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Improvement of the SEP Protocol based on Community Structure of Node Degree

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Abstract. Analyzing the Stable election protocol (SEP) in wireless sensor networks and aiming at the problem of inhomogeneous cluster-heads distribution and unreasonable cluster-heads selectivity and single hop transmission in the SEP, a SEP Protocol based on community structure of node degree (SEP-CSND) is proposed. In this algorithm, network node deployed by using grid deployment model, and the connection between nodes established by setting up the communication threshold. The community structure constructed by node degree, then cluster head is elected in the community structure. On the basis of SEP, the node's residual energy and node degree is added in cluster-heads election. The information is transmitted with mode of multiple hops between network nodes. The simulation experiments showed that compared to the classical LEACH and SEP, this algorithm balances the energy consumption of the entire network and significantly prolongs network lifetime.

Key words: Wireless sensor networks, SEP protocol, Community structure, Grid deployment, Multiple hops.

INTRODUCTION

Wireless Sensor Network (WSN) is a self-organizing network system formed by a large number of sensor nodes, such as data sensing, wireless communication and microcomputing, which are deployed in the monitoring range. According to the topology in WSN, the routing protocol of wireless sensor network can be divided into planar routing protocol and hierarchical routing protocol [1-2]. The LEACH [3] protocol is a Low-Energy Adaptive Clustering Hierarchy protocol as a classical algorithm in clustered routing protocols. It is clustered by the signal strength received by the node, and the cluster head node is selected in a random loop to balance the energy consumption of nodes within the network. The SEP [4] (Stable election protocol) algorithm is a kind of classical heterogeneous network clustering routing algorithm, which is based on the LEACH protocol. The SEP algorithm uses the energy heterogeneous approach, according to the initial energy of different sets of different cluster election probability, increase the high-level nodes become the probability of cluster head, so that the high-level nodes and ordinary nodes close to the same time death. However, the SEP algorithm still has the cluster head distribution uneven, the number of nodes in the cluster is large, and the residual energy of the node is not considered.

In the literature [5], an improved stable voting protocol based on node energy consumption is proposed. The algorithm updates the next round of cluster election probability according to the consumption of each node in the round. The main purpose of improving the possibility which the node with higher residual energy is selected as cluster head is to balance the energy consumption of the node. In the literature [6], a distributed non-uniform clustering routing algorithm is proposed, which integrates the position factor and the average energy factor in the cluster selection mechanism to balance the residual energy of the whole network node. The main purpose of using the multi-hop dynamic routing between clusters is to balance the network energy consumption. In the literature [7], a clustering multi-hop routing protocol based on energy equalization is proposed. This algorithm can save the energy of nodes by adding relay nodes to assist in data forwarding and sharing the work of cluster head nodes in order to

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extend the entire network life cycle. In the literature [5-7], many optimization methods are proposed, but none of the nodes in the cluster are optimized.

Aiming at the above problems, a SEP algorithm based on community division (SEP-CSND) is proposed. The algorithm introduces the residual energy and the node degree of the node to optimize the cluster selection mechanism. The nodes in the community are organized into clusters by using the degree of nodes, and the multi-hop transmission strategy is adopted in the cluster. Cluster head transports data to sink node through the multi-hop routing.

ANALYSIS OF SEP ALGORITHM

Principle of the SEP algorithm

The SEP algorithm is proposed by G. Maragdakis as a classical heterogeneous network clustering routing algorithm. This agreement is developed on the basis of the LEACH protocol, adding the initial energy isomorphism of this element, using the second energy heterogeneous network. According to the heterogeneous characteristics of the network is divided into ordinary nodes and high-level nodes, and set a different cluster election probability, so that the cluster election probability of high-level nodes is bigger more than the ordinary node. So that the high-level nodes and ordinary nodes close to the same time to death, and extend the stability of the network cycle.

