Wireless Sensor Network Topology Control Based on the Small World Theory

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***Abstract* — The paper analyzes the small-world networks theory and modeling process of wireless sensor network. In order to improve the lifetime of the network, a topology control algorithm which integrates the small-world theory and topology control of wireless sensor network is proposed .In the algorithm long-range links of small world theory is introduced into sensor network. So energy consumption of the network at process of sending and receiving information can be reduced effectively. Finally the algorithm is compare with the hierarchical topology control algorithm. Experimental data show that this method is effective to improve to some extent the network lifetime, simulation also prove that it is feasible to optimize topology construction of wireless sensor network by introducing small world theory. For example, shorter average path length and larger clustering coefficient can improve the lifetime of wireless sensor network and transmission efficiency. So the optimization builds a good foundation for improving the transmission efficiency of route.**

Keywords - Small World Theory; Wireless Sensor Network; Topology Control; Sensor Nodes; Life Cycle

I. INTRODUCTION

Wireless sensor networks is the current concern in the international community, involving highly multidisciplinary cross the frontier of knowledge highly integrated hot research field. Advances in sensor technology and micro-electromechanical systems, modern networking and wireless communications technologies promote the emergence and development of modern wireless sensor networks [1]. Wireless sensor networks extend people ability to obtain information; the objective world of physical information together with the transmission network in the next generation network will provide the most direct and most effective people real information [2]. Wireless sensor networks can get objective physical information, with a very broad application prospects, can be used in military defense, industrial and agricultural control, urban management, biomedical, environmental monitoring, disaster relief, remote control and other areas in hazardous areas. Has attracted attention of many countries academia and industry, is considered one of the technologies of the 21st century, a huge influence [3].

Wireless sensor network is deployed a large number of cheap micro-sensor nodes in the monitored area, a multi-hop self-organizing network formed by wireless communication systems, the purpose of collaboration and awareness, collection and processing of network coverage area is perceived information of the object, and send the viewer. Sensors, sensing the object and the observer constitute three elements of wireless sensor networks [5].

II. SMALL WORLD THEORY MODEL

Small-world network was first used by Duncan Watts and Steven Strogatz introduced in 1998, a high clustering coefficient and low average path length as a feature, we propose a the new network model, generally known as WS model, the model which is the most typical of small-world networks [13].

Because WS small-world model construction algorithm randomization process could undermine the network connectivity, Newman and Watts proposed small-world network model, which is by "randomization plus side" mode instead WS small-world network model constructed in the "randomized reconnect."[6]

In consideration of the characteristics of the network, the network is measured by the characteristic path length and clustering coefficient.

Characteristic path length: In a network, the optional two nodes, together with the average of the minimum number of edges in the path of these two nodes, is defined as the length of the path of these two nodes, all nodes in the network length, defined as the characteristic path length of the network. This is the global features of the network [7].

Clustering coefficient: Suppose a node has k edge, the number of edges which may exist between the edges connected to node k at most k (k-1)/2, the number of edges with actually existing fractional number of edges divided by the maximum possible obtained, the polymerization is defined as the coefficient of this node. Mean clustering coefficient is defined as the aggregation of all the nodes in the network coefficients. Aggregation factor is the local characteristics of the network,

reflecting the adjacent circle of friends degree of coincidence between two people, but also the extent that the node between friends [8].

A. The composition of NW small-world network principle

NW small-world networks constitute the principle as follows: from the beginning of a ring network rules, network with N nodes, each node of the K node and its nearest neighbors and even the K edges and meet N>> K >> In (N) >> 1. Followed by randomization plus side, with probability p between a pair of nodes are randomly selected plus an edge. Wherein, between any two different nodes can have at most one edge, and each node cannot have edges that connect with itself. P-value change can be achieved (p = 1) transition from the nearest neighbor coupling network (p = 0) to the global coupling network. At p small enough and large enough N, NW small-world model is essentially equivalent to the WS small-world model [14].

