
Step 4. End of algorithm.
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(2) Order broadcast phase

When BS generates the best scheme for every node in the network, it is ready to begin a query. For example, if BS wants to get data from node A, and the best path is A-B-C-BS. First, BS broadcasts three orders in which one is for node A, one is for node B and the other one is for node C. Second, each node receives the fore 8 bits from the data signal and compares it with its own ID, if they are same, then goes on receiving the rest signals, or stops receiving. Otherwise, order sent to A is different from the orders sent to B and C. These three orders' types are: "query", "set-next" and "set-next".

(3) Data transmission phase

For instance, BS asks for result data from node A, and the best path is A-B-C-BS. There are four steps in this procedure.

Step 1: Node A receives the order, then collects the result data and sets its Next-ID by "B"; Node B receives the order and sets its Next-ID by "C";Node C receives the order and sets its Next-ID by "BS";

Step 2: Node A forms the packet which consists of rest-energy information and the original data, and then transmits it to node B;

Step 3: Node B receives packet from node A, then adds its own rest-energy information to the tail of the packet to form a new packet and transmits it to node C;

Step 4: Node C receives packet from node B, then adds its own rest-energy information to the tail of the packet to form a new packet and transmits it to BS.

4. Performance Evaluation

To validate our proposed ALL algorithm, we simulate it and other two classic protocols to compare them in energy consumption and network lifetime. These two algorithms are Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm and Geographical Adaptive Fidelity (GAF) algorithm respectively. We compare these three algorithms in energy consumption details and network lifetime.

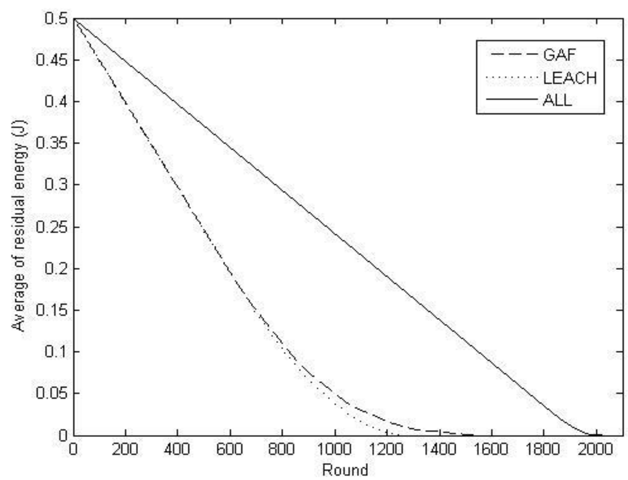

Figure 2. Detailed Information of Residual Energy

From Figure 2, we can know that average residual energy of the network using ALL algorithm decreases most slowly and steadily. That stands for ALL algorithm achieves balancing energy consumption among all nodes of the network.

In our simulation of the parameter of lifetime, we define the network lifetime as all nodes in an area which is one of the nine areas shown in Figure 1 die out. Figure 3 and Table 2 show us the network lifetimes using GAF, LEACH and ALL respectively. It is obvious that our ALL algorithm is more dominant at network lifetime extending. And the result is consistent with the analysis discussed above. These simulation results prove that our ALL algorithm can dramatically improve energy utilization and prolong network lifetime.

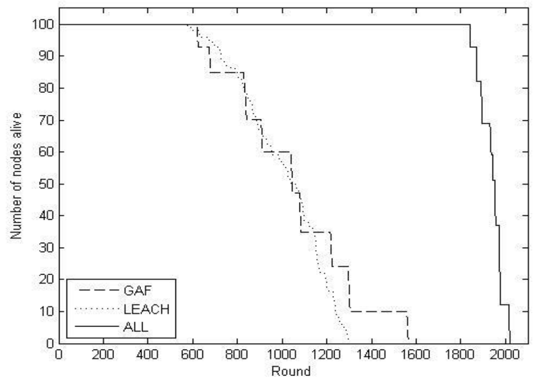

Figure 3. Detailed Information of Alive Nodes

Table 2. Network Lifetime using GAF, LEACH and ALL

Algorithm/Protocol	Network Lifetime(Round)
GAF	1586
LEACH	1283
GBP-MSSN	2022

5. Conclusions

In this paper, we propose a sub-optimum clustering communication algorithm called ALL for wireless sensor networks with static base station. It makes a tradeoff between energy cost and residual energy and balances lifetime among all sensor nodes to achieve dramatic lifetime prolongation for network. In transmission, it firstly estimates the energy cost of one path, and then computing weight for this path combining with residual energy. According to this weight, the best path was selected. Simulation results validate that ALL algorithm outperforms traditional protocols or algorithms and prolongs network lifetime dramatically. In our work, we use a very simple clustering method and ignore the distribution density of sensor nodes, next step we would like to use more complex and efficient clustering methods to optimize our algorithm.

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