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Improved LEACH Cluster Algorithm Based on Spatially Uniform Partitioning

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Abstract: *Aiming at the wireless sensor network in the sensor nodes exist in the energy is limited and in the three-dimensional space in the transmission of the signal attenuation is fast and other problems, this paper proposes a suitable for three-dimensional spatial structure of the wireless sensor network of the SUP-LCF clustering algorithm in the three-dimensional space for the process of the initialisation of the network clusters, according to the sensor node's residual energy, to the sink nodes of the distance as well as the nodes of the inter-node associativity to elect the cluster head. This method can effectively improve the uniformity of cluster head distribution, avoid the probabilistic election of cluster head caused by a certain region of the cluster head is too dense or sparse, as well as the unreasonable size of the clusters, and effectively equalise the energy loss of the network and extend the life cycle of the wireless sensor network. Simulation results show that the algorithm can better balance the energy consumption of the network in the three-dimensional space environment.*

Keywords: *three-dimensional space, wireless sensor network, energy balancing, cluster algorithm, uniform partitioning*

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I. Introduction

Wireless Sensor Networks (WSNs) can be defined as a collection of low-cost small sensor nodes with sensing capabilities that have limited energy, communication range, processing and storage capabilities [1-4]. Wireless sensor networks can help people to monitor data in complex three-dimensional spatial environments and play a great role in the field of food storage and national food security strategies and guarantees. The application of wireless sensor network technology in the field of food security monitoring can effectively reduce the cost of grain silo safety monitoring, and also break the limitations that exist in wired monitoring, improve the monitoring efficiency, and efficiently guarantee the safety of grain silos. However, in wireless sensor networks, the death of sensor nodes due to energy exhaustion often leads to the interruption of the routing path, so it is necessary to design a clustering algorithm based on energy balance to extend the life of the network as much as possible.

Grain silo communication is different from road-based communication in that when the signal propagates within the grain, the transmission delay is large, the channel quality is very poor, the signal attenuation is severe, and the transmission energy consumption is relatively high. A genetic algorithm based clustering protocol has been proposed in [5] to achieve the energy balancing of the cluster heads in the transmission process, which can better extend the network lifetime. In the clustering algorithm mentioned in the literature [6], an optimal cluster number theory is proposed, which reduces the consumption and delay of route establishment to a certain extent, and also prolongs the network lifetime effectively. In literature [7] a new clustering algorithm is proposed to improve the clustering algorithm based on the density of nodes. In [8], a three-dimensional WSN cluster routing algorithm with balanced energy consumption is proposed, a three-dimensional spherical network structure is constructed, and the cluster heads are reasonably selected based on this network structure, and the energy consumption of the network is balanced by constructing a multi-hop routing game model and combining with a greedy strategy. Literature [9] proposed an iterative split-cluster algorithm based on the theory of optimal number of cluster heads, which makes the cluster heads more evenly distributed in the network, and the nodes take turns to act as the cluster heads, which ensures the load balancing of the whole network; and based on the similarity between the selection of biocells and the design of computer distributed systems, the biocellular clustering algorithm was designed.

In this paper, a three-dimensional spatial structure of wireless sensor network clustering algorithm is proposed, the working principle is in the process of network clustering initialisation, first of all, according to the position of the node relative to the base station, each node is divided into the corresponding region, and then according to the remaining energy of the sensor nodes, the distance to the base station and the correlation between the nodes for the election of the subsequent cluster head within the cluster, which not only ensures that the data can be transmitted to the base station This ensures that the data can be transmitted to the base station and also ensures the load balancing of the whole network. This ensures that the data can be transmitted to the base station and also ensures that the energy consumption of the entire network is balanced.

II. Overview of the model

2.1 Network Modelling

N sensor nodes are randomly and uniformly distributed in a space of M × M × M as shown in Fig. 1 to achieve the monitoring of environmental data in the 3D space. sink node is deployed at the centre of the 3D space. Let the set of nearby nodes of the node be Snear, the node senses the surrounding with a radius of R and deposits the nearby node IDs into the respective set Snear. To facilitate the research experiments without loss of generality, the following assumptions are made:

(1) The sensor nodes remain stationary and their positions cannot be shifted.

(2) The sensor nodes within the WSN are of equal status and have a maximum communicable radius of R, but have limited energy, all with initial energy, and the cluster head sends data directly to the sink node.

(3) Sensor nodes have unique IDs and are equipped with satellite positioning devices.

