

## Multi-path routing algorithm in WSN using an improved particle swarm optimization

LI Hui-ling, DU Yong-wen, XU Ning

(School of Electronic and Information Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China)

**Abstract:** To solve the problems of constrained energy and unbalanced load of wireless sensor network (WSN) nodes, a multipath load balancing routing algorithm based on neighborhood subspace cooperation is proposed. The algorithm adopts the improved particle swarm optimization (PSO) algorithm, takes the shortest distance and minimum energy consumption as optimization target and divides the nodes in one-hop neighborhood near the base station area into different regions. Furthermore, the algorithm designs a fitness function to find the best node in each region as a relay node and forward the data in parallel through the different paths of the relay nodes. The simulation results show that the proposed algorithm can reduce energy consumption and average end-to-end delay, balance network load and prolong network lifetime effectively.

**Key words:** wireless sensor network (WSN); improved particle swarm optimization (PSO); regional division; multipath; load-balancing

**CLD number:** TP393

**Document code:** A

**Article ID:** 1674-8042(2019)04-0361-08

**doi:** 10.3969/j.issn.1674-8042.2019.04.008

### 0 Introduction

A wireless sensor network (WSN)<sup>[1]</sup> is a self-organizing wireless network system composed of multiple sensor nodes. The sensor node is the key component of WSN. The node energy is limited. Once the energy is exhausted, it is difficult to replenish it in time. Therefore, when designing the WSN routing protocol or deploying the network, the node energy consumption problem needs to be considered. In order to improve the energy efficiency of the whole network and make the load of the whole network balanced, some researchers have proposed the corresponding algorithms. The ant colony optimization multipath routing algorithm (ACOMP) proposed by Hou et al. uses an improved ant colony algorithm to find multiple paths<sup>[2]</sup>, and then a multipath decision model is established considering each energy state, thus the source node can select the path with the best performance at present. This algorithm has better balance and reliability, but it has slow convergence and is easy to fall into local optimum. A depth and children collection tree protocol (DC-CTP) based on path optimization was proposed by Wang et

al. for load imbalance<sup>[3]</sup>. The protocol determines the optimal path selection by optimizing the number of child nodes and path depth, but this algorithm has a large packet loss rate and poor reliability. The algorithm in Ref. [4] considers the residual energy of the node, and the inter-cluster communication uses the shortest path multi-hop routing to balance the network energy consumption, but the single-path transmission network has a large delay. The energy-efficient load-balancing multipath routing scheme (ELMR)<sup>[5]</sup>, taking into account the hop number, node residual energy and network energy status, is a new multipath routing algorithm for efficient energy load balancing, which makes the data pass through the path with the least hop number or the higher path key energy ratio, but it does not consider the distance and directivity between nodes. The energy balanced multipath routing protocol based on ant colony system (ACSBMR) in Ref. [6] considers the characteristics of the ant colony system to form multipath data transmission, so that the energy is balanced while the average end-to-end delay is reduced. But it only considers energy and time delay and the distance factor is not taken into

**Received date:** 2019-06-03

**Foundation items:** National Natural Science Foundation of China (No. 11461038); Science and Technology Plan of Gansu Province (No. 144NKCA040)

**Corresponding author:** LI Hui-ling (linglh0707@qq.com)

consideration, therefore the path routing is longer and the reliability is poor.

In order to comprehensively consider various factors, a new routing algorithm—multipath load balancing routing algorithm based on neighborhood subspace cooperation is proposed. The algorithm divides the area of the one-hop neighborhood near the base station into three parts. Taking the node energy consumption and the distance between nodes as two optimization targets, a fitness function is designed, and the improved particle swarm optimization (PSO) algorithm is used to find the optimal node in each region. The algorithm can balance network load and reduce end-to-end delay by data forwarding through the multiple paths at which the optimal node is located.

## 1 Network model and energy model

### 1.1 Network model

The perceptual nodes in WSNs typically use the unit circle communication model, as shown in Fig. 1. Within the maximum communication range of the node, the node communicates directly with other nodes in the wireless transmission mode. Taking a node as the center, a circular region formed by the node's maximum communication distance is called its one-hop neighborhood space, and the node in the circular region is called the node's one-hop neighbor node or direct neighbor node.

