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Research on Cluster Optimization Method of Node Clustering for PEGASIS Protocol

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Abstract. Chain-structured routing protocol PEGASIS can reduce redundant data and energy consumption in wireless sensor network, but topology adjustment will bring a lot of expense. The distributed and uneven nodes lead to a larger gap between the energy consumption and the larger delay distance of the nodes. The algorithm of the protocol leads to the formation of long chains. In order to improve the survival time and connectivity of WSN and increase the number of nodes in the network, we propose an improved node clustering cluster scheme, taking into account the residual energy of nodes. The simulation results show that the improved protocol has better performance than PEGASIS in balancing energy consumption and prolonging the network life cycle.

Keywords: Wireless Sensor Network (WSN), PEGASIS protocol, efficient energy saving, network life

1 Introduction

Wireless sensor network distributes a large number of sensor nodes in the detection area. According to the established routing protocol, a multi hop self-organized network system formed by wireless communication can effectively and autonomously communicate between nodes [1]. With the decline in computing costs and the development of the Internet of things, Wireless sensor networks are widely used in the fields of environmental testing, medical care, military and other fields. It has been greatly developed in this century, in which the wireless sensor routing protocol is the focus of development [2].

The energy devices of the sensor nodes are usually inconvenient to replace, energy problem becomes the key factor restricting wireless sensor [3]. Therefore, it is essential to reduce the overall energy consumption of the wireless sensor network, improve the energy utilization of the nodes, and prolong the network stability period and the survival time.

In wireless sensor networks, the wireless communication of nodes consumes most of the energy. The farther the distance, the larger the energy consumption of communication. How to make wireless sensor network transmit more data under limited energy becomes an important factor to measure routing algorithm. In this paper, an improved clustering routing protocol based on PEGASIS is proposed, which uses a subregion clustering algorithm for chain formation. Determining the reelection frequency of the chain head nodes based on the energy of the chain head node. The results of theoretical analysis and simulation show that the improved protocol is better than PEGASIS protocol in energy conservation and prolonging the network stability period.

2 Related Research of PEGASIS

At present, there are several common routing protocols, such as LEACH, HEED, EEUC and PEGASIS.

The basic idea of LEACH algorithm is to randomly select cluster head nodes (all nodes in the

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management group) in a cyclic manner, so that the energy load of the network is evenly distributed to each node of the network, so as to improve the network lifetime and reduce the energy consumption of the network [4]. Leach has two phases: setup phase and ready phase. In the setup phase, leach will select a cluster head node, and then allocate time slots to other members in the way of TDMA. In the ready phase stage, the collected data will be transmitted to the sink node. After a period of time, it will enter the setup phase again. The selection of cluster head is random, and each node will be randomly selected as cluster head node, which makes the energy consumption balanced and prolongs the network lifetime.

The basic idea of the heed algorithm is: the heed algorithm is to improve the leach clustering algorithm for the uneven distribution of cluster heads in LEACH algorithm [5-6]. It extends the network life cycle by distributing the energy consumption evenly to the whole network [7]. Because the selection probability of cluster head nodes in LEACH algorithm is cyclic random, there will be uneven distribution of cluster heads. In the heed algorithm, the residual energy of nodes is added to the selection of cluster head nodes. Nodes with higher energy will have a higher probability of selecting cluster head nodes, while nodes with lower energy will have a lower probability of selecting cluster head nodes, which can ensure better performance the unification of quantity can prolong the service life of network. At the same time, the secondary parameter is the density of nearby nodes. When a nearby node is selected as a temporary cluster head node, it will judge by itself. If its communication cost is less than the temporary cluster head node, it will be selected as the temporary cluster head node, and so on, the cluster head node with low communication cost and balanced energy consumption will be selected for communication.

