Improvement of LEACH in Wireless Sensor Networks Based on Balanced Energy Strategy

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Abstract—LEACH (Low Energy Adaptive Clustering Hierarchy) routing protocol is the conventional clustering communication protocol which is widely used in Wireless Sensor Networks. However, in LEACH, the nodes consume their energy quickly and the efficiency of energy deceases because the nodes with low energy and far away from base station become the cluster head nodes. By analyzing the energy model and considering three important factors: The energy of each node, the number of times of nodes that are chosen to be the cluster heads and the distances between nodes and base station, we change the node's threshold function to prolong the network's lifetime and realize the balance of energy in network. The simulation results indicate that the new protocol can prolong network’s life time and balance energy consumption of nodes.

Key words: Wireless Sensor Networks; improvement of LEACH; choosing of cluster head

I. INTRODUCTION (HEADING I)

Wireless Sensor Networks (WSN) is a kind of network which can deploy small sensor nodes randomly in a surveillance area, in order to realize real-time data monitoring and effective transmission. With the development of information technology, WSN is considered as the most important technology in 21st century. WSN is widely applied to medical treatment, military and environment detection, industry and other fields. The communication devices of WSN have the advantages because of their small volume and low-price [6-7]. Their power is supplied by batteries. These batteries cannot be replaced when WSN works because large amount of nodes are distributed in a wide area and it is impossible to be watched. Therefore, prolonging lifetime of WSN which has only limited energy becomes a significant research area.

In order to solve the problems mentioned above, communication protocol must be modified. The existing wireless sensor routing protocol can be divided into two kinds: the plane routing protocol and layered routing protocol. Plane routing protocol requires a large number of storage spaces. So it does not apply to large-scale networks. But layered routing protocol can be applied in these networks. LEACH (low energy adaptive clustering hierarchy) is one kind of layered routing protocol. It can affect lifetime of WSN by choosing cluster heads periodically and restructuring network. So it can avoid cluster head node perishing because of excessive energy consumption. However, due to the randomness of the election of cluster head nodes, these nodes are distributed unevenly, which causes uneven distribution and decrease of life expectancy of WSN.

In order to realize the balance of energy, the improvement of the utilization rate of energy and the extension of survival lifetime of WSN, the paper mends the threshold function based on the existing classical LEACH algorithm, considering three important factors: the residual energy of each node; the times of being selected as cluster head nodes of each node; distances between nodes and base station.

II. CLASSICAL LEACH PROTOCOL

A. The method of clustering in LEACH protocol

LEACH protocol is proposed by Chandrakasan and others in MIT. It is based on the low power consumption adaptive routing algorithm of WSN. In LEACH, in order to balance energy consumption of each node, nodes are selected as cluster head nodes circularly and randomly. This algorithm makes every node has a chance to become a cluster head. Then normal nodes join the corresponding cluster head nodes following the principle of proximity. These normal nodes deliver their data directly to cluster head nodes. Cluster head nodes receive the data and send it to the base station. So this process reduces the loss of energy and extends the lifetime of WSN.

The process of the formation schemes of cluster in LEACH is shown in Fig. 1.

B. Running process of LEACH

Clustering process is executed continuously and circularly in LEACH. Each reconstruction process of clusters is called a round. Each round can be divided into two stages: The Set-up stage of cluster; the steady-state for data transmission. In order to effectively save resources, the Set-up stage is longer than the steady-state.
1) The Set-up stage of cluster: The process of establishing the cluster is divided into four stages: the selection of cluster head nodes, the broadcast of cluster head nodes, the establishment of clusters and the formation of scheduling mechanism.

In the initial stage, LEACH protocol randomly selects a node as cluster head node in WSN. The principle of selecting is: randomly generating a number between 0 and 1 for each node. If this number is less than the threshold value, the node would be elected as a cluster head node. The formula for threshold value $T(n)$ is shown in formula (1).

$$T(n) = \begin{cases} \frac{p}{1 - p \cdot \lfloor r \mod \left( \frac{1}{p} \right) \rfloor} & n \in G \\ 0 & \text{otherwise} \end{cases}$$

In the threshold value expression, $n$ is node identification; $p$ is the expectations of number of cluster head nodes accounts for the total nodes (such as 5% or 10%); $r$ represents the current round; $G$ represents the set in which nodes never be chosen as cluster head nodes before $1/p$ round.

