A Novel Algorithm for Optimized Cluster Head Selection

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ABSTRACT

In wireless sensor network (WSN), each node has limited energy resources and the lifetime of network is one of the most critical issues in WSNs. Because LEACH protocol has some defects including indefinite and unevenly distributed cluster heads. By studying the energy consumption of nodes and cluster heads on data acquisition and transmission, we propose Balancing Energy Consumption LEACH (BEC-LEACH) protocol to prolong the lifetime of the network. The protocol proposed aims to study the clustering algorithm and take geographical location and remaining energy of nodes as the main factor for cluster heads selection. The simulation results show that BEC-LEACH algorithm can more effectively balance the energy consumption of nodes and prolong the lifetime of network compared with LEACH.

KEYWORDS: clustering algorithms; BEC-LEACH; cluster head; energy consumption

1.0 INTRODUCTION

A wireless sensor network (WSN) node is equipped with a radio transceiver or other wireless communication devices, a tiny microcontroller (CPU, storage, embedded operating system, etc.), the sensing unit (A/D conversion module) and battery [1]. The energy consumption and the lifetime of nodes are the most critical issues in WSNs. According to the network structure, routing in WSNs can be divided into flat-based routing, hierarchical-based routing, and location-based routing. Nodes grouped together to form a cluster in hierarchical routing, the cluster head (CH) acts as the leader collects and aggregates the data from their respective clusters and send the data to base station (BS). Hierarchical routing is the most desirable routing for prolong the life time of wireless sensor network [2-3].

2.0 RELATED WORK

The most well-known hierarchical routing protocols are LEACH, HEED, TEEN, PEGASIS [4-5] etc. The LEACH is the most representative routing protocols among these protocols, whose purpose is to balance the energy consumption of all nodes and prolong the lifetime of network. The sensor nodes are grouped together to form a cluster or clusters. LEACH protocol chooses cluster head from high energy nodes. [8].

The Operation of LEACH protocol is divided into two steps, set-up phase and steady-state phase, as shown in figure 1. In the LEACH protocol, each round have set-up and steady-state phases. In set-up phase cluster heads are randomly chosen and normal nodes choose the closest cluster to join. In the steady-state phase, Cluster heads collect the data from nodes and send the data to the BS. Set-up phase and steady-state phase are divided into multiple sub-phases. That is: advertising phase, cluster set-up phase, Schedule Creation Phase and data transmission phase [4].

The flow chart of LEACH protocol is shown in figure 2.
Figure 2: Process of the LEACH protocol

A. Phases Description

In the advertising phase, each node selects a random number between 0 and 1, the node becomes the cluster head if the randomly number is less than \( T(n) \) in the current round. \( T(n) \) is calculated as shown in equation 1.

\[
T(n) = \begin{cases} 
  p & \text{if } n \in G \\
  1 - p \times (r \mod \frac{1}{p}) & \text{otherwise} 
\end{cases}
\]

Where \( n \) is the total number of nodes, \( P \) is the predetermined percentage of cluster heads \( r \) is the current round, and \( G \) is the set of nodes that have not been elected as cluster heads in the last \( 1/P \) rounds.

B. Drawbacks of LEACH

Serving as the most representative hierarchical routing protocol in WSN, the LEACH still has some drawbacks as described below:

1. LEACH assumes that network is small size and all nodes can communicate with each other, which is not always true for large-scale network. [1]
2. LEACH randomly selects cluster-head, the probability of all nodes elected as cluster head is equal, which would consume unnecessary energy if one round cluster heads are generated in a small region.
3. The number of cluster heads is uncertain in LEACH [7], which will consume a large amount of energy when the number of cluster heads is too many or too few because of the base station being usually far away from the network.
4. LEACH conducts cluster head selection in each round which need all nodes broadcast their messages and geographical location, which will significantly increase energy consumption.
5. LEACH assumes that all nodes are uniformly distributed and each node has the same initial energy, however it is often impossible in actual operation.

