Distributed Energy Balance Routing Based on Multiple Attribute Decision Making

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Abstract. To extend the survival time of the Wireless Sensor Networks (WSNs) and decrease the energy it consumes. The method of multiple attribute decision making is used in Leach: firstly, the distance between the node and the base station, the surplus energy of nodes and the amount of neighbor nodes of each node are optimization properties which can obtained the set of optimal Cluster Heads(CHs) in each round; Then using the minimum Manhattan distance method to select and sort the sensor nodes in the set then the optimal nodes are chosen as the CHs. According to a large number of simulation experiments, the proposed protocol is more reasonable for the selection of CHs in the network, the distribution of death nodes is outside-in and the energy load is more balanced.

1. Introduction
The Wireless Sensor Networks (WSNs) contain the amount of sensor nodes which scattered randomly, sink nodes, the Internet and the user terminal. The data can be sent to the base station(sink node) through the self-organizing multi-hop mode by the sensor nodes scattered in the perceptive environment in the network. Sink node can use all kinds of ways to communicate with the external network. The data of the entire area can be transferred to the user terminal. The user could collocate the whole WSN through the management of nodes[1]-[2]. Routing protocol is an significant factor to affect the network’s property and the key to ensure the normal operation of WSNs. In the WSN, the energy of the nodes are restricted, so it is significant to design the energy efficient routing protocol to extend the network's overall length of life.

Scholars at home and abroad have put forward several kinds of typical routing protocols: In Leach, it selects CHs randomly:making the whole network’s energy load distributed to each sensor node evenly, for the sake of decreasing the energy consumption and prolonging the network’s overall survival[3]-[4]. The Leach-C is a centralized cluster routing protocol. All nodes send message about their locations and residual energy to the base station at the start of each round. After the base station accepts the message, the average energy value of all nodes is computed and the energy is not lower than the average energy value of the node as candidate node[5]. Sep adopts a weighted cluster head selection method: the high level nodes with higher initial energy are more likely to be CHs, which can survive longer[6]. In the literature[7]-[11], they selected the optimized CHs by different attributes and didn’t take whether the sensor nodes are suitable for data transmission in each round into account. Therefore, the purpose of this paper is to choose the optimal CHs in each round, minimize the energy consumption and improve survival of the whole network. In the process of selecting CHs in Leach, each node sends data to the base station, each node that elected to the CH sends information to the other nodes which were not CHs to declare to be cluster head. The other nodes judge distances after
receiving the information to the CHs and choose the nearest cluster head into a cluster. In this process, clusters need to transmit data and compared with the partial nodes to transfer message to the base station, which one consume more energy? In the next, the problem is put forward based on the minimum Manhattan distance of multiple attribute decision making method for the optimal selection of CHs, to extend the survival time and reduce unnecessary energy consumption.

This article is structured as following: section 1 describes the implementation of Leach. Section 2 and Section 3 introduces the protocols in the WSNs and the minimum Manhattan distance approach to multiple criteria decision making respectively. Section 4 obtains the CH set of each round, using the minimum Manhattan distance method sorts and selects CHs from the sensor nodes in the set. Section 5 gives the relevant analysis about the experiments. Finally, there is a summary and conclusion of this paper.

2. WSN Protocol

2.1 Leach

Leach was proposed by Chandrakasan of MIT, which is a low power adaptive clustering protocol[3] and was designed for the WSNs. Leach contains two phases: the establishment of cluster head and the stable phase. In order to reduce the energy consumption, the last time of the stable phase is longer than the establishment of the Cluster Heads(CHs). The duration of the two phases is a round.

At the establishment stage of CHs, CHs are generated by selecting randomly. Firstly, the sensor node selects a random digit between 0 and 1. If the number generated is less than T(n), then the node is elected as the CH. T(n) is calculated as follows:

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

(1)

In this paper, \( p \) is the likelihood that the sensor node be a CH. \( r \) is the present of round; \( N \) is the total number of the sensor nodes in the network; \( G_r \) is the set of sensor nodes that are not selected in the final \( p^{-1} \) round.

