International Journal of Hybrid Information Technology
Vol.7, No.2 (2014), pp.71-82
http://dx.doi.org/10.14257/ijhit.2014.7.2.08

A Clustering Routing Protocol for Energy Balance of Wireless Sensor Network based on Simulated Annealing and Genetic Algorithm

Haitao Zhang, Shiwei Zhang* and Wenshao Bu

Information Engineering College, Henan University of Science and Technology, Luoyang, Henan, 471023, China

**Corresponding author: zhang_shiwei_haust @163.com*

Abstract

The LEACH is a popular protocol used in wireless sensor network analysis and simulation. This paper analyses the advantages and disadvantages of LEACH protocol and then puts forward a clustering routing protocol for energy balance of wireless sensor network based on simulated annealing and genetic algorithm. When the sensor nodes are deployed randomly in the area, Firstly, we cluster the sensor nodes by simulated annealing and genetic algorithm and then calculate the cluster center of each cluster. If the energy of the node in the cluster is higher than the average energy of the cluster, it will become the candidate cluster head; at last the candidate cluster head becomes the cluster head according to the distance from the cluster center of the cluster. Simulations show that the new program could improve Energy Hotspot caused by the uneven distribution of cluster head in LEACH protocol, thus it can balance the wireless sensor network load balance and extend the lifecycle of wireless sensor network.

Keywords: *LEACH; Simulated Annealing Algorithm; Genetic Algorithm; Average energy*

1. Introduction

In recent years, as wireless communication technology and the rapid development of the miniaturization and low cost of the sensor nodes, that has accelerated the development of the wireless sensor network [1-3]. Wireless sensor network is a large number of static or mobile sensor nodes which form the wireless network using self-organization and multi-hop method, its purpose is to collaborate detection, processing and transmitting the object monitoring information in areas where the network coverage [4].

Wireless sensor network routing protocols can be divided into flat routing and hierarchical routing protocol in the network structure. All sensor nodes in the flat routing protocol generally have the same function. However, the nodes in the hierarchical routing protocol usually play different roles. The high energy node in the hierarchical routing protocol is used to process and send a message, while the low energy of the node is used to sense the target area information. Hierarchical routing protocol has good scalability and efficiency, which is the focus of current research. Common hierarchical routing protocols: LEACH [5], PEGASIS [6] and TEEN [7] and so on.

We study the LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol which is proposed by Wendi B. Heinzelman; and we also pay more attention to the cluster head election strategy and cluster head data transmission routing, in view of the existing problems,

ISSN: 1738-9968 IJHIT

we put forward the improvement program and compare simulation analysis. The simulation results show that the new scheme can ensure the energy load balances in the network, thus saving the energy consumption of the network, and ultimately prolong the lifetime of wireless sensor networks.

2. Leach protocol

The main goal of clustering routing protocol is the introduction of multi-hop communication and data fusion within a cluster to reduce node transmission distance and the amount of information transmitted to the sink, thus effectively maintain the node energy consumption [8].

LEACH protocol is the classical routing protocol in wireless sensor networks. LEACH protocol selects some nodes randomly as the cluster head, and converts this role to balance the energy consumption of nodes in the network. The cluster head fuse the data which is sent by the ordinary nodes within the cluster, and then send them to sink, thereby reducing the amount of redundant data transmission. The LEACH protocol is divided into two stages: setup phase and ready phase. The total time of setup phase and ready phase is called a round. In the setup phase, it will select cluster head and form a cluster. In the ready phase, the cluster head will send the data to the sink.

In the setup phase, when create a cluster, each node according to a given probability and threshold $T(s)$ decides whether to become a cluster head in the current round. In the formula (1), $Popt$ is the percentage of cluster heads in the whole network nodes; r is the current number of rounds; G is not become a cluster head collection in the final round $1/Popt$. In the LEACH protocol, the cluster head node for the best percentage of all nodes is 5%. Once a node is selected as the cluster head, it will broadcast the message to the entire network in the current round. All non-cluster-head nodes, after receiving this message, according to the intensity of the received broadcast signal to determine to add the cluster in the current round. Finally, the cluster head receives non-cluster head node join request message and uses TDMA allocates time slots to each node in the cluster to transmit data.