C. Advancements of LEACH

Since LEACH is defective, much works and many investments have been done to improve LEACH protocol, such as S-LEACH [5], GS-LEACH [9], LEACH-C. LEACH-C is the most representative protocol proposed by Heinzelman [10], which require all nodes to broadcast their own position and energy to the base station in set-up phase, base station selects cluster heads depending on the remaining energy. Although it prolong the lifetime of the low-energy nodes, the number of cluster heads is still indefinite, the drawback of irrational distribution cluster heads still exists.

Based on the above, we propose BEC-LEACH protocol. Through studying the energy consumption of nodes and cluster heads on data reception and transmission, we propose a novel clustering algorithm which takes geographical location and remaining energy of nodes as the main factor for cluster heads selection.

3.0 OPTIMIZATION ALGORITHM

In routing protocol, to transmit \( n \)-bit message along the distance \( d \), the energy consumption of cluster heads and nodes is given by:

\[
E_{Tx}(n, d) = E_{Tx-mp}(n, d) + E_{Tx-elec}(n) = \\
\begin{cases} 
  n \times E_{elec} + n \times E_{mp} \times d^4 & d \geq d_0 \\
  n \times E_{elec} + n \times E_{fs} \times d^2 & d < d_0 
\end{cases}
\]

Where \( E_{elec} \) denotes radio electronics transmission/reception energy which depends on factors such as modulation, digital coding, filtering, and spreading of the signal, \( E_{mp} \) denotes the amount of energy consumption of multipath fading, \( E_{fs} \) denotes the amount of energy consumption of free space.

To receive \( n \)-bit message, the energy consumption of cluster heads and nodes is shown in equation 3.

\[
E_{Rx}(n) = E_{Rx-elec}(n) = nE_{elec} 
\]

The up expression of equation 2 is an energy consumption value spent by transmission of electronic device and the down expression is the value by transmission amplifier. If the distance is less than a threshold \( d_0 \) which is shown in equation 4, the free space (fs) model is used, whatever, the multipath (mp) model is used.

\[
d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} 
\]

We assume that the number of nodes in network is \( M \), and all nodes placed randomly within \( L \times L \) meter area. The number of cluster heads is assumed to be \( K \), so the average number of members of each cluster is \( M/K-1 \). The energy
The energy consumption of each node is computed by:

\[ E_{\text{node}} = n \times E_{\text{elec}} + n \times E_{\text{fs}} \times d_{\text{node}}^2 \]  

Through (5) and (6), we can obtain the energy consumption of each cluster in one round as shown in (7).

\[ E_{\text{cluster}} = E_{\text{CH}} +  \left( \frac{M}{K} - 1 \right) \times E_{\text{no-CH}} \]  

The energy consumption of all nodes and cluster heads in one round is given by:

\[ E_{\text{total}} = K \times E_{\text{elec}} + K \left( \frac{M}{K} - 1 \right) \times E_{\text{no-CH}} \]

\[ = n \times (2Mk + Kc_{\text{e}} + d_{\text{node}}^2 + M + Kc_{\text{e}} + d_{\text{node}}^2) \]  

(8)

Compare to other parameters in equation 8, \( \frac{1}{K} - 1 \) is so small that it can be ignored, so Equation 8 can be simplified to equation 9.

\[ E_{\text{total}} = n \times (2Mk + Kc_{\text{e}} + d_{\text{node}}^2 + M + Kc_{\text{e}} + d_{\text{node}}^2) \]

Since M nodes placed irregularly within a \( L \times L \) meter area, we assume that each cluster is a circle with the radius of \( \frac{\sqrt{m}}{k} \), and the area of each cluster is \( \frac{L^2}{K} \), the expected distance between all points and the centre of the circle is shown in equation 10.

\[ E(d) = \int \int (x^2 + y^2)^2 \rho(x,y) dx dy - \int \int r^2 \rho(r,\theta) r dr d\theta \]

In this way, the average distance from all nodes to the cluster head is as follows:

\[ E(d_{\text{no-CH}}) = \rho \int_{0}^{2\pi} \int_{0}^{\frac{L}{\sqrt{m}}} r^3 dr d\theta = \frac{\rho L^4}{2\pi K^2} = \frac{L^2}{2\pi K} \]  

In wireless sensor networks, all nodes are far away from the base station because of it usually being arranged in complex environment. We assume that the optimum number of cluster heads is 4. The two distribution models of clusters are shown in Figure 3.

