Journal of Information & Computational Science 11:8 (2014) 2747–2757 May 20, 2014
Available at http://www.joics.com

An Improved LEACH Multi-hop Routing Protocol Based on Intelligent Ant Colony Algorithm for Wireless Sensor Networks

Chengzhi Long [a,*], Sha Liao [a], Xu Zou [b], Xiaoming Zhou [a], Na Zhang [a]

[a] *Department of Electronic Information Engineering, Nanchang University, Nanchang 330031, China*

[b] *Jiangxi Analysis and Testing Research Institute, Nanchang 330031, China*

Abstract

In view of limited node energy, how to reduce energy consumption and improve the network lifetime is an important issue in wireless sensor networks. In this paper, by integrating the theory of intelligent ant colony algorithm with LEACH, we proposed an improving routing algorithm LEACH-IACA (LEACH-Intelligent Ant Colony Algorithm) based on multi-hop routing protocol. The core idea is to evaluate cluster heads' current residual energy and location information from the perspective of overall network in real-time, and single ant traverses all nodes in one time, forming a dendritic multi-hop path. While the path is rebuilt, low-energy nodes select energy-saving path, high energy nodes increase energy consumption as consideration to prolong the network lifetime. The simulation shows that the new method is superior to tranditional LEACH routing algorithm, since it effectively improves the network lifetime, reduces average energy consumption.

Keywords: Multi-hop; Ant Colony Algorithm; Wireless Sensor Networks; LEACH

1 Introduction

As a new way of information acquisition and processing mode, wireless sensor networks (referred WSNs) is widespread concerned by scholars at home and abroad and has become their research hotspots. Especially that in recent years, with the appearance of small, inexpensive sensor based on MEMS technology, a large amount of wireless sensor networks have been applied in practice and widely accepted by users. So WSNs will be a valuable research area in the future [1]. Wireless sensor networks powered by finite energy battery, so its constituent elements - the sensor node have a life cycle. When the energy is exhausted, the sensor nodes will not work. Therefore, how to reduce energy consumption and extend the network lifetime are important issues as well as core problems in WSNs [2].

In wireless sensor network, routes are used to send the data which are collected and fused by the source node to the target node, this process consumes most energy of the whole network.

*Corresponding author.
Email address: `long.chengzhi@ztenc.com.cn` (Chengzhi Long).

DOI: 10.12733/jics20103577

Thus improving routing method is the main way to reduce energy consumption. LEACH protocol, proposed by W. R. Heinzelman et al. in 2000, is a relatively mature low energy adaptive clustering routing protocol. Many other hierarchical protocols such as TEEN, PEGASIS are developed on the basis of LEACH [3]. The basic idea of LEACH protocol is to select cluster heads randomly in a circular fashion, and allocate the whole network energy load evenly to each node, so as to reduce the energy consumption of the network and improve network overall survival time.

In LEACH, cluster heads communicate with SINK directly, but in a large-scale network, long distance communication makes nodes which are far away from SINK death quickly. This paper proposed an improved protocol LEACH-IACA taking the idea of multi-hop to construct the routing link. Through the improvement of ant colony algorithm, so that individual ant can build complete dendritic link. Therefore, energy can be taking into consideration in ant transfer process to achieve a global optimal path. The simulation results show that, comparing with LEACH, LEACH-IACA effectively reduces the energy consumption and improves the network lifetime.

2 Basic Theory

2.1 LEACH Protocol

LEACH protocol continually reconstruct clusters during operation, each process is called a "round" which divided into two phases, namely the cluster establishment phase and stable communication phase. Cluster establishment phase can be described as four phases: the selection of the cluster head, information broadcasting of the cluster head, the cluster establishment and its scheduling mechanism cluster formation. Cluster heads selection probability depends largely on the number of nodes and the times that the nodes have been cluster heads [4] [5]. Specifically, each node generates a random value between 0 and 1, if this number is small than the threshold value $T(n)$, then the node is elected as a cluster head.