(4) The sink node has a fixed location, can be continuously recharged, has the ability to store and calculate, and knows the exact location of the nodes in the network.

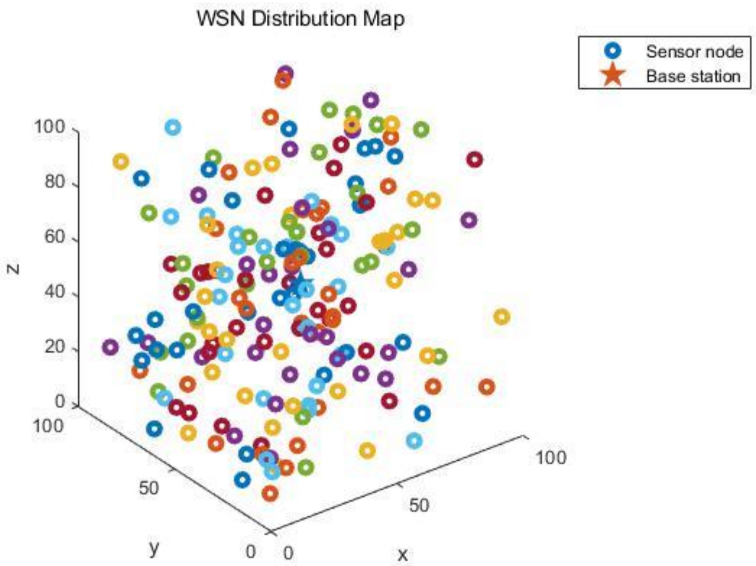

Fig. 1 Distribution of wireless sensor nodes Energy consumption modelling

2.2 Energy consumption model

The energy consumption of a wireless sensor network node is mainly the energy generated by sending and receiving information when the node communicates. In specific cases, the difference in the actual distance from the cluster head to the base station also affects the value of the energy consumption model.

The SUP-LCF algorithm adopts the energy consumption model from the literature [10]:

$$E_t(\mathrm{d}) = \begin{cases} e_{elec} + \omega_{fs} d^2, \ d < d_0 \\ e_{elec} + \omega_{amp} d^4, \ d \geq d_0 \end{cases} \qquad (1)$$

$$E_r = e_{elec} \qquad (2)$$

Sensor nodes generally consist of sensor module, processor module and wireless communication module etc., where the highest energy consumption is in the wireless communication module. In this module it is mainly the transmitting circuit and power amplification circuit that generates high energy consumption. For every bit of data sent, the transmitting circuit generates k energy consumption, and the energy consumption of the power amplification circuit needs to be judged according to the specific transmission range. When the transmission distance is less than the distance threshold, the power amplification circuit energy consumption is, otherwise the energy consumption is, calculated as shown in equation (3). Equation (2) is the energy consumption generated by the sensor node receiving bit data. Because the energy consumption of data processing is much lower than the energy consumption of sending and receiving, it can sometimes be ignored.

$$d_0 = \sqrt{\omega_{fs}/\omega_{amp}} \qquad (3)$$

III. Clustering algorithm

3.1 Spatially Uniformly Differentiated Clusters Based on Correlation Factors (SUP-LCF) Algorithm

The internal structure of a cube is composed of six faces and the pattern on each face is perfectly symmetric, so the internal structure of a cube is also perfectly symmetric.The BS sends partition information to all nodes, and then each node detects the partition in which it is located based on its position information. The nodes are randomly distributed in the communication area and then the nodes in the space can be projected onto the corresponding planes and then the node position (X, Y coordinates) relative to the BS position is used to detect the partition number to which the node belongs [11]. By using Equation (4), the partition selection is shown in Fig. 2.

$$\mathrm{If}\left(\frac{\mathrm{y}}{\mathrm{x}} < \tan(\theta)\right)$$

$$\mathrm{Region} = 2 \qquad (4)$$

Else

$$\mathrm{Region} = 1$$

The BS position is set as the coordinate origin; the same process is repeated for the other partitions considering the selection of the corresponding region based on the offset of the X and Y positions of the BS [12].

