An improved Multi-hop Routing Protocol for Large-Scale Wireless Sensor Network Based on Merging Adjacent Clusters

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***Abstract*—It is a great challenge for designing a routing protocol that can maximize the survival time of WSN (Wireless Sensor Network), due to the limited energy of sensor node. As a well-known hierarchical routing protocol in WSN, LEACH protocol could extend the WSN lifetime effectively. It assumes that all nodes can communicate with SINK node directly. With the expansion of WSN scale, the average distances between cluster head node and base station (BS) increase significantly, which results in much more communication energy cost. For the large-scale WSN, this paper proposes a new protocol LEACH-MM. LEACH-MM merges adjacent clusters according to the residual energy of adjacent cluster head nodes. It regards the distance between the cluster head node and SINK node as a measure to construct a multilayer structure of clusters. The experimental result shows that, LEACH-MM can reduce the energy consumption of the whole network effectively and prolong the survival time of the system.**

***Index Terms*—Wireless Sensor Network, LEACH, LEACH-MF, energy consumption.**

I. INTRODUCTION

Wireless Sensor Network (WSN)[1] is composed of a large number of cheap micro sensors, through wireless communication to form a self-organizing network system. A sensor node is composed of four parts: data processing unit, a sensing unit, a wireless communication unit and power unit[3]. WSN has been widely used in the military, scientific research, industry and environmental protection[2] and ect.

WSN is a special ad-hoc network. The main difference aspects between WSN and traditional ad-hoc network [4] are listed below:

(1) Nodes don't have global ID. Because WSN is composed of a large number of sensors which enrgy spending is too expensive to maintain global ID.

(2) Many-to-one communication. Almost all applications require multiple nodes to carry out the transmission data packets to any particular node.

(3) Data fusion. The data that is collected by a large number of nodes is similar or identical. Therefore, the network has massive redundant data.

(4) Limited resources. Each node is limited in the energy, computing power and memory.

Based on the energy of sensor node cannot either be replaced or changed[12]. Therefore, the lifetime of WSN highly depends on the energy consumption of sensor node. The conservation of energy is the main challenge for designing a WSN routing protocol.

The WSN routing protocol [5] is divided into flatting routing protocol, hierarchical routing protocol and geographical routing protocol based on location. The hierarchical routing protocol consists of LEACH[6], LEACH-C[7], PEGASIS[8], TEEN[9] and so on. Heinzelman Et al proposed Low-Energy Adaptive Clustering Hierarchy protocol (LEACH). LEACH reduces data quantity that sents to the SINK node, and uses the TDMA/CDMA MAC layer protocol to reduce the number of collisions between different clusters. LEACH can effectively reduces the energy consumption of the network and prolongs the lifetime of the network.

But LEACH still has some deficiencies[13]: single hop communication between node and the SINK node consumes a lot of energy that result in degradation of the LEACH's performance. LEACH select cluster head node without considering the residual energy of node. LEACH-MF protocol improves the LEACH protocol by selecting super cluster head nodes in the selected cluster head nodes It reduces the average distance between cluster head node and SINK node, so reducing the energy consumption of WSN. Literature [11] chooses cluster head node based on the residual energy of node.

In the large-scale WSN, the distance of some cluster head nodes is approach; and the data that is collected by those cluster head nodes are similar.

For the several above mentioned deficiencies, this paper proposed that merging adjacent clusters in accordance with the residual energy of cluster head node, and according to the distance between the cluster head node and SINK node as an measure to construct a multilayer structure of clusters, thus reducing the energy consumption of the whole network.

The structure of the remainingr part of this paper is organized as follows, the second part decribs in more details the improvement of LEACH routing protocol which is named as LEACH-MM, the third part is

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devoted on the simulation and the analys of results; the fourth part talk about the conclusions and future work.

II. Proposed Algorithm

Algorithm hypothesis:

(1) All initial energy of sensor nodes and the status of sensor nodes are same, the energy of SINK node is infinite.

(2) Sensor node can't move.