NW small-world network topology structure as shown in the Fig.1 below:

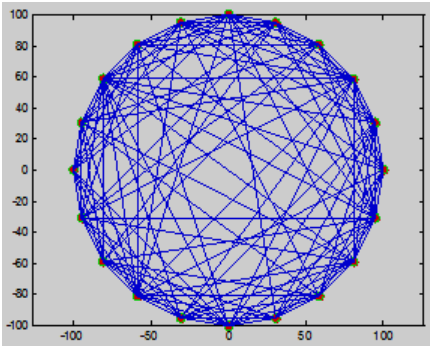

Fig.1 NW small-world network topology

III. RESEARCH AND IMPLEMENTATION OF SMALL-WORLD THEORY TOPOLOGY CONTROL ALGORITHM

A. Leads to problems

Wireless sensor networks is consist of some small intelligent nodes, those nodes generally have a perception, calculation and the ability to communicate with other devices, these nodes are generally embedded devices, and some also support the operating system intelligence is evident. Even now the level of wireless sensor development has very high production costs continue to decrease with the development of technology, integration of continuous improvement, but its price is still a must to consider [9]. Since the deployment of wireless sensor networks in the region, the majority of the general environment is very harsh, possibly accompanied by arctic, high temperature and even toxic gases into the human inconvenience, but people need to have access to certain information in this area, such as the need in the mine detect temperature, humidity, gas concentration, then the deployment of wireless sensor networks in these areas is a good choice. As mentioned earlier, these areas are generally harsh environment for humans to get involved, which means that sensor networks will be completed once the pavers can only be completed by its own ad hoc network of work to complete the sense of mission, until the energy is depleted [10]. Once a node fails or if the battery runs out, only to be abandoned in general, can not be done by manual inspection or charging task, so in some cases the deployment of wireless sensor networks can be seen as "disposable" a. These factors determine the sensor node is facing many challenges, including the two most important and should not be overlooked is the energy and bandwidth-constrained supply [11]. In summary, in the case of existing limited storage of sensor nodes, we should try to extend the life of the network, so that the input-output network optimization.

Energy consumption of sensor nodes is affected by many factors, such as the communication distance between nodes, the nodes themselves sending and receiving efficiency of information, network topology, routing path information to improve the energy efficiency of nodes can start in many ways. Algorithms mentioned sensor network topology from improvements to precede, the small world theory into sensor networks by adding nodes to add advanced long-range links, thus greatly reducing the number of hops sink node to node to send information, in order to reduce energy consumption and prolong the life of the network communication.

B. Algorithm topology

For the small world theory into wireless sensor networks, the need for some changes in the topology. Small world theory has two important features: high clustering coefficient and short average path length. To these two important features into the sensor network, an important way is to join the advanced node in the sensor node. Thus, the network topology contains three types of nodes, namely ordinary nodes, advanced node (heterogeneous nodes) and the sink. Wireless sensor network topology is as follows [12]:

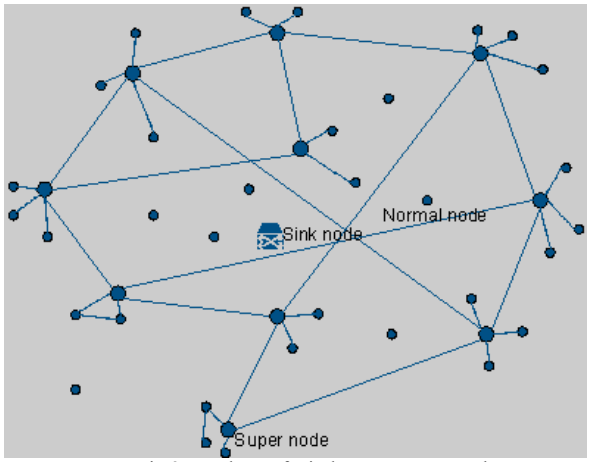

Fig.2 Topology of wireless sensor networks

Next, the sensor network topology for further explanation:

1). Ordinary sensor network node is the most important part, which is mainly responsible for information collection, processing, transmission function, in the network, the vast majority are of such nodes, their prices low, easy to spread, in this algorithm application environment, the normal node failure or battery power once appeared exhausted, that believes his death, not make any repair or charging operation. Ordinary nodes can communicate with any other ordinary nodes, it is possible and super nodes and aggregation nodes communicate communication contains direct and indirect aggregation node communication node communicates with the convergence of multi-hop manner.