In the ready phase, sensor nodes can percept data and send the data to the cluster head. All non-cluster head nodes can turn off the wireless switch to save energy before the arrival of the allocation of transmission time. The cluster head integrates the data from the non-cluster head nodes of the cluster and then sends them to the sink. Each cluster head uses different CDMA encoding mode to communicate, so as to avoid conflicting with other cluster nodes.

$$T(s) = \begin{cases} \dfrac{Popt}{1 - Popt \times \left(r \times \mathrm{mod} \dfrac{1}{Popt} \right)} & if \ s \in G \\ 0 & otherwise \end{cases} \tag{1}$$

3. Leach-saga Protocol

3.1. The disadvantages of leach algorithm

By analyzing the formation of cluster in LEACH protocol, we find that it just considers the cost of communication between the cluster head and ordinary node; it did not consider the remaining energy of cluster head and current location information. Regardless of the current energy of the node, the probability of the node to become a cluster head is roughly the same in the round. This may lead to the energy of small residual energy node rapid depletion, which may result in the monitoring region appearing "blind area", it not conducive to the life cycle of the network, also affects the robustness of the network.

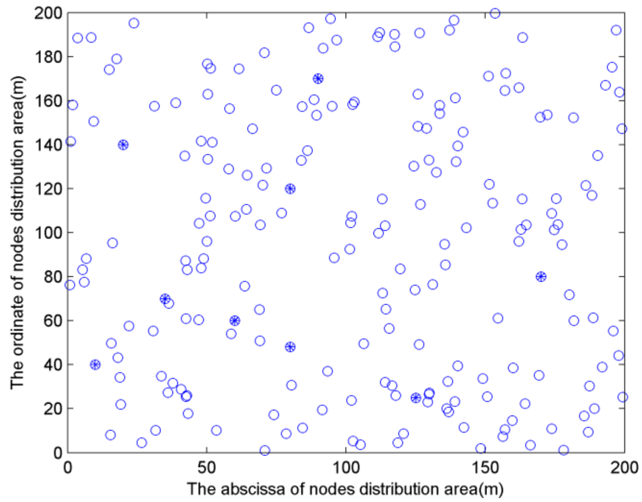

Figure 1. Uneven distribution

On the other hand, LEACH protocol uses random cluster head selection mechanism to select a cluster head which can easily lead to uneven distribution of cluster head node. LEACH protocol select cluster head randomly, it can not guarantee the number of cluster heads, also easily lead to the location of cluster head can not do the best, it may appear that there are no cluster heads around some normal nodes, this will lead to the transmission distance is too far and consume more energy. On the other hand, if the nodes in a region is too concentrated, members within a cluster may be redundant to other cluster members, thus, the energy consumption rate of the cluster head is the faster, may lead to the problem of unbalanced energy dissipation of cluster head, thereby affecting the life cycle of the network [9]. Cluster head load uneven clustering shown in Figure 1. And the cluster head approximately uniformly distributed is show in Figure 2.

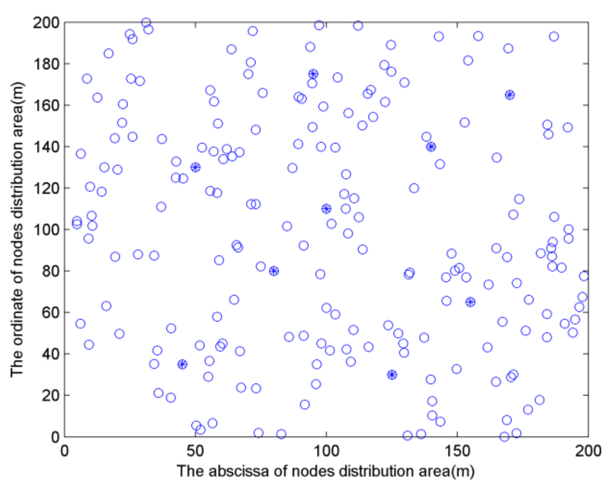

Figure 2. Approximately uniformly distributed

3.2. Leach-saga protocol

For the lack of LEACH protocol, we propose a clustering routing protocol for energy balance of wireless sensor network based on simulated annealing and genetic algorithm. The main operational difference between the proposed protocol and LEACH is the selection process of cluster heads; clustering head selection is performed by simulated annealing and genetic algorithm in proposed protocol while LEACH uses a random selection method. The proposed network clustering protocol is based on a centralized control algorithm that is implemented at the base station. The base station is a node with unlimited energy supply.