EEUC protocol is a typical hierarchical network routing protocol based on the idea of non-uniform clustering. Compared with LEACH protocol using single hop transmission mode between cluster head and sink point, EEUC protocol uses multi hop mode to prevent cluster head from premature death when far away from the aggregation point, balancing the energy consumption of cluster head in the network and prolonging the network life cycle [8]. EEUC adopts multi hop transmission mode, that is, the cluster head far away from the base station transmits data to the near cluster head, and then the closer cluster head sends data to the base station. This can avoid the problem of high communication cost in other transmission modes, but at the same time, it will lead to the problem that the energy consumption of cluster head close to the base station will be too fast. Therefore, the EEUC protocol also proposes the cluster radius, which balances the energy between each other by constructing different cluster radius. The closer the cluster head is to the base station, the smaller the cluster radius will be, and the smaller the radius will be, the more energy will be saved. The saved energy can be used to send data from other cluster heads, so as to achieve energy balance and prolong the network life cycle. However, this can only be achieved under ideal conditions, because the problem of residual energy is not considered in the selection of cluster heads, so some nodes with less energy may be selected as cluster heads. At the same time, due to the use of multi hop transmission mode, the probability of data transmission problems will increase, resulting in packet loss and retransmission probability will also increase, which will lead to uneven energy consumption.

In summary, each of these agreements has its own advantages and disadvantages [9]:

For LEACH protocol, the probability of selecting each node as cluster head is equal, so it may have a good effect of energy consumption uniformity in energy balanced network. The cluster head node will collect the data from different nodes in the cluster, and the data transmission distance will be relatively short, which can achieve energy saving [10]. But leach also has some shortcomings, such as the cluster head must be re selected every round, which is relatively troublesome. In addition, the protocol does not specify the distribution of cluster head nodes. Cluster heads will be distributed in a certain area of the network, forming a hot issue. In some regions, there are few cluster heads or even no cluster heads, which affects the data transmission.

For the heed protocol, the main parameter of residual energy is added in the process of cluster head selection, which makes the energy consumption more balanced. In addition, the secondary parameter of density of surrounding nodes can select nodes with lower communication cost as cluster heads, which can save energy and prolong network life cycle. But at the same time, some problems of LEACH protocol can’t be avoided, such as hot issues and repeated cluster head selection problems, which may have bad effects in large-scale wireless sensor networks.

For EEUC protocol, the cost of data communication is much lower by using multi hop method, while the cluster head near the base station which needs to transmit more data can bear less nodes, which is more conducive to energy balance. However, there are still some problems in EEUC protocol. Firstly, many factors need to be considered in the process of cluster generation, which is expensive. Secondly, because the residual energy is not taken into account, the nodes with less energy may still be selected as the cluster head, which is unfavorable to the energy balance. The half paths of clusters will cover each other, and the interference between clusters will be serious.

PEGASIS protocol [11] adopts chain structure to connect sensor nodes, which is an improvement of LEACH in energy saving. It is different from LEACH protocol's multi cluster structure and data transmission method. The traditional LEACH protocol adopts the idea of clustering and cluster head selection in turn. It is a low energy adaptive clustering algorithm based on PEGASIS protocol, and adopts the communication chain structure with the nearest neighbor node. The basic idea of PEGASIS algorithm is to choose the node by greedy algorithm, make local optimal selection from outside to inside, and eventually form chain structure. In the communication phase, sensor nodes only communicate with the nearest neighbor nodes. In addition to the node at the end of the chain, the rest of the nodes can integrate data from other nodes and their own data. Then the next node is sent to the next node, and a node is selected as the chain head node to transmit the data to the base station. The first node of the chain is not fixed. The node is elected as the first node of the chain and then communicates with the convergence node, and then starts a new cycle. This kind of rotation communication mechanism can make the energy consumption of the network distributed reasonably to each node. The structure diagram is shown in Fig. 1.

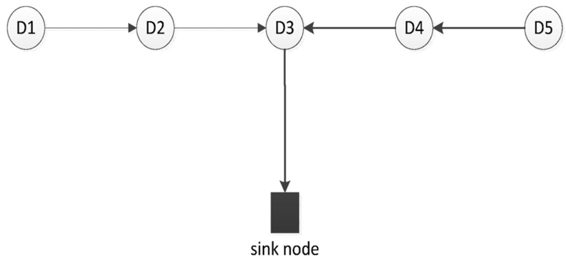

Fig. 1. PEGASIS structure

Compared with the traditional LEACH protocol, PEGASIS protocol reduces the energy consumption in the process of cluster reconstruction, and data fusion reduces the number of sending the same information and reduces the number of transmissions, but the disadvantages are as follows [12].

(1) The data will spend more time because of the long transmission distance, resulting in excessive transmission delay, and it is not applicable to the environment with high demand for real time.

