Optimal Design on Clustering Routing Protocol for Wireless Sensor Network

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Abstract

Due to the limited energy for sensor nodes in wireless sensor network (WSN), the clustering for nodes becomes an effective scheme to save energy, but it is premature to appear the phenomenon of blind nodes because of ignoring the state information for neighbor nodes in determining cluster-head, accordingly leads to waste energy. So a novel clustering protocol based on evolutionary computation is studied in accordance with the point of energy saving optimization, which includes the construction of fitness function using the information of neighbor nodes within the cluster energy and the distribution, and determining cluster-head using Particle swarm optimization (PSO). The results of simulation experiment show that the improved protocol can effectively avoid the blind nodes phenomenon in LEACH protocol, can save energy and prolong the network lifetime.

Keywords: Wireless Sensor Network; Clustering Routing Protocol; Particle Swarm Optimization Style Guide; Examples; Latex Style

1 Problem Posing

Wireless sensor network (WSN) [1, 2] is a network system integrated monitoring, control and wireless communication. Compared with the wireless self-organized network, its node-number is larger and the node distribution is more intensive. In general, the sensor node is fixed, but the energy, processing power, storage capacity and communication capacity of the sensor node are very limited, the efficient use of energy becomes the primary goal for design, therefore the nodes clustering method [3] becomes an effective scheme on saving energy for wireless sensor network.

1.1 Fundamental principle of LEACH routing protocol

LEACH routing protocol [5, 6], namely low energy adaptive clustering hierarchy protocol, which is the earliest clustering routing protocol presented in wireless sensor network, its executive process...
is recycling and it adopts adaptive clustering technique and cluster-head node rotation technique. All the nodes are divided into several clusters, each cluster is selected from a cluster-head, and rest nodes of the cluster are as the cluster member.

The process of LEACH protocol to select cluster-head is as follows: The node generates a random number between 0 and 1, if the number is less than the threshold value $T(n)$, then broadcast the message that its own is a cluster-head. In each round of cycle, if the node has been selected as the cluster-head, then set $T(n)$ as 0, so the node will not be re-elected as the cluster-head.

For the node not being elected to the cluster-head node, it will be elected as the cluster-head node according to the probability of $T(n)$. The threshold value $T(n)$ can be expressed as:

$$T(n) = \begin{cases} \frac{P}{1 - P \times \text{r mod}(1/P)} & n \in G, \\ 0 & \text{otherwise} \end{cases}$$  

(1)

Here, $P$ is the percentage of cluster-head accounted for all nodes, $r$ is the round in current cycle, and $G$ is the nodes set which has not been elected as cluster-head in the latest cycle of $1/P$ round.

From the formula (1), the node ever elected as cluster-head node will not become a cluster-head in the following cycle of $1/P$ round, the threshold $T(n)$ of the residual nodes elected as the cluster-head increases, and the probability that the node produce random number less than $T(n)$ will also increase. So the probability of nodes elected as the cluster-head increases. When only one node is not selected as the cluster-head, the value of $T(n)$ equals to 0, so the node must be elected.

### 1.2 Shortage of the LEACH routing protocol

In the clustering routing protocol [3], cluster-head nodes are not only responsible for information collection in the internal cluster and fusion processing, but also responsible for transmitting data between clusters, so the choice of cluster-head is very important. The current typical clustering routing algorithm, such as LEACH solves many different problems from the point of saving energy, but these algorithms in choosing the cluster-head only rely on the state information of candidate nodes, and neglect the state of circumjacent neighbour node [6].

When the energy of neighbour nodes presents the unbalanced situations, the communication between cluster-head and neighbor nodes away from the cluster-head will consume more energy, if the residual energy of the node is limited at this time, and soon the node will run out of existing energy and becomes a blind node, frequent appearance of blind nodes will reduce the network average lifetime and lead to low efficiency of routing protocol.

