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Prolong life-span of WSN using clustering method via swarm intelligence and dynamical threshold control scheme

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Abstract

Wireless sensors are always deployed in brutal environments, but as we know, the nodes are powered only by non-replaceable batteries with limited energy. Sending, receiving and transporting information require the supply of energy. The essential problem of wireless sensor network (WSN) is to save energy consumption and prolong network lifetime. This paper presents a new communication protocol for WSN called Dynamical Threshold Control Algorithm with three-parameter Particle Swarm Optimization and Ant Colony Optimization based on residual energy (DPA). We first use the state of WSN to partition the region adaptively. Moreover, a three-parameter of particle swarm optimization (PSO) algorithm is proposed and a new fitness function is obtained. The optimal path among the CHs and Base Station (BS) is obtained by the ant colony optimization (ACO) algorithm based on residual energy. Dynamical threshold control algorithm (DTCA) is introduced when we re-select the CHs. Compared to the results obtained by using APSO, ANT and I-LEACH protocols, our DPA protocol tremendously prolongs the lifecycle of network. We observe 48.3%, 43.0%, and 24.9% more percentages of rounds respectively performed by DPA over APSO, ANT and I-LEACH.

Keywords: Wireless sensor network, Particle swarm optimization, Ant colony optimization, Dynamical threshold, Swarm intelligence.

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1. Introduction

Wireless Sensor Network (WSN) is composed of a large number of micro sensor nodes, which possess the ability of sensing, computing and communicating. The nodes are self-organized into a network and collaboratively complete the detection task. Without any infrastructure, WSNs can easily get the various physical information into the Internet in the real world, therefore they have been widely used in many fields, such as national defense and military, health care and smart home [1-3]. Compared with traditional network, sensor network is a kind of resource constrained network, which is restricted to the limited computing power, storage capacity and energy[4, 5]. The energy consumption of nodes is mainly in the communication module, so the design of energy-efficient routing algorithm is of highly practical value. The theoretical and practical point of routing algorithm has been becoming a focus of research[6].

Clustering algorithm divides WSN into a logical hierarchy structure, which can effectively reduce overhead cost of the route maintenance, strengthen the stability of the network, and improve spatial reuse ratio of channel[7, 8]. Therefore, it has a critical value in the application system of large scale network. In the clustering algorithm, nodes within the cluster and between the clusters form two-tier structure. The LEACH[9] protocol and some improved algorithms all adopt sensor nodes cluster-based organization. However, several problems still exist in many clustering protocols. The first defect is the uncertainty of the number of Cluster Head (CH) [10-12]. As the number of cluster head is random, the condition with less number of CH will cause a lot of pressure to the cluster heads. The second defect is the uncertainty of the position and energy of CH. When selecting the cluster head, the protocol does not weigh the relationship between the residual energy of CH, the relationship between the position of the CH and the ordinary nodes. It may not consider the distance between CH and base station. These problems drastically reduce the longevity and also shorten the network lifecycle. Thirdly, CHs can communicate with the BS directly. When the CH is far from the base station, the process of sending information to the BS consumes large energy. The main contributions of this paper are as follows:

(1) In view of the uncertainty of the number of CH, we adaptively partition the region of the network according to the network states which are related to the number of live nodes and node energy. Combined with selecting the optimal number of CH[13], we reduce the number of dynamic region with the decrease in the number of live nodes and node energy. The number of CHs also makes dynamic adjustment correspondingly.

(2) Aiming at the uncertainty of the position and the energy of CH, we take full account of the relationship in position between the CHs and ordinary nodes. Meanwhile, we consider the relationship in position between the CHs and BS, and regard the residual energy of CHs as another important parameter, so as to choose the optimal CH at a different phase. As these contexts are adequately considered, this paper uses PSO[14] to propose the fitness function based on three parameters.

(3) We take advantage of the ACO algorithm[15] to acquire the optimum route. We introduce residual energy factor into planning path and adopt multi-hop as the communication mode. When it comes to selecting CHs again, we put forward a dynamical threshold control algorithm based on the weight of residual energy of

different CHs. Provided that one CH reaches the threshold, the whole network re-select CH.

The results show that, DPA tremendously prolongs the lifecycle of network and keeps a balance of load. The rest of this paper is organized as follows. Section 2 briefly summarizes the related work. Section 3 describes the application scenarios, the system network model and radio energy model. Section 4 presents our DPA protocol. Section 5 is the experimental simulation results and analysis. Section 6 concludes our work.

2. Related Work

Among the clustering routing protocols, LEACH[9] is one of the most popular hierarchical routing protocols for wireless sensor networks. In LEACH the thought of 'round' is proposed, which is composed of two parts, namely, the cluster formation process and stable data transmission process. In the literature, various modifications have been made to the LEACH protocol, which from LEACH family, such as LEACH-C[13], I-LEACH[16], LEACH-FL[17], W-LEACH[18], T-LEACH[19], etc.

In addition, as a new evolutionary computation technology, swarm intelligence theories are gradually being used as research methods in the field of wireless sensor networks, including the ant colony optimization algorithm and the particle swarm optimization algorithm.

Most of the swarm intelligence routing algorithms inspired by ant behaviors have been developed in the context of the framework of ACO. EEABR[20], based on a ACO metaheuristic, has introduced the energy level of nodes and transmission distance into ACO pheromone increment formula which made ACO adapt better to routing protocol in WSN. ABEBR[21] has designed a new pheromone update operator to integrate energy consumption and hops into routing choice. ANT[22] put ant colony algorithm in existing LEACH protocols. The node with maximum energy and higher probability than the preset value becomes the cluster head. The results show that the network lifetime can be improved. Yan et al. [23] has proposed a new pheromone update formula to decrease the pheromone concentration on the traversed edges so that the ants encourage subsequent ants to choose other edges. The protocol has successfully reduced energy consumption in WSNs routing process. In[24], an uneven clustering routing algorithm for Wireless Sensor Networks based on ant colony optimization is proposed. This method reduces the burden of cluster heads. In IC-ACO[25], ant colony optimization is applied within the cluster to transmit the data packets from the source node to the sink in densely deployed network. An effort has been made to minimize the redundant data transmission.