(2) The first node of the chain will only limit the amount of data transmission, and the whole network will be affected once the chain head node has problems.

(3) The protocol does not need to cluster and reduces the cost of clustering, but nodes need to perceive the state of neighboring nodes, and transmit data sequentially through neighboring nodes. It still needs to dynamically adjust the topology structure and consume more energy according to the state of neighbor nodes. So PEGASIS protocol has been studied since it was proposed.

Literature [13] proposed the EECB protocol on the study of the PEGASIS protocol. The protocol considers the distance from the base station and the residual energy of the node in the selection stage of the chain header, sets the energy threshold and prolongs the lifetime of the network, but the problem of data transmission delay has not been solved yet. Literature [14] combines LEACH with PEGASIS to propose an improved protocol. This protocol combines the LEACH cluster head selection with the single hop communication of PEGASIS, reducing the communication delay, but there is still a long chain. A new geometric algorithm with tree is proposed in the literature [15]. The algorithm solves the problem of long chain through tree structure. A layered routing protocol HCRP is proposed in the literature [16]. The distance between the base station and the node is taken as a parameter, which is divided into a ring area with the base station as the center, and then cross layer data transmission path is constructed for data transmission, which prolongs the life cycle of the network. The EEPB protocol is proposed in the literature [17]. The protocol avoids the long chain between adjacent nodes by introducing the distance threshold, which avoids long chains and improves the energy utilization rate.

On the basis of PEGASIS protocol [18], this paper proposes a zoning routing protocol based on the idea of region. First, the nodes of the monitoring region are subregions based on the received signal intensity by the base station. Then the small range is chain, and finally the chain head is elected to transfer the data to the base station.

3 Network Model

3.1 Ring-shaped Network Structure Model

Fig. 2 below is the structure of the network, and the base station is located in the center of a circular network. Taking the base station as the center, the relative positions of the other nodes are determined by the base station, and the positive coordinates are formed.

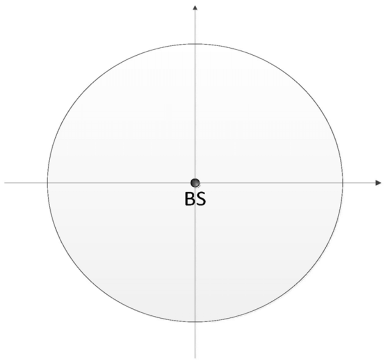

Fig. 2. Ring network structure

In this environment, wireless sensor network nodes have the following features:

(1) All sensor nodes are exactly the same and can communicate with the converging nodes;

(2) The location of the sensor nodes and the base station is fixed, and the initial allocation will not change;

(3) The base station contains the location information of all nodes;

(4) In the communication range of the nodes, the distance between the other nodes can be calculated by the intensity of the transmitted signal.

(5) The nodes have the function of data fusion.

3.2 Energy Consumption Model

Fig. 3 below is the basic hardware energy consumption model [19]:

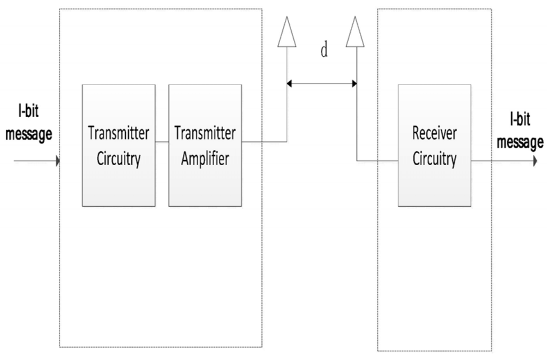

Fig. 3. Hardware consumption model

The amount of energy consumed by nodes in data transmission is the largest in wireless sensor networks. The energy consumption formula for sending data is as follows:

$$E_{TX}(l,d)=\begin{cases} lE_{elec}+l\varepsilon_{fsp}d^2 & d<d_c \\ lE_{elec}+l\varepsilon_{two-ray}d^4 & d\geq d_c \end{cases} \quad (1)$$

In the upper form: IEelec is the circuit energy consumed by the node to send or receive unit data. Its size is affected by the encoding, processing and propagation of the signal. L is the length of data to be sent or accepted (bits). D represents the effective distance of data transmission. When $d < d_c$, energy consumption is free space model; When $d \geq d_c$, energy consumption is multipath attenuation model. $l\varepsilon_{fsp}$ and $\varepsilon_{two-ray}$ are power magnification respectively. The following formula 2 is the energy consumed by the node to receive L bit data:

$$E_{rx} l = lE_{elec} \tag{2}$$

When the node accepts the data sent by its adjacent nodes, the data will be fused to reduce the redundancy of the data, and it will also consume a certain amount of energy. But the focus of this study is not here.