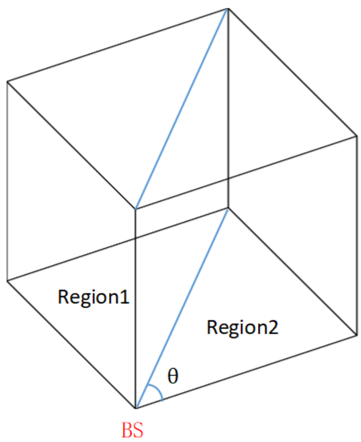

Fig 2 Schematic diagram of partition selection

According to the limitations of LEACH algorithm and the design objectives of the clustering algorithm, this paper proposes a Spatial Uniform Partitioning and Clustering (SUP-LCF) algorithm to achieve reasonable clustering.The basic idea of SUP-LCF is to reduce the transmission distance between nodes by dividing the communication area into areas with uniform shape and size centred on the BS: firstly, divide the three-dimensional space into several areas of uniform shape and size, and then divide each node into the corresponding partition according to the node's location coordinates. The three-dimensional space is first divided into several regions of uniform shape and size, and then each node is divided into the corresponding partition according to the positional coordinates of the nodes, and then the cluster head is selected in the subsequent cluster head election based on the residual energy of each node in the partition, the distance from the base station, and the correlation between the nodes [13] and other factors. In the algorithm the cluster head is selected in the first round by comparing the residual energy of each node as well as a random number; in the second and subsequent rounds, there is no need to re-divide the clusters and the cluster members are fixed. At the beginning of a new round, the clusters screen out the candidate cluster head nodes based on the correlation between the nodes, and then the new cluster head for the next round is calculated based on the residual energy of the candidate nodes and the distance to the base station.

The SUP-LCF algorithm takes into account the residual energy of the sensor nodes, the distance to the base station and the correlation between the nodes. By limiting the transmission distance between nodes, it improves the uniformity of cluster head distribution, avoids too dense or sparse cluster heads in a certain region caused by probabilistic election of cluster heads, and unreasonable cluster size, effectively balances the energy loss of the network, and prolongs the lifecycle of the wireless sensor network.

3.2 Node correlation

The nodes are judged to be related to each other by the correlation factor. The definition is as in equation (5):

$$r_{node} = \frac{N_{same}}{N_{total}} \qquad (5)$$

Where is the number of sensor nodes with the same ID in the set Snear of node Nj (j=1,2,3...N) and nearby node Si (Si∈Nj.Snear); is the number of sensor nodes in the set Snear of nearby nodes (). If it is greater than the threshold (between 0 and 1), node Nj is correlated with the nearby node Si, and vice versa is not correlated; if there is a case that the size of the nearby node collection Snear of a node is 1, i.e., only one node is stored, then the nodes are judged to be correlated with each other. In the application of practical scenarios, the appropriate threshold value can be set according to the specific size of the monitoring area, the density of the nodes, etc.

3.3 Algorithm design

In order to reduce the energy consumption of intra-cluster data transmission, the SUP-LCF algorithm restricts the intra-cluster data transmission distance by dividing the region equally in space. Meanwhile, the algorithm, in order to avoid the situation of multiple cluster heads within the maximum cluster radius R or nodes have no cluster heads to choose from within the communicable range, after the first cluster head election, each election needs to screen out candidate cluster head nodes based on the correlation between nodes, and then determine the cluster head based on the remaining energy of the candidate nodes and the distance to the base station. This algorithm effectively solves the problem of uneven distribution of cluster heads while fixing the clusters and makes the formation of clusters more reasonable.

The cluster head election steps for the SUP-LCF algorithm are as follows:

(1) First round of cluster splitting

The first round cluster splitting step in SUP-LCF algorithm is described as follows:

The cluster head election within the partition depends on the energy of the remaining nodes.

1)Cluster head selection is done according to LEACH algorithm: each node passes its remaining energy in the form of a random number to all other nodes within the same partition;

2)Each node compares its residual energy with the residual energy of other nodes and selects the node with the highest residual energy as the cluster head.

3)If there exists a situation where nodes have equal remaining energy, a random number is used and the node with the largest random number is selected as the cluster head.

4)End the cluster splitting.

(2) Cluster head election in the second and subsequent rounds

After the first round of clustering, the cluster members are fixed and the subsequent cluster head election is simply a re-election within the cluster based on the correlation between the nodes, the remaining energy of the candidate nodes, and the distance from the base station. Before the cluster head election, the base station counts the number of remaining nodes in the network and puts their IDs into the set M . The base station will elect the cluster head in an iterative manner every round based on the remaining energy of the candidate cluster head nodes and the distance to the base station. After each iteration, the cluster head will be the node with the largest F(E,d) value (Equation 6).

$$F(E,d) = \frac{E_r}{E_0} + \frac{d_{max} - d_{cur}}{d_{max} - d_{min}} \qquad (6)$$