Particle Swarm Optimization (PSO) is a swarm intelligence based metaheuristic algorithm which takes its inspiration from the cooperation and communications of a swarm of birds. Here we discuss some PSO-based protocols. PSO-C[26] introduces the PSO algorithm into CH selection. Cai et al. [27] has introduced a novel clustering routing algorithm based on adaptive particle swarm optimization(APSO). It selects the high-energy nodes as CHs and makes the position evenly. It uses the new designed nonlinear weights to make the PSO become adaptive and better convergent. Soleimanzadeh et al. [28] has proposed three dynamic PSO-based deployment algorithms. The implementation of multi-hop routing among the cluster heads to further improve energy efficiency should be included. In PSO-WSN[29], the fitness function is modified which reflects the distance from the surrounding neighbors and the energy distribution. The PSO-WSN has better training performance, better convergence behavior. ENPC-NPSO[30] first runs ENPC-NPSO algorithm in the candidate

CHs to select the CHs. When the maximum number of iterations is reached, it will select out certain CHs as the best solution. The fitness function has considered the residual energy of the node and the average distance between the CH and its member nodes. Rathee et al. [31] have combined the PSO technique with DDEEC protocol[32] and has optimized the selection of cluster-heads via using fitness function of the PSO algorithm for maximum life-cycle. The sink and source nodes communicate with each other and maintain the routing with enough residual energy so that the clustered structure may claim for maximum lifetime.

In addition, ABC[33] is another kind of the swarm-based artificial intelligence protocol. Babu et al.[34], Ajayan et al.[35] and Thenral et al.[36] have proposed the modified algorithms of ABC. Artificial bee colony algorithm has a good performance in selection of CHs. Artificial bee colony algorithm and the particle swarm optimization algorithm have many common characteristics. However, the artificial bee colony algorithm needs three kinds of roles to search the best CH, which may increase the consumption of memory and energy. That is also one of the motivations of choosing the PSO algorithm in this paper.

Corresponding to the research work of the related field, our experiment establishes the following model system.

3. System Model

In this paper, we adopt a simple model as used in [9]. Let E_{Tx} and E_{Rx} respectively represent the energy needed to send and receive the information.

$$E_{Tx}(m,d)=\begin{cases} mE_{elec}+m\varepsilon_{free}d^2 & d<d_{gate} \\ mE_{elec}+m\varepsilon_{multi\text{-}path}d^4 & d\ge d_{gate} \end{cases} \tag{1}$$

$$E_{Rx}(m)=mE_{elec} \tag{2}$$

Where E_{elec} denotes the energy spent to activate the baseband circuits to transmit or receive 1 bit and $\varepsilon_{free}, \varepsilon_{multi\text{-}path}$ separately denotes the required energy to run the RF module to transmit 1 bit in free space and multi-path space. d_{gate} is the threshold of the distance and d is the distance between the transmitter and the receiver. m denotes the bits to be transmitted. From Eq.(1), we can derive d_{gate} as

$$d_{gate}=\sqrt{\frac{\varepsilon_{free}}{\varepsilon_{multi\text{-}path}}} \tag{3}$$

Nodes utilize power control capability to control the transmit power according to the distance. If the distance is less than the threshold, we use the free space channel model. Otherwise, we adopt the multipath fading channel model. The communication energy parameters are set as: $E_{elec}=50nJ/bit$, $\varepsilon_{free}=10pJ/bit/m^2$, $\varepsilon_{multi\text{-}path}=0.0013pJ/bit/m^4$. The energy for data aggregation is set as $E_{DA}=5nJ/bit/signal$. Therefore, the energy dissipated in the CH node during a single frame is

$$E_{CH}=E_{Rx}+E_{DA}m+E_{Tx} \tag{4}$$

Based on the establishment of the system model, we will determine the dynamic optimal partition and the selection of the optimal cluster head in each partition.

4.The proposed DPA protocol

In this section, we present a new communication protocol for WSN called dynamical threshold control algorithm with three-parameter particle swarm optimization and ant colony optimization based on residual energy (DPA). We first use the state of WSN to partition the region adaptively. Moreover, a three-parameter of particle swarm optimization (PSO) algorithm is proposed and a new fitness function is obtained. The optimal path among the CHs and Base Station (BS) is obtained by the ant colony optimization (ACO) algorithm based on residual energy. Dynamical threshold control algorithm (DTCA) is introduced when we re-select the CHs.

4.1 Determine the optimal number of partitions

4.1.1 The influence of node number on the partition

100 random nodes of uniform energy are deployed in an area of 100m*100m, with the distance from the sensor nodes to the BS more than 75m but less than 185m. The results of the simulation show that the best number of CHs is 5[13]. The optimum number of clusters is:

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{free}}{\varepsilon_{multi\text{-}path}}} \frac{M}{d_{toBS}^2} \tag{5}$$

Where N is the number of nodes, M is the length of the side of the square, ε_{free} and $\varepsilon_{multi\text{-}path}$ are parameters of the emission amplifier model, and d_{toBS} is the distance between the CH and BS. For our experiments, N=100, M=100m.

In the experiment, we set the initial partition number as 5. During the running process of the system, the number of alive nodes will gradually become less and less, but the other parameters are not changed in Eq.(5). That is the reason why we consider the influence of N on k_{opt} in this paper.

$$\frac{k'_{opt}}{k_{opt}} = \frac{\sqrt{N'}}{\sqrt{N}} \tag{6}$$

Where k'_{opt} and N' are on behalf of the latest number of clusters and the number of nodes. Therefore, when the number of nodes N' is equal to 81 and $\sqrt{81}/\sqrt{100} = 0.9$, k'_{opt} is set to 4.5(we use the integer value 4). So the partition number will be reduced to 4. Similarly, when the number of survival nodes is less than 49, 25 or 9, the number of partitions is reduced to 3, 2 and 1 correspondingly.

4.1.2 The influence of residual energy of inner-cluster nodes on the partition

In this experiment, after the partition number is determined and each interval is fixed, we may still encounter the problem that the residual energy of all nodes are less than what it needs to become a cluster head. The minimum cluster head energy ($E_{min\_cluster}$) equals to the energy (E_{one_round}) for system running one round plus the energy for broadcasting two advertisement messages. One advertisement message for re-selecting CHs ($E_{select\_cluster\_head}$) and the other one for re-partitioning ($E_{divide\_cluster}$).

$$E_{min\_cluster} = E_{one\_round} + E_{select\_cluster\_head} + E_{divide\_cluster} \quad (7)$$

In our algorithms, when one CH (eg. its number is t) reaches its dynamical threshold, it will send a packet to all of the CHs, run three-parameter PSO algorithm on them to continue the process of CH reselection. The energy $E_{select\_cluster\_head}$ equals to the dissipation of the broadcasting this message to all CHs. After the reselection of CHs, if the new CHs are the same with the original one, which means show that no nodes are more appropriate to be the CHs. Then the CH (its number is t) sends a packet to all of the nodes, making them continue the process of re-partition. The energy $E_{divide\_cluster}$ is equal to the dissipation of the broadcasting this message to all nodes. As a result, we will choose the node which has the energy larger than $E_{min\_cluster}$ to be the CH.