2). Advanced node (heterogeneous nodes) is the key to the small world theory into sensor networks, compared with its ordinary nodes, it is not much difference between ordinary node, also completed the acquisition, processing and sending of information, but they have more power and greater energy reserves to send information processing function, in other words, they can send the information to get further a field, this is the introduction of long-range links the key, set up by between super node ring to complete the majority of the network to forward the task of gathering information node communication, and as a long-range link exists between the super nodes, formerly ordinary nodes to pass information to the sink need to go through multiple forwarding information is sent to complete the task, now these long-range links, can greatly reduce the number of hops required to send information, send a message hops less, on the one hand to simplify the topology of the network, can provide a good foundation for the design of better routing algorithms, on the other hand possible to reduce the information transmission time complexity, reduce the requirements of TDMA time slots, so that the error rate can be reduced, improving the reliability of information transmission.

3). Sink node wireless sensor networks for information exchange center, which is generally higher cost, reusable, when deploying aggregation node, its location will be designed both to improve the effectiveness of topology control, installed in specific location can shorten the super node sends information to its desired path length, so it can save more energy, improve network lifetime; on the other hand is constrained environment, it cannot be deployed to the environment is very bad repair or maintenance of artificial inconvenient places. Task sink node is to receive information from the common node and the high-level node, the received information is processed, it has a higher node more processing capability information, information processing is a small network, various information processing will be Upon completion, the network, or other line to send information to the monitoring center for network managers to view. The working schematic of Aggregation nodes are shown in Fig.3.

4). The main role of the gateway is to collect information from multiple aggregation nodes, processing the information integration, because the communication protocol and Internet protocol sensor networks are not the same, you need a special device to convert, it is the gateway to complete a job , it is generally located on the edge region of the sensor network.

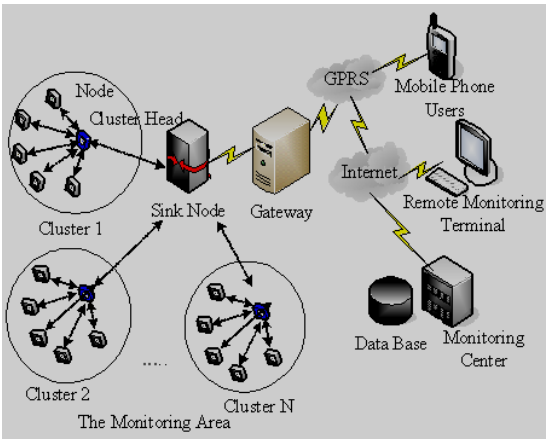

Fig.3 Working schematic of Aggregation nodes

5). Monitoring and other mobile terminal can be a computer user or a remote terminal, typically a terminal can simultaneously monitor multiple sensors regulatory networks, mobile users a variety of data via GPRS network detection area of real-time information inquiry, and the computer network, you can through the Internet

network for information processing, evaluation, the valuable information stored in the database.

C. Working principle of the algorithm

The traditional model of small-world theory there are two: WSNW network model and network model. Both are essentially the same, is the use of small-world networks have large clustering coefficient characteristics and shorter average path length. If the NW network model is introduced directly into the sensor network, although this could make the sensor network small world the largest expression, but because of the need to establish a long-range link, then the ability to send and receive data sensor nodes must be strong enough, but also requires each node has a long battery life, which is a ideal state, but this design has been greatly constrained in real network deployments. Because the use of small-world characteristics of the core idea is to establish a long-range link, if long-distance link is damaged, the entire network will fall into a state of disorder, resulting in network completely paralyzed. Sensor network node ordinary inexpensive, data processing and sending capability is very limited, if you let this kind of node to assume the task of establishing a long-range links, due to the long-range communication links need to take a lot of tasks, data exchange capacity, which will make the ordinary node premature death; the entire network life cycle is shortened. If the ordinary nodes are replaced by the data processing and the ability to send a strong super-node, although NW network model to meet the requirements of long-range link stability is guaranteed, but to establish such a sensor network cost is too high, not easy to promote the use of large-scale, big limitations. To address these shortcomings, the algorithm introduces a super node, so this type of node to complete the establishment of long-range links and forwarding most of the tasks of information, such node data transmission capacity, long life, and they will send the data to the sink node when, due to the presence of long-range links between them, can be forwarded via a few hops will be able to complete the task of data, thus saving a lot of energy required to send data, even super-node data transfer tasks take a lot of their relatively long life cycle.

