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LEACH Protocol based Two-Level Clustering Algorithm

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Abstract

For wireless sensor networks, it is difficult to balance the energy distribution and reduce the energy consumption in the data transmission process. On the basis of the original LEACH protocol and level technique, a new method of cluster heads collection and two-level clustering transmission is proposed. By controlling the distances among the cluster heads, the uniform distribution of cluster heads is satisfied. And then using two-level mode, the data are transmitted to the base station. LEACH is compared with the improved method about the remaining energy and alive nodes. Simulation results show that the improved method can reduce the network consumption energy greatly and lengthens the network lifetime efficiently.

Keywords: *Wireless sensor network, LEACH, two-level clustering, master cluster head*

1. Introduction

Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power, and multifunctional sensor nodes that are small in size and communicate untethered in short distances [1]. Wireless sensor networks consist of small nodes with sensing, computation, and wireless communication capabilities. Wireless sensor networks have some unique advantages such as strong adaptability, comprehensive sensing coverage, and high fault tolerance. The applications of WSNs are quite numerous. For example, WSNs have profound effects on military and civil applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance, distributed computing, detecting ambient conditions such as temperature, movement, sound, light, or the presence of certain objects, inventory control, and disaster management[2]. Most of the time, wireless sensor nodes are located in extreme environments. Sensor nodes must conserve their scarce energy by all means and stay active in order to maintain the required sensing coverage of the environment. Energy reducing is always crucial to the lifetime of a wireless sensor network. Recently, many algorithms are proposed to tackle the energy reducing problem in wireless sensor networks [3].

There are several communication protocols such as direct transmission, minimum-transmission-energy, multi-hop routing, static clustering, and LEACH (Low Energy Adaptive Clustering Hierarchy). These protocols can have significant impact on the overall energy dissipation of these networks. Among these protocols, Leach is considered as one of the most popular routing protocols, which uses cluster-based routing to minimize the energy consumption [4]. In addition, some other versions are proposed. Heinzelman, *et al.*, [5] proposed LEACH-C, which uses a centralized clustering algorithm and the same steady-state protocol as LEACH. During the set-up phase of LEACH-C, each node sends information about its current location and energy level to the base station. In addition to determining proper clusters, the base station needs to ensure that the energy load is uniformly distributed among all nodes. Thus, the base station computes the average energy of the sensor nodes, and any node whose energy is below this average cannot be selected as the cluster head for the current round. Fan and Song [6] put forward energy-LEACH and multi-hop LEACH protocols. Energy-LEACH protocol improves the

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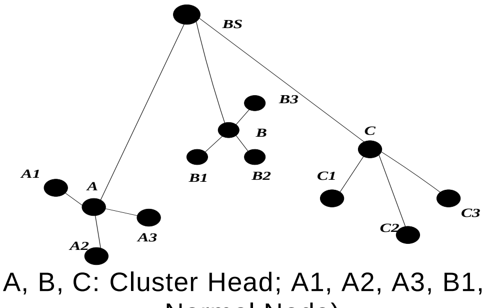
cluster head selection procedure. It makes remaining energy of node as the main matrix which decides whether these nodes turn into cluster head or not in the next round. For multi-hop LEACH protocol, multi-hop communication is adopted among cluster heads firstly, and then, according to the selected optimal path, these cluster heads transmit data to the corresponding cluster head nearest to sink. This cluster head sends data to sink finally. Bani Yassein, *et al.*, [7] propose a new version of LEACH protocol, called VLEACH, which contains cluster head, vice cluster head, and cluster nodes. Cluster head is only responsible for sending data to the base station. Once the cluster head is dead, the vice cluster head will be the substitute. Cluster nodes gather data from environment and send them to cluster head.