4.2 Generation of Cluster Head

4.2.1 PSO algorithm based on Two-dimensional discrete space

When the PSO algorithm is applied to the sensor network nodes in cluster head selection, the location information of each node includes information of X axis denoted as x_{id} and Y axis denoted as y_{id}. The speed information of each node includes X axis speed V_{xid}^{k+1} and Y axis speed V_{yid}^{k+1}. Then, the update equation of velocity and position of the nodes are shown as follows.

$$V_{xid}^{k+1} = WV_{xid}^{k} + c_1 \cdot rand^k \cdot \left(P_{id}^k - X_{xid}^k\right) + c_2 \cdot Rand^k \cdot (P_{gd}^k - X_{xid}^k) \quad (8)$$

$$V_{yid}^{k+1} = WV_{yid}^{k} + c_1 \cdot rand^k \cdot \left(P_{id}^k - X_{yid}^k\right) + c_2 \cdot Rand^k \cdot (P_{gd}^k - X_{yid}^k) \quad (9)$$

$$X_{xid}^{k+1} = X_{xid}^{k} + V_{xid}^{k+1} \quad (10)$$

$$X_{yid}^{k+1} = X_{yid}^{k} + V_{yid}^{k+1} \quad (11)$$

Table 1. Definitions of some notations

k	The number of iteration.
P_{id}^k	The best individual position of node i found in D dimension space after k iterations.
P_{gd}^k	The best position found from the niching it belongs after k iterations.
c_1, c_2	Acceleration coefficient.
Rand, rand	A random number between 0 and 1.
W	The weight coefficient, which determines the influence of the previous velocity on the current velocity. The larger W can strengthen the global search ability of PSO, while the smaller W can strengthen the local search ability.

As the distribution of nodes in wireless sensor networks is discrete, the coordinate of the positions calculated by Eq. (10) and Eq. (11) cannot be matched to the sensor nodes. Particles need to be mapped to the nodes that have the closest position.

4.2.2 Fitness function of PSO based on three parameters

When we begin to redefine fitness function, we take full account of the relationship between the position of the CHs and ordinary nodes. Meanwhile, we also consider the relationship between the position of the CHs and BS, and regard the residual energy of CHs as another important index. When the energy of the nodes is the same, only the locations of nodes make an impact on the fitness function. When the energy distribution of the nodes is inconsistent, the residual energy of nodes may have a greater effect while the influence of the position is decreasing.

Firstly, we define the fitness function $\mathrm{P_{fit}(i)}$ for node i based on the above considerations.

$$P_{fit}(i) = \alpha f_1(i) + \beta f_2(i) + \gamma f_3(i) \tag{12}$$

$$f_1(i) = E_{res}(\mathrm{i}) / \frac{\sum_{j=1}^{k} E_{res}(\mathrm{j})}{k} \tag{13}$$

$$f_2(i) = \frac{1}{k} \cdot \left(\sum_{j=1}^{k} d_{BS}(\mathrm{j}) \right) / d_{BS}(\mathrm{i}) \tag{14}$$

$$f_3(i) = \frac{1}{k \cdot (k-1)} \cdot \left(\sum_{j=1}^{k} \sum_{h=1, h \neq j}^{k} d(\mathrm{j}, \mathrm{h}) \right) / \left(\frac{1}{k} \cdot \sum_{j=1}^{k} d(\mathrm{i}, \mathrm{j}) \right) \tag{15}$$

Table 2. Definitions of some parameters

α , β , γ	The evaluation factor weight coefficient..
k	The number of nodes in the partition which node i belongs to.
$E_{res}(\mathrm{i})$	The residual energy of the node i.
$d_{BS}(\mathrm{i})$	The distance between the node i and the BS.
$d(j,h)$	The distance between the node j and the node h.
f_1	It demonstrates the importance of the residual energy of nodes, which is the ratio of residual energy of node i and the average energy of its region.
f_2	It reflects the importance of the distance between the node and the BS.
f_3	It reflects the close relation between the CH node and non-CH nodes in the region.

We make $\alpha + \beta + \gamma = 1$. During the initialization phase, α, β, γ equals to 1/3. However, as the program goes on, the node energy decreases thereby showing that the residual energy is becoming more crucial during the CH selection process. So we define the α, β, γ as:

$$\alpha = \frac{1}{\frac{3}{2} + \frac{3}{2} \times \frac{E_{res}(i)}{E_{ini}}} \tag{16}$$

$$\beta = \gamma = 1 - \frac{1}{\frac{3}{2} + \frac{3}{2} \times \frac{E_{res}(i)}{E_{ini}}} \tag{17}$$

The coefficient of f_1 varies from 1/3 to 2/3, which increases the weight of residual energy and decreases the weight of other factors during the CH selection process. By this evolution, we drastically prolong the time of the first node death, as the remaining energy has greater weight.

The following equation is the fitness function with three parameters we defined finally:

$$P_{fit}(i) = \frac{1}{\frac{3}{2} + \frac{3}{2} \times \frac{E_{res}(i)}{E_{ini}}} \times f_1(i) + \left(1 - \frac{1}{\frac{3}{2} + \frac{3}{2} \times \frac{E_{res}(i)}{E_{ini}}} \right) \times \left(\frac{1}{2} \times f_2(i) + \frac{1}{2} \times f_3(i) \right) \tag{18}$$

In the initial stage of system, the position and the partition of each node are known to us. In each area, base station randomly selects a node as the candidate cluster, which contains all the node locations and remaining energy information of the region. The candidate cluster head runs three-parameter PSO algorithm to select the CH.

The candidate cluster uses the three-parameter PSO algorithm to select the best cluster head for each partition and utilizes the CSMA protocol of MAC layer to broadcast an advertisement. The message is a short message containing the ID of node, the position of the CH, and the region number of cluster nodes. Each CH node will know the position information and the ID of the other CH nodes. Non-CH nodes will match their region number and region number of CH nodes. Therefore, non-CH nodes will know their own interval cluster head ID and position information. In order to reduce the communication interference, the CH nodes distribute the slot to the member nodes within the region based on TDMA mode.