4 Improved PEGASIS Routing Protocol

In order to prolong the stable period of the network and reduce the energy consumption of the network, a new protocol PEGASIS-C is proposed based on the study of the PEGASIS protocol. This agreement consists of four parts:

1. Subregional phase;
2. Intra regional chain formation stage;
3. LEADER node selection stage;
4. Data transmission phase.

The phases mentioned above will be described in detail below.

4.1 Subregional Phase

In heterogeneous network environment, each node in the PEGASIS-C protocol determines its own area according to the following steps:

(1) First, the location of the base station is fixed, located in the center of the monitoring area. The base station regards the whole monitoring area as a circular area with itself as a center. The broadcast information is then sent to each node in the network, telling the location of the network center. This ensures that there is only one central node in the network. The sensor nodes use RSSI to calculate the distance from the base station based on the 6 information of their ID information, and feed the distance back to the base station. The base station monitors 4 directional antennas to broadcast the information and the distance information returned by the node. Then, using the direction based self-localization method of wireless sensor network, the location information of each node is determined by the sine theorem.

(2) The base station divides the monitoring area into subregions with itself as a center, as shown in Fig. 4:

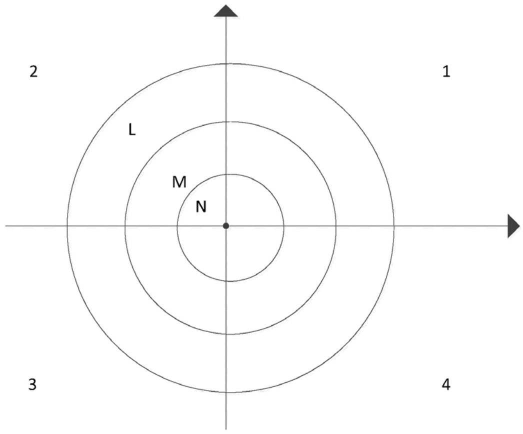

Fig. 4. Hierarchical division

Taking the base station as the center, the concentric circle dimension is divided into L, M and N levels according to the different radius. It is divided into 1, 2, 3 and 4 regions in the direction of the Cartesian coordinate system, which are identified as L1, L2, M1, M2, etc. Then the base station calculates the specific area of each node according to the received location information and distance of the node, and the node ID corresponds to the number one by one.

(3) After the base station completes the corresponding node to the region, it will broadcast the information of each node to let the node know its own area.

In this way, a base station centered on the hierarchical model of regional cluster is formed. The division of the region is not invariable, and the parameters can be adjusted according to the different conditions of the actual environment.

In addition, when there are no other nodes around the node, it is considered that the node will not appear in the area formed by the wireless network, does not participate in the formation process of the chain, and becomes an isolated node, and communicate directly with the Sink node [20].

4.2 Intra Regional Chain Formation Stage

After the PEGASIS-C algorithm is completed in the partitioned domain, chain operations are performed on each region. The nodes in the area send broadcast messages to the nodes in the communication range. The broadcast messages contain the location information, node ID and residual energy of the nodes. If a node receives information that does not belong to its own area, it will be discarded so that each node can know the area number of the surrounding nodes and other information. In the same area, only nodes with the same area number can communication with each other, and the chain structure is formed. This method of zoning can avoid the energy loss of the whole chain in the data transmission, and also avoid the generation of long chain. Each node has two node tags, and the first tag is the same area node tag. When the area is a chain, the tag is set to true. The second tag is a markup of nodes in different regions, which is true when the interregional nodes are chains. In each region, unlike the classic PEGASIS protocol chain rule, it forms a chain from a free node V of a regional boundary. Firstly, node V sends request information to the nearest nodes in the same area. It contains the state information of the node V and the request chain information, and if X satisfies the following conditions, it will become the parent node of the node V:

(1) The node X is the same as the node V's area number;

(2) The nodes of the same area are marked as false;

If the node V wants the node X to be its own parent, the node V will send the request information to the node X. When the node X receives the request information, it will confirm that the above two conditions are met, and sends a confirmation information to the node V. Then the node X becomes the parent node of the node V. At the same time, the mark of X becomes true, and the connection between the two nodes is formed. Repeat the above steps until all nodes in the region form a chain structure. When the nodes in all regions of the network complete the second step, the node structure is shown in Fig. 5.