$T(n)$ is calculated as follows:

$$T\left(n\right)=\begin{cases}\frac{p}{1-p\left(r mod \frac{1}{p}\right)} & n\in G\\ 0 & else\end{cases} \tag{1}$$

Here, p is the percentage of cluster heads among the total nodes in entire network; r is the current election round number; G are nodes that are not cluster heads of the recent $1/p$ rounds.

After then, the nodes which have become cluster heads broadcast information, non-cluster heads decide which clusters to join based on the strength of the received information, and notify the corresponding cluster heads, thus completing the establishment of cluster and scheduling mechanisms.

In stable communication phase, non-cluster head nodes send collected data to the cluster head. Cluster heads fuse received data, and then transmit them to SINK, thereby reducing communication data. After a period of stable communication, the network re-establishes clusters, entering the next round. The network re-entries stable communication phase and entries the next round.

2.2 Ant Colony Algorithm

Ant colony algorithm, a bionic optimization heuristic search algorithm, was first proposed by M.Dorigo, an Italian scholar, in 1992 in his doctoral thesis. He was inspired by the ants' behavior when they find a shortcut foods. According to entomologists' research, when searching for food, ants can find the shortest path to the food without any visible prompt. The study found that, in the process of foraging, ants secrete a chemical substance–pheromone in the path they traversed. During movement ants can sense the presence of this substance and its concentration, which guide them in moving toward direct with high concentration of the substance. With ants walking across one path, the path will have higher concentration of the pheromone, and then more ants will choose this path. It is this positive feedback mechanism that makes a colony centralizes in the optimal path [6] [7].

Ant colony algorithm achieves the path selection from point to another [8]. So using ant colony algorithm simply, the ant can only find the shortest path from a sensor node to SINK, but lack of a global state considerations. This paper presents an intelligent ant colony algorithm in which the single ant can traverse all nodes and forming a dendritic routing structure, during this process we consider the global change information, and finally we can achieve the global optimal solution.

3 LEACH-IACA

In establishment phase LEACH-IACA use the same mechanism as LEACH. When transmitting data, non-cluster heads in a cluster send data directly to the cluster head. Here we use LEACH-IACA to achieve the routing between cluster heads and SINK. The energy consumption during data transmission model is as follows:

$$E_{Tx}(L,d) = \begin{cases} L \cdot E_{elec} + L \cdot \varepsilon_{fs} \cdot d^2 & d \leqslant d_0 \\ L \cdot E_{elec} + L \cdot \varepsilon_{mp} \cdot d^4 & d > d_0 \end{cases} \tag{2}$$

$$E_{Rx}(L) = L \cdot E_{elec} \tag{3}$$

$$E_{Fs}(L) = L \cdot E_{fusion} \tag{4}$$

Herein, $E_{Tx}(L,d)$ is the energy consumption when the sensor node sends L bits data to the node d away from it. $E_{Rx}(L)$ and $E_{Fs}(L)$ are energy consumption for receive or fuse L bit data. E_{elec} is energy consumption for receiving or fusing 1 bit data. ε_{fs}, ε_{mp} is amplifier power consumption model parameters, d is the distance of transmission, $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$.

3.1 Intelligent Ant

In ant colony algorithm, ant has a certain memory that can record the past information, such as nodes the ant has traversed; ants have the capability of determining when and how much pheromones to be released to the environment; besides, to some degree, ants are also capable of calculating the transition probability and judge the transfer direction. Intelligence of LEACH-IACA mentioned in this paper is mainly reflected in a more powerful memory of ants, variant of decision-making capability, and more frequent calculation. In order to take every cluster head node real-time energy and its variation into consideration, each ant sets an energy predicted table which records the current residual energy of all cluster heads before the ant begins to search the path. And ants will update their tables in the transfer process. This table is used to reflect the influence to all cluster heads after an ant selects a path. Here we set current cluster heads residual energy as E_1, E_2, ..., E_n, (cluster head n is SINK), the calculation formula is as follows:

$$e\left(k,i\right)=E_i \quad i=1,2,\ldots,n-1 \tag{5}$$

$$e\left(k,n\right)=t\cdot max\left(E_i\right) \quad i=1,2,\ldots,n-1 \tag{6}$$

Herein, $e\left(k,i\right)$ is the current residual energy of node i which ant k records before searching the path. $e\left(k,n\right)$ is the current residual energy of SINK, it is n times of the current maximum residual energy, which means compared with other cluster heads, SINK is more attractive to ants.