For a wireless sensor network with 200 nodes and k number of clusters, the wireless sensor network can be clustered as two phases: In the setup phase, the base station clusters the random deployment of sensor nodes using simulated annealing and genetic algorithm. When it selects the cluster head of each cluster, it will consider the residual energy of the sensor node and the average energy of the cluster, if the residual energy of sensor node is larger than the average energy and nearest to cluster center; it will become a cluster head. In the ready phase, the common node communicates with cluster head and the cluster head will send the data to the sink using one hop or multi-hop mode.

3.3. Simulated Annealing and Genetic Algorithm

In the past few decades, genetic algorithm has been widely used in scientific issues, from construction of the wind turbine [10] to pattern recognition systems. The genetic algorithm is an efficient search algorithm that simulates the adaptive evolution process of natural systems. It has been successfully applied to many similar problems such as multi-processor task scheduling, optimization, and traveling salesman problems [11]. In the genetic algorithm population, each individual represents a possible solution to the problem. Finding the best individual to the problem, combining the best individual into a new individual is an important stage in the evolutionary process. Using this method repeatedly, the population will evolve a fine individual. Specifically, the elements of the genetic algorithm are: selection (according to some fitness standards), crossover (one way of breeding), and mutation (adding a little noise to the off-spring, changing their "genes").

The simulated annealing algorithm is based on the physical process of metallurgical annealing [12]. When we give a solution, evaluate the solution, and make a small modification on the solution. The new candidate solution is evaluated and if it is better than the previous solution, the simulated annealing algorithm accepts this new solution, and assumes it to the current solution, If it is not better than the previous solution, it will accept this new worst solution in a certain probability according to the current temperature of the system and the cost of each solution. In the formula (2), A represents the probability of accepting the worst solution; c (N) represents the cost of new solution; c (P) represents the cost of current solution, T represents the current temperature.

$$A = e^{-\frac{c(N)-c(P)}{T}} \tag{2}$$

The simulated annealing algorithm is used to exchange contrast randomly, the regularity of the exchange is poor, and the convergence rate is relatively slow; but the crossover, mutation operation of genetic algorithm is strong regularity, and the convergence speed is relatively faster. In the late of genetic algorithm, the advantage is not obvious; it is easy to make the whole population evolution remain stagnant. Therefore, it is necessary and proper to stretch the fitness. If you join the simulated annealing algorithm, at high temperatures, the individuals with the similar degree have the near probability to produce offspring. When the temperature is falling, it will make the individuals with the similar degree have a big different, so that the advantages of the best individual are more obvious.

For these reasons, we combine the simulated annealing algorithm and genetic algorithm for clustering for wireless sensor network. As the simulated annealing algorithm and genetic algorithm can learn from each other, therefore, it overcomes the premature phenomenon of genetic algorithm effectively. At the same time, according to specific circumstances of the wireless sensor network clustering to design the genetic encoding and fitness function. The method is more efficient, faster convergence to the global optimal solution, which makes the clusters more reasonable.

3.4. Simulated Annealing and Genetic Algorithm clustering process

Using simulated annealing and genetic algorithm to cluster the random deployed nodes is shown in Figure 3.