Wairagu [8] proposes a more energy efficient routing algorithm called Hierarchical LEACH (H-LEACH). H-LEACH focuses mainly on energy usage and end-to-end performance characteristics of both algorithms. H-LEACH employs the same clustering approach as LEACH during initial phases. Adjacent nodes are organized by clusters. In each cluster, one node acts as the cluster head. The choice of the cluster head is determined by the amount of energy remaining in a node. Hoang, *et al.*, [9] implement a harmony search algorithm-based clustering protocol for wireless sensor networks to minimize the intra-cluster distances from the cluster members to their cluster heads, and optimize the energy distribution of the WSNs. Tripathi, *et al.*, [10] propose a clustering algorithm for non-uniformly distributed nodes to balance the energy consumption of sensor nodes and to increase network lifetime. Wei, *et al.*, [11] propose an energy-efficient clustering algorithm, which determines suitable cluster sizes depending on the hop distance to the data sink, while achieving approximate balance of node lifetimes and reducing energy consumption levels. Ren, *et al.*, [12] design an Energy-Balanced Routing Protocol (EBRP) by constructing a mixed virtual potential field in terms of depth, energy density, and remaining energy. The objective of this approach is to force packets to move toward the sink through the dense energy area so as to protect the nodes with relatively low remaining energy. Quang and Kim [13] propose a gradient routing method with two-hop information for industrial wireless sensor networks to enhance real-time performance with energy efficiency. Pantazis, *et al.*, [14] present an analytical survey on energy-efficient routing protocols in wireless sensor networks.

In this paper, based on the thoughts of above literature, a new clustering mechanism and a two-level data transmission mode are proposed to improve LEACH protocol.

2. LEACH Protocol

LEACH protocol is a clustering-based protocol that utilizes randomized rotation of local cluster heads to uniformly distribute the energy load among the sensors in the network. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster-head. Other nodes are called cluster members. Cluster-head receives data sent by cluster members, performs data fusion, and sends data to the base station. LEACH can be depicted in Figure 1.



(BS: Base Station; A, B, C: Cluster Head; A1, A2, A3, B1, B2, B3, C1, C2, C3: Normal Node)

Figure 1. Model of LEACH Protocol

Comparing with ordinary node, cluster head nodes finish dual tasks of data fusion and forwarding. For LEACH, energy load is higher and energy consumption is faster. So, in order to balance the energy consumption between network nodes and avoid more early death of cluster heads, the method of periodical cluster head selection is adopted. Each period is defined as the round. Each round begins with a set-up phase, when the clusters are organized, followed by a steady-state phase, data transfer to the base station. In order to minimize overhead, the steady-state phase is long compared to the set-up phase.

When clusters are created, each node decides whether it can become a cluster head for the current round. This is determined by the suggested percentage of cluster heads for the network and the number of times that the node has been a cluster-head so far. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold T (n), the node becomes a cluster-head for the current round. The threshold is set as

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

where p is the desired percentage of cluster heads; r is the current round; G is the set of nodes that have not been selected as cluster heads in the last $1/p$ round; n is the number of sensor nodes. By using this threshold, each node will be a cluster-head at some point within $1/p$ rounds.

From above analysis, LEACH protocol select cluster head randomly and distribution of cluster heads is random. When cluster is built, unreasonable sub-cluster perhaps appears. Cluster heads may distribute too concentrated or too close to the network edge. The node number of each cluster is distributed non-uniformly. The distances from the cluster head to the cluster nodes are too long, which will lead to unnecessary energy consumption. At the same time, the communication distance between cluster heads and base station is also too long and data transmission with long distance is needed. So, this paper will improve the LEACH from the above discussed aspects.

3. Radio Model

When analyzing wireless sensor work, assume that each sensor in wireless sensor network can intercommunicate and each sensor can communicate with base station directly. When using single hop communication protocol of direct transmission, each sensor directly sends data to the base station. If not, the distances from the base station to other nodes are too far and more power will be needed when nodes send data to the base station. This mode will quickly exhaust battery energy carried on the nodes and the network system is easy to paralyze. Data are transmitted through radio model, as depicted in Figure 2.

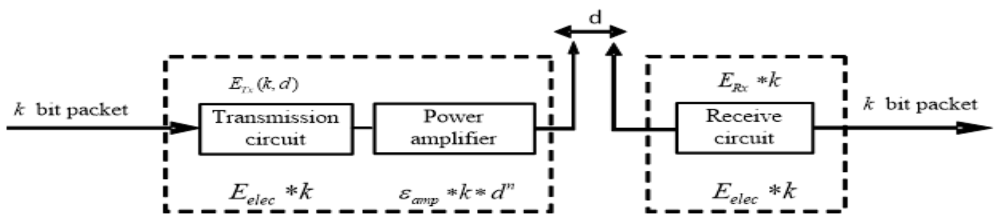


Figure 2. Radio Model [5]