(3) The transmission power of sensor node can be adjusted, because the transmission power and the transmission distance are relevant. Sensor node can adjust transmission energy dynamically according to the transmission distance.

(4) It is difficult to achieve the global information in practice for all nodes.

(5) The distribution of sensor nodes are random.

A. Merging Adjacent Clusters

The operation of LEACH is divided into rounds, each round includes two phases: establishment phase and stabilization phase. During the establishment phase of cluster, all nodes obtain the random number between 0 and 1. If the random number is smaller than the threshold value T(n), the node becomes the cluster head node (The election formula of cluster head is shown in formula (1), p represents the proportion of cluster head node, r denotes the current number of rounds, G represents a set of nodes that doesn't become a cluster head nodes in the past 1 / p rounds). Formula (1) can ensures that all nodes in 1 / p rounds can become cluster head node once.

$$T(n)=\begin{cases}\dfrac{p}{1-p\times\left(r \bmod \dfrac{1}{p}\right)} & if\ n\in G\\ 0 & otherwise\end{cases} \quad (1)$$

Formula (1) doesn't consider the residual energy of the node. Formula (2) gains the new threshold $T(n)_{new}$ by considering the residual energy of the node. Rs represents the number of consecutive 1/p rounds in which a node has not been cluster-head, En_current represents the current energy and En_max denote the initial energy of the node. Rs is reset to 0 when a node becomes a cluster head node [12].

$$T(n)_{new}=\begin{cases}\dfrac{p}{1-p\times\left(r \bmod \dfrac{1}{p}\right)}\left[\dfrac{E_{n\_current}}{E_{n\_max}}+\left(r_s div \dfrac{1}{p}\right)\left(1-\dfrac{E_{n-current}}{E_{n\_max}}\right)\right] & if\ n\in G\\ 0 & otherwise\end{cases} \quad (2)$$

When the election of cluster head node is completed, cluster head begins to broadcast the information of cluster head. Non-cluster head nodes receive the information from cluster head nodes and select the best cluster that is based on the received signal strength. Non-cluster head node sends a join message to the cluster head node. Then cluster head node sends a TDMA table to the cluster member nodes. Cluster member node can only send data in the allotted slot time; otherwise the node gets into sleep.

The distance of some cluster head nodes is approached; and the data that is collected by those cluster head nodes are similar. Therefore, choosing a cluster head node in the some near cluster head nodes to communicate with the super cluster head node(Discussing how to choose super cluster head nodes in 2.2). It can reduces the number of long-distance communication between cluster head nodes and super cluster head node. Therefore, this paper proposes the method of merging adjacent clusters.

Due to the large-scale WSN contains a large number of sensor nodes, so the number of cluster head nodes are also huge. LEACH selects cluster head node randomly, so the distance of some cluster head nodes is approach (as shown in Figure 1). C1, C2, C3 are cluster head nodes, cluster head nodes can communicate with SINK node directly. If the distance between cluster head nodes and SINK node is too far, then the energy consumption of C1, C2, C3 will become very high. Therefore, Selecting the cluster head node which the residual energy is greater than the average residual energy of adjacent cluster nodes become the ms-cluster head node (minsuper-cluster head node).

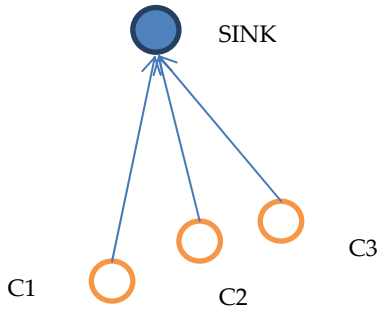

Figure 1: Sending data packet of LEACH

The specific method of LEACH-MM to chooses ms-cluster head nodes as follows:

Cluster head nodes are selected randomly in accordance with the method that election of cluster head node in the LEACH protocol. Cluster head node creates a TDMA table and broadcast it to notify the cluster member nodes. The cluster member nodes send data packets to the cluster head node in the allotted slot time. LEACH-MM selects the cluster head node whose residual energy is greater than the average residual energy of adjacent cluster node to become the ms-cluster head node. Then ms-cluster head node broadcast information, cluster head nodes join the ms-cluster (as shown in Figure 2) that are based on the broadcast area of ms-cluster head (dis represents the broadcast distance of ms-cluster head node, great circle represents for the broadcast area of ms-cluster head node). The election of ms-cluster head node is completed.

