Layer Based and Energy-Balanced Clustering Protocol for Wireless Sensor Network

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Abstract: Hierarchical routing algorithm is the most important method for prolonging lifetime of wireless sensor networks, which can not only decrease the energy consumption of the nodes, but also balance the energy dissipation of the entire network. Therefore, this paper proposes a new layer based and energy-balanced clustering protocol which was compacted energy-aware and energy-consumption-balanced. In the lower layer of the protocol, the optimal cluster of all nodes using particle swarm optimization algorithm was realized. And in the upper layer, the chief-cluster-head, which was responsible for collecting, aggregating the data of all cluster heads and sending the fused data to the base station, was selected. Simulation results demonstrated that the protocol can efficiently decrease the dead speed of the nodes and prolong the network lifetime.

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Keywords: Energy equilibrium, Wireless sensor network (WSN), PSO, Asynchronous clustering.

1. Introduction

Since wireless sensor networks (WSN) [1] nodes are usually deployed in inaccessible areas and usually powered by very limited micro-power battery, it is almost impossible to renewal the battery of the nodes again. Therefore, it is vital to improve the energy efficiency of nodes to extend the network lifetime of a wireless sensor network routing. In order to extend the network lifetime by saving nodes' energy and balancing energy consumption, this paper proposed using the particle swarm to help balancing energy consumption in wireless sensor networks from the master and vice cluster-head clustering routing protocol (PSO-MV), which chooses two of the best nodes as the cluster-head nodes at first, namely the master cluster-head (MCH) and the vice cluster-head (VCH), through particle swarm algorithm. Then, MCH and VCH work in phase. MCH is responsible for collecting information from cluster member nodes and sending the fused data to the nearest VCH. Inter-cluster routings are established among VCH, which communicate with the base station in the combinatory method of single-way and multi-way.

2. Particle Swarm Optimization (PSO)

The PSO [2, 3] is initialized to a group of random particles, and then find the optimal solution by iteration. All the particles have to be optimized by a decision of the fitness function, each particle has a speed to determine the direction of its flight and distance, and particles will follow the best particle in
the solution space seeking for the next best location. During iteration, the particles update themselves by tracking the two extremes. The first one is, by the particle itself, to find the optimal solution \( P_{id} \); the other extreme is the most optimal solution of the current population \( P_{gd} \). The updating formulas [4] as follows:

\[
V_{id}(t + 1) = wV_{id}(t) + c_1 r_1 (P_{id} - X_{id}(t)) + c_2 r_2 (P_{gd} - X_{id}(t))
\]

\[
X_{id}(t + 1) = X_{id}(t) + V_{id}(t + 1)
\]

In this formula, \( t \) stands for time of iterations; \( v_{id} \) is the speed of particle \( i \); \( x_{id} \) is the location of particle \( i \); \( r_1 \) and \( r_2 \) are random numbers between 0~1; \( c_1 \) and \( c_2 \) are accelerating factors; \( w \) is weighting coefficient.

3. Algorithm Review

PSO-MV clusters base on clustering routing, including the stages of generation and data transferring.

3.1. Cluster Formation

3.1.1. Initialize the Cluster-Heads

Selected candidate cluster-head nodes compose the set of initial cluster, set the energy threshold \( E_\lambda \):

\[
E_\lambda = \sum_{i=1}^{n} E_i / N
\]

3.1.2. Information Gathering Stage of Cluster Members

Nodes will send the remaining energy, position and ID numbers and other information of the members to the base station through the candidate cluster. Then each neighboring candidate cluster-head node obtains the ID, location and residual energy, and more.

3.1.3. PSO-Based Optimization of Cluster Head Election Phase

Using PSO algorithm to optimize the choice of master-slave cluster-head is the core of this algorithm, the algorithm follows these steps:

Step1: Initialize Q particles: randomly initialize swarm cluster head’s \( X \) and \( V \) from candidate particle.

Step2: Calculate the adaptive value of every particle cost by using formula (5).

Step3: Determine the optimal solution for each individual particle and population optimal solution.

Step4: Update the speed and location of particles by formula (1) and (2).

Step5: Repeat the step 2~4 until meet pre-defined iterations, then choose the most optimal solution and the second-best interpreted as the main from the cluster head.