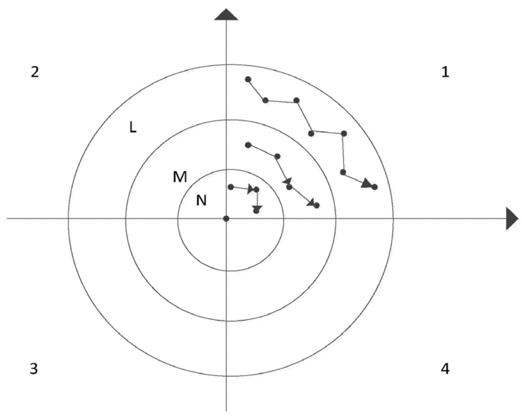

Fig. 5. Intra-regional linked graph

4.3 Chain Head Node Selection Stage

4.3.1 Chain Head Selection

The PEGASIS-C algorithm first selects the chain head in the outermost layer of the network. The L layer is the outermost layer of the network, and the number of N_{L1} is the number of sensor nodes in the L layer 1 region. All nodes are numbered in the range [0- N_{L1}]. In this area, each node has a probability of 1% (N_{L1} -i) in the i wheel as the candidate chain. Then the remaining energy of the candidate chain head is determined by the distance from the base station.

```
If r mod 2==1
 μ=RAND (0,1)
 If μ<T then
 bePrepareHead=true
 End if
If bePrepareHead==true then
 Broadcast Prepare_Message (ID, Area, E)
 Else
 Sleep
```

4.3.2 Interregional Chain

Follow the above rules to complete the selection of the chain head of the region. When the node is elected as the head of the chain, the following steps are made to the chain:

(1) Firstly, the chain head node sends broadcast information to its surrounding nodes, telling the node to be selected as the chain head node of L1 area in the first round I. Other nodes in this area do not react to enter the dormancy state.

(2) After receiving the broadcast information from the chain header of L1 area, M1 area will return its residual energy and location information to the chain head node of L1 area, and the other nodes will not return information after receiving the information. The L1 region chain head node will calculate the feedback information in Formula 3;

$$Q = E_{Left} / d \tag{3}$$

E_{Left} represents the residual energy of the M1 region nodes; D represents the distance between nodes; Q represents the remaining functions of D and E_{Left} .

(3) After receiving the remaining energy and location information of the M1 area nodes, the L1 regional chain header nodes will choose the node with the higher residual energy, the minimum distance from the base station and the minimum distance from the node as the M1 area chain head node, and send a request information to the node.

(4) M1 area node receives the request information from the chain head node of the L1 region, and will carry out different regional nodes labeled judgment. If the node is labeled as false, it will return ACK to confirm the information and declare that it is elected as the node of M1 area in I round, and then repeat the above steps to select the nodes of N1 region.

According to the above method, the interregional chain head connection is finally formed. The node nearest to the base station analyses the received data and eventually sends it to the base station. The above process is shown in Fig. 6:

4.4 Data Transmission Phase

The data transmission phase of PEGASIS-C is similar to the PEGASIS algorithm. In the same area, data is transmitted from two end nodes to the LEADER node. End nodes collect their own information along the direction of the LEADER node to the adjacent node until the LEADER node is reached. When the LEADER node receives the information, it will make the received data for efficient data fusion [21] processing.

