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Improvement on LEACH-C Protocol of Wireless Sensor Network (LEACH-CC)

Zhenfu Ma[1], Guangming Li[1*] and Qingchao Gong[1]

[1]School of Communication and Information System,
Shandong University, Weihai, 264209, China
1039871950@qq.com, gmli@sdu.edu.cn, gongqchao@163.com.com

Abstract

Wireless Sensor Network (WSN) has been considered as a promising method for reliably monitoring civil and military environment in hazardous or dangerous conditions. Usually, sensor webs consisting of nodes with limited power and limited wireless communications are deployed to collect useful information from the field. Due to these reasons, how to improve energy efficiency is a critical issue for WSN protocols. The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol puts forward an algorithm where sensor nodes are built into clusters to fuse data before transmitting to Base Station (BS). An improved version of LEACH, called Low-Energy Adaptive Clustering Hierarchy-centralized (LEACH-C), is presented, where the central Base Station (BS) executes the clustering to improve energy efficiency. This paper presents an improvement of LEACH-C based on power, called Low-Energy Adaptive Clustering Hierarchy-central constrained (LEACH-CC), which balances energy distribution of network by means of changing range of nodes being cluster head. Stimulation results show that LEACH-CC can improve system lifetime over its comparatives.

Keywords: *Wireless Sensor Network (WSN), Low-Energy Adaptive Clustering Hierarchy-centralized (LEACH-C), Energy distribution*

1. Introduction

Wireless Sensor Network [1, 2] (WSN) consists of sensor nodes, Base Station (BS), internet or communication satellite and some other parts. Like Figure 1, the end-user does not connect directly to network but via a BS. Sensor nodes disperse within the specified sensing regions. Each node can receive and transfer data to sink node through multi-hop routing. BS can collect, process, upload data. BS can also send information to each node in the same way.

Because of the stringent environment of the application, once deployed, the small sensor nodes are far away from users, and therefore, it is infeasible to replace the energy source [12]. Gathering sensed information in an energy efficient manner is critical to operating the sensor network for a long period of time [3]. Hence reducing energy consumption and prolonging network lifetime is one of the most important design factors in WSN [4, 5].

Traditional multi-hop routing schemes such as the Minimum Transmission Energy (MTE) will result in an undesirable effect [8]. In MTE, nodes need to send sensed data to their nearest neighbors in the direction to BS. Nodes need not only perceive environmental information, but also act as transfer station of other nodes. Hence nodes closest to BS will deplete their energy quickly. If there is no correlation among the data, MTE outperforms other protocols. But there is a high probability that nodes within in appropriate space have correlated data. Therefore, it

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is a good way that data can be aggregated before transmission. Clustering of nodes [9, 10] maybe a more apt solution.

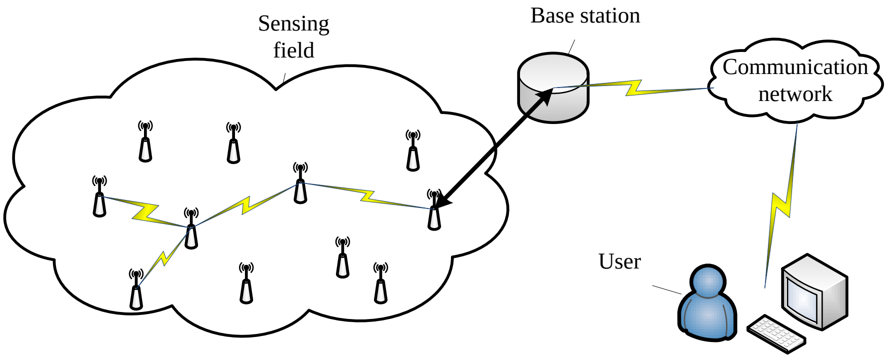


Figure 1. Wireless Sensor Networks.

Static clustering protocols form fixed clusters using a fixed cluster head. After member nodes sending data to cluster heads in its time slot, cluster heads send fused data to the BS. The advantage is that there is no need to re-cluster, but the drawback is that when the cluster head depletion of energy, nodes within cluster will lose connectivity with the base station.