Therefore, we must research the new routing protocol to overcome the shortage of LEACH protocol. From the point of energy saving optimization, the clustering routing protocol in WSN based on evolutionary computation is researched in this paper.
2 Clustering Routing Protocol Based on Evolutionary Computation

2.1 Description of evolutionary computation

Evolutionary computation is bionic intelligent stochastic optimization algorithm based on biological evolutionary rule, which mainly includes genetic algorithm (GA), evolutionary programming (EP) and evolution strategy (ES), and also includes the swarm intelligent method such as the ant colony optimization (ACO), particle swarm optimization (PSO) and fish swarm optimization (FSO), etc. It has been widely used in every filed by virtues of its wide range of application, highly nonlinear, easy to modify and parallel computing. Evolutionary computation is a kind of iterative algorithm, and the main steps are as follows:

Step 1 Given a group of initial solution.

Step 2 Evaluation the performance of this group of solution.

Step 3 According to the performance index from step 2, selecting a number of Solution from the current group as the basis of iteration.

Step 4 Evolutionary operation on the solution, such as gene recombination and mutation, then take the result as the solution after iteration.

Step 5 If the solution has meet the requirements, then stop the iteration; otherwise, make the iterative solution as the current solution, then return to step 2.

In the specific application, the construction of performance index and the choice of evolutionary operation are particularly important, which are directly related to the effect of optimization.

2.2 Construction of fitness function

Fitness function is a performance index which can directly reflect the evolutionary computation, but the construction of fitness function should rely on specific problems. In order to overcome the shortage of LEACH routing protocol, the fitness value of nodes in WSN should not only reflect the size of the node energy itself, but also reflect the energy distribution around the node. In addition, the farther neighbor nodes around the node, the larger its energy, the closer neighbor nodes around the node, the smaller its energy. We construct the fitness function according to these characteristics [6].

\[
f(k) = \eta e_k + \frac{\lambda}{n - 1} \sum_{i=1, i \neq k}^{n} \frac{e_i}{r_i + 1}.
\]  

(2)

Here, \( \eta + \lambda = 1 \), and \( \eta, \lambda \in [0, 1] \), \( \eta \) is the energy impact factor of the current node \( k \), \( \lambda \) is the energy impact factor of the neighbor node \( i (i \neq k) \), \( e_i \) is the residual energy of the node \( i \), \( r_i \) is the distance between the node and the current node \( k \).


2.3 Selection on evolutionary operation

The selection on evolutionary operation is that of evolutionary algorithm actually; for example, there are genetic algorithm, PSO algorithm and the improvement of all kinds of algorithms. Considering the PSO algorithm for its simple operation and easily realization, we use the pso algorithm to optimize design on WSN clustering routing.

Assume $x_i$ and $v_i$ are the position and speed of the current particle respectively, $pbest$ and $gbest$ are the best position on single particle and the best position on all particles respectively, the evolutionary operation is as follows [7]:

$$
\begin{align*}
    v_i &= w v_{i-1} + c_1 \cdot r_1 \cdot (pbest - x_{i-1}) + c_2 \cdot r_2 \cdot (gbest - x_{i-1}), \\
    x_i &= x_{i-1} + v_i
\end{align*}
$$

Here, $w$ is inertia weight, its value start by 0.9 and linear decease to 0.4 along with the epoch (iteration number); $c_1$ and $c_2$ are accelerated constants, generally $c_1 = c_2 = 2$, $r_1$ and $r_2$ are random number between 0 and 1.

2.4 The WSN clustering routing protocol based on PSO

The clustering routing protocol optimized by PSO is called the improved protocol in this paper, its main idea is: Firstly the network is divided preliminarily in accordance with the cluster, and then using the PSO algorithm and synthesizing the state information of neighbor nodes to select cluster-head, finally broadcasting the cluster-head information to the whole internal cluster. The specific steps of improved protocol are as follows:

Step 1 The preliminary stage of cluster

First we adopt LEACH algorithm to take a preliminary division on clusters in WSN, then the clusters and cluster-head can be determined roughly. For this reason of that the formed cluster is very easy to appear blind node, so the cluster-head of the formed cluster is called auxiliary cluster-head.

Step 2 The stage that auxiliary cluster-head collects state information from nodes in the cluster

The each neighbor node in the cluster transmits the location and the energy state information of the own node to the auxiliary cluster-head.

Step 3 Cluster-head determining stage using PSO algorithm

This stage is the core of optimization algorithm, according to the formula (2), we select the node having a greater fitness value in particles as the cluster-head after optimization.