Where is the remaining energy of the target node, is the maximum absolute distance between the node and the sink node in the monitoring area, then is the shortest absolute distance and is the absolute distance between the target node and the base station. When a node is selected as a cluster head, its neighbouring nodes are able to communicate with that node within R.In order to avoid the existence of multiple candidate cluster head nodes within the maximum communication range, the nearby nodes should no longer participate in the election of the cluster head in this round; however, there exists a situation in which the candidate cluster head node may be the desired cluster head of other nodes within the communicatable range R. Therefore, before the node is elected as the cluster head in each iteration, the correlation factor between it and each nearby node needs to be calculated. If the value is greater than the threshold, it indicates that the node is associated with the cluster head, the associated node is labelled as associated and the node exits the cluster head election. Conversely, it indicates that the nodes are not associated with each other and the node continues to participate in the cluster head election. When there is a node in the cluster head set that has only one node in the set of nearby nodes, i.e., the value is 1, then the node is associated with the cluster head. Before each cluster head election, the lower set Snear will be updated by removing the node IDs of nodes that are no longer participating in the cluster head competition (cluster heads and nodes with correlation) and the dead node IDs from the Snear set of the remaining candidate nodes, and at the same time, the base station will remove the node IDs of nodes that have participated in the cluster head election and those that have given up on the election from the set M.

In summary, the SUP-LCF algorithm significantly reduces the network energy consumption based on the uniform partitioning method centred on the base station; the idea of fixed clustering in the second and subsequent rounds reduces the overhead of frequent cluster building; the correlation factor between the nodes, the residual energy of the nodes and the distance to the base station are taken into account while selecting the cluster head and are used to equalise the energy consumption of the network.

IV. Experimental simulation

The experiments use MATLAB R2018a platform to simulate and analyse the SUP-LCF algorithm in order to verify the rationality and effectiveness of the algorithm.

4.1 Simulation parameter setting

In the simulation experiment, the size of the wireless sensor network is set to 400×400×400. some of the parameters required for the experiment are shown in the table below.

Table 1 Parameters of simulation experiment

parametric	worth
Number of nodes	200
starting energy	0.5J
packet length	4000bit

Control packet length	200bit
w_{fs}	10 pJ /(bit·m^2)
w_{amp}	0.0013 pJ /(bit·m^4)
e_{elec}	50 nJ /bit
R	50
T_{rele}	0.7

4.2 Experimental results and analysis

The proposed algorithm is compared with LEACH protocol and DEEC protocol. The variation in the number of surviving nodes for each protocol is shown below.