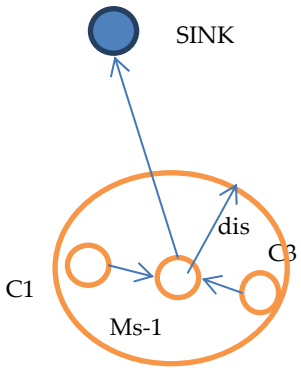

Figure 2: Sending data packet of merging adjacent clusters

After using the algorithm of merging adjacent clusters, the cluster head node C1 and C3 don't send data packet to the SINK node directly, but forward the data packet to the SINK node via Ms-1 node.

B. Multilayer Clusters

Based on the single-hop transmission data packet of the cluster head node, it consumes a lot of energy. Multi-hop transmission packet reduces the distance of the WSN, so, the energy consumption of WSN decreases. This paper proposes multi-level cluster:

In the large-scale WSN, the long-distance communication between the cluster head node and the SINK node consumes a lot of energy. Therefore, single-hop transmission data packet of the cluster head node is not suitable for the large-scale sensor networks(Single-hop transmission data packet of the cluster head node as shown in Figure 3).

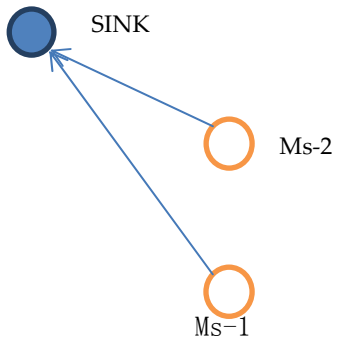

Figure3: Sending data packet of single-hop

The energy consumption of the node is non-linear. The expression that the node send the energy consumption of k-bits data is shown below:

$$E(k,d)=\begin{cases} k*Erx + k*Efs*d^2 & d \le do \\ k*Erx + k*Emp*d^4 & d > do \end{cases} \quad (3)$$

As shown in formula (3), do is the threshold; If d <= do, the energy consumption of node is proportional to the square of the distance. If d> do, the energy consumption of node is proportional to the fourth power of the distance. With the increasing of distance, communication between the node and the SINK node consume a lot of energy. Therefore, single-hop transmission data packet of the node is not suitable for large-scale WSN.

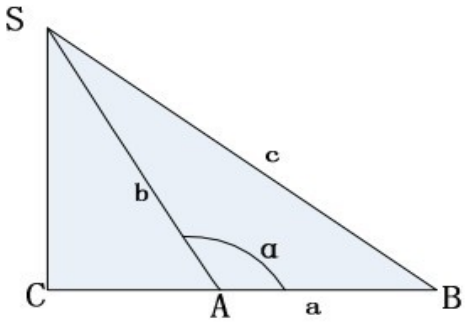

Figure4: Selecting the super cluster head node of LEACH-MM

From the above deficiencies, this paper join the advantages of LEACH-MF to LEACH-MM. The way of selecting the super cluster head node in the LEACH-MF protocol is shown in Figure 4[10].

The Figure 4 shows that $a^2 + b^2 < c^2$, $a^4 + b^4 < c^4$. we prove it with more details in the next following paragraph.

In the triangle SCB, (a, b, c) separately represent for the three sides of the SAB, respectively. Result obtained by using the Pythagorean theorem in the right-angled triangle:

$$(b*\cos(\pi-\alpha)+c)^2+(b*\sin\alpha)^2=c^2 \quad (4)$$

$$c^2-(a^2+b^2)=2ab\cos(\pi-\alpha) \quad (5)$$

Because α is obtuse angle, so $\cos(\pi-\alpha)>0$, $a^2 + b^2 < c^2$, $a^4 + b^4 < c^4$. A become B's super cluster head node in Fugure 4.