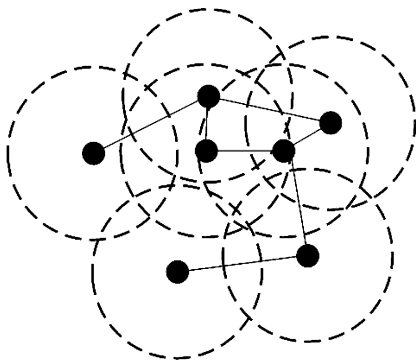


Fig. 1 Unit circle communication model

In proposed routing scheme, the following network assumptions are given:

1) The sensor nodes and base station are stationary after network deployment, which is typical for sensor network applications, and each node knows its location and the location of base station;

2) Initial energy is the same for all the sensor nodes, and the network is considered to be

homogeneous;

3) All the nodes are impossible to recharge the battery;

4) All the sensor nodes have its own unique ID number;

5) The radius of the maximum communication range of the node is  $R$ , and the communication model adopts the unit circle model in Fig. 1;

6) All the sensor nodes have the same ability to perceive environmental parameters or send data to the base station;

7) All the sensor nodes have the same transmission power and can adjust the transmission power according to the distance.

### 1.2 Energy model

Most of the energy of nodes in WSN is consumed in the communication process, and here the wireless communication model presented in Ref. [7] is adopted. This first-order radio energy dissipation model uses both free space model and multipath fading channel model. The selection of free space and multipath fading models depends upon the threshold distance  $d_0$ . The required energy to transmit  $k$  bytes message over the distance  $d$  from the transmitter to the receiver can be calculated by

$$E_{TX} = \begin{cases} k(E_{elec} + d^2 E_{fs}), & d \leq d_0, \\ k(E_{elec} + d^4 E_{mp}), & d > d_0, \end{cases} \quad (1)$$

and the energy consumed to receive this message can be calculated by

$$E_{RX} = kE_{elec}, \quad (2)$$

where  $E_{TX}$  is the transmission energy;  $E_{RX}$  is the consumed energy for reception of the message;  $d$  is the distance between two nodes or between a node and the sink;  $E_{elec}$  indicates the electronics energy required to run the electronics circuit and it is related to encoding, modulation and filtering techniques;  $E_{fs}$  and  $E_{mp}$  depend on the transmission amplifier model;  $k$  is the length of the data transmitted; and  $d_0$  is the threshold of transmission distance given by

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}}. \quad (3)$$

We mainly consider the distance between the nodes and energy consumption, transforms the minimum energy consumption and the shortest distance into multi-objective optimization problems, and solves them by improved PSO algorithm. The shortest distance is the sum of the distances between the

sensing node  $i$  and the node  $j$  in its one-hop neighborhood to the base station. Let the coordinates of the base station  $S$  be  $(x_s, y_s)$ , the coordinates of the sensor node  $i$  be  $(x_i, y_i)$ , and the coordinates of the neighboring one-hop node  $j$  of the node  $i$  be  $(x_j, y_j)$ , the distance from the node  $i$  to the base station  $S$  is  $d_1 = \sqrt{(x_s - x_i)^2 + (y_s - y_i)^2}$ , and the distance from the node  $i$  to the node  $j$  is  $d_2 = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}$ . Set the total number of the nodes in the network is  $M$ , the network energy efficiency optimization model is established as

$$E_{\text{sum}}(k, d) = \sum_{i=1}^M E_{\text{con}}(k, d) = \sum_{i=1}^M [E_{\text{TX}}(k, d) + E_{\text{RX}}(k, d)], \quad (4)$$

where  $E_{\text{sum}}(k, d)$  is the total energy consumption and  $E_{\text{con}}(k, d)$  is the energy consumption of a single node.

## 2 Improved PSO algorithm

The idea of PSO algorithm derives from the study of bird flocking social behavior. Due to the simple concept and efficient operation, the PSO algorithm has been widely used in many fields. However, it has defects in local search and premature convergence. For this reason, an improved PSO algorithm based on orthogonal learning (OLPSO)<sup>[8]</sup> is proposed to search for the optimal solution by adjusting the inertia weight to avoid this defect, which consists of the following four main steps:

1) Initialize parameters. In the  $q$ -dimensional (dimension of each particle) space, a group of  $n$  particles is searched. The position of the  $i$ th particle at the  $t$ th iteration is expressed as  $x_i^t = (x_{i1}^t, x_{i2}^t, \dots, x_{iq}^t)$ . The velocity of particle  $i$  is defined as the distance that the particle moves in each iteration, and the velocity corresponding to each particle can be expressed as  $v_i^t = (v_{i1}^t, v_{i2}^t, \dots, v_{iq}^t)$ ,  $i = (1, 2, \dots, n)$ .