Energy consumption for sending *k*-bit data can expressed as

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \\ &= E_{elec} * k + \varepsilon_{amp} * k * d^2 \end{aligned} \tag{2}$$

Radio consumption for receiving these data can be expressed as

$$E_{Rx}(k) = E_{Rx-elec}(k) = E_{elec} * k \tag{3}$$

where $E_{Tx-elce}$ denotes the circuit energy consumption for sending unit bit data; $E_{Rx-elec}(E_{Tx-elec} = E_{Rx-elec} = E_{elec})$ denotes the circuit energy consumption for receiving unit bit data; ε_{amp} denotes the transmission amplification coefficient.

From these parameters, sending data and receiving data are not a low-cost operation. So, this multiple-hops network should decrease the transmission distance and the operation for sending and receiving data as well.

For the minimum-transmission-energy (MTE) routing protocol, the protocol defines data transmission. Especially for transmitting high-energy data, each data information must go through low-energy transmissions and receives. The energy consumption depends on the relative costs of transmission amplifier and the radio circuit. If there are too many multi-hops, the total energy expended might actually be greater than that by using MTE routing. Figure 3 shows a linear network.

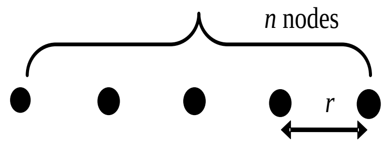


Figure 3. Linear Network

Energy consumption for direct data transmission can be expressed as

$$\begin{aligned} E_{direct} &= E_{Tx}(k, d = n * r) \\ &= E_{elec} * k + \varepsilon_{amp} * k * (nr)^2 \\ &= k(E_{elec} + \varepsilon_{amp} n^2 r^2) \end{aligned} \tag{4}$$

In MTE routing, each node sends a message to the closest node on the way to the base station. Thus the node located a distance *nr* from the base station would require *n* transmissions and $n - l$ receives.

$$\begin{aligned} E_{MH} &= nE_{Tx}(k, d = r) + (n-1)E_{Rx}(k) \\ &= n(E_{elec}k + \varepsilon_{amp}kr^2) + (n-1)E_{elec}k \\ &= k((2n-1)E_{elec} + \varepsilon_{amp} nr^2) \end{aligned} \tag{5}$$

Therefore, the condition that energy consumption in the multi-hops mode is less than that in single-hop can expressed as

$$\begin{aligned} & E_{direct} < E_{MTE} \\ & E_{elec} + \varepsilon_{amp} n^2 r^2 < (2n-1)E_{elec} + \varepsilon_{amp} nr^2 \\ & \frac{E_{elec}}{\varepsilon_{amp}} > \frac{r^2 n}{2} \end{aligned} \tag{6}$$

Comprehensively consider the energy consumption in multi-hops network, and it is not the case that the more hops, and the less energy is. In this context, two-level clustering model is selected in the data transmission.

4. Improvement on LEACH Protocol

In this paper, we adopt two kinds of methods to improve the energy efficiency. First make the radio communication distance as short as possible. Then, in the stage of cluster heads selection, by balancing the distribution of cluster heads, the network energy consumption is balanced. On this basis, two-level clustering is proposed. The clusters are divided into two levels. In the first level, the cluster heads are formed. Normal nodes send data to their own cluster heads. The cluster heads fuse the data and send them to the master cluster heads in the second level. In the processing of forming the master cluster heads and building the transmission path, by computing the distances from the cluster heads to the master heads, each cluster head select the nearest master head as its target node. By this manner, the master cluster heads receive the data from their own nearest cluster heads. The master cluster heads, as the transfer nodes, fuse all the data and transit them to the base station [14]. The two-level clustering model is shown in Figure 4.

4.1. Clustering Mechanism

How to uniformly distribute cluster heads to the whole network is not touched in LEACH protocol. Thus, clusters may intensely appear in a certain area of the network, or none of cluster heads distributes around some nodes. The nodes are too far from the cluster head. This will lead to non-uniform distribution in network and waste of resources. As shown in Figure 5, for the 100m□100m network model, the cluster is randomly formed according to LEACH protocol. Owing to the random selection of cluster heads, the upper left area belongs to a cluster and some other clusters have few members. So, restriction mechanism is needed to control the distribution of cluster heads.