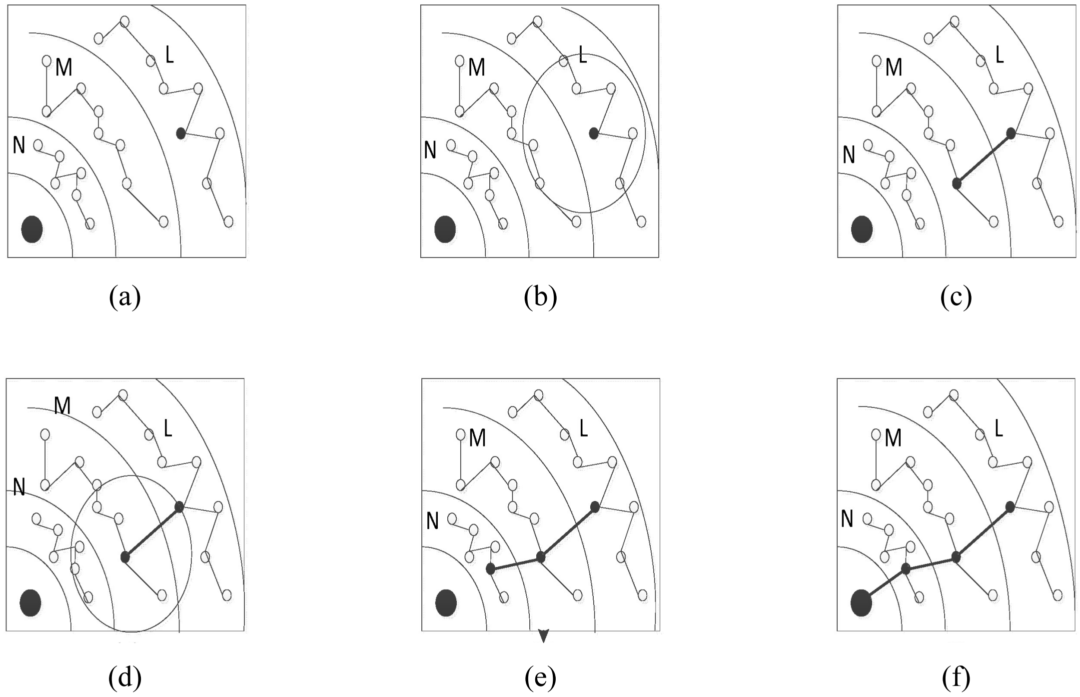

Fig. 6. Inter-Regional linked graph

Then it participates in interregional transmission. The data transmission between regions is transmitted from the outer layer to the inner layer, the data is finally transferred to the base station, and the data transmission phase is completed. PEGASIS-C does not pick up the chain head after every round. Then it determined the reelection frequency of the chain head nodes according to the ratio of the total energy of the chain to the energy of the chain head node. When the energy occupying ratio of the zoning head node is lower than the rated value, the chain head node is selected again, and the next round is started.

5 Analysis

5.1 Chain Formation

The traditional PEGASIS protocol uses chain routing architecture [22]. A long chain containing all nodes is formed by the greedy algorithm. Each node communicates and transfers data only with adjacent nodes and the data is transferred along the chain to the LEADER node in turn. The LEADER node eventually fused the received data and eventually sent the data to the base station. This method causes a long chain between nodes, and a node that is far away from the LEADER node will die early. The PEGASIS-C protocol adopts a hierarchical zoning method. Each area selects the most suitable chain head nodes based on the remaining energy and the distance from the base station. This ensures that the final chain is made up of the best nodes in each layer.

5.2 Communication and Storage Overhead

The PEGASIS-C protocol is in the chain phase and the node sends a broadcast message to the neighbor node [23]. The complexity of the broadcast is O(N). In the process of PEGASIS-C final chain formation, the chain head nodes in each area send a broadcast information to the chain head nodes in the adjacent area. The complexity of the process is O(M). In addition, the high area chain head node will return the additional reply information to the node of the lower region, the complexity of the process is O(M. n_1), and the M is far less than the N. As shown in formula 4:

$$
\begin{aligned}
T_N &= O(N) + O(M \cdot n_1) \\
&= O(N) + O(\frac{N}{N_L} \cdot n_1) \text{ Because } \frac{n_1}{N_L} < 1 \\
&\approx O(N)
\end{aligned} \quad \textbf{(4)}
$$

Upper expression of the overall is the overhead of the PEGASIS protocol communication process. n_1 is the number of neighbor nodes. N_L is the number of nodes in the L region and L belongs to (0, M). The communication complexity of the PEGASIS-C protocol has not changed much compared to the PEGASIS, but the overall performance has been improved.