The SEP algorithm assigns each node a weight corresponding to the optimal probability P_{opt} , and its weight is the ratio of the initial energy of each node to the initial energy of the normal node. And define P_{nrm} for the probability of ordinary node-weighted elections, P_{adv} for the probability of ordinary node-weighted elections. The formula is:

$$\begin{cases} P_{\text{nrm}} = \dfrac{P_{\text{opt}}}{1+\alpha m} \\ P_{\text{adv}} = \dfrac{P_{\text{opt}}}{1+\alpha m}(1+\alpha) \end{cases} \tag{1}$$

Where α is the ratio of the initial energy of the higher node to the initial energy of the normal node. m is the proportion of the advanced nodes in the total number of nodes.

Ordinary nodes and high-level nodes become cluster head threshold $T(S_{\text{nrm}})$ and $T(S_{\text{adv}})$, the formula is:

$$\begin{cases} T(S_{\text{nrm}}) = \dfrac{P_{\text{nrm}}}{1-P_{\text{nrm}}\left[r \bmod \left(1/P_{\text{nrm}} \right)\right]} \\ T(S_{\text{adv}}) = \dfrac{P_{adv}}{1-P_{\text{adv}}\left[r \bmod \left(1/P_{\text{adv}} \right)\right]} \end{cases} \tag{2}$$

Where r is the current numbers of turns.

The shortcomings of SEP algorithm

(1) The SEP algorithm is still a random selection cluster head mechanism using LEACH algorithm. The clustering process is to select whether to join the cluster according to the received cluster head node signal strength through the non-cluster head node. In this way, the cluster head is not evenly distributed, and its clustering method makes the number of nodes in the cluster random.

(2) In the SEP algorithm, the election probability is only related to the initial energy of the node, but not with the residual energy; After the network is running for some time, the residual energy of the high-level node may not have the residual energy of the ordinary node, and the probability of becoming the cluster head is still higher than that of the ordinary node. This speeds up the death of some advanced nodes and reduces the overall survival time of the network.

(3) SEP algorithm is used in single-hop transmission mode, such a transmission so far away from the cluster head nodes need to spend a lot of energy to carry out long-distance information transmission, making the nodes in the network premature death, reducing the network life cycle.

MODEL AND ASSUMPTIONS

In the study, in order to analyze the performance and energy consumption of SEP-CSND, the following network model and energy consumption model are assumed.

Network model

1) The location of the sink node is fixed at the geometric center of the monitoring area.
2) After the node is deployed, the location no longer moves.
3) The node has a location-aware function.
4) Nodes have the same processing and communication capabilities and transmit power.
5) The node can reduce the amount of data transmission through data fusion technology.
6) Node energy is heterogeneous way, divided into high-level nodes and ordinary nodes, the energy of high-level node is $(1+\alpha)$ times the energy of ordinary nodes, and all nodes are able to know their current residual energy.

Communication energy consumption model

In this paper, the wireless communication energy consumption model in the SEP protocol is used. The energy consumption of the data transmission is mainly composed of the energy consumed by the wireless transceiver and the power amplifier. As shown in Figure 1.

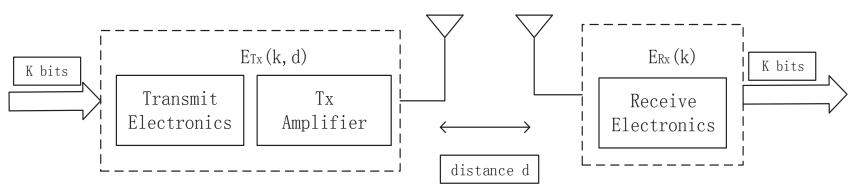

FIGURE 1. Energy Consumption Model

The energy consumption of the power amplifier and the transmission environment are related to the transmission distance, and the energy consumption is divided into free space transfer mode and multipath transfer mode.

The transmitter sends k bits of energy consumed, as shown in the formula (3):

$$E_{\mathrm{Tx}}(k,d)=\begin{cases} k*E_{\mathrm{elec}}+k*E_{\mathrm{fs}}*d^2, & d<\mathrm{d}_0 \\ k*E_{\mathrm{elec}}+k*E_{\mathrm{amp}}*d^4, & d>\mathrm{d}_0 \end{cases} \tag{3}$$

In the formula (3): The k represents the number of data bits; The E_{elec} is the energy consumption of the transceiver circuit; The d is the distance between the sending node and the receiving node; The d_0 is the threshold for switching between free space and multipath mode and $d_0=\sqrt{E_{\mathrm{fs}}/E_{\mathrm{amp}}}$;The E_{fs} and E_{amp} represent the energy dissipation coefficients of the free-space and multipath models respectively.