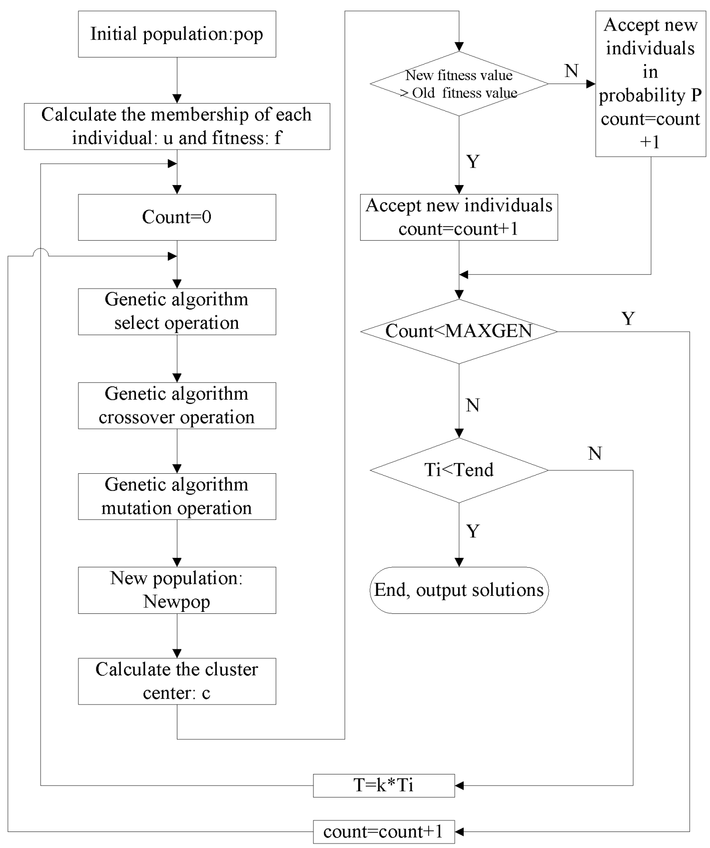

Figure 3. The process of using simulated annealing and genetic algorithm to cluster the nodes

(1) Initialize the control parameters: the size of individual in a population num; Maximum evolution times MAXGEN; Crossover probability Pc; Mutation probability Pm; The initial temperature To; Temperature cooling coefficient k; End temperature Tend.

(2) Random initialization c cluster centers, and generate the initial population pop, Using equation (3) to calculate membership to each cluster center v_i .

$$u_{ik} = \frac{1}{\sum_{j=1}^{n}\left(\frac{d_{ik}}{d_{lk}}\right)^{\frac{2}{b-1}}} \tag{3}$$

In equation (3) d_{ik} is the Euclidean Distance (shown in equation (4)). x_{ij} is a data sample of $X = \{x_1, x_2, x_3, \dots x_n\}$.

$$d_{ik} = \sqrt{\sum_{j=1}^{m}\left(x_{ij} - v_{kj}\right)^2} \tag{4}$$

In equation (4) v_{ij} (shown in equation (5)) is the cluster center, b is the weighting parameters ($1 \le b \le \infty$).m is the number of characteristics of the sample.

$$v_{ij} = \frac{\sum_{k=1}^{n}\left(u_{ik}\right)^b x_{kj}}{\sum_{k=1}^{n}\left(u_{ik}\right)^b} \tag{5}$$

(3) Set the loop count variable count = 0.

(4) Then begin to select, crossover, mutation operation and calculate the membership degree and cluster center of new populations, as well as the fitness value $f_i^{'}$ (shown in equation (6)) of each individual. If $f_i^{'} > f_i$, using new individual to replace the old individual; otherwise accept this new individual in probability P, shown in equation (7).

$$f_i^{'} = \sum_{i=1}^{n}\sum_{k=1}^{c}\left(u_{ik}\right)^b\left(d_{ik}\right)^2 \tag{6}$$

$$P = \exp\left(\left(f_i - f^{'}_i\right)T\right) \tag{7}$$

(5) If count<MAXGEN, then count=count+1, go to step (4); otherwise go to step (6).

(6) If Ti<Tend, the algorithm is end, get the global optimal solution. Otherwise, performing the cooling operation T = kTi, go to step (3).

After using simulated annealing and genetic algorithm to cluster the random deployed nodes, we get the clustering Figure 4. × stands for sink node and the ▽ stands for cluster center.

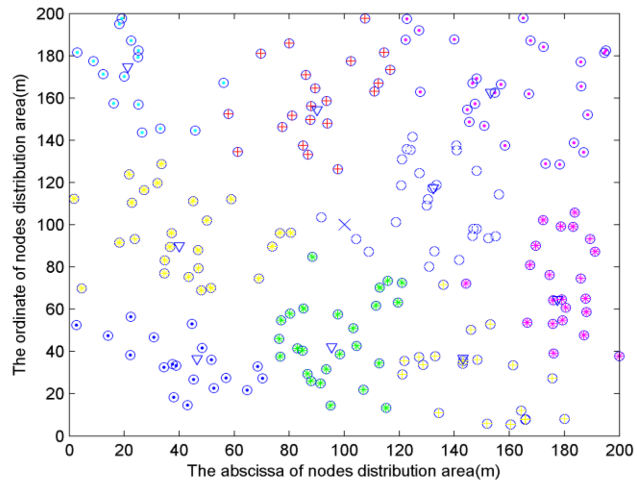

Figure 4. Using simulated annealing and genetic algorithm to cluster the nodes

3.5. Objective function

We use the objective function in equation (8) to evaluate the structure of cluster. J_b is smaller, the higher individual fitness, and vice versa, the lower the fitness of individual.