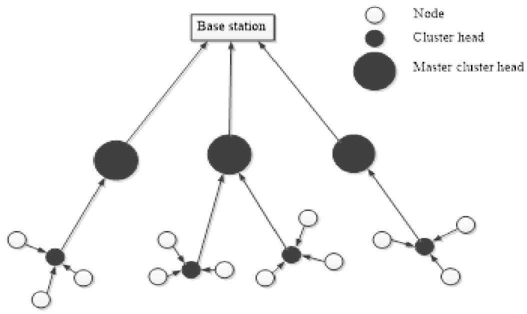


Figure 4. Two-level Clustering Model

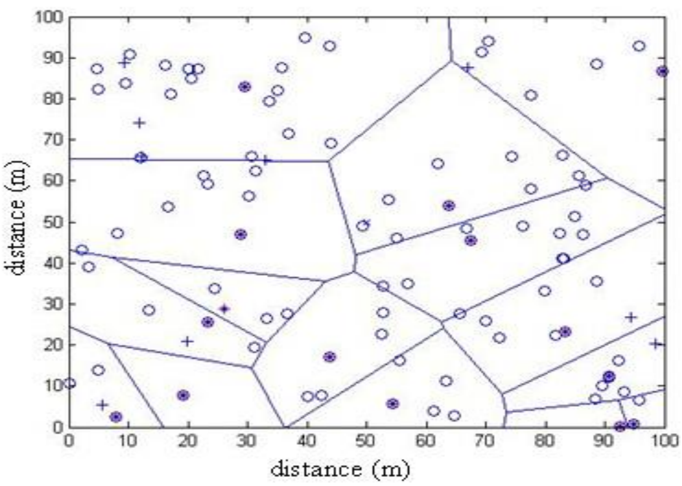
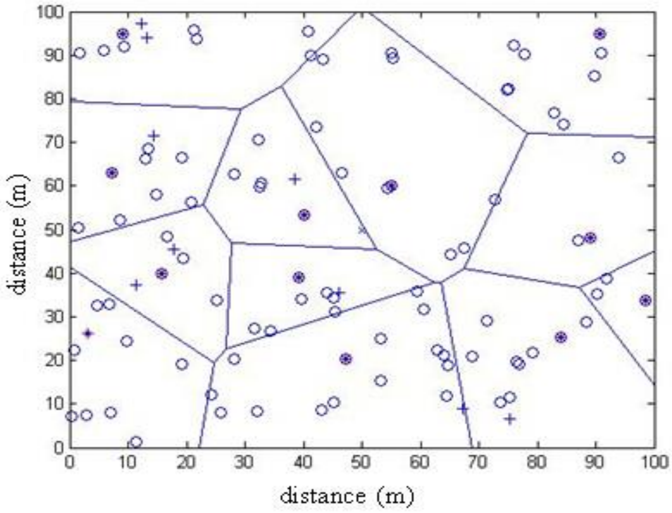


Figure 5. Non-uniform Distribution of the Nodes

Like LEACH, Optimization selection of cluster head is determined in the following optimization way.

Randomly compare the random number with threshold value, and generate candidate cluster head nodes. When determining candidate cluster head node i , transmit the cluster heads information (including own positions information) to the whole network. When candidate cluster head i receives the position information transmitted by other cluster heads, compute the distance $H_i = \{H_{i1}, H_{i2} ... H_{ii-1}, H_{ii+1} ... H_{in}\}$ between cluster head i and other cluster heads. Set threshold value S. S is related to the established model. While the distance $H_i < S$, determine candidate head i as the cluster head of that round. While the distance $H_i > S$, go on selecting the candidate cluster head. By optimizing the mechanism of cluster head selection, the more balanced node distribution can be obtained as shown in Figure 6.



(◦ Normal node, + Advanced Node, ∗ Cluster Head, × Base Station)

Figure 6. Uniform Distribution of the Node

4.1. Two-level Transmission

In this paper, the selection of cluster head is optimized. The master cluster head is introduced. The strategy of cluster head selection is similar to that of LEACH protocol. But in the selection of cluster heads of each round, master cluster head is required and its node is also selected as the father node of cluster head nodes. In the selection of master cluster head, the father node, as the cluster head nodes, receives the data transmitted from cluster head and then forwards the data to the base station. We hope that the master cluster heads are closer to the base station and have the function of intermediate nodes forwarding. Assume that L is the radius of monitoring area range. The master heads are restricted to the range of $L/2$. The detailed algorithm is depicted in the following steps.