Receiver energy consumption as shown in formula (4):

$$E_{\mathrm{Tx}}\left(k\right)=E_{\mathrm{Rx}}\left(k\right)=k*E_{\mathrm{elec}} \tag{4}$$

SEP-CSDN ALGORITHM

Node deployment and connection between nodes

Node deployment

According to the grid deployment model, the target area is divided into four equal-sized rectangular areas. In the well-divided area, the advanced nodes are deployed near the geometric center of the area, and the common nodes are randomly deployed. As shown in Figure 2:

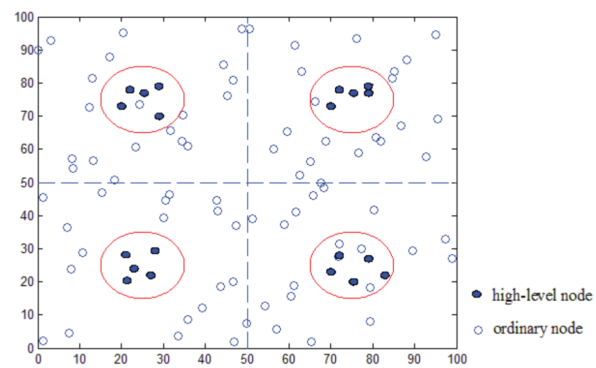

FIGURE 2. Node deployment

The connection between nodes

Considering the large distance between node nodes when deploying large nodes, the transmission energy consumption is big when the node carries on the long-distance data transmission. And the energy consumption is proportional to n-th power communication distance (generally 2≤n≤4). d_0 is the threshold for free space mode and multipath mode switching. The formula of the threshold is calculated to be about 87.7 meters. When the transmission distance is less than d_0, its energy consumption is proportional to the square of the transmission distance. When the transmission distance is more than d_0, the energy consumption is proportional to the fourth power of the transmission distance. So the main purpose of setting the communication threshold which $d_S=87.7$ is to reduce the single node long-distance transmission of energy consumption. The value of its ds by observing there is sudden increase in the node consumption for long-distance information transmission. If the two nodes have a geographical distance less than ds, a communication connection is established, but not necessarily for communication. It means it is possible to use this path for communication. If the geographical distance of two nodes is greater than ds, you cannot establish a communication connection; If a separate single node with no other nodes to establish a communication connection, adjust the transmission power and geographical location of the nearest node and establish a communication connection.

The construction of the community

According to the definition of community structure [8] in complex networks, the target network is divided into several "group" or "cluster". The internal nodes of each "group" are very close to each other, and the interconnection between "group" and "group" is relatively sparse. For a wireless sensor network, it can be seen as a network with a community structure, that is, the nodes in the target area that are relatively connected are equivalent to the "group" or "cluster" defined in the complex network.

In this paper, the SEP-CSDN algorithm of specific rules in the community is established as follows:

After connecting the nodes according to the divided grid area, select the nodes with the largest node degree as the community center in each region. In this paper, the degree k_i of the node is the number of nodes that establish a communication connection with node i. The remaining nodes in the area join the community as the community center with the largest node of the node degree. And then disconnect the connection between nodes in different regions, leaving only the nearest two nodes at the distance between the two connections, as shown in Figure 3. This ensures that the nodes within the community are closely linked, and the nodes of the community are sparse. This reduces the connection of nodes in different regions, reduces the average path length, and forms a network with a certain small world [9].