After cluster head nodes being selected, each cluster head node will send information to other nodes. The information contains the CDMA code which the cluster head node is going to use. Then, normal nodes join those cluster head nodes by corresponding CDMA code. According to the quantity of information received, cluster head nodes use TDMA clearance table to distribute data transmission time for every node. The establishment of the clusters finishes.

2) The steady-state for data transmission: In this stage, normal nodes send data to cluster head nodes. Cluster head nodes process this received data. Then the processed data will be sent to the base station. This method reduces the quantity of transmitting information. After stable stage lasting for a certain time, WSN carries out a new round. In the process of transmitting data, each cluster uses different CDMA code to avoid interference of information. The running process in LEACH protocol is in Fig. 2

C. Energy model of data transmission in LEACH protocol

Energy model in WSN is usually a kind of simple wireless energy consumption model, as shown in Fig. 3. In this model, Transmit electronics and power amplifiers consume the total energy in circuit. Receive electronics also consume energy in receiving circuit.

![Fig. 3 Energy model of data transmission in LEACH protocol](image)

In [1], it points out that the transmitting terminal and receiving terminal in a sensor node would consume energy. The formula of energy consumption of transmitting terminal is shown in Formula (2).

$$E_{\text{transmit}}(k,d) = \begin{cases} kE_{\text{elec}} + kE_{\text{amp}}d^2 & d \leq d_0 \\ kE_{\text{elec}} + kE_{\text{amp}}d^4 & d > d_0 \end{cases}$$

The formula of energy consumption of receiving terminal is shown in Formula (3).

$$E_{\text{receive}}(k,d) = kE_{\text{elec}}$$

In formula (2) and (3), $E_{\text{elec}}$ represents energy consumption in transmitting procedure between Transmit electronics and Receive electronics. $E_{\text{amp}}$ represents the gain of the amplifier when distance is less than $d_0$ and over (or equal to) $d_0$. The expression of $d_0$ is shown in Formula (4):

$$d_0 = \sqrt{\frac{E_{\text{transmit}}}{E_{\text{receive}}}}$$

In [2], it proposes the formula $k \times E_{\text{elec}} << k \times E_{\text{amp}} \times d^2$, and $k \times E_{\text{elec}} << k \times E_{\text{amp}} \times d^4$. It shows that the shorter transmission distance is, the less energy is consumed.

D. The problems of classical LEACH protocol

1) the randomness of choosing head node: Classical LEACH algorithm makes nodes form clusters randomly. It does not take the following two factors into consideration: residual energy in each node and the number of times that each node has been chosen as a cluster head node. A low-energy node being chosen as a cluster head node will lead to premature death of the node. This condition will decrease the lifetime of WSN. In addition, Choosing nodes which serve as cluster head nodes too many times would cause too much energy consumed by those normal nodes which are far away from cluster head nodes in data transmission process. This condition also results in higher speed of death and lower survival time of WSN.

2) The problem of energy load imbalance in cluster head nodes: Due to the randomness of the choice of the cluster head nodes, it sometimes brings the problem of imbalance in energy load. According to [3], energy consumption of each cluster head node mainly results from the message transmission between cluster head node and base station. Farther the distance between head node and base station is, the more energy the nodes will consume.

3) The improvement of energy utilization rate of head nodes: WSN is defined as a system in which many nodes work coordinately. It needs large quantities of sensor nodes to accomplish measurement. This condition ensures the validity of monitored data. The validity will not be affected by the death of few nodes. However, when the number of dead nodes comes to a certain amount, the utilization rate of alive nodes
with higher energy would decrease. It will accelerate the speed of the energy loss in alive nodes. It means that those residual alive nodes would die quickly, and the lifetime of WSN will be reduced[4].

Based on problems of LEACH protocol proposed above, this paper will put forward a new protocol to overcome the disadvantages in classical LEACH protocol.

III. THE IMPROVEMENT OF LEACH PROTOCOL

This paper proposes a new protocol called NEWLEACH. NEWLEACH modify the threshold function. It changes the way to select cluster head node. Such modification would prolong lifetime of WSN and realize the balanced energy in space.