Step 4 Optimizing stage of cluster formation

In this stage, the auxiliary cluster-head nodes broadcast the optimized cluster-head information to the nodes in the cluster, so as to realize that the cluster-head collects and fuses the cluster nodes information in cluster. For synthesizing the state information of neighbor nodes in cluster-head forming, the energy consumption of nodes in the cluster is balanced, thus the phenomenon that the blind nodes frequent appearance can be avoided effectively.
3 Simulation Experiment

3.1 The WSN clustering routing protocol based on PSO

In the simulation experiment, the wireless sensor network consists of multiple nodes with GPS positioning function; all nodes are randomly distributed in the region of simulation environment, and the base station is located in the center of coordinate.

The parameters of WSN model are as follows: the initial energy of each node is 0.5J, initial division on the network using the LEACH algorithm, each node sends a data packet of 20000 bit to its cluster-head in each round of the cluster reconstruction process. The parameters values in the PSO algorithm are as follows: $\eta = 0.6$, $\lambda = 0.4$, $c_1 = c_2 = 2$, $w = 0.9$, and the values of the $r_1$ and $r_2$ are random given dynamically during operation; The End condition is that the maximum epoch (iteration times) is 1000.

In order to test energy efficiency of the improved protocol, we will make a comparative analysis with typical LEACH protocol, and the network lifetime is selected as performance evaluation parameter in the analysis; which is the number of rounds from the beginning of the simulation to 20% nodes run out of energy, here the number of rounds is the number of the cluster reconstruction process in algorithm execution.

3.2 Simulation results and analysis

The distribution of sensor nodes and cluster-head in LEACH protocol is shown as in Fig. 1, in which blue * is for ordinary sensor nodes, □ is for the nodes ever elected as cluster-head nodes; The distribution of sensor nodes and cluster-head in improved protocol is shown as in Fig. 2, in which blue * is for ordinary sensor nodes, red * is for the nodes ever elected as cluster-head nodes.

![Fig. 1: Sensor Nodes Distribution for LEACH](image-url)
To compare Fig. 1 with Fig. 2, it is easy to find that all the nodes in the LEACH protocol are ever elected as the cluster-head, but only part of nodes in improved protocol is selected as cluster-head.

The comparative analysis of the two protocols is as follows.

(1) Select 50 network nodes randomly distributed within the region of 50m × 50m simulation environment, meanwhile the base station is located in the center of coordinate, the situation of surviving nodes in the two protocols is shown in Fig. 3.

Fig. 3: Situation for surviving nodes
(2) Select 25 network nodes randomly distributed within the region of $50\text{m} \times 50\text{m}$ simulation environment, meanwhile the base station is located in the center of coordinate, the situation of surviving nodes in the two protocols is shown in Fig. 4.

(3) Select 25 network nodes randomly distributed within the region of $30\text{m} \times 30\text{m}$ simulation environment, meanwhile the base station is located in the center of coordinate, the situation of surviving nodes in the two protocols is shown in Fig. 5.
From the Fig. 3, Fig. 4 and Fig. 5, we can see the network lifetime of the improved protocol is significantly longer than that of LEACH protocol, and the lifetime of the first node is significantly delayed, for the reason of residual energy of network node in LEACH appears unbalanced state after operating for a period of time, but improved protocol can balance the energy consumption of nodes in cluster, and avoid appearance of the blind nodes, so as to prolong the network lifetime. From Figure 3 and Figure 4, the smaller the distribution range for the same number of nodes is, the more prominent the advantages of improved protocol are, and the lifetime of nodes is longer relatively. From Figure 4 and Figure 5, the more widely the distribution range for the same number of nodes is, the more prominent the advantages of the improved protocol are, and the life time of nodes is longer relatively.

4 Conclusions

In the wireless sensor network, the performance of routing protocol determines the overall performance of network. According to the shortage of LEACH protocol, a clustering routing protocol based on evolutionary computation is researched from the point of energy optimization. Simulation experiments show that the PSO-based clustering routing protocol can effectively avoid the phenomenon of blind nodes that easily appeared in LEACH protocol, save energy and prolong the lifetime of wireless sensor network.

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