After that, every time ant transfers from node i to node j, the energy predicted table will be updated. In the table node i is to send data, node j is to receive and fuse data, and corresponding calculation formula is used to update the table. In the transfer process, ant can judge whether to release pheromone according to its need.

3.2 Search Table

In ant colony algorithm, the goal is to find an non-repetition traversal, the next hop node selection range of ants is cluster heads that the ant has never traversed. But in LEACH-IACA, the goal is different, the next hop node selection range of ants is all cluster heads. The nodes in wireless sensor networks are usually large-scaled, if we still adopt search method of traditional ant colony algorithm, which is a measure of all nodes transition probability calculation, it would be a heavy work. This paper put forward the concept of search table, ant has a certain scope to search in any node, and the next hop node can only be selected in this range.

Fig. 1 is a schematic diagram of search table, only cluster heads in the scope surrounded by two arcs can be choose as the next hop nodes. $C1$ is the arc which takes SINK as the center and $R1$ as the radius, $R1$ is the distance between SINK and ant location. This arc ensures that the ant always approach SINK. $C2$ is the arc which takes the ant location as the center and $R2$ as

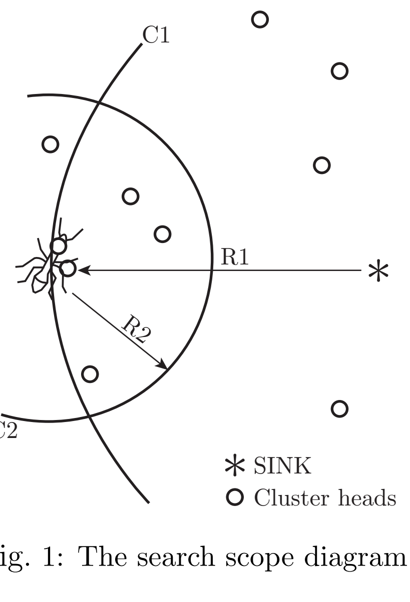


Fig. 1: The search scope diagram

the radius, this arc limits the search scope. When there is no node in the scope, ant will selects the nearest node in the direction of approaching SINK as the transfer node. Setting such a scope limiting can decrease the calculation time, and because the search direction is determined the improved algorithm can quickly converge to the optimal path.

3.3 Transition Probability

The transition probability model in ant colony algorithm only considers two factors: pheromone and distance, but the energy is also an important factor because it will change and differ from each other after many rounds of communication, so the new transition probability model takes this factor into consideration. In order to extend the lifetime, it should avoid the early death of some nodes when the general energy is in a high level. Therefore, we make low energy nodes to select energy-saving path, while the high energy nodes consume more energy to achieve the global optimum.

Therefore, the improved transition probability is as follows:

$$p^k(i,j) = \begin{cases} \frac{Tau_{ij}{}^{\alpha} \cdot Eta_{ij}{}^{\beta} \cdot E_j{}^{\gamma}}{\sum\limits_{s \in allowed_k} Tau_{is}{}^{\alpha} \cdot Eta_{is}{}^{\beta} \cdot E_s{}^{\gamma}} & if\ j \in allowed_k \\ 0 & else \end{cases} \tag{7}$$

$$\beta = \beta' \cdot \left[\sum_{t=1}^{n} e_t / (n \cdot e_i) \right]^4 \tag{8}$$

$$E_j = e_j / \sum_{t=1}^{n} e_t \tag{9}$$

Herein, $p^k(i,j)$ describes the probability of ant k move from node i to node j. $allowed_k$ is a set of the nodes which ant k can select as the next hop. α, β, γ are the inspired factors which reflect the importance of all the factors in the transfer process. Tau is the concentration of pheromone on the path node i to node j. Eta represents the visibility of node j, $Eta = 1/d$. e_i, e_j are energy of node i and node j in predicted energy table of ant k.

