

A Novel Clustering Routing Protocol in Wireless Sensor Network

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Abstract

The phenomenon of network resource-constrained often appears in wireless sensor network (WSN) because of nodes with energy-limited, so it becomes a research topic to study on high-performance routing protocol in wireless sensor network. In accordance with the characteristic of quantum particle swarm optimization (QPSO), a novel clustering routing protocol with QPSO algorithm is proposed based on the low energy adaptive clustering hierarchy (LEACH), which includes several steps, such as determining the number of cluster-head, preliminary clustering, optimization on temporary cluster by QPSO algorithm, clustering after optimization, and so on. Comparative analysis on simulation experiments show that the proposed routing protocol is superior to that of LEACH, and saves energy consumption of network excellently and balances energy of nodes so as to prolong the life of the network.

Keywords: wireless sensor network, clustering routing protocol, quantum particle swarm optimization

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1. Introduction

The advances in wireless communication technology, electronic technology, sensor technology and micro-electromechanical systems (MEMS) has promoted the development of wireless sensor network(WSN) applications and research. Wireless sensor network is a network composed of numerous sensor nodes which have the powers of perception, communication and computing, it is connected by wireless mode, and it has a wide application prospect in many fields [1, 2]. As the important part of the network layer, the network routing deliver the information from the source node to network, and it's the efficient communication of the network. Due to the limitations of the hardware which has the wide distribution of nodes, limited energy [3], the small memory, the bad computing power and narrow bandwidth in wireless sensor networks, the routing algorithms used in many traditional fixed-network and mobile self-organizing network can not be effectively used in wireless sensor network [4]. In this case, it has extremely important significance to the proposed routing protocol of low energy adaptive clustering hierarchy (LEACH) [5], which defines the "round" concept and allows different nodes become the cluster-head with the random probability P in different time, the relay communication business is average shared in WSN. Compared to the same plane routing protocols, LEACH protocol improves the overall performance of the network and balances energy consumption of nodes. Based on LEACH, this paper proposes the improvements to solve inadequacies of LEACH.

Sun Jun et al [6] proposes a kind of quantum particle swarm optimization (QPSO) algorithm based on quantum computing, due to the particle can appear any position in the entire feasible search space with a certain probability, and has a better fitness value, so the global search performance for QPSO algorithm is superior to that of PSO algorithm. The state of particle is only described with the position vector, and only one parameter β needs to be determined in QPSO algorithm, so the QPSO algorithm has more advantages:

- (1) The few parameters, simple programming and easy to implement;
- (2) The rapid convergence, and quickly find the optimal solution in the global scope.

Therefore, according to the advantages or characteristics of the QPSO algorithm, literature is replete with applications of QPSO in WSNs [7]. Low energy aware clustering hierarchy (LEACH) is a simple and efficient algorithm. Clustering is an NP-hard optimization problem [8], which QPSO can handle efficiently. Clustering or cluster-head selection is not a

one-time activity; therefore, the simpler the optimization algorithm, the better the network efficiency is. This is a reason why QPSO is an efficient choice for WSN clustering. This paper proposes a novel WSN clustering routing protocol combining with LEACH, which is used in actual application. The main work or innovation is as follows.

(1) The number of fixed cluster-head is at 5% of the total number of sensor nodes in LEACH [6], which is only experimental data without any basis. This paper optimizes the number of cluster-head based on the mathematical model of the physical image sensor network, and dynamically adjusts the proportion so as to decrease the network energy consumption.

(2) The energy consumption between the nodes is only balanced by clustering in LEACH. On the basis of LEACH, the proposed routing protocol in this paper can rebalance the energy of each node in cluster, and effectively avoid the emergence of a lot of blind nodes and further prolong the network lifetime.

2. Principle of QPSO Algorithm

2.1. Algorithm Overview

Quantum particle swarm optimization (QPSO) algorithm is the improvement of the classical PSO algorithm [5], the velocity and position of particle are closely related with a parameter γ in the QPSO algorithm. To ensure the convergence of the algorithm, a median optimal position is adopted to calculate the next iterative variable for particle, which is defined as the average value of personal best positions for all particles ($mbest$). The formula for $mbest$ is as follows:

$$mbest = \frac{1}{M} \sum_{i=1}^M P_i = \left(\frac{1}{M} \sum_{i=1}^M P_{i1}, \dots, \frac{1}{M} \sum_{i=1}^M P_{id} \right) \quad (1)$$

Here, M is the number of particles, P_i is the personal best position of the i -th particle in d -dimension space.