To address this shortcoming, an adaptive clustering scheme called Low-Energy Adaptive Clustering Hierarchy (LEACH) [6] that employs the technique of nodes randomly rotating as cluster heads in WSN is proposed. In LEACH, nodes organize themselves into clusters and each cluster selects a cluster heads. Cluster heads receive data from nodes within cluster and then send fusion data to BS directly. Simulation results show that, compared with general multi-hop routing protocols and static hierarchical algorithm, LEACH clustering protocol can prolong the lifetime of the network by 15%.

LEACH-centralized (LEACH-C) [7] is an improved version based on LEACH. Unlike LEACH, in which nodes self-organize themselves into clusters, LEACH-C adopts BS to form cluster. Because LEACH-C reduces energy consumption of nodes intercommunication when constituting clusters, LEACH-C performs better than LEACH.

In this paper, we propose a modification of LEACH-C's cluster-head selection algorithm, called Low-Energy Adaptive Clustering Hierarchy-central constrained (LEACH-CC), to balance the total energy dissipation of sensors. The rest of the paper is organized as follows: in section 2, LEACH and LEACH-C algorithm are reviewed. Section 3 presents the network model used. Section 4 describes the problems and proposed approach. Stimulation results are shown in section 5. Finally we discuss shortages of improved scheme and conclude the paper.

2. LEACH and LEACH-C Algorithm

2.1. LEACH

LEACH protocol uses a hierarchical network structure. In LEACH algorithm, nodes are self-organized into different clusters, and each cluster has only one cluster head. Every node decides independently whether to be their own cluster head according to a certain probability. In order to avoiding cluster head nodes excessive energy consumption and influencing the network lifetime, periodic cluster head election and network restructuring process are necessary.

In the process of LEACH running cycle, the cluster reconstruction executes circularly. The reconstruction process can be described as the concept of round. Each round can be divided into two phases: setup phase and transmission phase.

In setup phase, cluster head is randomly selected. The randomness of cluster heads can ensure the high energy consumption for data transmission between BS and cluster heads is evenly apportioned among all nodes. After the cluster heads selected, they will broadcast a packet which includes information of cluster head to all nodes. Once the sensor nodes receive the broadcast packet, they will decide to join in the cluster according to signal strength of received information. Then sensor nodes send message to the cluster head to indicate that they will join in this cluster. Cluster adopts TDMA sequence to distribute channel within the cluster nodes.

The election process of cluster head is: the node selects a random value from 0 to 1. If the value of current round is less than the set threshold $T(n)$, the node becomes the cluster head $T(n)$ is calculated as follows:

$$T(n) = \begin{cases} \dfrac{p}{1-p*(r \bmod \dfrac{1}{p})}, & n \in G \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where p is the desired cluster head's percentage in all sensor nodes, r is the current round number, G is the collection of nodes that have not been cluster head node in last $1/p$ rounds.

In transmission phase, cluster members continue to collect monitoring data and send the data to the cluster heads in the given slot time. Then through necessary data fusion, cluster heads send it to the BS. Cluster heads will be re-selected in the next round of work.

As the first dynamic clustering routing protocol, LEACH protocol still has some deficiencies. First, the number of node in cluster cannot be sure. There may be a condition that burden of some cluster head is so heavy that energy cost is quite fast. In addition, the selection of cluster head did not take the energy state of the node into account. The nodes with low residual energy have the same priority to be a cluster head as the node with high residual energy, resulting in that nodes with low residual energy may die first. Thus LEACH cannot effectively improve the survival time of the network.

2.2. Leach-C

LEACH-C, a centralized version of LEACH, also divides each round into two phases, setup phase and transmission phase. During the setup phase of LEACH-C, every node of WSN sends their information, including the location and energy level, to BS. Then BS calculates the average energy value of all the nodes. Only the nodes with more energy than the average value have chance to be cluster heads. The BS uses annealing algorithm to establish clusters. The cluster groupings are selected to minimize the energy consumption needed for ordinary nodes to transmit data to their respective cluster heads. The other operations of LEACH-C are same to those of LEACH [10], but stimulation result shows that LEACH-C has an obvious improvement over LEACH. There are several reasons for the improvement:

- In LEACH-C, the BS has a global station of network to form better clusters that need less energy for data transmission.
- There is no communication between nodes when building clusters. Hence more energy can be used for data transmission.