A. The introduction of optimum factor

Based on given threshold function, NEWLEACH introduces the following three parameters: Current energy in each node: $E_{\text{current}}$, the times of a node which is chosen as a head node: $\text{CH\_times}$, and distances from nodes to the base station: $d_{\text{bs}}$. These three parameters are combined together to form optimum factor $F$. The modification to threshold function is realized by multiplying the original threshold function and optimum factor $F$.

The requirements of choosing cluster head nodes would be improved when the threshold value decrease. The threshold value would decrease with Optimum factor $F$ which can be affected by the three parameters mentioned above.

First of all, there must be a larger possibility for higher energy nodes to be chosen as cluster head nodes. To reach this goal, the optimum factor $F$ which we design should increase with node residual energy.

Secondly, in order to avoid imbalance of energy consumption, the increase of CH times should decrease the value of $F$. It makes those nodes which have been chosen too many times as head nodes have less possibility to be chosen again.

At last, nodes near the base station also have the priority to become head nodes. When a head node is near the base station, the energy consumption of message transmission is lower. Optimum factor $F$ should increase with distances between base station and nodes $d_{\text{bs}}$ decreasing. So the nodes which are near the base station have more probability to be chosen as head nodes.

Referring to existing modification on threshold function in [4], this paper proposes an expression for $F$ containing $E_{\text{current}}$, $d_{\text{bs}}$, and $\text{CH\_times}$ which is shown in Figure (5):

$$F = w_1 \times \frac{E_{\text{current}}}{E_{\text{total}}} + w_2 \times \left(1 - \frac{E_{\text{current}}}{E_{\text{total}}}\right) \times \frac{p}{(CH\_\text{Times}+1)} + w_3 \times \left(1 - \frac{d_{\text{bs}}}{\text{Max}_n}\right)$$  \hspace{1cm} (5)

B. The improved threshold function

The new threshold function synthesizes classical threshold function and optimum factor $F$, and its expression is shown in Formula (6)

$$T(n) = \frac{p}{1 - p \left\lceil r \mod \left(\frac{1}{F}\right)\right\rceil} \left[ w_1 \times \frac{E_{\text{current}}}{E_{\text{total}}} + w_2 \times \left(1 - \frac{E_{\text{current}}}{E_{\text{total}}}\right) \times \frac{p}{(CH\_\text{Times}+1)} + w_3 \times \left(1 - \frac{d_{\text{bs}}}{\text{Max}_n}\right)\right] \quad n \in G \hspace{1cm} (6)$$

In this formula, $p$ represents the percentage of head nodes. $r$ represents current round. $G$ represents the set in which nodes have not been chosen as cluster head nodes before 1/p round. $E_{\text{initial}}$ represents the initial energy in each wireless sensor node. $\text{Max}_n$ represents the farthest distances between base station and nodes. $w_1$, $w_2$, $w_3$ represents weight coefficients. $E_{\text{current}}$ represents current energy in each node. $\text{CH\_times}$ represents the times of a node which is chosen as a head node. $d_{\text{bs}}$ represents distances from nodes to the base station.

C. The method for normal nodes join head nodes

The normal nodes consume less energy when they send messages to the nearest nodes [2]. This means the normal nodes should join the nearest head nodes to save energy. The pseudo code of the method for a normal node to choose its cluster head node is:

\begin{align*}
\text{d}_{\text{min}} &= 0; \\
&\text{for } n = 1; n < j + 1; n++ \\
&\text{for } j = 1; j < s + 1; j++ \\
&\text{if } d_{\text{min}} = d_{nj}\{ \\
&\text{C}_n = j; \\
&d_{\text{diss}} = d_{nj}\}
\end{align*}

$n$ represents the identification number of normal nodes. $j$ represents the identification number of cluster head nodes. $d_{nj}$ represents the distance between a head node $j$ and a normal node $n$. $d_{\text{diss}}$ represents the minimal distance between a normal node and all the head nodes. $s$ represents the number of head nodes. $t$ represents number of normal nodes, $C_n$ represents the identification number of head nodes finally chosen by normal node $n$.