And the particle evolution equation can be obtained as follows:

$$P_{id} = (\phi_1 \cdot P_{id} + \phi_2 \cdot P_{gd}) / (\phi_1 + \phi_2) \quad (2)$$

$$X_{id}(t+1) = P_{id} \pm \gamma |mbest - X(t) \ln(1/u)| \quad (3)$$

Here, P_{id} is d -th dimension coordinate of i -th particle, P_{gd} is the global best position in all particles, X_{id} is d -th dimension coordinate of i -th particle in particle quantum particle swarm space; ϕ_1, ϕ_2, u are the random number between 0 and 1; γ is contraction-expansion coefficient, whose role is to control the speed of convergence, when $u \geq 0.5$, the formula (3) takes “-”, otherwise takes “+”.

The algorithm steps for QPSO are as follows:

Step 1: Initialize each quantum particle position $X_i = (x_{i1}, x_{i2}, \dots, x_{id})$ in d -dimension space.

Step 2: Evaluate the fitness value of particle. If the fitness $f(x_i)$ in current position is bigger than the fitness $f(pbest_i)$ of the past best position, then $pbest_i = x_i$; then compare the fitness values of all current particles, if $f(x_i)$ is bigger than the fitness of global best position ($f(gbest)$), the global optimal solution is $gbest = x_i$.

Step 3: Update the quantum particle swarm in accordance with formula (2) and (3).

Step 4: Check whether the end condition is satisfied or not. If it is met, Stop the iteration; otherwise, return to Step 2 to continue the iteration.

2.2. Application and Analysis on QPSO Algorithm

In order to verify the validity of QPSO algorithm, we compare the QPSO, Basic PSO (BPSO) and Genetic Algorithm (GA) by computer simulation. The following common test function is selected for comparison.

Sphere function: $f(x) = \sum_{i=1}^n x_i^2$, find a minimum value in the range [-5,5].

The maximum number of iteration max iter is set to 100 times for three algorithms, the size M of the particle swarm is 10, the number of particle dimension (d) is 2, γ is 0.75. The crossover probability is 0.95 and the mutation probability is 0.05 in GA.

For the sake of comparison, the performance indicator for evaluation is set as mean square error, which is as follows.

$$e = \frac{1}{n} \sqrt{\sum_{i=1}^n (x_i - \hat{x}_i)^2} \quad (4)$$

Here, x_i is the actual output value, \hat{x}_i is the desired output value.

The error e represents the mean square error between the iteration result in function optimization and the true value, which displays the optimization precision of the algorithm. Figure 1 shows the iteration error curve of Sphere function.

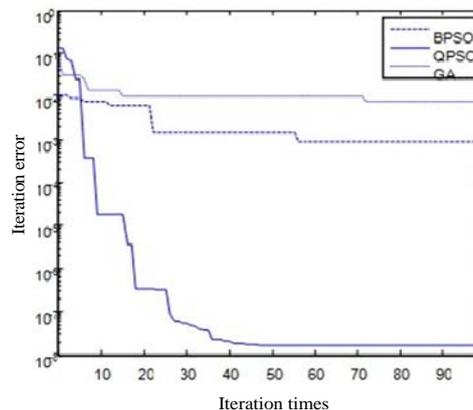


Figure 1. The Iteration Error Curve for Sphere Function

From Figure 1, the GA and BPSO algorithm still maintain a big error value after 70 iteration times, but the error curve of QPSO algorithm decreases rapidly with the number of iteration times increasing. After 42th iteration times, the error value becomes small and stable. Among them, error $e=2.7385 \times 10^{-2}$ when iteration times at 73 for GA, error $e=1.6582 \times 10^{-3}$ when iteration times at 53 for BPSO algorithm, and the error $e=1.8578 \times 10^{-7}$ when iteration times at 45 for QPSO algorithm. Obviously, QPSO algorithm is far superior to GA and BPSO algorithm in the convergence speed and optimization precision.

3. Clustering Routing Protocol Based on QPSO

3.1. Network Modeling

We adopt the wireless communication system model in reference [10] to calculate, which is constituted by the transmission circuit, power amplifier, and the receiving circuit. When the b bit data in transmission port is transmitted to the receiving port through the distance d , the energy consumption by transmitting is as follows:

$$\begin{cases} E_{Tx} = bE_{elec} + bu_1d^2 & d < d_0 \\ E_{Tx} = bE_{elec} + bu_2d^4 & d \geq d_0 \end{cases} \quad (5)$$

The energy consumption by receiving is as follows:

$$E_{Rx} = bE_{elec} \quad (6)$$

Here, $d_0 = \sqrt{u_1^2/u_2}$ is the critical value of distance. The energy consumption from the transmitting circuit to receiving circuit is $E_{elec} = 50\text{nJ/bit}$, the energy consumption of the amplifier circuit is $u_1 = 10\text{pJ/b/m}^2$ and $u_2 = 0.0013\text{pJ/b/m}^4$, the energy consumption of data fusion is $E_f = 5\text{nJ/bit}$.