Super nodes in a network deployment and ordinary nodes combined division of labor, the super node sends data to make up for weak ordinary nodes shortcomings ordinary nodes to solve the root node of the more expensive enough to bear the majority of sensor network information collection, processing tasks, forming a hierarchical network between them, the community has displayed the characteristics of small-world networks.

When the algorithm starts with the NW network model is similar to the joint between the ring generated super node. Super node does not own the data collected or forwarded to it by ordinary nodes send data directly to the sink node, which data can be sent first to the neighboring super-node, then forwarded by the super node to sink node neighbors. Significance of this is the formation of super-node ring where, the number of long-range links are limited, not all super-long-range link nodes are present, although the energy contained in the higher super node itself, but to maximize the lifetime of the network to be considered in this regard should also save the super node sends data consuming energy as possible. As a sensor network in a specific number of super nodes deployed, can be determined according to the size of the actual monitoring of the area, this may be before the actual deployment of the monitoring network, the first simulation tests to arrive at a good number of super nodes to ensure network the small-world characteristics. Super node relative to all nodes in the network is very small proportion in the economy does not produce a significant rise in the cost of more traditional deployment, so the impact of economic factors on the number of super nodes can be ignored. May be used when the super node to send and receive data shortest path or least energy consumption mode, and the energy consumed by the transmission data from the sensor is not a linear relationship, all the energy may be forwarded through a longer path repeatedly consumed instead than through the shortest path consuming less energy, specifically the use of which according to the actual situation to be reflected in the use of algorithms and simulation experiments.

After the super-node ring to form a stable, and then in the super node randomly selected node on the formation of long-range links, in order to ensure the network's largest small-world characteristics, the number of long-range links rigorously calculated Once a long-distance links due to the death of super nodes and fracture, then immediately generate new links, and always maintain maximize small world characteristics. Randomly selected super node does not coincide with the neighbor nodes to generate long-range links are not coincident with the super-node ring, so that once the existence of a super-node needs to send information to the sink node, it will have three ways to send a mission to complete this: data from its own sent directly to the sink; data from its first forwarded to the super node neighbors, then forwarded by the super node neighbors to the sink; data from it to be forwarded to non-neighbor nodes via long-range link, and then from the non-neighbor forwarded to the sink node.

After the formation of long-range links, ordinary nodes join the network. All ordinary nodes together to form the common node in the network layer, which mainly complete the acquisition and processing of

information, common node priority to join the nearest super node, unified management by the super-nodes, each node only join a recent general super-node, All ordinary nodes will form a cluster, the cluster node is the super cluster head. Once the clusters are formed after not change, unless the super node cluster management failure or death, a new cluster will be regenerated, in order to prevent crosstalk between the clusters, each cluster are relatively independent, not between the cluster and the cluster information exchange.

IV. ALGORITHMS AND SIMULATION EXPERIMENTS

After completion of the theory of wireless sensor network topology control algorithm based on the small world theory analysis, the next experiment simulation algorithm. In order to verify the effectiveness of the algorithm, it is compared with the classic hierarchical topology control algorithm LEACH algorithm. The simulation parameters are as follows:

Randomly disposed super nodes and common nodes within a region 100m× 100m, the number of super node is 80, the number of common node is 20, the initial energy of two types of nodes is fixed, not on its energy supply, energy of the super node is three times the normal node energy, coordinate sink node randomly generated, simulation of 200 total rounds, small world parameter $K = 4$, $P = 0.2$.