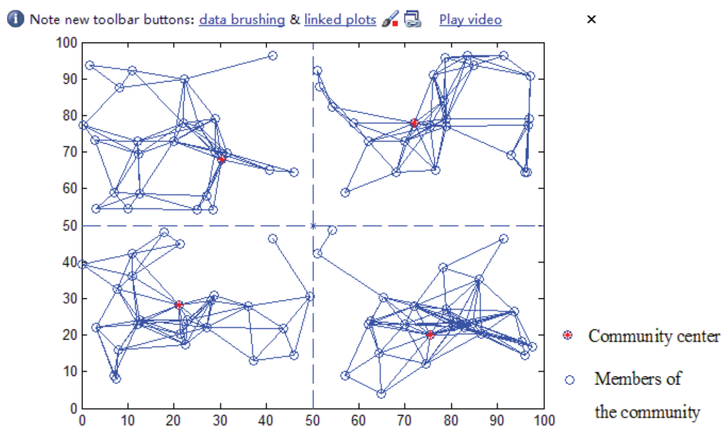

FIGURE 3. Community building

Cluster construction and data transmission

In this paper, the SEP-CSDN algorithm introduces the residual energy of the node and the degree of the node in the cluster selection mechanism. The formula is:

$$\begin{cases} T'(S_{\text{nrm}}) = \dfrac{P_{\text{nrm}} * H}{1 - P_{\text{nrm}}\left[r \bmod \left(1/P_{\text{nrm}}\right)\right]} \\ T'(S_{\text{adv}}) = \dfrac{P_{\text{adv}} * H}{1 - P_{\text{adv}}\left[r \bmod \left(1/P_{\text{adv}}\right)\right]} \end{cases} \tag{5}$$

In equation (5), H is the adjustment function:

$$H(r) = \alpha \frac{E_i(r)}{E_{\max}(r)} + \beta \frac{k_i(r)}{k_{\max}(r)} \tag{6}$$

In equation (6), α and β are the adjustment factors; $E_i(r)$ is the residual energy of the node i in the r rounds; $E_{\max}(r)$ is the maximum value of residual energy in the r rounds. $k_i(r)$ is the node degree of i in the r rounds; $k_{\max}(r)$ is the maximum value of the node in the r rounds.

From equation (6), we can see that the probability of the node being elected as cluster head increases when the node's residual energy increases, the threshold becomes larger.

After the cluster heads are arranged in the community, the nodes within the community choose to join the cluster based on the number of hops in the cluster. Where the hop count is defined as the number of times the message is forwarded during the process by which the node sends information to the destination node. Multi-hop transmission mechanism is adopted within the cluster. If the nodes in the cluster are directly connected with the cluster head, the information can be sent directly to the cluster head node; If the nodes in the cluster are not directly connected with the cluster head, the information is transmitted to the cluster head node by multi-hop. If the number of hops is equal, the cluster head with fewer nodes in the cluster is selected as the cluster head and join the cluster, which is advantageous for the size of the uniform cluster. Multi-hop transmission mechanism is also adopted between the cluster heads. The cluster head node, which is farther from the sink node, transmits the information to the cluster head near the convergence node until it is forwarded to the sink node. Through the purpose of forwarding information between the cluster head is to reduce the cluster head nodes and the convergence nodes for long-distance transmission of energy consumption.

SIMULATION AND ANALYSIS

In order to verify the effectiveness and performance of this algorithm. The SEP-CSND algorithm, LEACH algorithm and SEP algorithm are simulated and the results are compared and analyzed.

The simulation is carried out by Matlab simulation. The simulation scene is in the monitoring area of 100m × 100m. The sink node is located at plane coordinates (50m, 50m). Specific parameters are shown in Table 1.

TABLE 1. Experimental simulation parameters

parameter	value
Cover range (circle radius)	50m
Sink node location	(50,50)
Nodes (N)	100
Send and receive information Required Energy(E_{elec})	50nJ/bit
Free Space Model Amplifier Required Energy (E_{fs})	10pJ/(bit • m^2)
Multipath attenuation model amplifier required energy (E_{amp})	0.013pJ/(bit • m^4)
Data fusion required energy (E_{DA})	5nJ/(bit • singal)
Packet length (k)	4000 bit
Ordinary node initial energy (Eo)	0.2J
Special node energy coefficient(a)	4
Special node energy coefficient(β)	2

Figure 4 shows the number of surviving nodes per round. The number of SEP-CSND algorithm survives the other two algorithms at r = 100 rounds. And the death time of the first node in the network is significantly longer than that of the other two algorithms. This is due to SEP-CSDN algorithm using a community division algorithm, so that close nodes are concentrated in the same community. This not only reduces the node connections between different communities, but also reduces the average path length of the cluster nodes to the cluster head.