Assume that there is N nodes which are distributed in the square area of side length A with Poisson distribution of distribution density $\lambda = N/A^2$, aggregation node (Sink) is located outside the distribution area, radius of propagation range of nodes is r , clustering probability is P , final clustering number is $K = N \cdot P$. Distribution density of cluster-head is $\lambda_1 = \lambda \cdot P$, and distribution density of ordinary node is $\lambda_0 = \lambda \cdot (1-P)$. If λ_0 and λ_1 are each independent, we can get the number $E[n_c] = (1-P)/P$ of member nodes in each cluster, and the average distance from cluster members to cluster-head is $d_{toCH} = 1/\pi\lambda_1$.

Above mathematical model is established, we can get the total energy consumption of WSN [9]:

$$E_{total} = 2bNE_{elec} + \frac{u_1bA^2}{\pi} \left(\frac{N}{K} - 1 \right) + bE_fN + Kb(u_2d_{tosink}^4 - E_{elec}) \quad (7)$$

Where d_{tosink} is the distance between cluster-head and aggregation node(Sink).

Formula (7) is the function with an independent variable K , then using the method of Laplace extremum, let $\frac{\partial E_{total}}{\partial K} = 0$, and we can get as follows:

$$K = \sqrt{\frac{u_1}{\pi(u_2d_{tosink}^4 - E_{elec})}} A\sqrt{N} \quad (8)$$

From formula (8), it is obvious that the ideal clustering number K is related to size of a given area and the number of the sensor nodes, not $N * 5\%$ in LEACH protocol.

3.2. The Specific Steps of Clustering Routing Protocol

(1) Determination of the number of cluster-head

To determine the clustering number K based on the mathematical model and the formula (8), then get clustering probability $P = K/N$.

(2) Preliminary clustering

Firstly, the network should be initialized and preliminary clustered with LEACH, determining the temporary clusters and cluster-head. At the same time, the temporary cluster-head collects the state information of each member in cluster, including location information (spatial coordinates) and energy information.

(3) Optimize the temporary cluster with the QPSO algorithm

The population size of quantum particles are initialized with cluster number K , and the spatial coordinates of the sensor nodes correspond to the position of quantum particles.

Because the spatial coordinates of the sensor nodes are random and discrete, quantum particle's position should be adjusted after particle updating with Step 3, which is adjusted by the minimum Euclidean distance method in this paper, that mean solving the Euclidean distances between updated quantum particles and all sensor nodes, and position of quantum particle is adjusted to spatial coordinate values of the nearest sensor node. Then the total energy consumption of WSN can be calculated on Equation (7).

To determine the fitness function is the most important thing in the stage. Based on the mathematical model and the equalization requirements, the fitness value of cluster-head not only relates to own state information, but also should be affected by state information of member nodes in cluster. Because the routing protocol with a single-hop transmission mode (i.e., transmit information directly between member node in cluster and cluster-head node), the farther distance the cluster-head node, the more relative energy the member node in cluster, on the contrary, the less energy the near member node in cluster. So the fitness function can be established as follows:

$$f(j) = \alpha \cdot e_j + \frac{\beta}{n-1} \sum_{\substack{i=1 \\ i \neq j}}^n e_i \cdot \ln \frac{1}{r_i} \quad (9)$$

Here, α , $\beta \in [0,1]$ and $\alpha + \beta = 1$, represent the energy impact factor of the node j and the remaining node in cluster respectively, e_j represents the energy of the node j , r_i represents the distance between node i and node j , n represents the number of nodes in cluster. The more suitable the cluster-head nodes, the bigger the fitness function value.

The positions of quantum particles are updated with the steps of QPSO. The $pbest_i$ and $gbest_i$ of particle is confirmed according to the value of fitness. The temporary cluster-head can be optimized in accordance, and the formal cluster-head in this round is determined so as to achieve to rebalance the energy of nodes in cluster.

(4) Clustering after optimization

The temporary cluster-head broadcasts the information of formal cluster-head to the nodes in cluster, then the clustering in this round and the determination of cluster-head are finished.

4. Simulation and Analysis

4.1. Simulation Environment

In the simulation experiment, the wireless sensor network consists of 100 sensor nodes with GPS positioning function in the area of 150m×150m. The distance between the Sink (base station) node and the center of the area is 150m. γ , the contraction-expansion coefficient, values 0.75. α and β in the fitness function value 0.6 and 0.4, respectively. The number of iterations is 100. The simulation parameters for radio model and network are given in Table 1.