$$J_b = \sum_{i=1}^{n}\sum_{k=1}^{c}(u_{ik})^b (d_{ik})^2 \tag{8}$$

3.6. Cluster head formation process

After using simulated annealing and genetic algorithm to cluster the random deployed nodes, we obtain an approximate optimal clustering structure. In the formation stage of the cluster head, using the equation (9) to calculate the average energy $Eave(i)$ of each cluster, If a node's energy is greater than the average energy of the cluster, then the node become one member of the candidate cluster head queue, Then we use Equation (10) to calculate the distance between each candidate cluster head and it's cluster center. The node nearest to the cluster center will become the cluster head of this cluster, the remaining sensor nodes in this cluster will become common nodes. In data transmission phase, the common nodes send data to the cluster head, and the cluster heads communicate with base station directly.

$$Eave(i) = \frac{E(1) + E(2) + \cdots + E(n_i)}{n_i} \tag{9}$$

Where $i \in 1, 2 \cdots c$ and n_i is the total number of nodes in the cluster i.

$$dist = \sqrt{(x_1^2 - x_2^2)^2 + (y_1^2 - y_2^2)^2} \tag{10}$$

After a complete cycle, as the cluster head need to forward the data packets from the common nodes and data integration in the first round, so the energy consumption is higher than the ordinary nodes. In the second round of the election process of the cluster head, the cluster head in the first round of the election will not be selected as the cluster head. Another node whose remaining energy is greater than the average energy and nearest to the cluster center of the cluster will be the new cluster head. After such multiple rounds of circulation, the distribution of cluster head will spread around the cluster center. This will avoid the cluster head concentrate relatively at some point, thus delaying the time of the first node death, thereby extending the life cycle of the wireless sensor networks.

4. Simulation and Results Analysis

4.1. Energy consumption model

We use the radio model (first order) improved by Wendi B. Heinzelman [5]. In this model, we use a different attenuation model depending on the distance between the sender and the receiver. The transmitter sends k bit data to the node where d meters from the transmitter, the energy consumption calculation formula as shown in (11); the energy consumption of receiver receives k bit information is shown in (12); the energy consumption of compressing fusion k bit information is shown in (13).

$$E_{TX}\left(k,d\right)=\begin{cases}kE_{elec}+k\varepsilon_{fs}d^{2} & d<d_{0}\\ kE_{elec}+k\varepsilon_{mp}d^{4} & d\geq d_{0}\end{cases} \tag{11}$$

$$E_{RX}(k)=kE_{elec} \tag{12}$$

$$E_{DA}(k)=kE_{da} \tag{13}$$

The circuit depletion of sender and receiver is E_{elec} , ε_{fs} and ε_{mp} is the amplifier coefficient of the free-space model and multi-path fading model, d_0 is the critical distance of the two models, E_{da} is the energy consumption to compress unit data.

4.2. Experiment setting

In this paper, we compare the LEACH protocol and LEACH-SAGA protocol (a clustering routing protocol for energy balance of wireless sensor network based on simulated annealing and genetic algorithm) in MATLAB. Experiment setting in this article are：

(1) All the nodes are deployed in the area randomly.

(2) The base station is located in the center position of the experimental region.

(3) All the nodes have the same initial energy.

(4) The base station knows the ID and location of each node.

(5) The communication link between the nodes is symmetrical, and has the same effective communication distance.