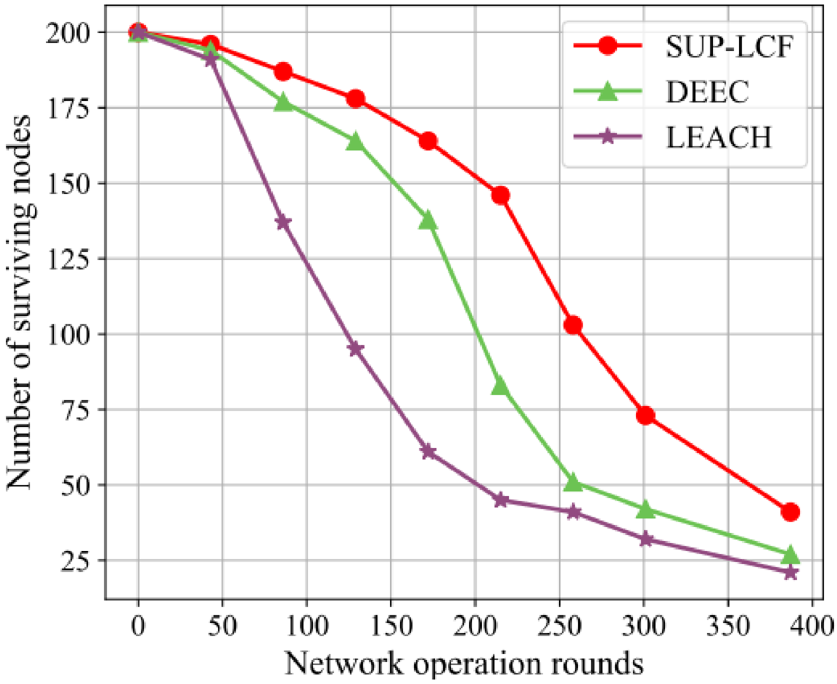

Fig. 3 Change in the number of surviving nodes

When the number of surviving nodes in the network is less than 25% of the total number of nodes, the network is considered "dead". As can be seen in Figure 3, when 75% of the nodes die, SUP-LCF, DEEC and LEACH protocols appear in 345, 269 and 192 rounds, respectively.SUP-LCF algorithm in rounds 1-60, the number of nodes surviving is not much different from LEACH and DEEC protocols; the 61st rounds began to change, the speed of node death began to slow down, and the number of nodes surviving is significantly higher than LEACH and DEEC protocols. slow down and the number of nodes surviving is significantly higher than LEACH and DEEC protocols. Compared to the LEACH and DEEC protocols, the SUP-LCF algorithm effectively equalises the global network energy consumption and effectively extends the life cycle of the network while reducing the node mortality.

Fig. 4 shows the comparison of the residual energy of the three protocols, from which it can be seen that the SUP-LCF algorithm curve is always on top of the curves of the other protocols with the same initial energy. From the figure, it can be seen that the proposed protocol has lower energy consumption and better energy utilisation.

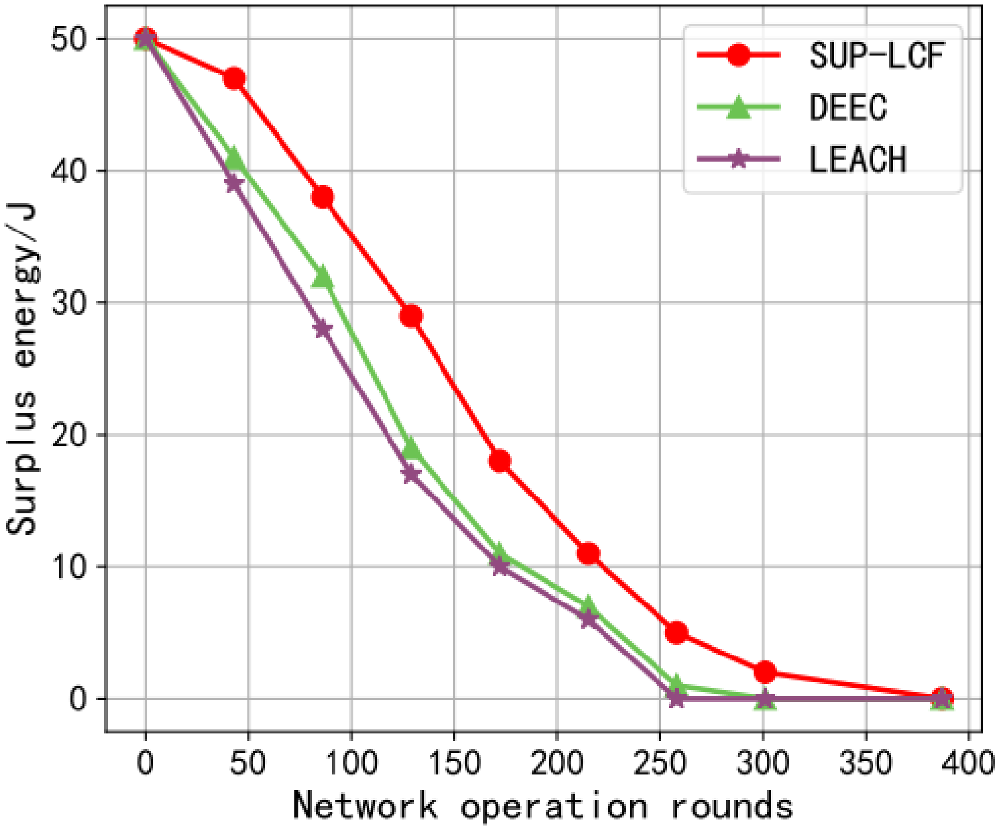

Fig. 4 Variation of residual energy

V. CONCLUSION

This paper is about a new improvement to the original LEACH algorithm.LEACH is a well-known routing algorithm for WSN to achieve scalability and robustness.The SUP-LCF algorithm presents a proposal to overcome the limitations present in the LEACH algorithm. The proposed improvement is to reduce the transmission distance by dividing the monitoring area into regions uniformly; this approach leads to a reduction in the overall communication range and energy consumed. The results of the simulation experiments show that the network lifetime, network stabilisation period and network throughput are improved.The experimental results show that SUP-LCF outperforms the other algorithms used for comparison in terms of performance metrics. In the future, node density can be considered in the cluster head selection process; moreover, artificial intelligence techniques or machine learning methods can be used to distribute nodes evenly within a sector.

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