Step 1: Divide the network into two levels; assume that the total monitoring area is $L * L$; there are n sensor nodes in the network; the base station is located in the center; the range within transmission radius $L/2$ is the second level; the sensor number in the second level is l .

Step 2: The selections of cluster heads and master cluster heads are carried out through rounds. At the beginning of each round, select the master cluster head nodes. Assign random number R_i to node $i (1 \le i \le l)$ in the second level network. If R_i <

threshold value (Tl), then the node i is selected as the master head cluster node and that node is assigned to 1. This means that no other nodes can be selected as the cluster head. After the selection of master head nodes, assign random number to each of the selected master cluster heads node $i(1 \le i \le n-l)$. Then the above mentioned method is adopted to select the cluster heads.

Step 3: Normal node receives the message transmitted by cluster head. The node will decide to communicate with the node that has the strongest signal strength. Through this way, the data transmission link is formed. Using the same method, cluster head nodes receive broadcast message transmitted by master cluster heads.

Step 4: Cluster heads fuse the data from normal nodes and then forward them to master cluster heads. Master cluster heads fuse the data from cluster heads and then forward them to the base station. When one round is over, reselect the master cluster heads and cluster heads of next round. This is shown in Figure 6.

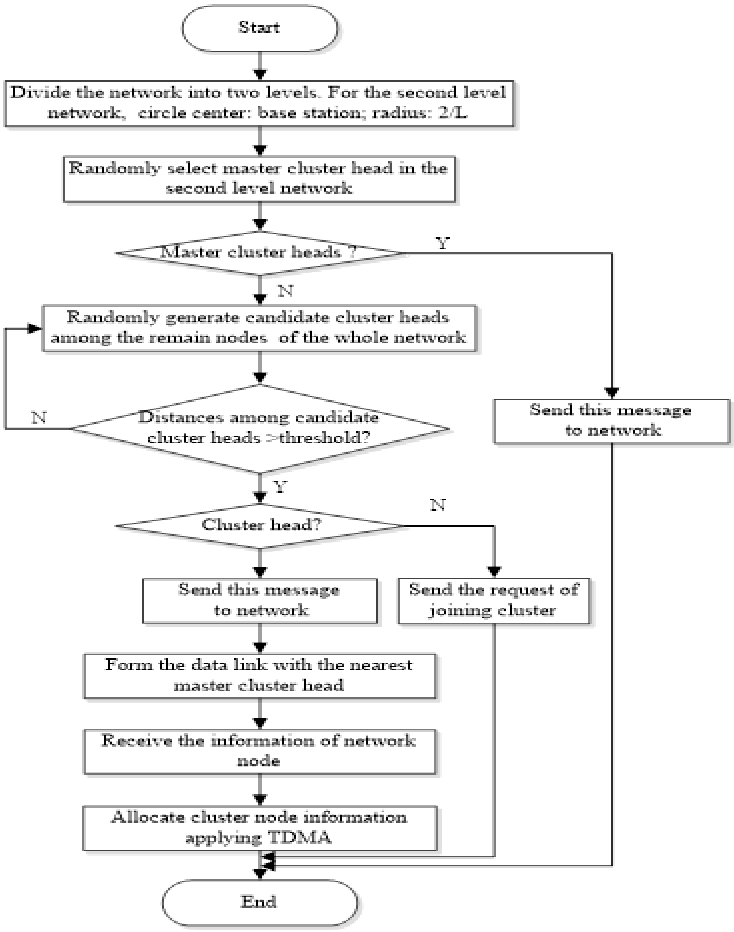
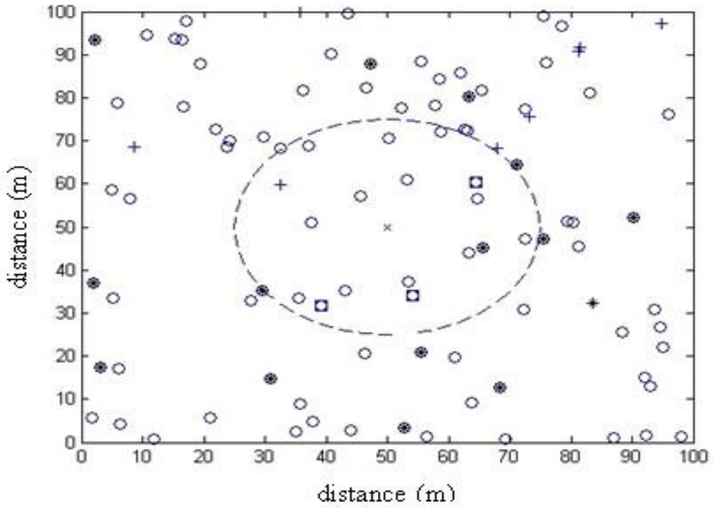