2) Calculate fitness function value. The fitness value is a criterion to judge the particle quality. A new fitness function is proposed according to the energy efficiency optimization model to calculate the fitness value of the particle, and the individual optimal value  $p_1$  and the global optimal value  $p_G$  of each particle are recorded. According to the energy efficiency optimization model, the fitness function is presented as

$$F = \delta \frac{E_{\text{ini}} - E_{\text{con}}(k, d)}{E_{\text{ini}}} + \epsilon \frac{d_2}{d_1 + d_2}, \quad (5)$$

where  $E_{\text{ini}}$  is the initial energy of node  $i$ ;  $\delta, \epsilon \in (0, 1)$ ,  $\delta + \epsilon = 1$ .

3) Change inertia weight. Compared with the standard PSO algorithm, the OLPSO algorithm has better optimization effect and improved searching ability. In this paper, the improved PSO algorithm is used to adjust the inertia weight with reference to the linear decreasing strategy of typical inertia weight<sup>[9]</sup>. The inertia weight adjustment formula is presented as

$$\omega = \omega_{\text{end}} + \frac{(\omega_{\text{int}} - \omega_{\text{end}})(k_{\text{max}} - k)}{k_{\text{max}}}, \quad (6)$$

where  $\omega_{\text{int}}$  is the initial inertia weight value,  $\omega_{\text{end}}$  is the inertia weight value when evolution reaches the maximum algebra,  $k$  is the current number of iterations, and  $k_{\text{max}}$  is the maximum number of iterations. Here the values of  $\omega_{\text{int}}$  and  $\omega_{\text{end}}$  take the typical values of 0.9 and 0.4<sup>[8]</sup>.

4) Update particle speed and position. The position and speed at the  $(t+1)$ th iteration are updated by Eqs. (7) and (8). The  $\omega$  in the update formula is adjusted by Eq. (6), there is

$$v_i^{t+1} = \omega v_i^t + c_1 r_1 (p_1^t - x_i^t) + c_2 r_2 (p_G^t - x_i^t), \quad (7)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1}. \quad (8)$$

The  $\omega$  in the formula is the inertia weight, which represents the influence of the speed of the previous moment on the current speed. The larger value indicates that the global search ability is stronger, and the smaller value indicates that the local search ability is stronger.  $c_1$  and  $c_2$  are acceleration factors, generally taking a value of 2, whose effect is to make the particles move quickly to their historical optimal position and global optimal position, in the range of two uniformly distributed random numbers ranging from (0,1).

## 3 Multipath load balancing routing algorithm based on neighborhood subspace cooperation algorithm

The algorithm is divided into three phases. In the first phase, the nodes in the range of the one-hop neighborhood of the node near the base station are divided to determine the area at which each neighbor node is located. In the second phase, the selection of the relay node is carried out, and the improved PSO algorithm is used to find the nodes with the smallest values of the adaptive function in the three regions as the relay nodes on the three optional forwarding paths. In the third phase, load weight ratio is

calculated. The network load is allocated in different paths according to the load weight ratio, and the data are forwarded in parallel through different paths.

### 3.1 Division of neighborhood subspace

The number of multipath routing paths has a certain impact on the performance of the algorithm. Multipath routing has a certain impact on the performance of the algorithm. If the number of the paths selected is too many, the cost of routine maintenance will increase. If the number is too small, the purpose of parallel transmission cannot be achieved. The traditional multipath routing algorithm is to find multiple paths from the whole region. If the multiple paths have long links, delay packet loss rate will increase. Moreover, the longer the links, the higher the packet loss rate, thus the reliability is poor. Here, the nodes are evenly distributed in the region, and the node one-hop neighborhood space is mainly divided into two parts: near the base station and away from the base station. In order to speed up the convergence rate to the base station, we will abandon half the region away from the base station and only divide half the base station remained. In Ref. [10], an ant colony-optimized load-balancing routing algorithm was used to determine the optimal path for the routing discovery process to be three. According to the verification analysis of the existing literature, the number of optimal paths is also obtained to be three. Thus we divide half the base station into three areas. The improved PSO algorithm is used to find the optimal nodes for the three regions as relay nodes on three paths. After the three paths are determined, load balancing is achieved by multipath parallel data transmission.