- The optimal number of cluster heads has been determined in advance. The network can use energy more effectively.

3. Network Model

In this article, we assume a sensor network model with the following properties:

- There is a fixed base station located far away from the sensor nodes. In the study, we do not consider the energy consumption of the BS and assume that it has sufficient energy supply.
- All nodes have same configuration and limited energy.
- Each node has the same starting energy in the network.
- All nodes are stationary.
- Nodes can perceive residual energy and change the transmission power.

Energy Model

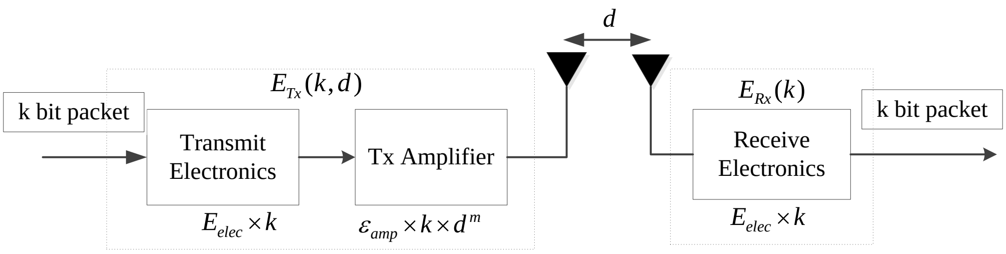


Figure 2. Radio Energy Dissipation Model

Usually, free space attenuation channel mode and multipath fading channel model are used to calculate energy consumption in the process of routing data transmission. The protocol chooses channel mode on the base of distance between the transmitters and receivers. If the distance between nodes is less than threshold d_0, free space attenuation channel model is proper, otherwise multipath fading channel model. Therefore, to transmit k bit data a distance d, the energy consumption is

$$E_{Tx}(k,d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^m \quad (2)$$

while the energy consumption for receiving k bit data is

$$E_{Rx}(k) = E_{elec} \times k \quad (3)$$

where E_{elec} is electronics energy, ε_{amp} is magnification times of amplifier. Consumption of amplifier, and distance d^m is in a scale. If transmission distance is short, $d < d_0$ and $m = 2$, otherwise $d \geq d_0$ and $m = 4$. Hence the energy consumption of sending k bit data is

$$E_{TX}(k,d) = \begin{cases} E_{elec} \times k + \varepsilon_{amp} \times k \times d^2, & d < d_0 \\ E_{elec} \times k + \varepsilon_{amp} \times k \times d^4, & d \geq d_0 \end{cases} \quad (4)$$

4. Problem Statement and Proposed Solution

LEACH selects cluster head randomly among all nodes completely. And LEACH-C sets a simple restriction for nodes which would be selected as cluster head—only the nodes that have more energy than average value can participate in the cluster head election. However, effect of this method is still limited. Especially when the average energy of nodes is low, even if the residual energy level of nodes is higher than the average value, it is still possible that the node would die after this round.

The work of this paper proposes an improved cluster head selection scheme. This scheme can further balance the energy distribution by means of re-defining the election range of the cluster heads according to the energy level of nodes.

During the setup phase of each round, like LEACH-C protocol, the BS collects information on the current energy status from all nodes. After receiving these information, the BS calculates the average energy level and difference between every nodes' energy and average value in the network. Then BS chooses a set of nodes, denoted G , whose difference satisfy a certain relation with energy consumption of each round. Specific process is as follows:

Step 1. The BS computes average energy level of all nodes in the network.

Step 2. The BS chooses the nodes which can participate in cluster head election based on formula (5),

$$E_{node\_egy} - E_{node\_avg\_egy} \geq n \cdot E_{round\_c} \qquad n = 1, 2, 3, \cdots \tag{5}$$

Step 3. Count the number (k) of nodes that satisfies the requirement above. If $k < k_{opt}$, the base station will redefine set G like LEACH-C. For the rest of the experiments, we set k_{opt} to 5.