4.3 Optimal Route between the CHs and BS

Assuming that each node has uniform initial energy, as the ant goes through the node, the node will consume some energy. With the simulation on energy consumption of the node sending and receiving information in WSN, we can figure out statistics on node energy consumption. In addition to the pheromone, we regard the residual energy as another significant factor on routing, which leads to the ants changing the algorithm adaptively to choose the path. Here is the path probability judgment rule. As the rule of the ants choosing the next node, it depends on probability:

$$p_k(\mathrm{t,q}) = \begin{cases} \dfrac{(\theta_k)^{\alpha} \times (\eta(\mathrm{t,q}))^{\beta}}{\sum_{\mu \in J_k(t)} (\theta_k)^{\alpha} \times (\eta(\mathrm{t},\mu))^{\beta}} & q \in J_k(t) \\ 0 & q \notin J_k(t) \end{cases} \tag{19}$$

$p_k(\mathrm{t,q})$ shows the probability which can be worked out by ant k choosing to move from node t to node q. η is the reciprocal of the distance between node t and node q. $J_k(t)$ is the node set that has not been visited yet. α is the key degree of the pheromone. β is the constant value which is equal to 2 and it also represents the energy consumption of seeking path and the relative importance of pheromone. θ_k is the calculation factor depending on the pheromone of ant k and the residual energy of the next node:

$$\theta_k = \frac{\tau_k(\mathrm{t,q}) \cdot W(q)}{\sum_{v \in J_k(t)} W(v)}, q \in J_k(t) \tag{20}$$

where τ_k is the pheromone and $W(q)$ is the residual energy of node q.

The global pheromone is updated according to the following equation:

$$\tau(\mathrm{t,p}) = (1-\rho) \cdot \tau(\mathrm{t,p}) + \sum \Delta\tau_k(\mathrm{t,q}) \tag{21}$$

where

$$\Delta\tau_k(\mathrm{t,q}) = \begin{cases} \dfrac{1}{L_k} & (\mathrm{t,q}) \text{ is the edge passed through} \\ 0 & \text{others} \end{cases} \tag{22}$$

where ρ is the pheromone evaporation coefficient and L_k denotes the consumption of completing seeking path.

4.4 Dynamical Threshold of the CH Re-selection

The CH nodes need to receive information from all the nodes in their own region, to aggregate information, and to perform transmitting information to next node. Thus, these processes take a lot of energy consumption. In many sensor network clustering protocols, they re-elect the cluster head each round. After the selection of cluster head, CHs broadcast an advertisement message so as to inform all the nodes their identities can be taken as CH. Then non-CH nodes send join packet to the CH node, and CH node sends acknowledgment packets as well as the TDMA table to the non-CH nodes. There is no doubt that this process requires a lot of energy consumption. Furthermore, CHs will die easily because of the large energy consumption, in other words, it also shortens the lifetime of network. When we design the CH reselection mechanism, we take full account of the residual energy of CHs in the whole network. Dynamical threshold is based on the weight of the residual energy, in order to achieve the equalization between the nodes energy.

Algorithm 1: Dynamic Threshold Control Algorithm

Assume: It has k CH nodes in this round.

Step1: Input the residual energy of CH nodes $E_{res1}...E_{resk}$

Step2: Record the value of the minimum energy E_{min}

Step3: Sum the values after the square of the ratios $\left(\frac{E_{res1}}{E_{min}}\right)^2 + ... + \left(\frac{E_{resk}}{E_{min}}\right)^2$

Step4: Calculate the threshold $\left(\frac{E_{res}}{E_{min}}\right)^2 / \sum_{i=1}^{k}\left(\frac{E_{resi}}{E_{min}}\right)^2$ for each CH node.

Step5: Each CH node will transmit the message to the base station.

Step6: Calculate its own energy consumption and judge whether it has reached the threshold or not. If one CH reaches the threshold, it will send a packet to all of the CH nodes, and make them run three-parameter PSO algorithm to execute CH reselection. After the CH re-election, the procedure turns to step 1 for the next round of transmission. Otherwise, the original CH nodes still transmit the message to the base station for the next round.

The calculation equation of threshold shows as follows:

$$T(i) = \frac{\left(\frac{E_{res}(i)}{E_{min}}\right)^2}{\sum_{j=1}^{k}\left(\frac{E_{res}(j)}{E_{min}}\right)^2} \tag{23}$$

where E_{min} represents the minimum residual energy of all CHs and k is the number of CHs. The weight of nodes with more energy has been amplified after taking the square ratio. The resulting threshold will be greater than the first power so as to be the CH for longer time. And the node whose residual energy is relatively small is allowed to send less information. After the process, it balances the energy of nodes in the network and prolongs the lifecycle of nodes.

When one CH reaches the threshold, it will send a packet to all of the CHs, making them run three-parameter PSO algorithm to carry out CH reselection.

We have described the optimal partition, the selection of cluster head, the communication between the CH and BS, and the dynamical threshold of CH reselection. Next we will carry on to the algorithm simulation.

5. Simulation Results and Analysis

MATLAB software tool is used for simulating different routing protocols. 100 random nodes of uniform energy are deployed in an area of 100m*100m, with base station at 50,175. The simulation parameters are given in **Table 3**.

Table 3. The fundamental simulation parameters

Description	Parameters	values
The sensing area	Network coverage	(0,0)~(100,100) m
Data packet	l	4000bits
Control packet	lc	200bits
The initial node energy	$E_{initial}$	0.5J
Energy consumed in the electronics circuit to transmit or receive the signal	E_{elec}	50nJ / bit
Energy consumed by the amplifier to transmit at a short distance	ε_{free}	$10pJ/bit/m^2$
Energy consumed by the amplifier to transmit at a longer distance	$\varepsilon_{multi-path}$	$0.0013pJ/bit/m^4$
Data aggregation energy	E_{DA}	5nJ / bit / signal

When using the three-parameter PSO algorithm to select the CH, the simulation parameters are given in **Table 4**.

Table 4. Three-parameter PSO algorithm parameters

Parameters	values
acceleration coefficients C_1, C_2	2
weight coefficient W	0.4~0.9
initial velocity V_x, V_y	2
maximum number of iterations	50

When utilizing the ACO algorithm based on residual energy to select the optimal route, the simulation parameters are given in

Table 5.