We assume that there are deployed 200 isomorphic sensor nodes randomly in a two-dimensional area of 200m × 200m square. Each node is in the same initial state, and having the same initial energy. The base station is located in (100,100). According to the literature [13] proposed method we get the optimal number of cluster is 9. The various parameters used in the simulation are shown in below: the node initial energy is 0.5J; the E_{elec} is $50\, nJ/bit$; the ε_{fs} is $10\, pJ/bit/m^2$; the ε_{mp} is $0.0013\, pJ/bit/m^4$; the E_{da} is $5\, nJ/bit/signal$; the d_0 is 87m; the data control packet size is 4000bit; the initial temperature T_0 100℃; the termination temperature T_{end} is 60℃; The maximum genetic algebra MAX is 10; the population size num is 10; the crossover probability P_c is 0.7; the mutation probability P_m is 0.01; the cooling coefficient k is 0.8.

4.3. Experimental result analysis

We compare the LEACH protocol and LEACH-SAGA protocol in four aspects: cluster head distribution, life cycle, the base station receives data packets and energy consumption.

Firstly, we compare LEACH protocol cluster head distribution map in Figure 5 and LEACH-SAGA protocol cluster head distribution map in Figure 6 at round 100.

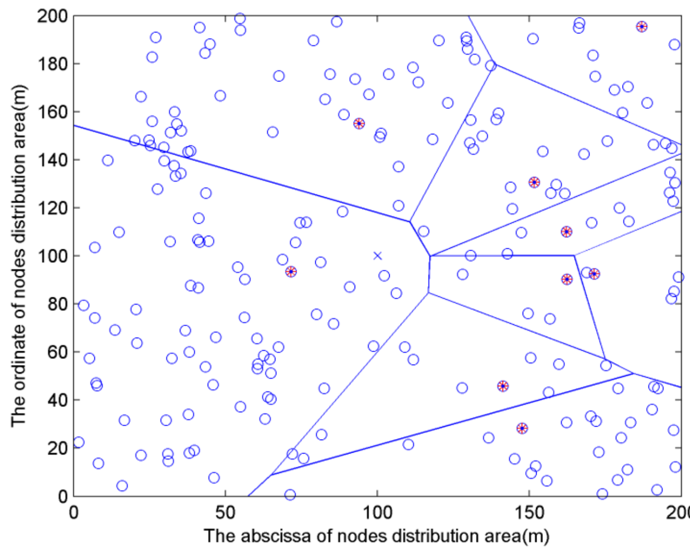

Figure 5. LEACH protocol cluster head distribution

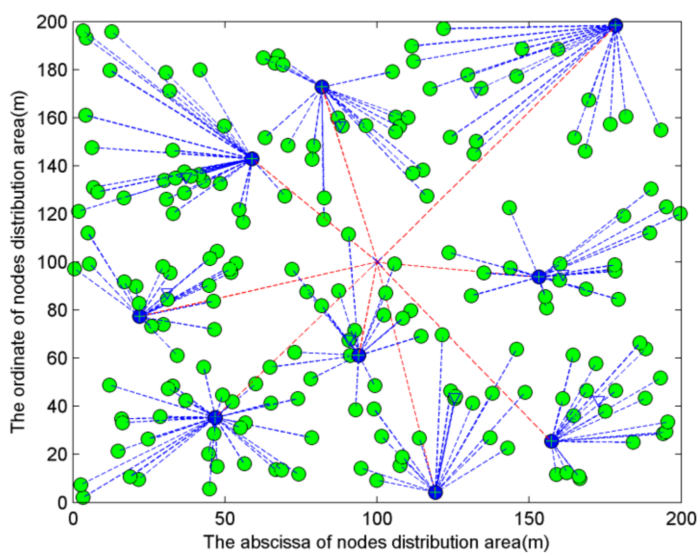

Figure 6. LEACH-SAGA protocol cluster head distribution

Since the LEACH protocol selects cluster head randomly, it is easy to lead to uneven distribution of cluster head. As can be seen from Figure 6, using the simulated annealing and genetic algorithm to cluster the nodes, the cluster heads can be distributed uniformly in the area, which can balance nodes energy consumption, thereby extending the life cycle of the wireless sensor networks.

Then we compare the LEACH protocol and LEACH-SAGA protocol in three aspects: life cycle, the base station receive data packets and energy consumption.

As can be seen from Figure 7, with the increase of rounds, the time of the first node dead of LEACH-SAGA is later than LEACH protocol. And the lifecycle of LEACH-SAGA is longer than LEACH protocol.