**Figure 3: Two distribution models of clusters**

Base station is far away from all nodes and cluster heads, the energy consumption in the process of cluster heads transmitting data to base station is usually much greater than that of nodes transmitting data to cluster heads. The distance between nodes and cluster heads in the left model of Figure 3 is longer than that of the right model. However, the cluster head of left model is much closer to base station, and the distance between nodes and cluster heads can be...
shorten by the use of the auxiliary cluster head. The energy consumption of the left model is less than that of the right model in real situation. The expected distance between all nodes and cluster heads is shown in equation 12.

\[
E (d_{i \to C_H}) = \frac{L^2}{4} + \frac{L^2}{4K^2}
\]  

(12)

The optimal numbers of cluster-head nodes of this paper is calculated as:

\[
K_{opt} = \sqrt{\frac{M}{2}} \frac{L^2d_0}{d_{CB}}
\]  

(13)

4.0 BEC-LEACH

The nodes are non-uniform distribution in network, so taking the center of gravity of the network get more accurate numerical than geometric center. Let \((X_i, Y_i)\) represent the coordinates of each node. The average horizontal coordinate of all nodes is as follows:

\[
X_0 = \frac{\sum_{i=1}^{M} X_i}{M}
\]  

(14)

The average Vertical coordinate of all nodes is shown in equation 15.

\[
Y_0 = \frac{\sum_{i=1}^{M} Y_i}{M}
\]  

(15)

The distance from Nodes to the center of gravity is as follows:

\[
d = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2}
\]  

(16)

BEC-LEACH chooses cluster heads based on the remaining energy of nodes, the distance from the center of gravity to node and the distance from node to BS. We propose a data model of nodes, which is as shown in equation 17.

\[
CH - E = a \cdot e + b/d_1 + c/d_2
\]  

(17)

Where \(e\) is the remaining energy of nodes, \(d_1\) is the distance from \(s\) node to the center of gravity and \(d_2\) is the distance from a node to the base station.

In the set-up phase, all nodes broadcast information, which causes useless duplication of information and leads to “Information Collision” and “Broadcast Storm” phenomenon [11]. Based on this, we use the “reciprocal mechanism”. Each node generates a random digital in the initial, the initial digital starts decreasing reciprocal, when countdown to zero, it starts compare the CH-E value with around nodes and the specific process is as follows:

1. At the beginning, the information from base station is broadcast to the whole networks, each node computes it coordinates by the information they received.

2. Each node calculates their own CH - E value according to their own energy and geographical location.

3. In the advertising phase, each node generates a random number from 1 to 20, and starts to countdown.

4. When one node countdown to zero , it sends energy comparison requirement to around nodes . The node which has higher energy becomes the temporary cluster head while the node which is closest to the center of gravity becomes auxiliary cluster head.

5. All nodes countdown simultaneously till the smallest of them reaches zero, the current temporary cluster heads become cluster heads, while auxiliary cluster head is decided to become auxiliary cluster head or normal node depends on the position of the cluster head.