Table 5. ACO algorithm based on residual energy parameters

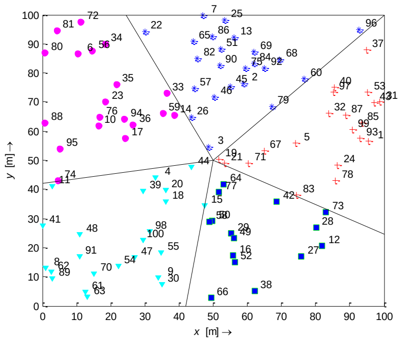
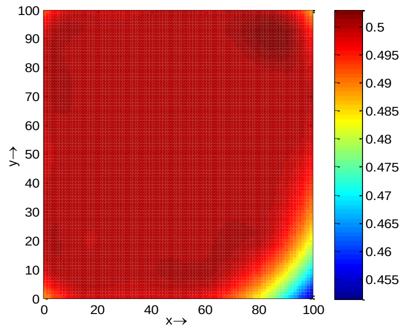
Parameters	values
the important degree of the pheromone α	1.5
The important degree of the heuristic factor β	2
Pheromone evaporation factor ρ	0.1
the maximum number of iterations	50

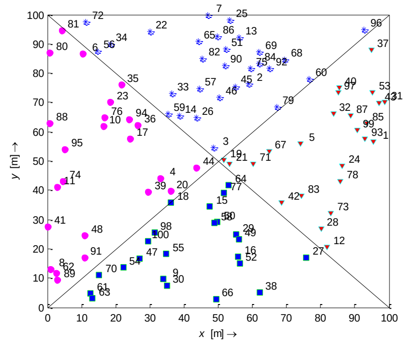
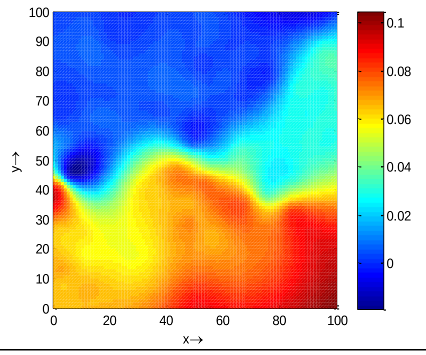
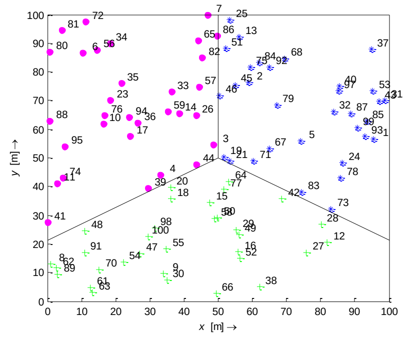
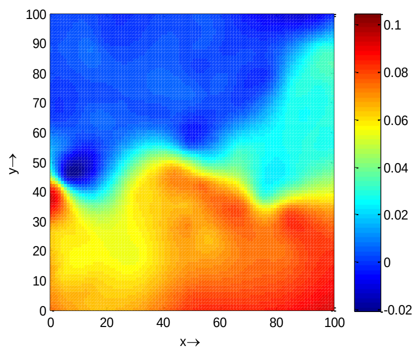
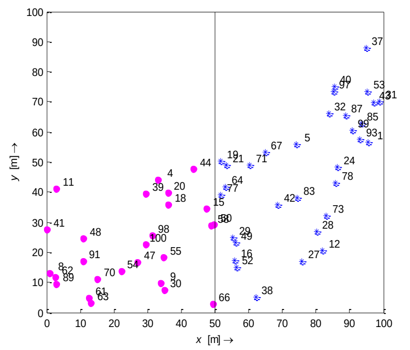
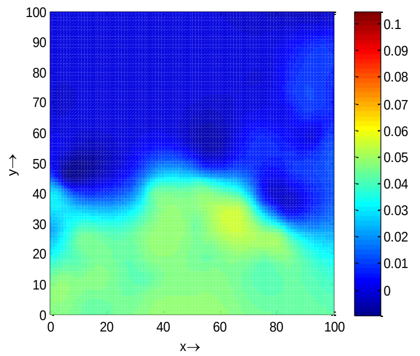
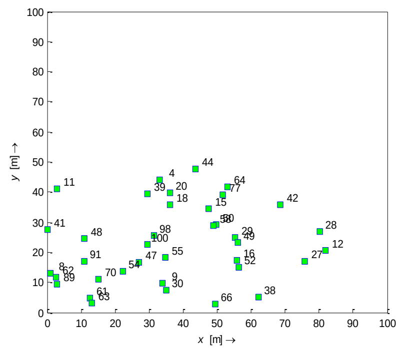
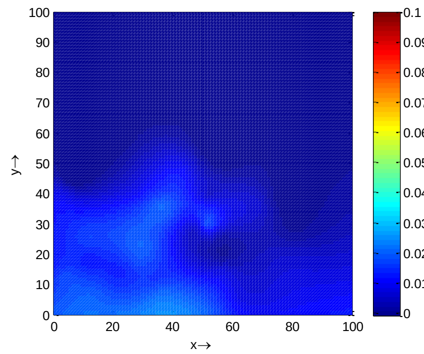
In this paper, in order to simplify the scenario, we assume that each partition has an equal area. With the increase of number of rounds, the table below explains the partition numbers continuing to become lower.

5.1 Changes of Partition Number

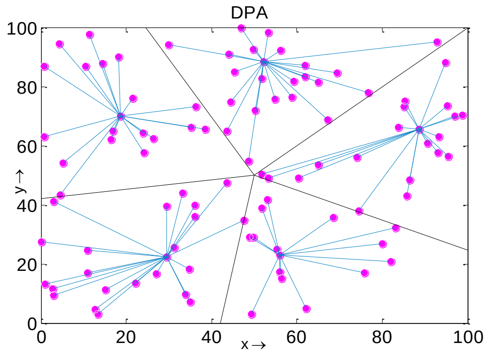
Table 6 shows the course of the experiment. As shown in Fig. A in **Table 6**, our network is divided into five areas in the first stage. The residual energy of each node in the top range of Fig. A is minimal. The partition number is adaptively reduced to 4 as shown in Fig. B. **Table 6**. Other circumstances are similar to this process. With the reduction in the residual energy of nodes and the number of survival nodes, the sensor network reduces partition number adaptively. $A \rightarrow B \rightarrow C \rightarrow D \rightarrow E$. The process A is the primitive stage, which shows that the 5 partitions all have nodes to be elected as cluster head (the energy of the node is sufficient). As the experiment proceeds and the residual energy of all nodes in a partition is less than $E_{min\_cluster}$, no node can be competent for the cluster head node. The partition number will be reduced to 4, as shown in **Table 6** Fig. B. The situation of C, D and E are similar to Fig. B.