IV. SIMULATED AND MEASURED RESULTS

The simulated and measured results are obtained by using the software MATLAB. In order to get the conclusion of whether the NEWLEACH protocol will improve the quality of WSN system better than the classical LEACH protocol. The simulated results under the classical LEACH protocol must be compared with the results of the WSN which uses the NEWLEACH protocol to choose cluster head nodes. The parameters in the process of measurement are in the Table 1

<table>
<thead>
<tr>
<th>Parameters in the Simulation</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of nodes</td>
<td>100</td>
</tr>
<tr>
<td>Area distribution</td>
<td>100m*100m</td>
</tr>
<tr>
<td>Position of the base station</td>
<td>(50,50)</td>
</tr>
<tr>
<td>The length of information</td>
<td>500byte</td>
</tr>
<tr>
<td>The length of information packet</td>
<td>25byte</td>
</tr>
<tr>
<td>The initial energy of each node</td>
<td>0.5J</td>
</tr>
<tr>
<td>The number of cluster head nodes</td>
<td>10</td>
</tr>
<tr>
<td>The number of running rounds</td>
<td>4000</td>
</tr>
<tr>
<td>$E_{\text{elec}}$</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>$E_{\text{mp}}$</td>
<td>0.0013 pJ/(bit*m4)</td>
</tr>
<tr>
<td>$E_{\text{ip}}$</td>
<td>10pJ/(bit*m2)</td>
</tr>
</tbody>
</table>
In addition, after many simulations, we can conclude that the quality of WSN system can be improved better when \( w_1 = 0.33, \ w_2 = 0.65, \ w_3 = 0.02 \).

Two standards which mentioned in [5] can be used to evaluate the quality of a WSN system. They are First Node Dies (FND) and Half Node Alive (HNA). Firstly, FND can evaluate whether the WSN can work in a long time by observing in which round the nodes start to die, because the quality of the WSN system will become bad obviously when the first node dies. Secondly, HNA can evaluate the quality of a WSN system by observing in which round half of the nodes die, because the node may record the same data as the node which is near to it, especially when the nodes are distributed tightly in a small region. In this way, the death of the first node sometimes can not affect the evaluation of the quality of a WSN system. So HNA can be used into the evaluation of the quality of a WSN system.

After doing experiments eighty times, the results are shown in Figure 4 that: By using FND to evaluate a WSN system, the system’s quality improves 15.7% after using the NEWLEACH protocol instead of LEACH protocol. On the other hand, the system’s quality will be increased 21.5% by HNA.

![Fig. 4](image_url) The evaluation of quality of WSN system in LEACH and NEWLEACH by using FND and HNA

The Fig.5 describes the number of nodes which is alive in a WSN system when this system is working. In Fig.5, it is obvious that the system will prolong its lifetime if using the NEWLEACH protocol to choose cluster head nodes instead of the classic LEACH protocol.

![Fig. 5](image_url) The comparison of lifetime in NEWLEACH and LEACH

Finally, Fig.6-1 and Fig.6-2 show the process of the death of nodes in a limited area. In these two figures, “+” represents a head cluster node; “•” represents a dead node; “○” represents a normal node; “×” represents base station; By observing the position of died nodes, the two figures show that died nodes are distributed evenly when using NEWLEACH to choose the cluster head nodes. However, the classical LEACH protocol makes died nodes distributed less evenly. The even distribution of dead nodes indicates the even distribution of energy in two dimension space [8]. So NEWLEACH protocol has advantages to balance energy to prolong the lifetime of the WSN system.

![Fig. 6-1](image_url) The condition of having half died nodes in a two dimension area by using LEACH

![Fig. 6-2](image_url) The condition of having half died nodes in a two dimension area by using NEWLEACH

V. CONCLUSION

The paper analyses classical LEACH protocol from the formation schemes of cluster, the method to select cluster head nodes transmitting data in steady stage and energy model in transmitting data period. It points out the disadvantages of classical LEACH including the randomness of selecting cluster head nodes; energy load imbalance in cluster head nodes and low energy utilization rate. The paper proposes a new protocol called NEWLEACH which introduces a new concept named optimum factor by considering the residual energy of nodes, times of a node to be chosen as a cluster head node and the distances between nodes and base station. The simulation shows that NEWLEACH protocol can improve the quality of a WSN system under FND and HNA evaluation criterion. Specifically, it prolongs the lifetime of a WSN system. In addition, the even distribution of dead nodes indicates the balanced energy in the system. Therefore, based on the balanced energy strategy, the NEWLEACH protocol makes an improvement on the classical LEACH protocol.
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