Improved parameter β makes e_i determines the importance of Eta in the transition probability model. When e_i is smaller, β will be bigger, and proportion of Eta in the model becomes greater; while if e_i bigger, β will be smaller, and proportion of Eta in the model becomes smaller. That's say, the lower energy nodes select a more energy saving path, while the higher energy nodes consume more energy to achieve the overall optimum. β can be selected from $(0, \infty)$. In order to avoid bug in calculation on the computer, we limit it to $(0, B)$. E_j's join to make high energy nodes bear more relay tasks.

3.4 The Pheromone Updating Rule

There are three typical models in ant colony algorithm, in this paper we use the Ant-Cycle model, the pheromone updating rule is as follow:

$$\tau_{ij}[t + (n-1)] = (1-\rho) \cdot \tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k}[t, t + (n-1)] \tag{10}$$

$$\Delta\tau_{ij}^{k}\left[t,t+(n-1)\right]=\begin{cases}1/EC\left(k\right) & if\ ant\ k\ through\ path\ \left(i,j\right)\ in\ this\ cycle\\ 0 & else\end{cases} \quad (11)$$

$$EC\left(k\right)=\sum_{i=1}^{n}e_i-\sum_{i=1}^{n}e\left(k,i\right) \quad (12)$$

Herein, ρ, $(\rho < 1)$ is pheromone evaporation coefficient, $\Delta\tau_{ij}^{k}\left[t,t+(n-1)\right]$ represents updating the pheromone on the path ant k has traveled. $\left[t,t+(n-1)\right]$ represents that ant k completes a cycle after $(n-1)$ steps. $EC\left(k\right)$ is the total energy consumed by the ant k in this cycle.

3.5 Algorithm Design

The steps to build ant's path are as follows:

Step 1 At first, each ant builds their own predicted energy table to record the current residual energy of cluster heads. Then it adds SINK in the tabu list. After that each ant selects any cluster head A randomly as the starting point and adds A in the tabu list, too.

Step 2 Within the scope of the search table, take A as a starting point, determining the next hop node B accords the transition probability of ants to, updates predicted energy table.

Step 3 Judge wether node B is in the tabu list. If not, adds B in the tabu list, and set B as the starting point of the next hope path. If yes, select any node except the node in the tabu list as the starting point of the next hope path C, and adds C in the tabu list.

Step 4 Repeat steps 2 and 3 until tabu list contains all nodes, that is ant traverses all the nodes.

Step 5 Update the pheromone.

4 Results and Discussion

In order to test the performance of this improved algorithm, we use MATLAB to establish a simulation environment. We assume that the monitoring region size is 100 m×100 m in which 100 nodes are randomly placed, base station is located at $(50, 50)$. All the nodes are immovable. The relevant parameters in LEACH protocol are set as shown in Table 1.

Table 1: Parameter values

Parameters	Values
Initial energy of nodes: E_0	$0.05\,J$
Energy consumption for sending or receiving 1 bit data: E_{elec}	$0.5\,nJ/bit$
Energy consumption for fusing 1 bit data: EDA	$0.5\,nJ/bit/signal$
Transmitter power amplifier parameters in free space channel model: ε_{fs}	$10\,pJ/\left(bit\times m^2\right)$
Transmitter power amplifier parameters in multi-path fading channel model: ε_{mp}	$0.0013\,pJ/\left(bit\times m^4\right)$
Packet length: L	$4000\,bit$

Set ant amount $m = 5$, the iterations $N = 20$. According to previous experience and result of repeated tests, we set the parameters in ant colony algorithm:$\alpha = 1$, $\beta = 5$, $\rho = 0.3$. $R1 = R2$.

The main goal of the improved routing protocol is to prolong the lifetime of WSNs. The round of the specified nodes survived during the process of routing protocol is an important parameter to measure the lifetime of WSNs. If approximate 80% of the nodes dead, it's impossible for WSNs to perform its monitoring mission. Thus, we only need to observe the round when more than 20% of the nodes are still alive.