Table 6. Changes of partition number

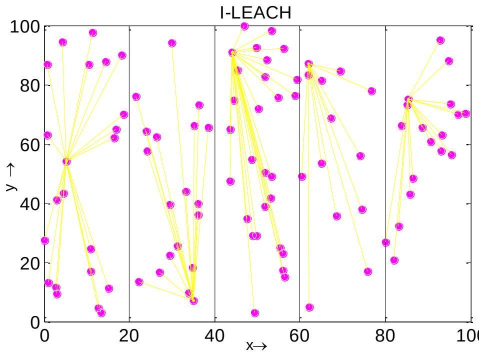
No	Partition	Residual Energy Distribution	Description
A			Stage one: The initial energy of each node is 0.5J.

B			Stage two: The residual energy of each node in the top range of Fig. A is minimal. The partition number is adaptively reduced to 4.
C			Stage three: The residual energy of each node in the top range of Fig. B is minimal. The partition number is adaptively reduced to 3.
D			Stage four: The residual energy of each node in the upper left range of Fig. C is minimal. The partition number is adaptively reduced to 2.
E			Stage five: The residual energy of each node in the right range of Fig. D is minimal. The partition number is adaptively reduced to 1.

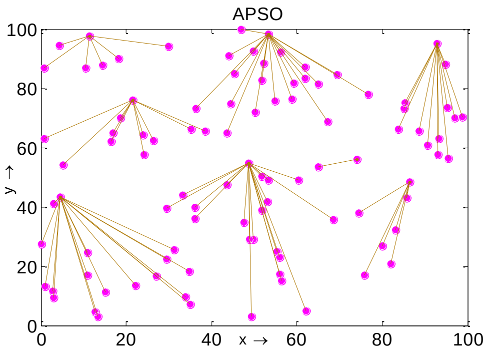
5.2 The Results of network partitioning



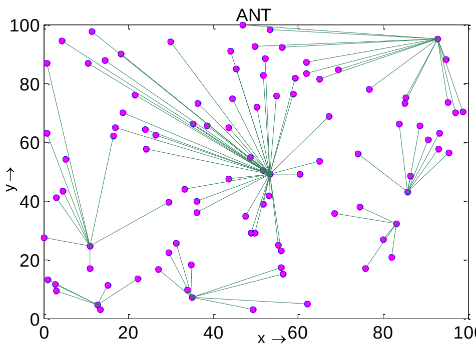
a. Results of network partitioning by DPA



b. Results of network partitioning by I-LEACH



c. Results of network partitioning by APSO



d. Results of network partitioning by ANT

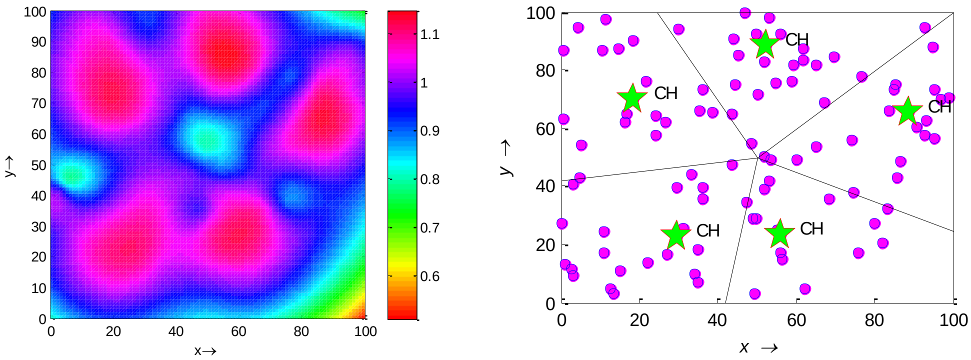
Fig. 1. Results of network partitioning by four protocols

Table 7. The number of nodes in each Cluster

	Cluster1	Cluster2	Cluster3	Cluster4	Cluster5	Cluster6	Cluster7	Cluster8
DPA	19	23	20	22	16			
I-LEACH	22	19	28	13	18			
ANT	42	10	16	9	6	10	7	
APSO	7	21	13	11	21	2	7	18

Fig. 1 (a) to (d) and

Table 7 show the results of CHs selection and clustering in a 100-node random test network. As can be seen from the figures and the table, the DPA can draw good CHs selection, and cluster head nodes have balanced load, where cluster heads are evenly positioned across the network and located at the center of each cluster. Each cluster head nearly has the same number of non-cluster head nodes. From another point of view, APSO and ANT, produce an uneven distribution of cluster heads throughout the sensor field. This is because a stochastic cluster head selection in ANT will not automatically lead to a good network portioning in which a cluster head may still be located near the edges of the cluster in a network. Though APSO has made efforts to make the cluster head nodes position better, there are still some problems which need to be considered further. Despite that I-LEACH chooses the cluster node in each partition. I-LEACH only considers the node which has the maximal residual energy but never considers the positions of cluster head nodes. As a contrast, DPA has done better in the above considerations. Our protocol produces better cluster head node selection with minimum intra-cluster distance and reasonable distance between the cluster head and BS. Thus, the energy consumed by all nodes for communication can be reduced since the distances between non-cluster head nodes and their cluster heads are decreased.