According to the unit circle communication model, the location  $(x_s, y_s)$  of the base station  $S$  and the location  $(x_i, y_i)$  of sensor node  $i$  are taken as the centers, respectively, drawing the corresponding circles  $O_s$  and  $O_i$ , with the radius of  $R$  being equal to the node maximum communication range.

The division of neighborhood space of the node takes the following steps:

1) Firstly, draw a line  $Si$  connecting the centers of circles  $O_s$  and  $O_i$ ; secondly, draw two tangent lines of circle  $O_i$ , starting from the center of the base station  $S$ ; finally, draw a line passing the center of circle  $O_i$ , perpendicular to the line  $Si$ , and intersecting the two tangent lines of  $O_i$  at point  $A$  whose coordinates are

$(x_a, y_a)$  and point  $B$  whose coordinates are  $(x_b, y_b)$ .

2) Similarly, draw two tangent lines of circle  $O_s$  first, starting from the center of node  $i$ , with the points of tangency of  $C$  whose coordinates are  $(x_c, y_c)$  and  $D$  whose coordinates are  $(x_d, y_d)$ , respectively; and then connecting the center  $O_s$  with points  $C$  and  $D$ , forming two lines  $CO_s$  and  $DO_s$ , respectively.

3) Finally, the neighborhood space of the node is divided into four parts:  $\angle CO_iD$ , forward area  $M_1$ ;  $\angle AO_iC$ , left area  $M_2$ ;  $\angle BO_iD$ , right area  $M_3$ ;  $\angle AO_iB$ , area  $M_4$  far from the base station (discarded), as shown in Fig. 2.

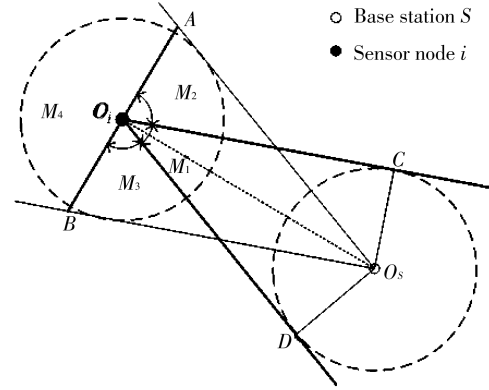


Fig. 2 Division of node area

As assumed in section 1.2 that the coordinates of the neighborhood one-hop node  $j$  of the node  $i$  are  $(x_j, y_j)$ . The distance from node  $j$  to point  $A$  is  $d_3 = \sqrt{(x_j - x_a)^2 + (y_j - y_a)^2}$ . The distance from node  $j$  to point  $B$  is  $d_4 = \sqrt{(x_j - x_b)^2 + (y_j - y_b)^2}$ . The distance from node  $j$  to base station  $S$  is  $d_5 = \sqrt{(x_j - x_s)^2 + (y_j - y_s)^2}$ . Let the angles of three areas  $M_1$ ,  $M_2$  and  $M_3$  be  $\theta_1$ ,  $\theta_2$  and  $\theta_3$ , respectively, the angles of the three areas can be obtained as follows:  $\theta_1 = 2\arcsin \frac{R}{d_1}$ ,  $\theta_2 = \theta_3 = \frac{\pi}{2} - \arcsin \frac{R}{d_1}$ . The area of node  $j$  is determined by angle  $\theta$  between nodes  $j$  and  $i$  and base station  $S$ . By calculating, it can be obtained as

$$\theta = \arccos \frac{d_1^2 + d_2^2 - d_5^2}{2d_1d_2}. \quad (9)$$

Then

$$\begin{cases} j \in M_1, & \theta = \left(0, \left|\arcsin \frac{R}{d_1}\right|\right], \\ j \in M_2, & d_3 \leq d_4 \text{ and } \theta \in \left(-\arcsin \frac{R}{d_1}, -\frac{\pi}{2}\right], \\ j \in M_3, & d_3 > d_4 \text{ and } \theta \in \left(\arcsin \frac{R}{d_1}, \frac{\pi}{2}\right]. \end{cases} \quad (10)$$

### 3.2 Selection of relay node

The one-hop neighborhood space of node  $i$  is divided into different areas by the above method, and the improved PSO algorithm is used to find the optimal node in each area, which is called relay node. The flow chart of relay node selection is shown in Fig.3. Considering the energy consumption and location of the node when selecting the relay node, the communication energy consumption and the distance to the base station are used as constraints. The less the communication energy consumption, the smaller the distance to the base station and the more likely it becomes the relay node.