3.1.4. Optimal Cluster Formation Stage

After the stage of selecting of PSO optimizing, the base station broadcast the most optimal set of cluster heads and cluster structure out. While each non-cluster head node chooses to join which of the cluster based on the received signal strength, they send their remaining energy, their location and other information to the cluster head nodes. Then, it waited for the cluster head node to be assigned TDMA time slots to avoid data conflicts.

3.2. Data Transfer Stage

3.2.1. Data Transfer within the Cluster

After the main cluster head node assigning TDMA time slot, the cluster member nodes send packets to the cluster head node in the corresponding time slot. And without the delivery time, the transceiver device could be turned off and turn into sleep mode to reduce the consumption.

3.2.2. Data Transfer Between the Clusters

The main cluster head node will send the data fusion of the members of nodes to the nearest slave cluster heads (including base station) after receiving the data. In order to overcome LEACH protocol which causes some nodes to die untimely in a way of single hop, the routing between clusters takes the way of combining single hop and multi-hop. Setting the distance between cluster head node and Sink nodes as \( d \), set the limit value of \( d_0 \), 1) If \( d \leq d_0 \), a single hop from the cluster head in the form of direct communication with the Sink node; 2) If \( d > d_0 \), using PSO to search the optimal path in the upper level to achieve plane data transmission between clusters and reduce energy consumption to extend network life cycle.
3.3. Improved Fitness Function

For wireless sensor network routing optimization model characteristics and goals, the following factors should be responsible for the fitness function: 1) cluster head energy rating factor $f_1$: the current candidate node’s remaining energy; 2) cluster head from the evaluation factor $f_2$: mainly considering the distance between the remaining members of the cluster nodes and this node, the smaller the average distance, the better for the node being the cluster; 3) the equilibrium level of residual energy evaluation factor $f_3$: the more balanced level of residual energy in the rest of the network nodes, the more easily for it to avoid the network empty; 4) the distance between base stations evaluation factor $f_4$. The fitness function is defined:

$$\text{cost} = \alpha_1 f_1 + \alpha_2 f_2 + \alpha_3 f_3 + \alpha_4 f_4 \quad (5)$$

$$f_1 = E_0 / E_i \quad (6)$$

$$f_2 = \sum_{\text{CH}_i \in C(i)} d(n_j, \text{CH}_i) / |C(i)| \quad (7)$$

$$f_3 = \sqrt{\sum_{j=1}^{i \in C(i)} (E_j - \mu)^2} \quad (8)$$

$$f_4 = \max_{k=1,2,\ldots,k} \{d(\text{BS}, \text{CH}_i) / d(\text{BS}, \text{NC})\} \quad (9)$$

$E_i$ is the current residual energy particle $i$, $\text{CH}_i$ stands for the first candidate cluster head $i$, $|C(i)|$ means the members of the nodes; $d(n_j, \text{CH}_i)$ is the distance between members of the node $j$ to the candidate cluster head node $\text{CH}_i$. BS is the representation of the base station, NC stands for the network center coordinates: $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are weight coefficients for each evaluation factor, $\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$, so the smaller the fitness function, the more fitness to be a cluster head.

4. Energy Consumption Model for Wireless Communication

In this paper, we will use that energy consumption model for wireless communication mentioned in paper [5, 6]. Wireless communication module has the function of power controlling: it can use the minimum energy to send data to the receiver, each $k$ bit of information sent to the distance $d$ will the amount of energy of:

$$E_{\text{trans}}(k, d) = \begin{cases} 
E_{\text{elec}} \times k + E_{\text{fs}} \times k \times d^2 & (d < d_0) \\
E_{\text{elec}} \times k + E_{\text{mp}} \times k \times d^4 & (d \geq d_0) 
\end{cases} \quad (10)$$

where, $k$ stands for the dispatching binary digits, $d$ is the sending distance, $d_0$ is the threshold of sending distance.