The process of generating multi-level clusters, Ms-1 is based on Pythagorean theorem to select super cluster head node Ms-2. Ms-1 node forwards data packet to the SINK node via Ms-2 node.

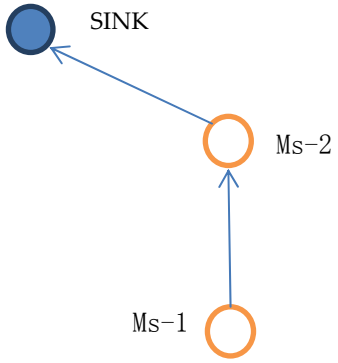

Figure 5: Sending data packet of multi-hop

When the election of ms-cluster head node and super cluster head node is completed.Then WSN getting into the stabilization phase. Cluster member node send data packet to the cluster head node, then cluster head node fuses data and sends the data packet to the ms-cluster head node. Ms-cluster head node fuses data and forwards the data packet to the SINK node via the selected super cluster head node.

LEACH-MM's pseudo-code is shown in Figure 6. Firstly, electing cluster head node with random number

between 0 and 1 is smaller than the threshold value T (n), then the node becomes cluster head node. Secondly, LEACH-MM elects ms-cluster head node that the residual energy of node is greater than the average residual energy of adjacent cluster node, then the node becomes ms-cluster head node ('energy' represents for the residual energy of node,'Average_energy' represents for the average residual energy of adjacent cluster node in Figure 6). Finally, LEACH-MM elects super cluster head node by Pythagorean theorem. C1.distance represents for the distance between C1 and SINK, C2.distance represents for the distance between C2 and SINK in Figure 6.

```
//Cluster head election
// 'N' represents  normal node
// 'H' represents cluster head node
1. state = N;
2. Random (0,1)→ u;
3. if (u<T(n)) then
4.  state=H;
5. calculate the value of Average_energy
6.end if
//Ms-Cluster head election
1.if(state=H) then
2.  if(energy > Average_energy) then
3.  state = MS
4.  broadcast MS_MSG within range R;
5.  wait for JOIN_MS_MSG;
6.end if
//Super-Cluster head election
//C1 , C2  are Ms-Cluster head node
//"distance" is the distance between C1 and C2
1.if(state= MS) then
2.  if(C1.distance * C1.distance + distance * distance <
          C2.distance + C2.distance) then
3.  C1 send data packet to SINK via C2
4.end if
```

Figure 6: Pseudo-code of LEACH-MM protocol

III. Simulations and Analysis

The performance of LEACH-MM protocol, LEACH protocol and LEACH-MF protocol are compared in simulation.

Before making the experiment, the value of the dis (dis represents the broadcast distance of ms-cluster head node) that has to be determined. If the value of dis is too small,that means some close cluster head nodes cannot join the ms-cluster any more and it further implies that LEACH-MM can't achieve the intended purpose. If the value of dis is too large, the energy to join the ms-clusters will be increased. The value of dis is do in this Simulation. If the value of dis is greater than do, the energy consumption is proportional to the fourth power of the distance. The definition of the threshold do is (Efs represents for the energy consumption of node sends 1-bit in free space model. Emp represents for the energy consumption of node sends 1-bit in multipath fading model) as follows:

$$do = \sqrt{\frac{Efs}{Emp}} \qquad (6)$$

Before carrying out the simulation, the parameters should be initialized. Then, using these parameters compares the performance of LEACH, LEACH-MF and LEACH-MM. The initialization parameters are shown in table1:

TABLE 1

THE INITIAL VALUE OF THE PARAMETER

Parameter	value
Etx	50e-9J/bit
Erx	50e-9J/bit
Efs	10e-12J/bit/m2
Emp	0.0013e-12J/bit/m4
EDA	5e-9J/bit/singal
Control packet length	100-bits
Data packet length	4000-bits
The Location of SINK	(0,0)

Distribution of LEACH-MM's nodes is shown in Figure 7:

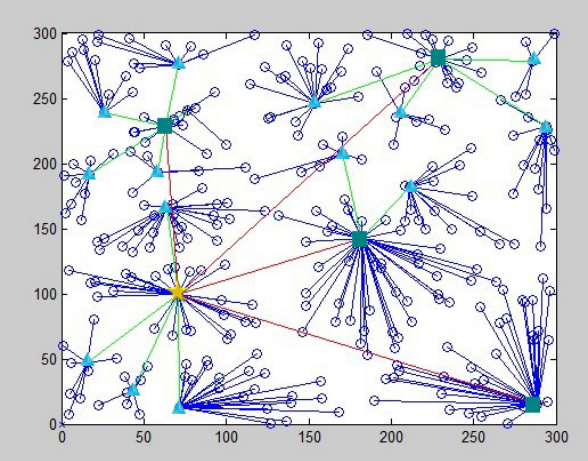

Figure 7: The distribution of nodes of the LEACH-MM

In Figure 7, the horizontal axis represents the distance; the vertical axis also represents the distance; circle represents for ordinary node, triangle represents for cluster head node, square represents for ms-cluster head node, the five-pointed star represents the super cluster head node. Figure 7 shows that the way of electing the cluster head node, ms-cluster head node and super cluster head node. The connection between the circle and triangle represents for the communication between ordinary node and cluster head node. The connection between the triangle and the square represents for the communication between cluster head node and ms-cluster head node. The connection between the square and the five-pointed star represents for the communication between the ms-cluster head node and super cluster head node.

Figure 8 and Figure 9 show the comparison chart of the residual energy and residual nodes of LEACH, LEACH-MF and LEACH-MM in the circumstances which the total number of nodes is 300, the experimental environment is 300*300 and the initial energy of node is 0.2J.

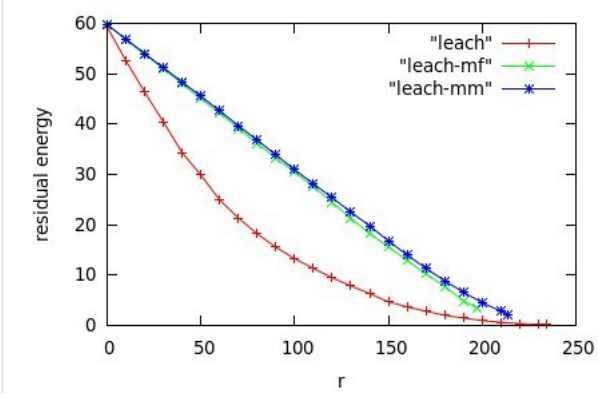

Figure 8: The comparison chart of residual energy of LEACH, LEACH-MF and LEACH-MM