Fig. 2 is box-plot that shows how the death time changes with g. Here, we only change the value of g, and the test is repeated 50 times. In Fig. 2, $(a)\,(b)\,(c)\,(d)$ respectively shows the death time of the first node, 20% of the nodes, 50% of the nodes and 80% of the nodes. We can see that when g takes 1 or 1.2, the four convergence time and the survival time are relatively stable and at a high level; when g is 0.5 or 0.7, $(b)\,(c)$ means the convergence time is not stable, the random probability increases and when g values greater than 1.5, all the lifetime reduces. That is, g is energy of SINK that partly decides attractiveness of SINK to ants on other nodes. When g is small, if some nodes near SINK have more energy than SINK, ants may tend to move toward the higher energy node instead of communicating with SINK directly with the minimal cost. However, such circumstance occurs randomly and only affects energy consumption of the nodes near SINK. So in (a), there is not big difference, but in $(b)\,(c)$, because of inappropriate values lead to inefficient use of energy, we can distinguish them and make judgment. If g value is big, the nodes far from SINK will communication with it. So we can see evident downward trend in Fig. 2 when g values greater than 1.5.

Fig. 3 is similar to Fig. 2. It only changes the value of γ in test. Comprehensive analysis from the round distribution of four death times, we can see when $\gamma = 4$, the algorithm performs best.

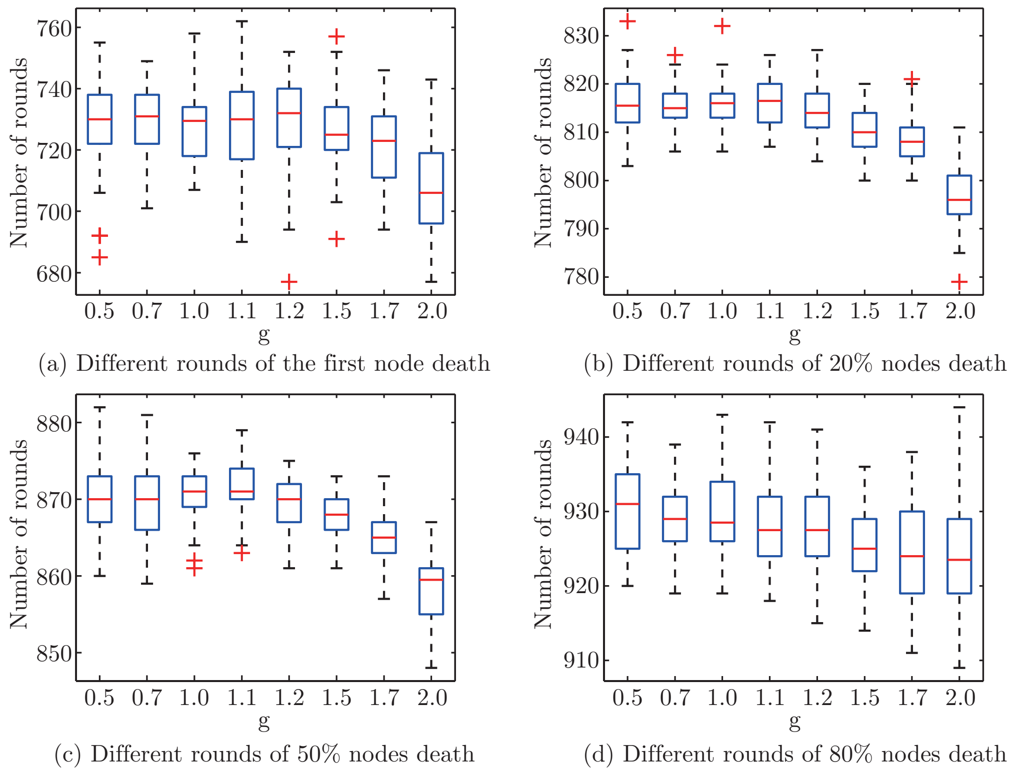
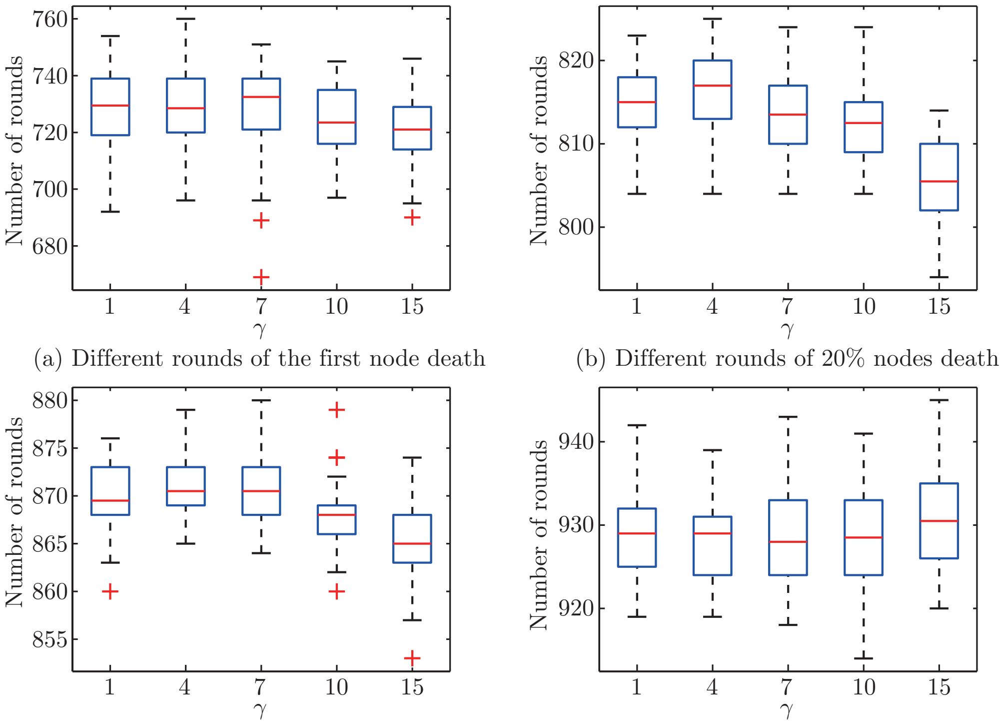