$$d_0 = \sqrt{E_{\beta} / E_{\text{mp}}} \quad (11)$$

$E_{\text{elec}}$ is the coefficient of RF energy consumption, its unit is nJ/bit. $E_{\text{fs}}, E_{\text{mp}}$ is the Energy coefficient of the amplifier circuit, unit is pJ/bit$m^2$. If the distance is less than $d_0$, power amplifier will use the free space loss model; if the distance is more than $d_0$, it will use multi-path fading model. Energy consumption [7, 8] of receiving data is:

$$E_{\text{fs}}(k) = E_{\text{elec}} \times k \quad (12)$$

So the energy consumption for one $k$ bit data transferring from node $n_i$ to $n_j$ is:

$$E_{\text{rc}}(k) = E_{\text{fs}}(k) + E_{\text{r}}(k, d) \quad (13)$$

5. Network Simulation and Protocol Analysis

We will use the model of wireless communication mentioned in section four. In the simulation, wireless sensor networks composed by 100 nodes, nodes randomly distributed in a 100 m × 100 m area. This paper will use Matlab to make the simulation. The main parameters of the wireless sensor network model are: the initial energy for each node is 0.5 J, population scale is: $Q=30$, $c_1 = c_2 = 2$, $w=0.9$. The rand will be given randomly during the processing. Evaluation factors: $\alpha_1=0.25$, $\alpha_2=0.3$, $\alpha_3=0.25$, $\alpha_4=0.2$. To test the effectiveness of the algorithm, when emulational base station locates in the center of monitoring area: (50,50) and the area limit (50,100), it will running the states of the remaining numbers of nodes after Master-slave cluster head algorithm and LEACH protocol. The comparison result as the Fig. 1.

The Fig. 1 stands for the comparison result of Network lifetime when the base station locates in (50,100) and (50,50) as running PSO-MV, LEACH and PSO. The result shows as following: overall, whether the base station is located in the monitoring of the regional center or edge of the area after the implementation of PSO-MV algorithm, the time that from starting the operation of the network to the death of the first node is longer than either the PSO or LEACH, the network lifetime has been renewed. This algorithm is due to the first elections in the cluster using PSO fully considered the balance of the remaining residual energy level, the average distance between neighboring node and candidate cluster head node and so on. To some degree, the better energy balance and the division of labor in the data transmission phase help the network avoiding some nodes to die for the heavy load. The Table 1 lists the rounds of dying for the first node, the rest half nodes, and 80 % of nodes.

Table 1: Network simulation results.

<table>
<thead>
<tr>
<th>Base Station Location</th>
<th>Round of Dying</th>
</tr>
</thead>
<tbody>
<tr>
<td>(50,50)</td>
<td>50</td>
</tr>
<tr>
<td>(50,100)</td>
<td>70</td>
</tr>
<tr>
<td>(50,50)</td>
<td>90</td>
</tr>
<tr>
<td>(50,100)</td>
<td>110</td>
</tr>
</tbody>
</table>

150
The Fig. 2 shows the total energy consumption of the LEACH, PSO and PSO-MV protocol agreement in the network when base station locate in (50,50). The figure shows that the proposed PSO-MV protocol is to be significantly lower than the total energy consumption of LEACH and the PSO agreement, indicating that although the PSO-MV protocol which is used in the clustering process of two-particle swarm cluster head needs more time consuming. But this Algorithm makes the network more balanced and compact, and greatly extends the network cluster head election cycle, thus saving more energy, so it balanced the energy of the network at the end, to extend the network cycle.

**Table 1.** Lifetime comparison.

<table>
<thead>
<tr>
<th></th>
<th>Base station at (50,100)</th>
<th>Base station at (50,100)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LEACH</td>
<td>PSO</td>
</tr>
<tr>
<td>Rounds for 1st node dying</td>
<td>667</td>
<td>892</td>
</tr>
<tr>
<td>Rounds for half of nodes dying</td>
<td>1206</td>
<td>1437</td>
</tr>
<tr>
<td>Rounds for 80% of the nodes dying</td>
<td>1375</td>
<td>1724</td>
</tr>
</tbody>
</table>

**6. Conclusions**

This paper proposed the double cluster head based on PSO clustering routing algorithm PSO-MV. Through simulation experiments, the result proves that it has good performance. Algorithm optimizes energy consumption by distributing the labor for cluster head node and subordinate ones, balancing energy consumption to extend the network life cycle effects. However, the main focus of this paper is to extend the network life cycle. Therefore, the choice of parameters of the algorithm is not considered deeper.

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**References**