2.2 Model of energy consumption in wireless sensor networks

When CHs are chosen, CHs go on the air the message to other sensor nodes in the network. According to the intensity of the received message, the node that received the message selects the cluster that it wants to join in and notifies the corresponding cluster head. Based on Time Division Multiple Address, CHs assign communication time gaps to every member of their cluster and notify all nodes in the cluster by the mean of broadcasting. In this way, each node in the cluster transmits data at the specified transmission time and in other time, it enters a dormant state. It reduces energy consumption. In the stable phase, the node collects monitoring data continuously and passes the monitoring data to the CH when its own transmission slot arrives. The data is fused and compressed by the CH and then sent to the sink node (base station), which is a rational working mode to decrease the traffic volume. The entire network enters the next round and the CHs are selected again over a period of time. The clustering mechanism of Leach can decrease the overall energy consumption of the network, extend the networks’ survival time and ensure valid transmission of information.

Because the data transformation and cluster head selection are all based on the nodes’ energy, it is essential to calculate the energy consumption of the sensor nodes in each round. If the distance between the node and the CH is less than the transmission distance \( d_0 \), we use the free space model. Conversely, multi-path model is adopted. The \( k \) bit energy transmitted in the path of distance \( d \) is as in equation (2):
\[
E_{TX} = \begin{cases} 
  k \times E_{elec} + k \times E_{fs} \times d^2 & \text{(if } d \leq d_0) \\
  k \times E_{elec} + k \times E_{mp} \times d^4 & \text{(if } d > d_0) 
\end{cases}
\]  
(2)

\(E_{fs}\) is the energy consumption of fusing unit data, \(E_{mp}\) is the energy consumption of transmitting and amplifying unit data, \(E_{elec}\) is the energy consumption of transmitting and receiving cell data, \(k\) is the bandwidth of the transmission data, \(d\) is the distance between nodes or the distance between the nodes and the base station, \(d_0\) is the threshold of transmission distance:

\[d_0 = \left( \frac{E_{fs}}{E_{mp}} \right)^{\frac{1}{2}}\]  
(3)

The distribution of the CHs, the sensor nodes and the base station of Leach is expressed in figure 1: the hollow circle denotes the sensor node, the asterisk circle denotes the CH, cross represents the base station, the red solid node represents the dead node as a result of energy depletion. From the image we can see, the distribution of CHs in Leach is not evenly and the large amount of nodes close to the base station are the first to die due to uneven energy consumption.

**Figure 1.** Random distribution of cluster heads and death nodes of Leach.

3. **Multiple Attribute Decision Making (MADM) and Minimum Manhattan Distance**

For a multiple attribute decision making problem \([12]\). If a multiple attribute decision making problem has \(n\) options \(A_1, A_2, \cdots A_n\), for each attribute \(X_1, X_2, \cdots X_m\), the value of the scheme \(A_i\) to the attribute \(X_j\) is \(d_{ij}\). \(D = (d_{ij})_{nm}\) is called the decision matrix, \(R = (r_{ij})_{nm}\) is a normalized decision matrix.

When decision matrix and the value of the attribute weights are determined, information of multiple attribute decision making problems is completed. Many ways can be adopted to deal with in math. Namely according to the policy makers’ need to determine an optimal solution, or the alternatives according to the order, until the comprehensive value of all the attributes of each alternative is given.

The Manhattan Distance is the sum of the distance between two points in the fixed rectangular coordinate system of Euclidean space. For example, in the plane, the distance between the \(i_{th}\) point \((X_1, Y_1)\) and the \(j_{th}\) point \((X_2, Y_2)\) is: \(d(i, j) = |X_1 - X_2| + |Y_1 - Y_2|\). In space, the distance between the \(i_{th}\) point \((X_1, Y_1, Z_1)\) and the \(j_{th}\) point \((X_2, Y_2, Z_2)\) is: \(d(i, j) = |X_1 - X_2| + |Y_1 - Y_2| + |Z_1 - Z_2|\).

The multiple attribute decision making problem with Minimum Manhattan Distance (MMD) in multi-objective optimization problems (MOPs) is proposed in literature \([13]\). In this article, we have shown that the minimum Manhattan method is equivalent to the weighted-sum approach. We will not repeat it here and use this conclusion in the following article.

4. **Distributed energy balance routing based on Multiple Criteria Decision Making**

In the following paper, the problem is put forward based on the minimum Manhattan distance method
of MADM for the optimal selection of CHs to prolong the network survival time, reduce unnecessary energy consumption. When the node has more energy, it can transmit the message to the base station. When the energy of the node is reduced, nodes gathered to be clusters: the process of clustering needs to collect information, transmit information that the node is elected as the cluster head etc, and consumes amount of energy.