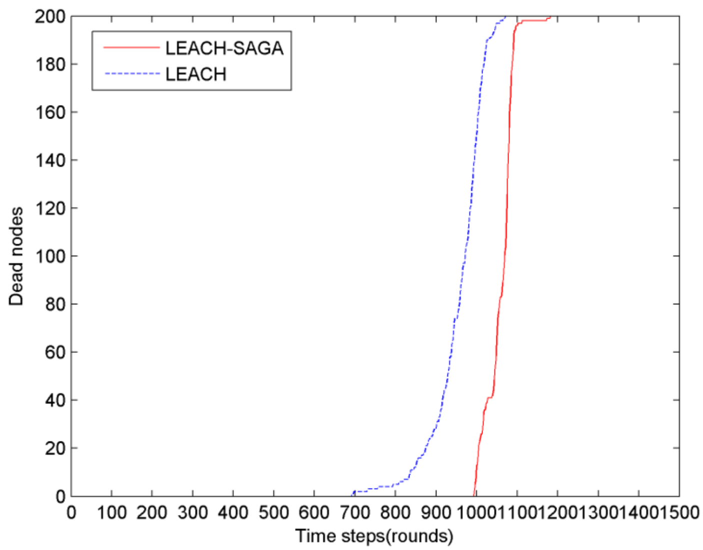

Figure 7. The number of dead nodes

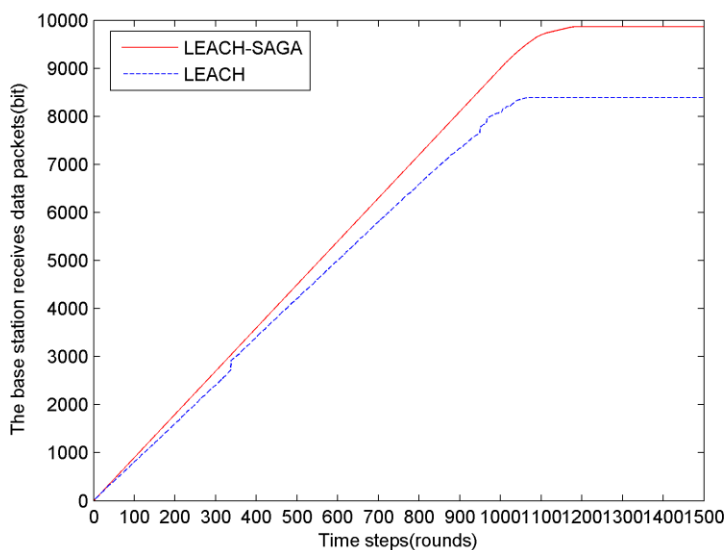

Figure 8. The **base station receives data packets**

From the Figure 8 we can see that, with the increasing of rounds, the number of packets transmitted to the base station also have a big change. The amount of data packets received within a certain time is an important indicator for measuring the quality of network service. The more data packet received, the more information we can obtain, so we can get the data faster. As can be seen from Figure 8, LEACH-SAGA algorithm can obtain more packets in the latter part of the data transmission. This is because we use LEACH-SAGA algorithm to cluster the nodes, the clusters are distributed evenly in the area and the cluster heads are also homogeneous distributed. If the more nodes are near to cluster head, the time of transmission data is less. Cluster heads can receive more packets sent from the cluster members; therefore, the data packets need to transmit are large.

In the Figure 9, we can see that the LEACH-SAGA consumes less energy than the LEACH at the same time, because the cluster heads of LEACH-SAGA can be distributed uniformly in the area and it also considers the residual energy of sensor nodes when selects cluster head.