According to the fitness function the optimal position  $p_1$  of node  $i$  and the optimal positions  $p_{G_i}$  ( $i=1, 2, 3$ ) of three regional nodes are updated, respectively. When it is the maximum number of iterations, these three optimal regional solutions  $p_{G1}$ ,  $p_{G2}$  and  $p_{G3}$  are sequenced from small to large to be the best, better and good next-hop nodes of node  $i$ . If the number of nodes in the divided area is zero, node  $i$  sends a routing error message to the upper node and reselects the optimal next-hop node. The flow chart of selection of relay nodes is shown in Fig. 3.

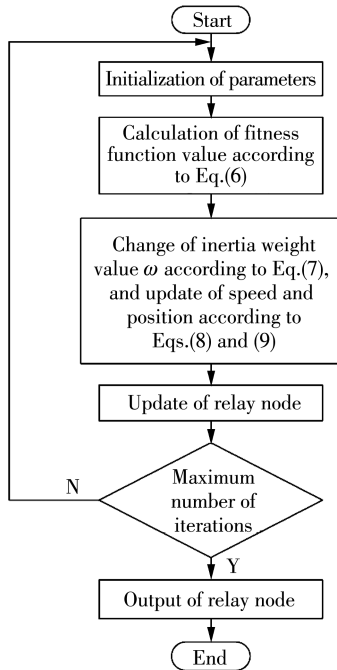


Fig. 3 Flow chart of selection of relay nodes

### 3.3 Load distribution among multiple paths

The multipath routing protocol is an important method to realize load balancing by finding multiple

disjoint paths between source and destination nodes. Firstly, the region is divided. Then the optimal solution of each subregion can be selected by means of cooperation of subdomains to determine optimized paths. Finally, load distribution can be accomplished among the optimized paths and the data can be forwarded through multiple paths concurrently. According to the coordinates of the related nodes in sections 1.2 and 3.1, the distance between the nodes can be calculated by using the method of Euclidean distance, thus the delay on each path can be calculated by

$$T_{\text{delay}} = \frac{d}{\frac{2}{3}C}, \quad (11)$$

where  $C$  is the speed of light. The load on a single path is calculated by

$$L_{\text{load}} = \frac{T_{\text{delay}}}{N_{\text{hop}}} = \frac{3d}{2CN_{\text{hop}}}. \quad (12)$$

According to the path load formula, the loads  $L_{\text{load1}}$ ,  $L_{\text{load2}}$  and  $L_{\text{load3}}$  on the three paths and the least common multiple  $N_{\text{LCM}}$  of the three values are calculated. The load weight ratio on three paths can be calculated as  $\alpha : \beta : \gamma = \frac{N_{\text{LCM}}}{L_{\text{load1}}} : \frac{N_{\text{LCM}}}{L_{\text{load2}}} : \frac{N_{\text{LCM}}}{L_{\text{load3}}}$ , and then the load is allocated according to the load weight ratio. The total network load is  $L_{\text{loads}}$ , the loads allocated to paths are  $\frac{\alpha}{\alpha+\beta+\gamma}L_{\text{loads}}$ ,  $\frac{\beta}{\alpha+\beta+\gamma}L_{\text{loads}}$  and  $\frac{\gamma}{\alpha+\beta+\gamma}L_{\text{loads}}$ , respectively.

Each node has its own routing table. When the state of routing table is empty, it indicates that the node does not have a path to the base station; otherwise there is a path to the base station. In the multipath load balancing routing process, the node actively constructs multiple paths to the base station. The specific steps are as follows:

- 1) Node  $i$  judges the state of its own routing table.
- 2) When the routing table is not empty, it is judged whether it is a one-hop neighbor node of node  $i$ . If not, a routing request message (RREQ) is sent to the source node, and then the ID of the neighbor node of node  $i$  can be obtained by "Hello" message; otherwise the routing table is updated.
- 3) If the number of the nodes in the area close to the base station is not zero, the area of the neighboring node close to the base station is divided according to the method in section 3.1; otherwise, a routine error message is sent to the upper node, and

the selection of the next one-hop node is performed again;

4) The relay node is selected according to the method described in section 3.2;

5) According to the above method, multiple paths from the source node to the destination node are found, and parallel transmission of data is performed through multiple paths. If there is only one path determined, the packet is forwarded along the only one.