After set G confirmed, BS selects cluster heads according to formula (1), and then finds clusters using the simulated annealing algorithm. Figure 3 is the flow chart of cluster head selection stage. And then cluster heads create TDMA sequence for each node within clusters.

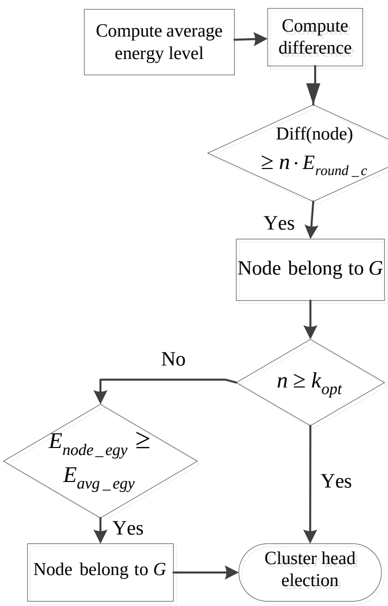


Figure 3. Flow Chart of Cluster Head Selection

In transmission phase, non-cluster-head nodes send their collected data to cluster head during their own TDMA sequences. In other time, nodes stay in sleeping state to save energy. Cluster heads processes data fusion and send them to BS. After a certain time, the network will enter into next round.

5. Stimulation Results

In formula (5), E_{round_c} is a key factor in our new scheme. How to decide its value will have a direct effect on the performance of protocol. From above presentation, compared with LEACH-C, we can find that new scheme do not put forward energy saving suggestion except for balancing energy distribution of network. Energy consumption of each round should be equal to that of LEACH-C. Therefore, it is all right that we utilize the experiment data of LEACH-C to get the value of E_{round_c} .

Except initial energy, we use same parameters in following simulations. The simulation parameters setting are listed in Table 1.

Table 1. Simulation Parameters Settings

Parameter Name	Default Parameter Value
Number of node	100
Initial energy	2J
Simulation area	1000*1000m^2
Channel bandwidth	1Mb/s
Packet size	100bytes

Figure 4 shows that network energy dissipation is stable in LEACH-C. Before first node death, energy consumption is approximately linear and agrees well with straight line. The linearity, R^2 , is up to 0.9888, which indicates that the straight line is feasibility and validity for splashes in Figure 4. The slope is directly related to the energy consumption of each round. Therefore, according to this line, we set to 0.03676.

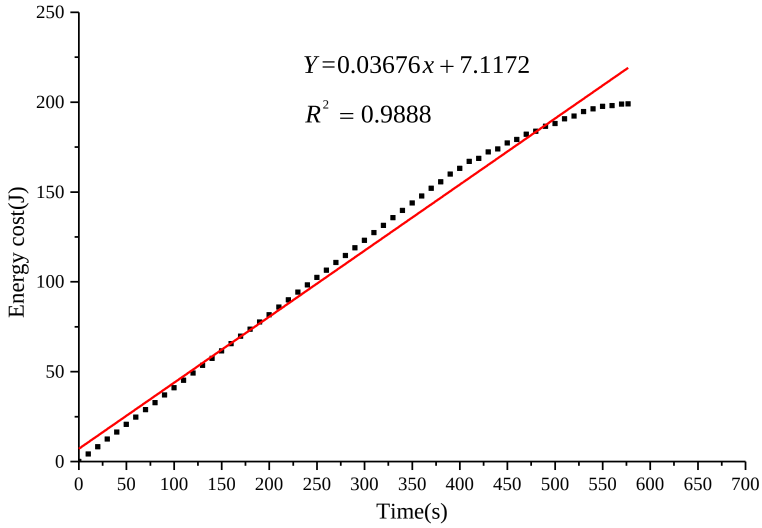


Figure 4. Energy Dissipation of LEACH-C

Another problem is how to set the value of n. If n is too small, the quantity of nodes that satisfy requirement in formula (5) is so large that the effect of new scheme is not obvious, on the contrary, if n is too large, there are not enough nodes meet the requirement and new scheme will be equal to LEACH-C. Here we will choose the n through simulation. Figure 5, which shows round of first node death when initial energy is 2J, shows that simulation agrees well with the analysis. This graph shows that the optimum value of n is around 2-18 for our network. For the rest of the experiments, we set n to 8.