Fig. 2: Different death time with different g



(a) Different rounds of the first node death

(b) Different rounds of 20% nodes death

(c) Different rounds of 50% nodes death

(d) Different rounds of 80% nodes death

Fig. 3: Different death time with different γ

According to the result of repeated tests above, we set the parameters as: $g = 1$, $\gamma = 4$ and observe alive rounds of the nodes in the two algorithms in the simulation experiment.

Fig. 4 shows alive rounds of 100 nodes within the area of $100\,m \times 100\,m$. It can be seen using LEACH-IACA, the first node's death is postponed, and the slope of the curve is steeper with the lifetime improved by 20%. This is mainly because that the nodes far away from SINK no longer communicate directly with SINK, but select cluster heads nearby to communicate. This method saves the nodes energy and prolongs their lifetime. Therefore, the lifetime of the entire network

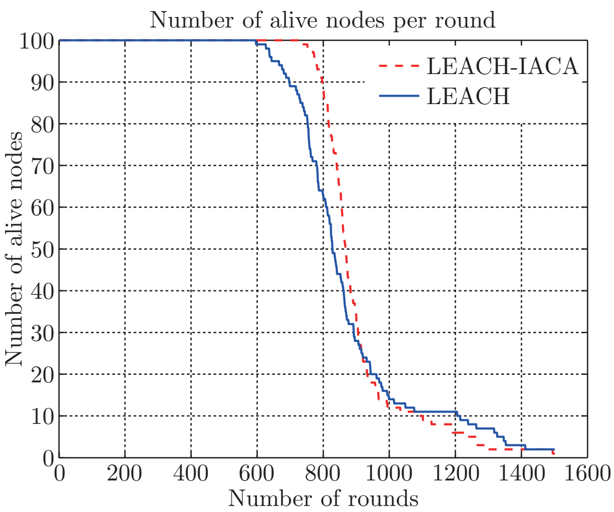


Fig. 4: 100 nodes within the area of 100 m×100 m

increases accordingly.

After that, we change the size of the monitoring region, the number of nodes to observe alive rounds of the nodes in the two algorithms.