5.3 Simulation and Experimental Results

In order to evaluate the performance of the PEGASIS-C algorithm, the simulation and comparison of the PEGASIS-C protocol, the PEGASIS protocol and the EECB protocol are carried out, and the NS2 running environment is adopted. The next Table 1 summarizes the parameters considered in the simulation environment, the sensor nodes are randomly distributed, and the energy of the data fusion is ignored by the chain head nodes.

Table 1. Simulation parameter setting

Parameter	Value
Simulation area	500*500m^2
Number of network nodes	500
Deployment type	Random allocation
Packet length	256 Bytes
The number of rounds	2500
Simulation time	3200 sec
Initial node energy	1J
Communication range	25 m
E_{elec}	50nJ

Fig. 7 shows a comparison of the average energy consumption of the nodes. It can be seen from the graph that the average energy consumption of the nodes in the PEGASIS-C protocol is obviously lower than that of the traditional PEGASIS. And the energy consumption is more stable with the increase of the number of wheels. This is due to the closer distance between the chain head nodes of the PEGASIS-C regions and the BS base station. The reason for the larger fluctuation in PEGASIS is that the distance between the chain head and the base station varies greatly with the increase of the number of wheels.

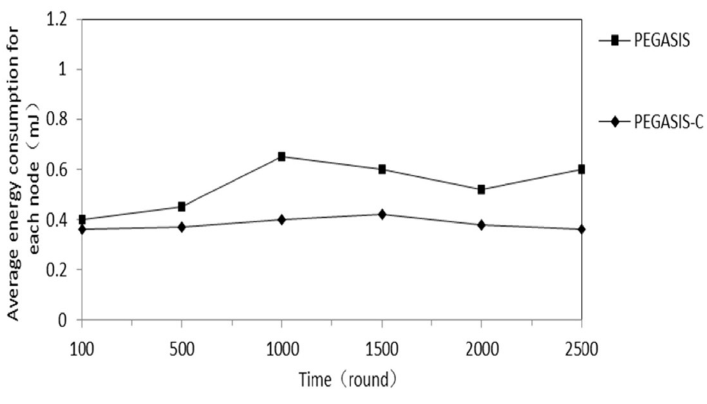

Fig. 7. Comparison of average energy consumption of nodes

In Fig. 8, it can be seen that the number of PEGASIS-C protocol surviving nodes is more than the PEGASIS protocol. This is because the PEGASIS-C protocol avoids the generation of long chains and reduces the cost of communication through partitioned domains. So that the residual energy of nodes is higher and the lifetime of the whole network is increased.

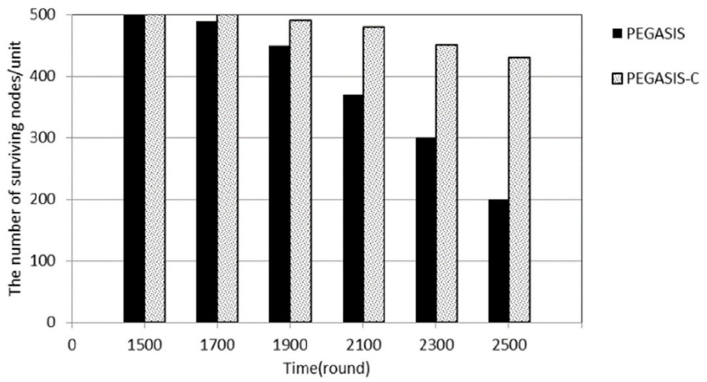

Fig. 8. Comparison of number of surviving nodes

6 Conclusion

An energy-efficient concentric partition protocol based on PEGASIS is proposed in this paper. The protocol increases the lifetime of the network by using the partition dynamic chain and reduces the delay in data transmission. First, a chain head node is selected in the outer sub region based on the residual energy and the distance from the base station. This node is the most robust node in the partition. Then the nodes with high residual energy and close distance from the base station are selected in the adjacent inner region, and eventually the chain is formed in the direction of the base station. From the experimental results, we can see that the network lifetime of PEGASIS-C protocol is longer than that of PEGASIS protocol, and the energy consumption of nodes is less, which prolongs the life cycle of nodes.

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