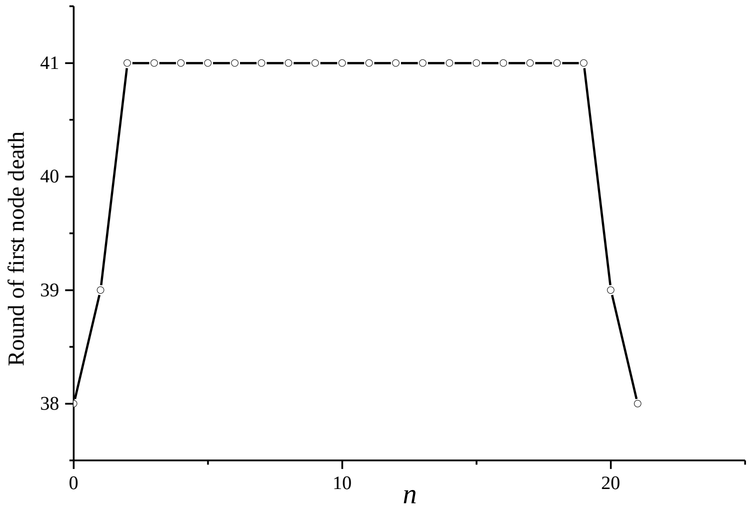


Figure 5. Round of First Node Death as the Value of n

Figure 6 shows comparison of network lifetimes among LEACH, LEACH-C, LEACH-CC, when initial energy is 2J. Seen from this figure, death time of first node in LEACH-CC algorithm is later than LEACH and LEACH-C protocol. In LEACH-C

C, the first node dies at the time of 440s, 60s and 30s later than LEACH and LEACH-CC. This is because, like LEACH-C, the BS has a global knowledge of location and energy level of all nodes in the network, so it can establish more efficient clusters that require less energy to transmit data. And LEACH-CC has adopted new algorithm to confirm the range of nodes that will join in cluster heads selection. It can avoid an early condition that the node exhausts its energy after being cluster head, especially when average energy is low in the network. This method can force the node that has more energy to consume energy through being cluster head and distribute energy more evenly in WSN.

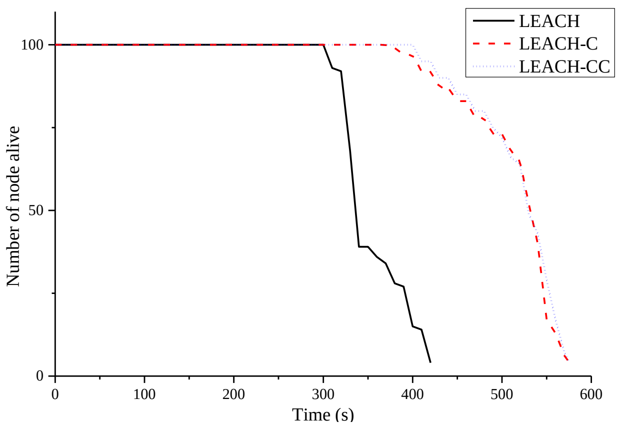
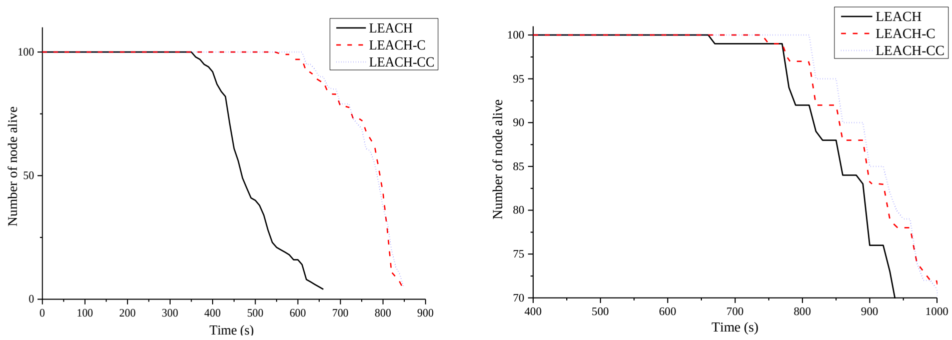