The path selection using the proposed routing algorithm for load balancing is shown in Fig. 4.

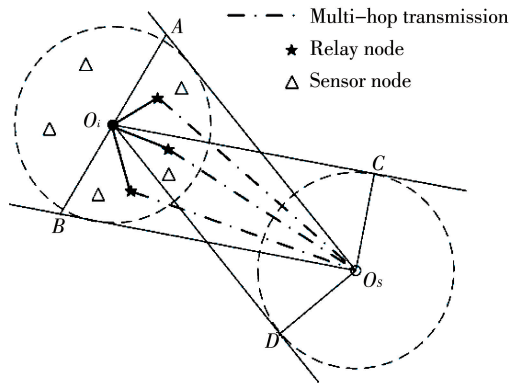


Fig. 4 Schematic diagram of routing algorithm for load balancing routing

## 4 Simulation

In order to evaluate the performance of the proposed routing algorithm, a simulation environment is built using Matlab R2014b simulation tool. Under the same conditions, the proposed routing algorithm, ACOMP<sup>[2]</sup>, ELMR<sup>[5]</sup> and the cluster-based multipath routing protocol (CMRP)<sup>[11]</sup> are compared and analyzed from the aspects of network lifecycle and network load balancing. In addition, because the proposed algorithm does not consider delay, it is compared with ACSBMR algorithm<sup>[6]</sup> and the efficient congestion traffic allocation (ECOTA) algorithm<sup>[12]</sup> about average end-to-end delay to verify the performance of the proposed routing algorithm.

### 4.1 Parameter settings

There are 100 nodes being evenly distributed in the square area of  $100\text{ m} \times 100\text{ m}$ , the base station is located at the center of the area, the energy is infinite, and the communication radius of all the nodes is 20 m. The sensor node acquisition packet size is 512 byte. The simulation parameters are listed

in Table 1.

Table 1 Simulation parameters

Parameter name	Parameter value
Number of particles	$N=100$
The maximum number of iterations	$k_{\max}=30$
Acceleration factor	$c_1=c_2=2$
Initial inertia weight	$\omega_{\text{ini}}=0.9$
Ultimate inertia weight	$\omega_{\text{end}}=0.4$
Initial energy of the node	$E_{\text{ini}}=20\text{ J}$
Base station node coordinates	$(50,50)$
Number of nodes	$M=100$
$E_{\text{elec}}$	$50\text{ nJ/bit}$
$E_{\text{fs}}$	$10\text{ pJ}/(\text{bit} \times \text{m}^2)$
$E_{\text{mp}}$	$0.0013\text{ pJ}/(\text{bit} \times \text{m}^4)$
$d_0$	$75\text{ m}$

The fitness function formula contains two parameters,  $\delta$  and  $\epsilon$ , which are the weights of different factors. In order to verify the impact of different factors on network life cycle, in the same network environment, different values of  $\delta$  and  $\epsilon$  are simulated. where  $\delta, \epsilon \in (0,1)$  and  $\delta + \epsilon = 1$ .  $\delta$  takes the value of  $0.1-0.9$  and  $\epsilon$  takes the corresponding value for simulation experiment. When  $\delta$  takes a value of  $0.2$  and  $\epsilon$  takes a value of  $0.8$ , the first dead node in the network appears later.

## 4.2 Results and analysis

### 4.2.1 Life cycle of network

An important factor to measure WSN load balancing is the life cycle of network. According to the relevant literature, we take the time span from the start of the network to the death of the first node as the life cycle of network<sup>[13]</sup>. The network life cycles can be obtained based on the death times of the first nodes of four algorithms. The number of surviving nodes of four algorithms varies with time, as shown in Fig. 5.