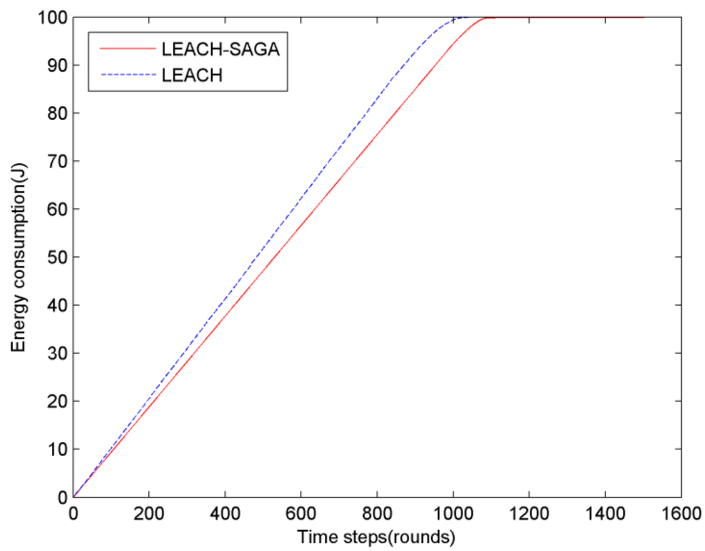

Figure 9. Energy consumption

5. Conclusion

In this paper, we put the wireless sensor networks as the research background. We have an in-depth study of LEACH protocol and analyze the shortcomings, and then we put forward the improved LEACH-SAGA protocol. In this protocol, we use the simulated annealing and genetic algorithm to cluster the sensor nodes, at the same time, we consider the residual energy of the nodes and the average energy of the cluster, so we can get a more reasonable cluster head distribution in the lower level of power consumption. Furthermore, it can balance the load balancing of network and extend the lifecycle of wireless sensor networks.

Acknowledgements

This work is supported by the National Natural Science Foundation of China. (No.51277053)

References

[1] Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A Survey on Sensor Networks", IEEE Communications Magazine, vol. 40, no. 8, **(2002)**, pp. 102–114.
[2] J. Yick, B. Mukherjee and D. Ghosal, "Wireless Sensor Network Survey", Computer Networks, vol. 50, no. 12, **(2008)**, pp. 2292–2330.
[3] M. Tubaishat and S. Madria, "Sensor Networks: an overview", IEEE Potentials, vol. 22, no. 2, **(2003)**, pp. 20–23.
[4] S. Zhang and H. Zhang, "A Review of Wireless Sensor Networks and Its Applications", IEEE International Conference on Automation and Logistics, (**2012**) August 15-17; Zhengzhou, China.
[5] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient Communication Protocol for Wireless Microsensor Networks", Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS-33), **(2000)** January 4-7, Maui, USA.
[6] S. Lindsey and C. S. Raghavendra, "PEGASIS: power efficient gathering in sensor information systems", Proceedings of the IEEE Aerospace Conference, **(2002)** March 9-16, Big Sky, MT, United states.
[7] A. Manjeshwar and D. P. Agrawal, "TEEN: a protocol for enhanced efficiency in wireless sensor networks", Proceedings of the 1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, **(2001)** April, San Francisco.
[8] H. Muktar and A. Farhat, "A survey of power-efficient gathering of sensor information system based routing protocols of wireless sensor networks", Sensors and Transducers, vol. 142, Issue 7, **(2012)**, pp. 10-22.
[9] N. Kumar and V. S. Prabha, "Comparative analysis of energy-efficient cluster-based routing protocols for wireless sensor networks", Sensors and Transducers, vol. 142, Issue 7, **(2012)**, pp. 23-32.
[10] E. Benini and Toffolo, "An Optimal design of horizontal-axis wind turbines using blade-element theory and evolutionary computation", J Solar Energy Eng, vol. 124, no. 4, **(2002)**, pp. 357–363.
[11] S. Jin, M. Zhou and A. S. Wu, "Sensor network optimization using a genetic algorithm", In: Proceedings of the 7th world multiconference on systemics, cybernetics, and informatics, **(2003)**.
[12] S. Kirkpatrick, C. D. Gelatt and M. P. Vecchi, "Optimization by simulated annealing, Science", vol. 220, no. 4598, **(1983)**, pp. 671–680.
[13] F. Li and J. Wang, "A Best Clustering Scheme Based on Simulated Annealing Algorithm in Wireless Sensor Networks", Chinese Journal of Sensous and Actuators, vol. 24, no. 6, **(2011)** pp. 900-904.

Authors

Haitao Zhang

He is an associate professor with a Ph.D. in Information Engineering College, Henan University of Science and Technology. His research interests in embedded system and intelligent network control.

Wenshao Bu

He is an associate professor with a Ph.D. in Information Engineering College, Henan University of Science and Technology. His research interests in new type of motor and electric drive control theory.

Shiwei Zhang

He is a master graduate student of Information Engineering College, Henan University of Science and Technology. His research interests in wireless sensor network.