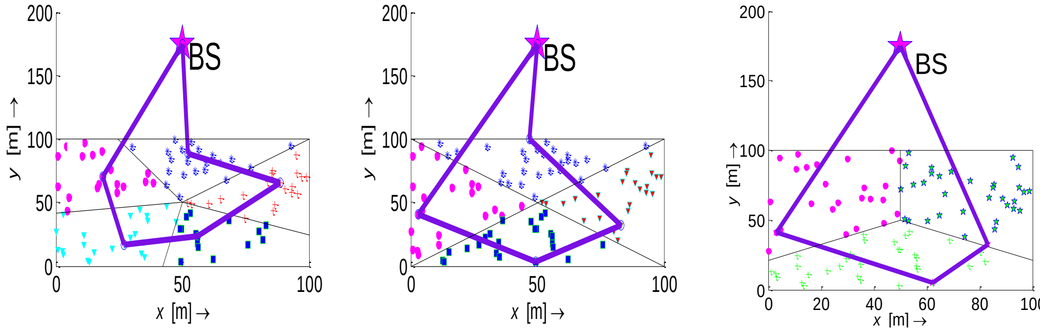
a.Fitness value distribution b. The CH nodes location distribution

Fig. 2. Fitness value distribution and the CH nodes location

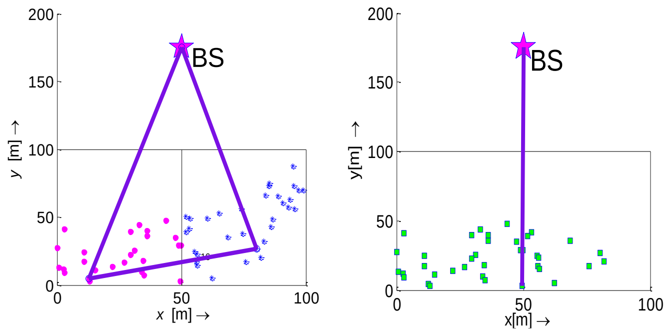
Fig. 2 shows the corresponding relationship between the results of the fitness values and the location distribution of the CH nodes. Next, CH nodes will run the following algorithm to get the optimal path between CH nodes and BS.

5.3 The trajectory between CH nodes and BS

In this section, we show the trajectory calculated by ACO algorithm as the partition number drops from five to one. As the ants traverse each node in the process of feeding, the CH nodes and BS are connected with each other forming into a ring. The CH nodes send information to the BS through the optimal path. The sensor nodes can act as end nodes to generate or receive data, and they can also act as a router to forward other packets. As the distance between the nodes and BS is relatively far, using multi-hop way to send information to the BS is conducive to reduce the consumption of energy.



a. The trajectory of five partitions. b. The trajectory of four partitions. c. The trajectory of three partitions.



d. The trajectory of two partitions. e. The trajectory of one partition.

Fig. 3. The trajectory between CH nodes and BS

5.4 Result of Dynamical Threshold Control Algorithm

Fig. 4 shows two cases of the residual energy's variance with constant threshold and dynamical threshold. With the constant threshold, the threshold of every node is the same, which is equal to the reciprocal of the CH number. Due to the dynamical threshold is set by the weight of the node's energy, so with decreasing of the overall variance, the property of balance is improved in the overall.

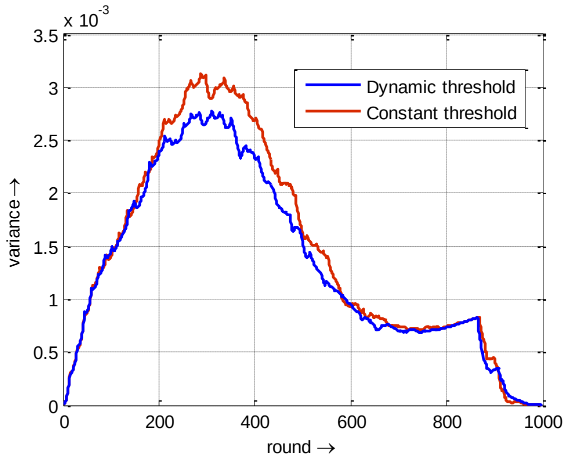


Fig. 4. The variance of residual energy

5.5 The Network Performance Evaluation

In this experiment, the number of data packets transmitted to the BS is not limited. We compare APSO[27], ANT[22], I-LEACH[16] with our DPA. Fig. 5 shows the relationship between the number of living nodes and the time. We record the number of alive nodes in every round. When the node is powered off, we will remove it from the network and it cannot send or receive information. Network lifetime is a key index to measure whether the energy consumption of the network is balanced or not. The longer length of the network lifecycle presents the more balanced energy consumption of network, and also proves the performance of the routing protocol is better. Otherwise, the network energy consumption is unbalanced. As it is clear from **Fig. 5**, DPA has the longest lifetime. The rounds of DPA are respectively higher than the rounds of APSO, ANT and I-LEACH with the over percentage of 48.3%, 43.0%, and 24.9%.