6. Cluster head broadcast messages to the surroundings, and nodes select the closest cluster head to join.
The choosing step is shown in figure 4. As shown in (a) and (b), each node generates a random number, and then begin to countdown. The node A firstly countdown to zero begin searching for the around nodes to compare the value of CH-E, A finds the nearest node C, B and compare with each other. After the comparison, the node C which has the highest CH-E value is elected as the temporary cluster head, and A is elected to be the auxiliary cluster head. All nodes countdown simultaneously till the smallest of them reaches zero. As it is shown in (d), it generates temporary cluster heads D, C, G and three auxiliary cluster heads. At last, the node C which has highest CH-E value becomes cluster head, and D becomes auxiliary cluster head. If node C is not far away from the center of gravity, node D becomes normal node.
Select of cluster head

Each node generates a random number and start to countdown

Whether or not countdown to zero

yes

Found around nodes compare the CH-E value

yes

Whether or not the highest energy node?

no

Become temporary cluster head

Become normal node

Find cluster to join

Becomes temporary cluster head

Continue compare to each other

Find out cluster Head and auxiliary cluster head

Cluster formed and become broadcast state in one round

Figure 5: Process of the BEC-LEACH protocol
In order to reduce energy consumption in the process of cluster head selection, after the data transmission phase, we calculate the CH-E value of the cluster head in every area. If its energy value is greater than the average value of networks, the node is still selected to the cluster head of this area in the next round.

5.0 SIMULATION RESULTS

In this section, we mainly use simulations to analyze and to evaluate the performance of the algorithm. This paper uses Matlab to simulate the method. Then, to verify the improved algorithm proposed in this paper, we will compare the results with LEACH and BEC-LEACH.

A. Simulation Setup

The simulation modeled a network of 100 nodes placed randomly within a 100×100 meter area. The communication energy parameters are set as follows: $E_{\text{elec}}$ is 50nJ/bit, $E_{\text{fs}}$ is 10 pJ/bit/m$^2$, $E_{\text{mp}}$ is 0.0013 pJ/bit/m$^4$, $E_{\text{da}}$ is 5nJ/bit/signal and the location of BS is (50,175). Apply energy parameters to Equation 13, we can concluded that the best number of cluster heads is 4.

B. Simulations and Analysis

Figure 6 illustrates the performance of BEC-LEACH comparing to LEACH algorithm in terms of network lifetime. As it is clear from Figure 6 that sensor network performs longer with BEC-LEACH in comparison to LEACH, the first node of BEC-LEACH dies later by 54.3%, the network has a 31.3% delay at time when the half number of nodes dead and the network lifetime decreased by 20%-30%. This power saving is due to: BEC-LEACH can save energy in the process of cluster transmit data to BS. Figure 7 shows the remaining energy in each round of BEC-LEACH and LEACH, after 200 rounds the amount of consume energy in LEACH is 13.7 J and in BEC-LEACH is 9.7 J, after 500 rounds he amount of consume energy in LEACH is more than 35 J when in BEC-LEACH is 31.7 J. Overall from each of these two graphs it is clear that in BEC-LEACH nodes survive longer than in LEACH. Thus BEC-LEACH prolong network lifetime than LEACH.

![Figure 6: Graph of node dead in LEACH and BEC-LEACH](image-url)
We use simulations to inspect the optimal numbers of cluster heads. As shown in Figure 8. The first node dead after 800 rounds when the number of cluster heads is 4, however, it is clearly shown that when the number of cluster heads is 5 the half number of cluster heads and the last node dead later than the number of cluster heads is 3 and 5.
6.0 CONCLUSION

Wireless sensor networks would balance the energy consumption significantly by using hierarchical routing, especially when LEACH stochastically chooses nodes as cluster heads to reduce the energy consumption. However, in LEACH the number of cluster heads is not clear and the cluster heads are distributed unevenly. In order to deal with these problems, a further protocol BEC-LEACH is discussed in this paper. By analyzing the manner and amount of energy used by nodes and cluster heads, in this paper we put out a better way to select cluster heads and we take geographical location and the remaining energy of nodes as an important factor to select cluster heads. If the node is far away from the center of network, an auxiliary node should be added to help collect data. Simulation results show that BEC-LEACH is more energy-efficient than LEACH with greater network lifetime. In this protocol, nodes would exist longer and energy consumption is slower. At the same time, the number of cluster heads chosen by BEC-LEACH is the best. Therefore, it is believed that BEC-LEACH would balance the energy consumption of network as well as make it live longer.

REFERENCES