Fig. 5, 6, 7 are alive round in different simulation environment where separately places 100, 200, 400 nodes in the monitoring area of 200 m×200 m. Repeat tests and then get the average first node death round in two algorithms, as shown in Table 2. Overall, in LEACH, with the monitoring region becoming larger, the average communication distance between sensor nodes and SINK increases, so increased the energy consumption of sensor nodes. The shortcoming of LEACH becomes more obvious. In contrast, because of the multi-hop communication method, the improved effect of LEACH-IACA is more significant.

In Fig. 5, the two curves seem to have a similar trend, but when applied in large-scale network, due to LEACH's own defects the lifetime in LEACH is greatly reduced. Compared with LEACH, the first death node appearing time by using LEACH-IACA is increased by 59.91%, obviously

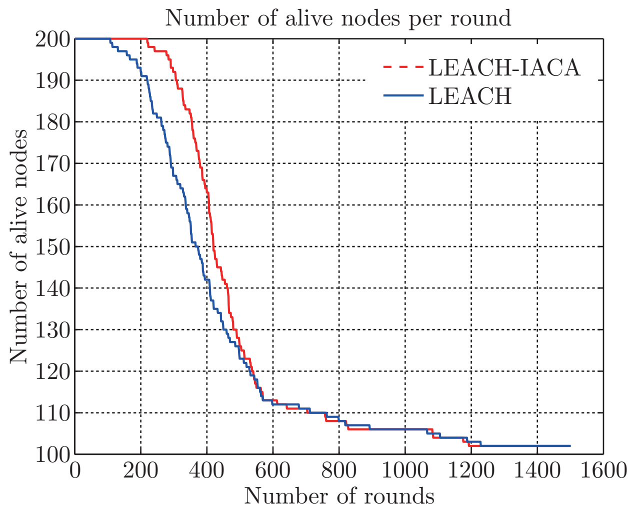


Fig. 5: 100 nodes within the area of 200 m×200 m

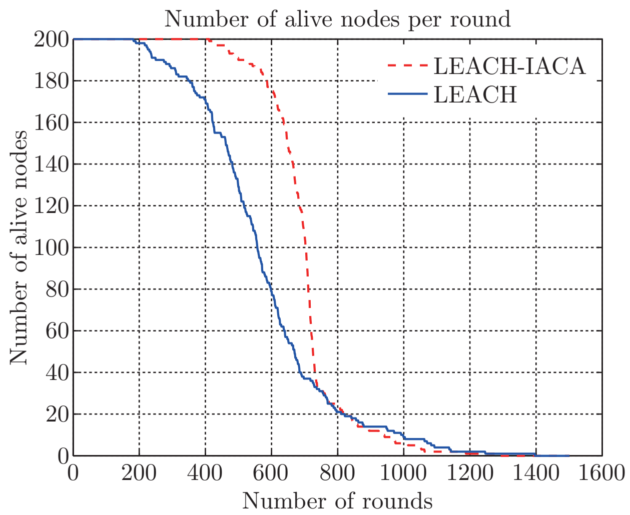


Fig. 6: 200 nodes within the area of 200 m×200 m

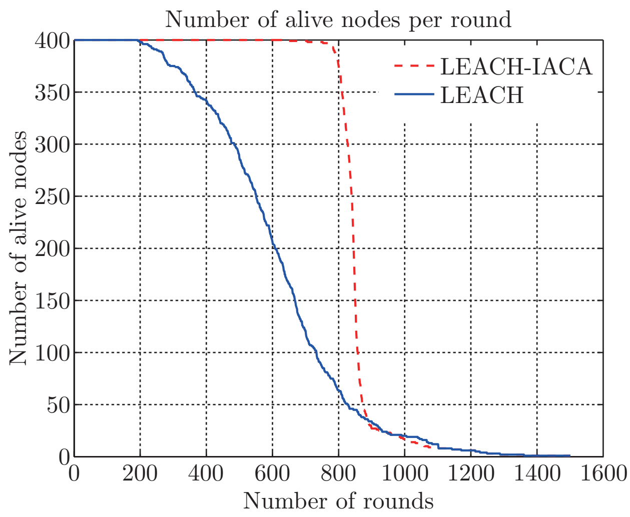


Fig. 7: 400 nodes within the area of 200 m×200 m

Table 2: Lifetime comparison of the two algorithms

The size of monitoring region	$100\,m \times 100\,m$	$200\,m \times 200\,m$	$200\,m \times 200\,m$	$200\,m \times 200\,m$
The number of nodes	100	100	200	400
LEACH	607	116	182	196
LEACH-IACA	732	185	418	644

outperforms 20.59% in Fig. 4.