Table 1. The Simulation Parameters

Parameter	Value
Network size	150m×150m
Base station location	X=75m,y=225m
Simulation round	450
Number of node, n	100
Cluster head probability of LEACH, P	0.05
Initial energy, E_0	0.1J
Packet size	5000bit
Transceiver energy, E_{elec}	50nJ/bit
Aggregation energy per bit, E_f	5nJ/bit
Multipath amplifier energy, u_2	0.0013pJ/bit/m ⁴

4.2. Simulation Results and Analysis

First of all, the simulation experiments and comparative analysis on energy consumption of network are carried out in accordance with the formula (7), Figure 2 shows the relationship between network energy consumption and the number of cluster-head.

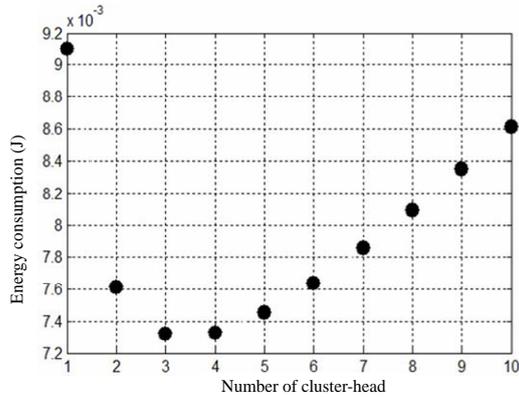


Figure 2. The Relationship between the Energy Consumption and the Number of Nodes

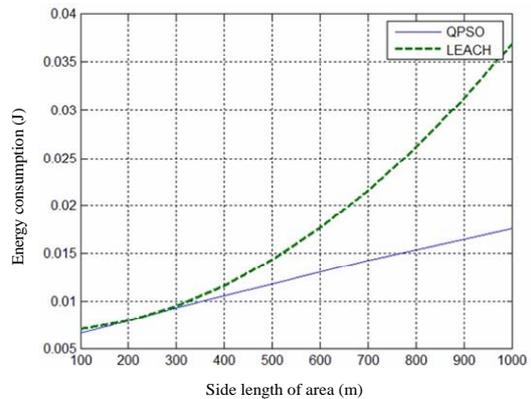


Figure 3. The Relationship between Network Energy Consumption and Side Length of Area

From Figure 2, there is a minimum in the network energy consumption when the number of cluster-head $K=3, 4$, and the theoretical result $K=3.4318$ calculated by the formula (8) is basically consistent with the actual value in Figure 2. It is clear that the minimization on network energy consumption can be achieved by optimization of the number of cluster-head.

Figure 3 shows the relationship between network energy consumption and side length of area. From Figure 3, with the increasing of the side length A of the network area, the energy consumption of two protocols increases. There is a little difference in energy consumption between the two protocols when the side length of area is small, but when the $A > 300m$, the energy consumption value of LEACH is higher than that of proposed protocol in this paper, with faster increasing rate almost in exponential form. This is because the clustering number of the proposed protocol is a dynamic variation, which is influenced by the factors such as the side length A and so on, but the clustering proportion of LEACH is fixed at 5%. Clearly, the proposed protocol is superior to LEACH protocol.

In order to analyze the performance of the entire WSN, we adopt the network lifetime parameter to evaluate performance of WSN. Figure 4 shows the simulation curves of network lifetime from two routing protocols. Here, the network lifetime is the time of all surviving nodes from the beginning of the simulation to the death.

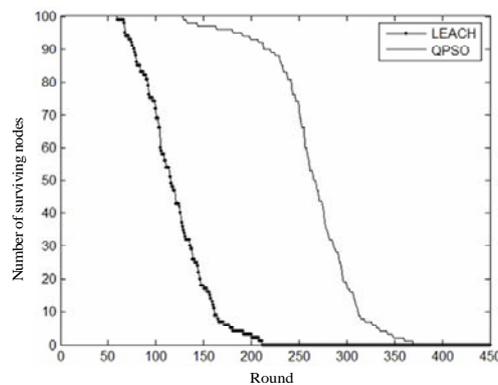


Figure 4. Comparison on Network Lifetime of Two Protocols

5. Conclusion

In this paper, the clustering routing protocol of wireless sensor networks based on the QPSO can effectively overcome the shortcomings, such as the low energy of wireless sensor, the poor utilization, and so on. By use of clustering optimization and energy equalization, the network lifetime is prolonged and network resource is better utilized.

In addition, for the single-hop communication may result in energy loss in the long-distance transmission [11], we can adopt the multi-hop communications or multi-layer clustering strategy to resolve.

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