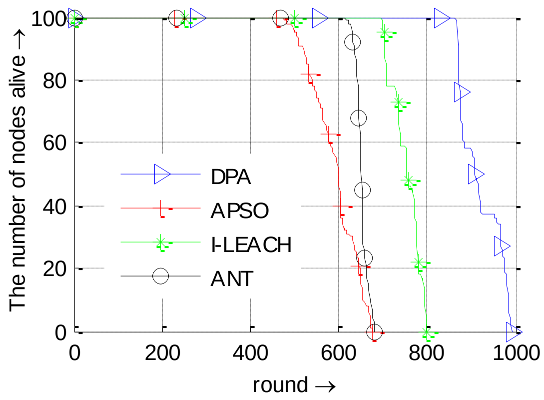


Fig. 5. The relationship between the number of alive nodes and the round

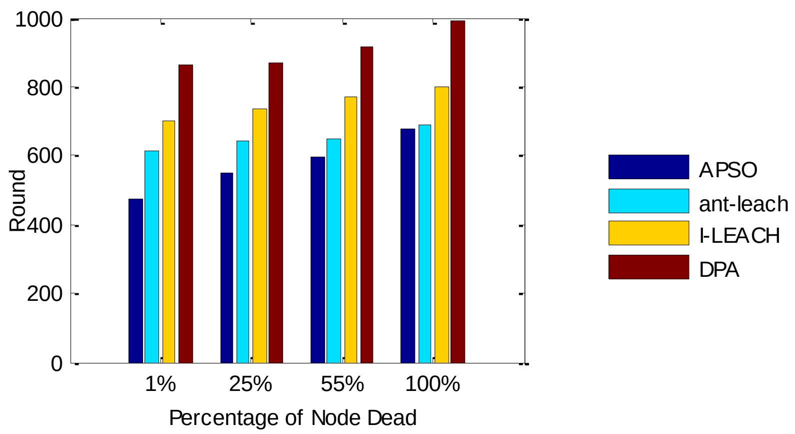


Fig. 6. The relationship between the death node proportion and the round

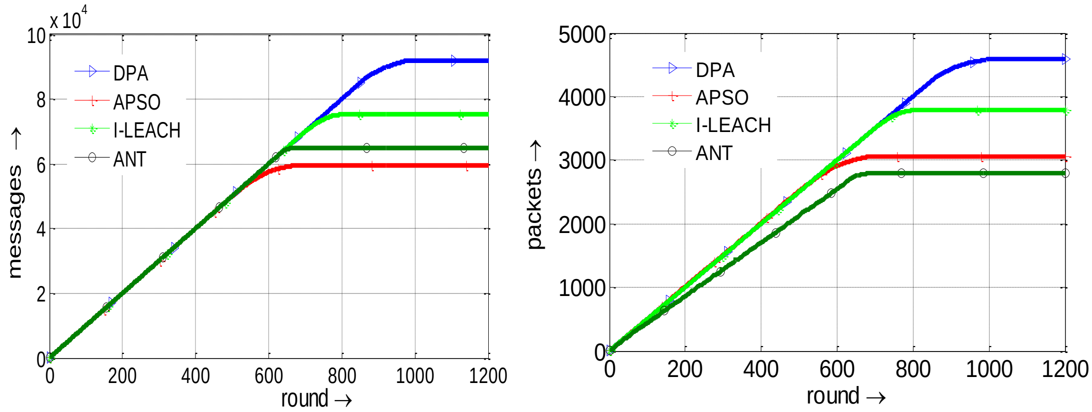
Table 8. The relationship between the death proportion and the number of rounds

Initial Energy	Protocol	1%	25%	55%	100%
0.5J	APSO	479	550	601	673
0.5J	ANT	621	641	648	698
0.5J	I-LEACH	698	733	768	799
0.5J	DPA	864	873	920	998

Fig. 6 shows the comparison of the round with the proportion of dead nodes.

Table 8 shows the specific value of the round corresponding to each proportion. APSO selects the high-energy nodes as CHs and makes the position evenly. APSO uses the new designed nonlinear weights to make the PSO adaptive. With regard to APSO, the multi-hop routing among the cluster heads which can further improve energy efficiency should be implemented. ANT uses the ant colony algorithm to find the best path in the network. However, it should take the location of the cluster head into account so as to optimize the cluster head selection. As the I-LEACH considers the residual energy in the selection of cluster head, the node with much residual energy is more easily to be selected as CH. The cluster head nodes are distributed uniformly along the X axis. Therefore, I-LEACH has better performance than the previous two protocols. The deficiency of this protocol is the single hop way to transmit the data. Our DPA protocol fully considers the weight of the residual energy, the tightness between the CH and the non-CH nodes, and the relationship between the CH's position and BS's position. We also adopt the multi-hop mode to transmit the messages. As a result, DPA prolongs the network lifecycle ultimately.

Fig. 7 (a) shows the relationship between APSO, ANT, I-LEACH and DPA on the amount of information that they transmit. The total amount of transmitted information is an important aspect to evaluate the quality of the network. In this experiment, the statistics is about the number of packets successfully sent to the BS. Assuming that the number of alive nodes is 100 and all of the information is successfully transmitted to the BS, the amount of messages in this round is 100. The number of messages they send is respectively: 59032, 64909, 75220, and 91686. We observe 55.6%, 41.3%, and 22% respectively more percentages performed by DPA over APSO, ANT and I-LEACH. DPA greatly improves the efficiency of energy utilization. Especially in the remote and harsh environment, it has created favorable conditions for the sensor network to transmit more data. **Fig. 7** (b) illustrates the performance in terms of the amount of packets received by BS. Assuming that the number of CHs is 5 and all of the information is successfully transmitted to the BS, and the amount of packets in this round is 5. With the protocol of ANT and APSO, the number of cluster heads is random. The number of clusters varies widely in each simulation. The condition with smaller number of CHs causes a lot of pressure to the cluster heads. Therefore, this defect severely shortens the lifetime of WSNs. By using the method of DPA, it can generate the number of CHs in the best reasonable situation. The tight connection of CH and non-CH nodes makes the nodes require less energy to send data to the CH. As there is a reasonable distance between the CH and BS, a lot of energy is saved. The CH nodes communicate with the BS by using the mode of multi-hop. Thus, DPA shows the obvious advantages in energy efficiency, prolonging the life cycle, and sending more data packets.



a. The contrast of total messages sent

b.The amount of packets received by BS

Fig. 7. The comparison of the amount of messages and packets

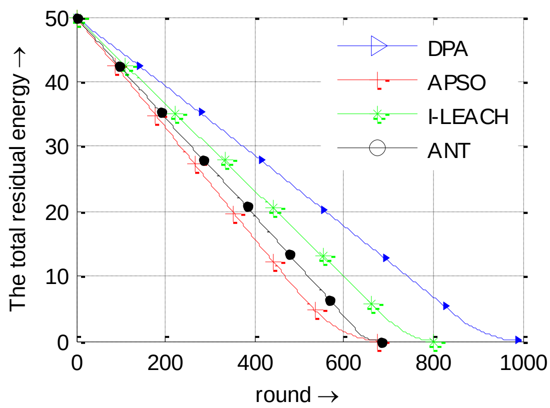


Fig. 8. The relationship between the network's total residual energy and round

Fig. 8 illustrates the performance of our algorithm comparing to APSO, ANT and I-LEACH in terms of the total residual energy. As it is clear from **Fig. 8**, DPA is the most energy efficient way. The residual energy curve slope of the APSO protocol is maximum, which denotes the maximum energy consumption for each round. On the contrary, the residual energy curve slope of the DPA protocol is minimum, which denotes the minimum energy consumption for each round.

6.Conclusions

This paper proposes a DPA protocol. We firstly use the state of WSNs to partition distribution adaptively. Combined with the choice of optimal number of cluster head and the different conditions of nodes, the partition changes dynamically. The three-parameter of particle swarm optimization (PSO) algorithm is proposed and a new fitness function is obtained. We take full account of the relationship between the position of the CHs and ordinary nodes. In addition, we also consider the relationship between the position of the CHs and BS and regard the residual energy of CHs as another important factor as well. Choose the best cluster head in a suitable moment. The optimal path among the CHs and BS is obtained by the ant colony optimization (ACO) based on residual energy. Dynamical threshold control algorithm (DTCA) is introduced when we select the CHs again. As long as one CH reaches the threshold, all of CH nodes will run three-parameter PSO algorithm to carry out CH reselection. These results show that it tremendously prolongs the lifecycle of network and keeps a balance of load. Meanwhile, it is definitely possible to increase the amount of information sent by the sensors as well as improving the equalization of energy consumption.

Acknowledgments

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