In the SEP-CSND algorithm, the information transmission in the cluster is done by multi-hop. The nodes which in the cluster cannot communicate directly with the cluster head forward the information to the cluster head through the other nodes in the cluster. The multi-hop transmission reduces the energy consumption required by a single node for long-distance transmission to the cluster head. And the information transmission between cluster heads still adopts multi-hop routing strategy. The cluster head node, which is far from the sink node, transmits the information to the cluster head near the convergence node. Through the p forwarding between the cluster heads is to reduce the long-distance transmission of energy consumption. Thus the energy of a single node which need carry out long-distance transmission is distributed to the forwarding node. Thus not only balance the network energy consumption, but also extend the network survival time.

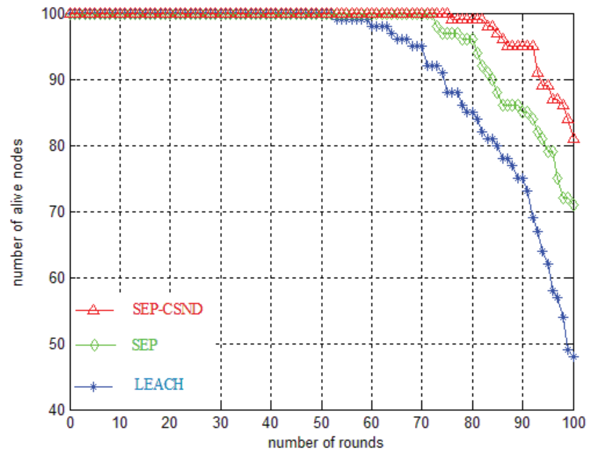

FIGURE 4. Number of alive nodes

Figure 5 is the total energy remaining for each round of the network. The total remaining energy of the SEP-CSND algorithm is more than the other two algorithms in the network. When the node is deployed in the target area, the nodes deployed in the geometric center of the grid are closer to the rest of the nodes and are easier to communicate with the rest of the nodes, so the nodes of node degree is large; On the contrary, the edge of the node of node degree is smaller. According to the cluster selection mechanism of SEP-CSDN algorithm, nodes with large nodes are more likely to serve as cluster heads. And nodes with large nodes have the probability of forwarding tasks, so the geometric center of the grid belongs to the concentrated area with high energy consumption. The multi-hop transmission is done by deploying the advanced node (see Figure 2) in the geometric center of the grid. So the SEP-CSND algorithm can balance the network energy consumption and extend the network life cycle.

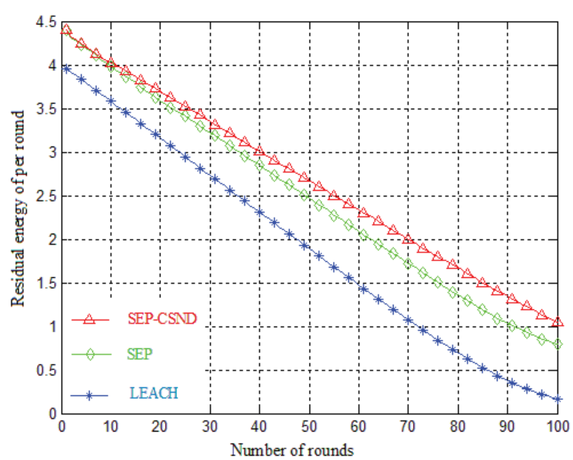

FIGURE 5. Residual energy of the Network

CONCLUSION

Aiming at the shortcomings of SEP algorithm, this paper proposes an improved SEP algorithm (SEP-CSND). On the MATLAB platform, this algorithm is compared with LEACH and SEP algorithm. It is concluded that this algorithm has good performance in balancing the network energy consumption and extending the network life cycle. The algorithm is mainly improved in the following aspects:

1) Increasing the deployment of nodes to make the distribution of cluster head more uniform;

2) Optimizing the cluster selection mechanism and introducing two factors about the node residual energy and node degrees. Using multi-hop routing in the cluster to reduce the energy consumption of single-hop.

3) The network nodes are divided into groups, and the multi - hop transmission mechanism is adopted in the cluster to optimize the communication between nodes in the cluster.

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