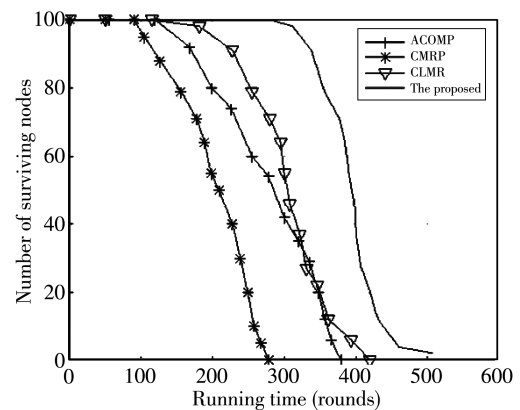


Fig. 5 Curves of the number of surviving nodes varying with time



It can be seen from Fig. 5 that the life cycles of ACOMP algorithm, CMRP algorithm, ELMR algorithm and the proposed algorithm are 168, 105 and 182 and 312 rounds, respectively. The number of rounds of the first dead node of the proposed algorithm is significantly larger than those of ACOMP algorithm, CMRP algorithm and ELMR algorithm, that is, the life cycle of proposed algorithm is longer than those of the former three algorithms.

#### 4.2.2 Load balancing of network

In this algorithm, the residual energy variance of nodes is used to evaluate the load balancing of network. The formula of residual energy variance of nodes is  $E_{\text{variance}} = \frac{1}{M} \sum_{N_{\text{alive}}} (E_{\text{rem}} - E_{\text{avr}})^2$ , where  $M$  is the total number of nodes,  $N_{\text{alive}}$  is the number of surviving nodes in the network,  $E_{\text{rem}}$  is the residual energy of neighbor node  $j$  and  $E_{\text{avr}}$  is the average residual energy of all surviving nodes. The smaller the residual energy variance, the better the load balancing of network. The residual energy variance values of four algorithms at different running times (rounds) are compared, as shown in Fig. 6.

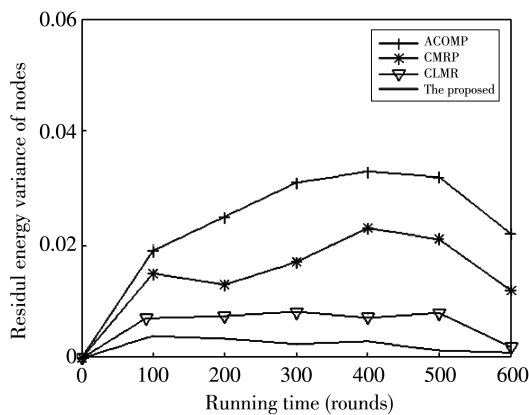


Fig. 6 Comparison of residual energy variance of nodes

It can be seen from Fig. 6 that the residual energy variances of four algorithms vary with the number of rounds. The residual energy variance of the proposed algorithm keeps basically unchanged in the same simulation time and is smaller than those of ACOMP, CMRP and ELMR algorithms. The variance of the residual energy of the proposed algorithm varies slowly, that is, the load balancing of the proposed algorithm is good.

#### 4.2.3 Average end-to-end delay

The average end-to-end delay is the average time difference between sending packets from the source node to the destination node. The comparison of the

average end-to-end delays among the proposed algorithm, ECOTA algorithm and ACSBMR algorithm is shown in Fig. 7.

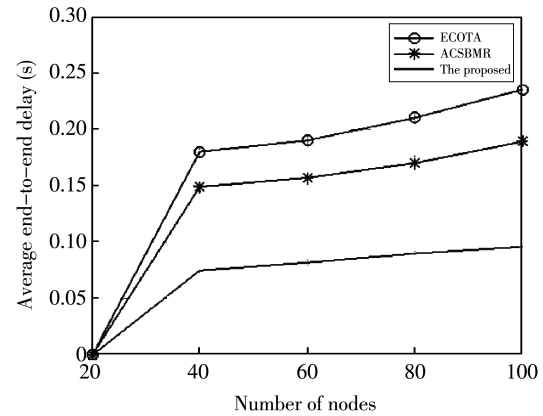


Fig. 7 Comparison of average end-to-end delays

It can be seen from Fig. 7 that with the increase of time, the average end-to-end delays of ECOTA, ACSBMR and the proposed algorithms increase gradually, the average end-to-end delay of ECOTA algorithm is the largest, and the average end-to-end delay of the proposed algorithms is less than those of ECOTA and ACSBMR algorithm as a whole. The probability of growth is reduced, therefore its delay growth rate is smaller than those of the other two algorithms.