Figure 6. Flowchart of the Algorithm

The distribution of the hierarchical network nodes is shown in Figure 7, where the center of the dashed circle is the base station. R(R=25) margins the second network.



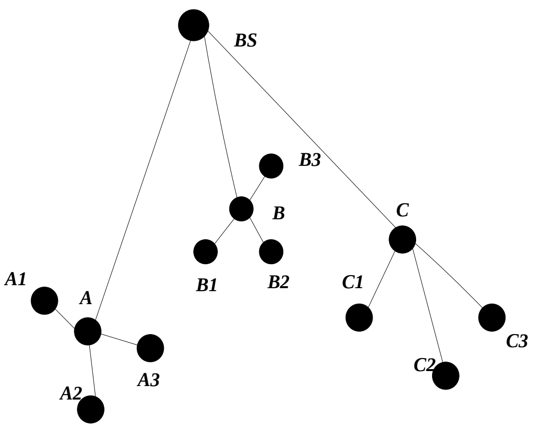
(● Master Cluster Head ◦ Normal Node, + Advanced Node, ∗ Cluster Head, × Base Station))

Figure 7. Hierarchical Node Distribution

5. Simulation Analysis

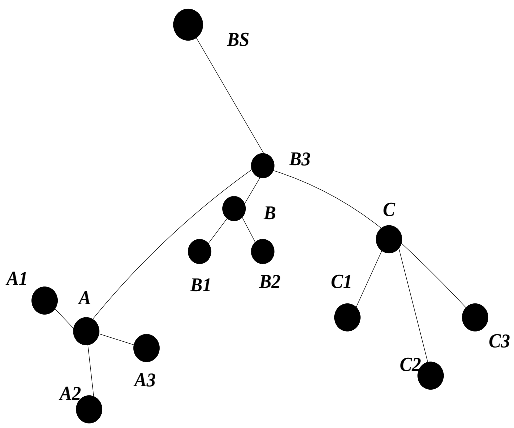
5.1. Theoretical Analysis

Compare the improved LEACH protocol with the original LEACH and deduce the energy consumption of the improved two-level protocol. The analysis model is shown in Figure 8.



(BS: base Station; A, B, C: Cluster Head; A1, A2, A3, B1, B2, B3, C1, C2, C3: Normal Node)

Figure 8(a). LEACH Protocol



(BS: base Station; B3: Master Cluster Head; A, B, C: Cluster Head; A1, A2, A3, B1, B2, B3, C1, C2, C3: Normal Node)

Figure 8(b). The Improved Two-level Protocol

For Figure 8(a), the total energy consumption in data transmission can be defined as E_{leach}

$$E_{leach} = E_A + E_B + E_C + E_{A-BS} + E_{B-BS} + E_{C-BS} \tag{9}$$

$$E_A = E_{A1send} + E_{A\_receive} + E_{A2send} + E_{A\_receive} + E_{A3send} + E_{A\_receive} + E_{da} \tag{10}$$

$$E_{A1send} = lE_{elec} + l\varepsilon r^{\lambda}_{A1-A} \tag{11}$$

$$E_{A\_receive} = lE_{elec} \tag{12}$$

$$E_{A2send} = lE_{elec} + l\varepsilon r^{\lambda}_{A2-A} \tag{13}$$

$$E_{A3send} = lE_{elec} + l\varepsilon r^{\lambda}_{A3-A} \tag{14}$$

$$E_{da} = 3le \tag{15}$$

$$E_A = 6lE_{elec} + 3l\varepsilon(r^{\lambda}_{A1-A} + r^{\lambda}_{A2-A} + r^{\lambda}_{A3-A}) + 3le \tag{16}$$