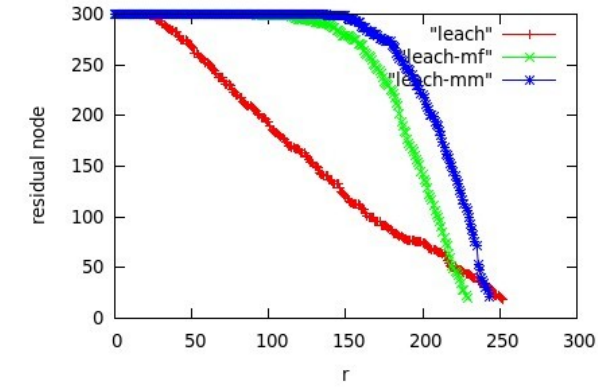

Figure 9: The comparison chart of residual nodes of LEACH, LEACH-MF and LEACH-MM

Figure 8 and Figure 9 show that the residual energy and residual nodes of LEACH-MM are more than LEACH-MF and LEACH. In the Figure 8, the horizontal axis represents the number of rounds; the vertical axis represents the residual energy of WSN. The residual energy of LEACH-MM is more 152% than the residual energy of LEACH, is more 7% than the residual energy of LEACH-MF. Because the single-hop transmission of data packet of LEACH consumes a lot of energy, the curve of LEACH decline rapidly. The multi-hop transmission of data packet of the LEACH-MF and LEACH-MM reduce a large number of energy consumption. In the Figure 9, the horizontal axis represents for the number of rounds; the vertical axis represents for the number of residual nodes. The residual nodes of LEACH-MM is more 68% than the residual nodes of LEACH, is more 7% than the residual nodes of LEACH-MF. Because the single-hop transmission of data packet consumes a lot of energy, the number of residual nodes of LEACH declines rapidly. The multi-hop transmission of data packet of the LEACH-MF and LEACH-MM prolong the lifetime of network. LEACH-MM reduces energy consumption and increase residual nodes by merging the adjacent clusters. So, the performance of LEACH-MM is better than LEACH-MF and LEACH.

TABLE II

THE AVERAGE ENERGY CONSUMPTION OF LEACH, LEACH-MF AND LEACH-MM (EACH ROUND)

Protocol	Average Energy(round)	CH energy(round)
LEACH	0.3272J	0.2117J
LEACH-MF	0.2867J	0.1560J
LEACH-MM	0.2675J	0.1512J

In table 2, first column represents the name of the protocol, second column represents the total energy consumption of all nodes in a round; third column represents the total energy consumption of all cluster head nodes in a round. From the table 2, it shows that the minimum energy consumption is LEACH-MM.

Adjusting the parameters, the number of nodes is 500, 700, 1000, respectively; the experimental environment is 300*300, 500*500, 700*700, respectively.

TABLE III

THE COMPARISON OF LIFETIME OF LEACH, LEACH-MF, AND LEACH-MM

Protocol	Total number of nodes			
	300	500	700	1000
LEACH	199.3	212.2	349	379
LEACH-MF	215.4	312.6	443.3	470.5
LEACH-MM	230.6	343.9	517.3	557.3

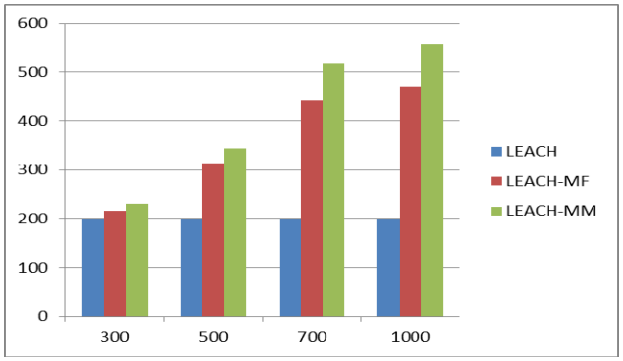

Figure 10: The column chart of lifetime of LEACH, LEACH-MF LEACH-MM

Table 3 shows the comparison of the lifetime of LEACH, LEACH-MF and LEACH-MM under above conditions. Under the circumstances of total number of nodes are 300,500,700,1000 respectively, lifetime of LEACH-MM is longer than lifetime of LEACH-MF 7%, 11.1%, 16.7%, 18.4%, respectively. With the increasing of scale of WSN, the number of cluster head nodes increases, so the number of communication between the cluster head node and super cluster head node increases. LEACH-MM elects ms-cluster head nodes to reduce the number of communication between cluster head node and super cluster head node. So, the performance of LEACH-MM is much better than the performance of LEACH-MF.

IV. CONCLUSIONS AND FUTURE WORK

LEACH assumes that all nodes to communicate with

SINK node directly. With the expansion of WSN scale, the average distance between the node and SINK node increases significantly, that result in much more communication energy cost. For these reasons, LEACH is not suitable for the application of the large-scale WSN. This paper proposes LEACH-MM that merge adjacent clusters according to the residual energy and choose multilayer clusters based on the distance. The experimental results show that LEACH-MM is better than LEACH-MF and LEACH.

In the large-scale WSN, LEACH-MM could make a long-live sensor network. Nonetheless, LEACH-MM still has some deficiencies: for example, it is difficult to achieve the global information for all cluster head node in practice, and they transmit data packet to SINK node only with a maximum of two hops. In the future work, we will focus on these problems to make some improvement.

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