Set threshold \( d = d_0 / 6 \) as the neighbor range for every node, the figure for the neighbor nodes around each node is uniform. When the CH is selected, the transmission pressure of the node is small. In other literature, the number of CHs in the area of 100 sensor nodes is 9~11. Most literature take 10 CHs (10% of the sensor nodes) directly. The number of cluster heads \( l \) in each round is uncertain in this paper and depends on the energy and range. Decision matrix \( A \) is \( 100 \times 3 \), the first column represents each node’s distance to the base station, the second column represents the number of neighbor nodes of each node within the scope of the threshold, the third column represents the remaining energy of the sensor nodes. \( A(l,2) > 0 \) insures there are nodes alive within the range of threshold, otherwise, the energy of the sensor node in the cluster is too large to consume unnecessary energy. The remaining energy \( A(l,3) \) must be greater than zero for the node to be selected. \( R \) is the normalized matrix of \( A \).

The specific steps are as follows:
Step1: parameter initialization.
Step2: generate the initial node location randomly: \((y_{j1}, y_{j2}), \quad j = 1,2,\cdots,n\).
Step3: the terminal condition judgment. If the number of cycles is \( r < r_{\text{max}} \), then go to Step4. Otherwise, the algorithm will be terminated.
Step4: for each round, the updated matrix \( R \) is embedded in the multi-attribute decision making process based on the MMD method, obtaining the optimal cluster head set and ranking. In the cluster head set, the quantity of nodes with the remaining energy is greater than zero and the number of living nodes is greater than zero. Each node computes the distance of each node to the CHs and selects the nearest CH into cluster. Then CHs send the message to the base station. Updating nodes’ energy formula and the number of live nodes around the node. Let \( r=r+1 \) and return Step3.

5. Discussions and Simulations Results
The improved routing protocol is simulated by MATLAB. Suppose \( n = 100 \) nodes scattered in the area of the rectangle randomly. \((50, 50)\) are the coordinates of the base station. \( p = 10\% \) was the probability of a node elected to be the CH, the largest round \( r_{\text{max}} = 3000 \). The initial energy of every node is \( E_0 = 0.5 \text{ J}, \quad E_{\text{ch}} = 10^{-11} \text{ J/bit} \) is the energy consumption of fusing unit data, \( E_{\text{mp}} = 1.3 \times 10^{-15} \text{ J/bit} \) is the energy consumption of transmitting and amplifying unit data, \( E_{\text{elec}} = 5.5 \times 10^{-9} \text{ J/bit} \) is the energy consumption of transmitting and receiving cell data, the energy of the base station is not restricted.

The distribution of death nodes of the improved routing protocol in this paper is shown in figure 2: the distribution of the death node is from the outside to the inside: the node that has the longest distance from the base station dies first and then the death distribution is random according to the energy consumption which extended the lifetime of the whole network.

To compare the improved routing protocol, Leach and Sep, we run programs 30 times respectively and get the mean of the first node death round numbers. The results shown in table 1 and figure 3: the improved routing protocol compared with Leach and Sep, the death of the first node’s round number is Leach’s 1.65 times and 1.3 times of Sep. As shown in figure 4, the speed of the improved protocol is the slowest in energy consumption compared to the other two protocols.
Figure 2. Random distribution of cluster heads and death nodes of improved protocol.

Table 1. The comparison of the first node death of different protocols.

| Protocol                  | The round number of the first dead node (r) | Compared with Leach |
|---------------------------|--------------------------------------------|---------------------|
| Leach                     | 773                                        | 1                   |
| Sep                       | 986                                        | 1.28                |
| The improved routing protocol | 1279                                      | 1.65                |

Figure 3. The comparison of the first dead node number of different protocols.

Figure 4. The comparison of energy consumption of various protocols
6. Conclusion
In this article, the improvements in this paper mainly includes: (1) Combined with energy information, the number of CHs, the distance information, using the method of multiple attribute decision based on the minimum Manhattan distance to generate global cluster heads makes the clusters’ power consumption is low on the overall and saves energy; (2) Making the base station as CH for transmitting the data ensures the randomness of the cluster head and reduces unnecessary energy consumption. The distribution of the energy depletion of nodes is outside-in and the survival time of the network is prolonged.

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