## 5 Conclusion

Based on the orthogonal learning PSO algorithm with better optimization effect and linear decreasing strategy to adjust the inertia weight, the paper presents a fitness function considering many factors as well as a new routing algorithm. The improved PSO algorithm can find the optimal nodes in different regions as the relay nodes, and then uses the multiple paths of the relay nodes for multi-path data forwarding. Compared with the existing routing algorithms, this algorithm considers many factors affecting load balancing and thus effectively prolongs network life cycle. When the amount of data needed to be sent in the network is large, sending data through multiple paths makes each node in the network bear some load, avoiding the overload of key nodes and balancing the network load. Thus transmitting data through multiple paths reduces the possibility of network congestion and average end-to-end delay.

## References

- [1] Zaman N, Low T J, Alghamdi T. Energy efficient routing

- protocol for wireless sensor network. In: Proceedings of International Conference on Advanced Communication Technology, IEEE, 2014: 808-814.
- [2] Hou M T, Zhao Z P, Gao M, et al. Ant colony optimization multipath routing algorithm adopted angle factor. Computer Engineering and Applications, 2017, 53(1): 107-112.
- [3] Wang Z Y, Chen H J, Li Y Q. CTP routing algorithm for wireless sensor networks based on path optimization. Transducer & Microsystem Technologies, 2016, 35(12): 122-124.
- [4] Zhang S W, Zhang H T, Zhang S J. Multi-hop routing algorithm for wireless sensor networks based on fixed cluster and energy-balance. Transducer & Microsystem Technologies, 2013, 32(8): 117-104.
- [5] Fan Z P, Xie D Q, Jin Z Z. Multipath routing strategy for energy payload balancing in wireless sensor networks. Journal of Chinese Computer Systems, 2013, 34(2): 253-257.
- [6] Xiao C, Sun Z W. Ant colony system based energy-balanced multi-path routing protocol for wireless sensor networks. Computer Engineering and Design, 2015, 36(7): 1695-1700.
- [7] Zhou Y, Wang N, Xiang W. Clustering hierarchy protocol in wireless sensor networks using an improved PSO algorithm. IEEE Access, 2017, PP(99): 1-1.
- [8] Zhan Z H, Zhang J, Li Y, et al. Orthogonal learning particle swarm optimization. IEEE Transactions on Evolutionary Computation, 2011, 15(6): 832-847.
- [9] Gao Z H, Mei L, Zhu Y J. Particle swarm optimization algorithm with composite strategy inertia weight. Journal of Computer Applications, 2012, 32(8): 2216-2218.
- [10] Bi J, Li Z, Wang R. An ant colony optimization-based load balancing routing algorithm for wireless multimedia sensor networks. In: Proceedings of IEEE International Conference on Communication Technology, 2010: 584-587.
- [11] Li X W. Research on wireless sensor network multi-path routing protocol based on cluster structure. Computer Simulation, 2018, (3): 205-209.
- [12] Wen H Y, Huo W D. A cross-layer congestion control algorithm based on traffic reallocation in wireless sensor network. International Journal of Computer and Communication Engineering, 2017, 6(2): 104-110.
- [13] Al-Turjman F M, Hassanein H S, Ibnkahla M A. Efficient deployment of wireless sensor networks targeting environment monitoring applications. Computer Communications, 2013, 36(2): 135-148.

## 基于改进粒子群的 WSN 多路径路由算法

李慧玲, 杜永文, 徐 宁

(兰州交通大学 电子与信息工程学院, 甘肃 兰州 730070)

**摘 要:** 为解决无线传感器网络(Wireless sensor network, WSN)节点能量受限、负载不均衡的问题, 提出了一种邻域子空间合作的多路径负载均衡路由算法。算法将节点一跳邻域靠近基站区域内的节点划分在不同区域中, 采用改进的粒子群优化算法, 以最短距离和最小能耗为优化目标, 设计了一个适应度函数来寻找每个区域中的最优节点作为中继节点, 通过中继节点所在的不同路径并行转发数据。仿真结果表明, 该算法相较于其他负载均衡算法可以更好地降低节点能耗及平均端到端时延, 从而使网络负载均衡, 有效延长了网络生命周期。

**关键词:** 无线传感器网络; 改进粒子群算法; 区域划分; 多路径; 负载均衡

**引用格式:** LI Hui-ling, DU Yong-wen, XU Ning. Multi-path routing algorithm in WSN using an improved particle swarm optimization. Journal of Measurement Science and Instrumentation, 2019, 10(4): 361-368. [doi: 10.3969/j.issn.1674-8042.2019.04.008]