In Fig. 6 and 7, because remote nodes still communicate with the SINK directly so the time when the first node dies is not changing with the increase of nodes density. But in LEACH-IACA, with the increase of cluster head density, the energy consumption of cluster heads reduced due to the shorter communication distance, so the overall performance improves greatly. While the number of nodes increases to 400 (Fig. 7), curve slope of LEACH-IACA is closer to the vertical (the time from the first node death to 80% nodes death is short), it can be seen that use of nodes energy has reached an ideal state.

5 Conclusion

Having learned ant colony algorithm and LEACH protocol, we proposed an improved algorithm that applied ant colony algorithm to LEACH protocol. Improved LEACH-IACA protocol considers the energy and location of cluster heads from the overall prospective in real-time, so the changeable energy can make the ants transfer direction accurately. Simulation results show that compared with LEACH, LEACH-IACA increases the network lifetime dramatically and the first node death time is significantly delayed. And the improvement is more obvious when applied in large-scale wireless sensor networks. Our next study will be focused on the relationship between the node distribution and lifetime of network.

Acknowledgement

This work was supported by the National Natural Science Foundation of China (Grant No. 20086136), the Special Youth Science Foundation of Jiangxi (Grant No. 20133ACB21007), the Natural Science Foundation of Jiangxi (Grant No. 20132BAB201018)and Scientific Research Fund of Jiangxi Provincial Education Department (Grant No. GJJ13060).

References

[1] Meritxell Vinyals, Juan A. Rodriguez-Aguilar, Jesus Cerquides, A survey on sensor networks from a multiagent perspective, The Computer Journal, 54(3), 2011, 455-470

[2] Guifeng Wang, Yong Wang, Xiaoling Tao, An ant colony clustering routing algorithm for wireless sensor networks, Genetic and Evolutionary Computing, 2009

[3] Yu Hu, Jing Wang, Analysis of LEACH protocol based on ant algorithm, Chinese Journal of Sensors and Actuators, 24(5), 2011

[4] Wendi Rabiner Heinzelman, Anantha P. Chandrakasan, Hari Balakrishnan, Energy-efficient communication protocol for wireless microsensor networks, Proceedings of the Hawaii International Conference on System Sciences, 2000

[5] Haicun Hang, Aihuang Guo, Wenjie Shu, Performance analysis of WSN routing scheme based on LEACH and ant algorithm, Chinese Journal of Sensors and Actuators, 21(10), 2008

[6] Marco Dorigo, Luca Maria Gambardella, Ant colony system: A cooperative learning approach to the traveling salesman problem, IEEE Transactions on Evolutionary Computation, 1(1), 1997

[7] Shiyong Li, Yongqiang Chen, Yan Li, Ant Colony Algorithm and Its Application, Harbin Industrial University Publishing House, 2004, 22-52

[8] Tiago Camilo, Carlos Carreto, Jorge Sá Silva, Fernando Boavida, An energy-efficient ant-based routing algorithm for wireless sensor networks, Ant Colony Optimization and Swarm Intelligence, 4150, 2006, 49-59

[9] Minghua Liao, Hua Zhang, Jiaquan Xie, Energy forecast routing protocol in wireless sensor network based on ant colony algorithm, Computer Engineering, 38(3), 2012

[10] Reza Ghasem Aghaeil, Md. Abdur Rahman, Wail Gueaieb, Abdulmotaleb El Saddik, Ant colony-based reinforcement learning algorithm for routing in wireless sensor networks, IMTC2007, Warsaw, Poland, May 1-3, 2007