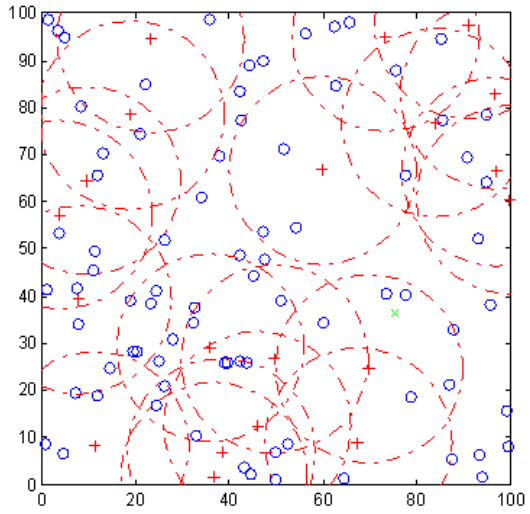

Fig.4 Super-node communication diagram

Fig.4 shows a communication range of the super node, "+" indicates the super node, a brokenline circle indicates the communication range, if the common node in the circle, it can be directly on the contrary cannot communicate with the super node o communicate with the super node.

Relationship with the number of rounds algorithm runs between surviving nodes Fig.5 shows, it can be seen from the figure, in the case of running the same number of rounds of the algorithm, based on topology control algorithm is always small world theory than hierarchical topology control algorithm LEACH algorithm surviving nodes more round.

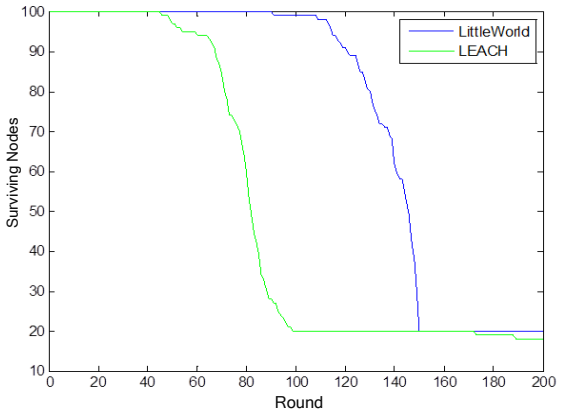

Fig.5 Surviving nodes per round in the algorithm

Relationship with the number of rounds algorithm runs between surviving nodes Fig.5 shows, it can be seen from the figure, in the case of running the same number of rounds of the algorithm, based on topology control algorithm is always small world theory than hierarchical topology control algorithm LEACH algorithm surviving nodes more round.

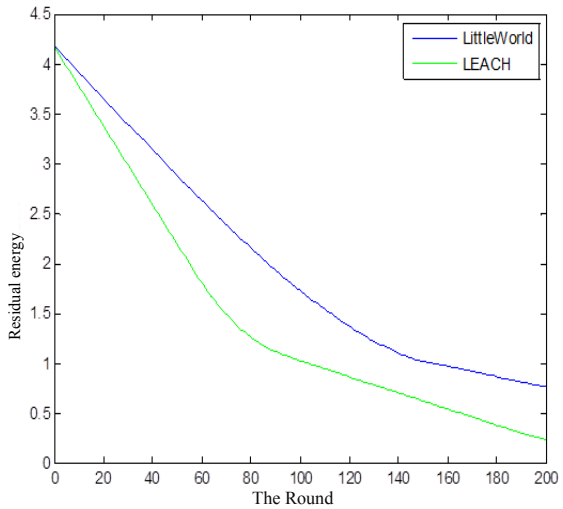

Fig.6 Residual energy per round in the algorithm

The relationship between the number of rounds and the residual energy of Fig.6 shows the algorithm runs, it can be seen from the figure, in the case of the algorithm running the same number of rounds, small world

topology control algorithm based on the theory of hierarchical topology is always more than the control algorithm of LEACH round remaining energy more.

IV. CONCLUSION

Through experiments simulation algorithm, we can see the small world theory into wireless sensor network topology to improve the feasibility, will be the use of a shorter average path length feature small world theory and a larger clustering coefficient to improve the wireless sensor networks life cycle, improve transmission efficiency by optimizing the topology, can lay a good foundation for improving the transmission efficiency of the route. Future research is the algorithm used in the actual wireless sensor networks, to test its feasibility in actual production practice.

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