$$E_{A-BS} = lE_{elec} + l\varepsilon r^{\lambda}_{A-BS} \tag{17}$$

$$E_{B-BS} = lE_{elec} + l\varepsilon r^{\lambda}_{B-BS} \tag{18}$$

$$E_{C-BS} = lE_{elec} + l\varepsilon r^{\lambda}_{C-BS} \tag{19}$$

In a similar way, we can obtain:

$$E_B = 6lE_{elec} + 3l\varepsilon(r^{\lambda}_{B1-B} + r^{\lambda}_{B2-B} + r^{\lambda}_{B3-B}) + 3le \tag{20}$$

$$E_C = 6lE_{elec} + 3l\varepsilon(r^{\lambda}_{C1-C} + r^{\lambda}_{C2-C} + r^{\lambda}_{C3-C}) + 3le \tag{21}$$

$$E_{leach} = 18lE_{elec} + 9le + 3l(\varepsilon r^{\lambda}_{A1-A} + r^{\lambda}_{A2-A} + r^{\lambda}_{A3-A} + r^{\lambda}_{B1-B} + r^{\lambda}_{B2-B} + r^{\lambda}_{B3-B} + r^{\lambda}_{C1-C} + r^{\lambda}_{C2-C} + r^{\lambda}_{C3-C}) \tag{22}$$

For Figure 8(b), the total energy consumption in data transmission can be defined as $E_{imleach}$

$$E_{imleach} = E_{B3} + E_{B3-BS} \tag{23}$$

$$E_{B3} = E_A + E_B + E_C + E_{A-B3} + E_{B-B3} + E_{C-B3} + E_{da} \tag{24}$$

$$E_A = 6lE_{elec} + 3l\varepsilon(r^{\lambda}_{A1-A} + r^{\lambda}_{A2-A} + r^{\lambda}_{A3-A}) + 3le \tag{25}$$

$$E_B = 4lE_{elec} + 2l\varepsilon(r^{\lambda}_{B1-B} + r^{\lambda}_{B2-B}) + 2le \tag{26}$$

$$E_C = 6lE_{elec} + 3l\varepsilon(r^{\lambda}_{C1-C} + r^{\lambda}_{C2-C} + r^{\lambda}_{C3-C}) + 3le \tag{27}$$

$$E_{A-B3} = lE_{elec} + l\varepsilon r^{\lambda}_{A-B3} \tag{28}$$

$$E_{B-B3} = lE_{elec} + l\varepsilon r^{\lambda}_{B-B3} \tag{29}$$

$$E_{C-B3} = lE_{elec} + l\varepsilon r^{\lambda}_{C-B3} \tag{30}$$

$$E_{B3-BS} = lE_{elec} + l\varepsilon r^{\lambda}_{B3-BS} \tag{31}$$

$$E_{imleach} = 20lE_{elec} + 11le + l\varepsilon(r^{\lambda}_{A1-A} + r^{\lambda}_{A2-A} + r^{\lambda}_{A3-A} + r^{\lambda}_{B1-B} + r^{\lambda}_{B2-B} + r^{\lambda}_{C1-C} + r^{\lambda}_{C2-C} + r^{\lambda}_{C3-C} + r^{\lambda}_{A-B3} + r^{\lambda}_{B-B3} + r^{\lambda}_{C-B3} + r^{\lambda}_{B3-BS}) \quad (32)$$

Compare the energy consumption of LEACH protocol with that of the improved LEACH, the improved LEACH transmits data by shorter distance way, and the former energy consumption is obviously less than the latter energy consumption.

5.2. Simulation

Build the monitoring region with 100 nodes and 100m*100m area. The base station is located in the center of the region. For this network model, the simulations of LEACH protocol and the improved LEACH protocol are carried out by using MATLAB. The parameters are set in Table 1.