Figure 6. A Comparison of Node Alive Of Different Protocols

Except for the last one, we do other two stimulations to check the number of node alive at different initial energy, 3J and 4J. Figure 7 shows that LEACH-CC has more apparent advantage when initial energy is larger compared with LEACH-C (60s and 80s later than LEACH-C respectively when initial energy is 3j and 4j). It can be explained this way: more energy will increase the chance of unbalance distribution of energy and there will be more probability that nodes come to premature death. LEACH-CC can avoid this condition effectively.

In order to validate the correctness of analysis, we calculate variance of residual energy before the 100s of the first node death. Figure 8, which shows that, in LEACH-CC, energy variance is always less than that in LEACH-C, shows that energy distribution is more even in LEACH-CC. New algorithm can prolong network lifetime in the way of avoiding nodes which do not have enough energy being cluster heads.



(a) (b)

Figure 7. Node Alive in Different Initial Energy

6. Discussion

LEACH-CC appears to be a promising protocol, but there are some fields to be improvement for its more widely applicable. In the simulations above, we assume all sensors always have data to their cluster heads in their TDMA slots. However, in order to save energy nodes only transmit their interested data. Therefore, how to improve the utilization efficiency of bandwidth is a problem need to think.

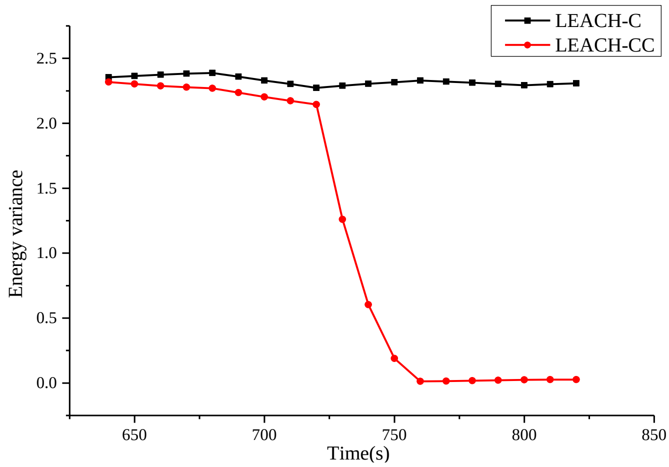


Figure 8. A Comparison of Energy Variance between LEACH-C and LEACH-CC

Another problem is that E_{round_c} is got through previous simulation of LEACH-C. In practical application, it is not a reasonable method, because sensors are deployed in an unstable environment and E_{round_c} is not fixed value. One approach to solve this problem is that new algorithm can get this value through its last several rounds of simulations. In this way, LEACH-CC can have a more rational performance in practical application.

7. Conclusion

Energy efficiency is a very important issue in WSN. In this paper we present a centralized clustering-based routing protocol, LEACH-CC, based on LEACH-C protocol which is an important and classic protocol and widely used in WSN. Proposed scheme determines the scope of cluster head selection according to energy level of nodes. Proposed scheme balances the distribution of energy in the network. Compared with LEACH-C algorithm, stimulation results demonstrate that new scheme can improve energy efficiency and prolong the network survival time.

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Authors

Zhenfu Ma, He received his B.E. degree in electronic information science and technology from Shandong University, China in 2012. Now he is studying toward the M.S. degree in communication and information system at Shandong University. His current research interests focus on wireless sensor networks.

Guangming Li, He received his B.S. degree from Shandong University, China, in 1996, his M.S. degree from the State Key Laboratory of Crystal Materials, Shandong University, in 1999, and his Ph.D. degree from the University of Hong Kong, Hong Kong, in 2006. Now he is an associate professor and supervisor of the Master in Shandong University, Weihai, China. His research interest includes optical networks and internet of things.

Qingchao Gong, He received his B.E. degree in electronic and information engineering from Harbin Institute of Technology, China in 2013. Now he is studying toward the M.S. degree in electronic and communication engineering at Shandong University. His current research interests focus on wireless sensor networks.