Table 1. Parameter Settings

Parameter	Related description	Value
E_0	Original energy	0.5J
E_{fs}	Amplifier coefficient of freedom space signal channel	10pJ/bit/m2
E_{amp}	Amplifier coefficient of multipath fading signal channel	0.0013pJ/bit/m4
E_{elec}	Energy of transmission circuit and receive circuit	50nJ/bit
E_{da}	Energy consumption of data fusion	5 nJ/bit/signal
P1	Generating probability of mater cluster heads	0.05
P2	Generating probability of cluster heads	0.1
w*w	monitoring region	100m*100m
n	Node number	100

Network remaining energy and network alive nodes are shown in Figure 9. From Figure 9, after the data transmission of same rounds, energy consumption of the improved LEACH is obviously lower than that of the original LEACH. For the former, the energy depletes after about 4000 rounds, while, for the latter, the energy exhausts after 3000 rounds. Simulation results show that the improved LEACH can not only balance the node distribution but also build more optimal transmission path to lengthen the network lifetime through two-level mode.

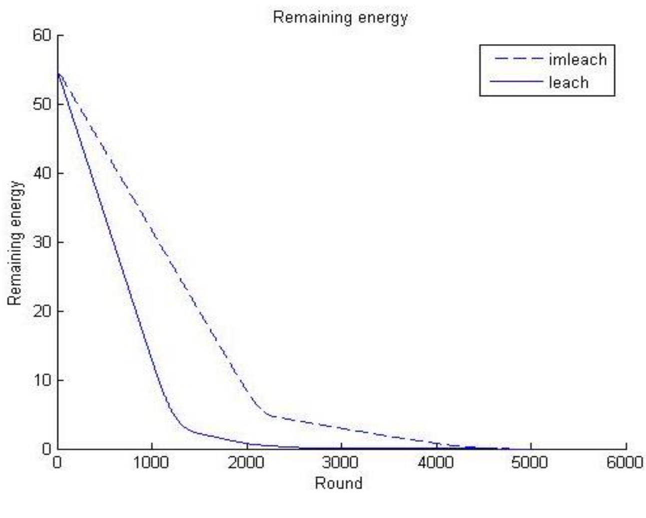


Figure 9 (a). Remaining Energy

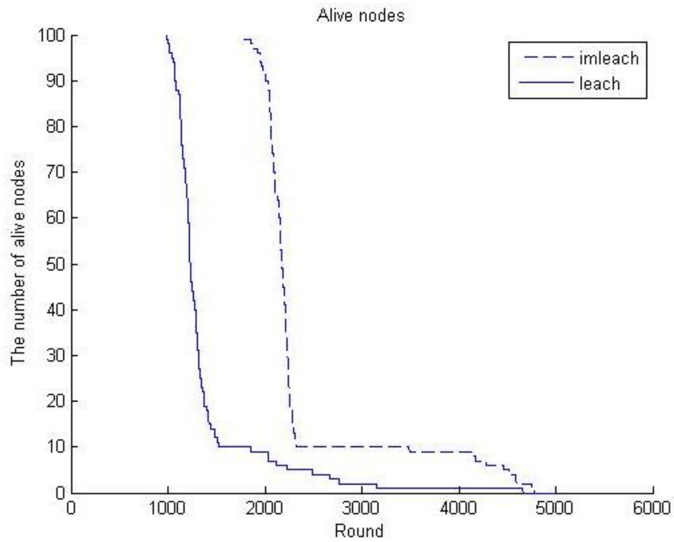


Figure 9 (b). Alive Nodes

6. Conclusions

Based on the hierarchical principle of LEACH algorithm, a new cluster forming mechanism and multi-lops data transmission mode is proposed. Firstly, by controlling the distances between nodes, control uniform distribution of cluster heads to balance the network energy consumption. Secondly, by using two-level data transmission, send data to the base station to decrease the data transmission energy consumption. Finally, compare the improved LEACH protocol with LEACH. Through MATLAB simulation, compare remaining energy and alive nodes. The results verify that the improved LEACH can reduce the energy consumption efficiently and lengthen the network lifetime greatly.

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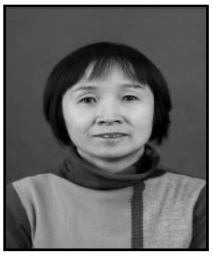

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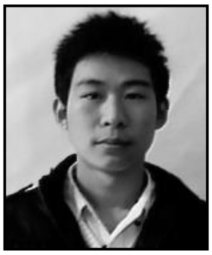

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