Energy Aware Routing Algorithm for Wireless Sensor Network Based on Ant Colony Principle

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Abstract

This paper proposed a wireless sensor network routing protocol base on ant colony principle and LEACH protocol with energy prediction. The new algorithm added the factor of energy in the procedure that ants had been searching the optimal path. Cluster-head sent data to sink by multiple hops transmission. Therefore, the new algorithm reduced cluster-heads energy consumption. In order to avoid route over-concentration, the new algorithm predicted energy consumption of nodes when it calculated probability of next-hop. The simulation results showed that the new algorithm had the better energy efficiency and the more balanced energy consumption. At the same time, it extended the network lifetime.

Keywords: Wireless Sensor Network, LEACH Protocol, Ant Colony, Prediction, Clustering

1. Introduction

Wireless Sensor Network (WSN) is a multiple hops communication network that it has many sensor nodes with communication and computing power. It has characteristics of no central control and dynamic topological structure [1]. It is the core issue how to reduce energy consumption of sensor nodes and prolong the network lifetime due to the sensor node energy limited [2].

Because the network routing nodes are in charge of sending the information from source nodes to destination nodes, therefore, selecting routing nodes has become the research hot spot on the energy-efficient of wireless sensor network. According to the topology of the network, WSN routing protocol has three categories, the planar routing protocols, the level routing protocols and the routing based on geography [3-4]. LEACH (Low Energy Adaptive Clustering Hierarchy) is a low energy adaptive clustering routing protocol [5]; it is a more efficiency routing protocols. But, the cluster-head in LEACH protocol directly communicates with the sink and the cluster-head losses energy quickly far from the sink. The paper [6] put forward the Ant Colony Optimization (ACO) routing algorithm that it exchanged datum through online delay. The distributed algorithm based on the ant colony optimization was proposed in [7], each region explored approximate optimal transmission distance according to its nodes distribution. The paper [8] made ACO better meeting the routing protocol on WSN by the pheromone incremental formula which introduced the nodes energy and the transmission distance into ACO. The paper [9] proposed a new algorithm based on ant routing optimization using the BEIDOU positioning system. The paper [10] proposed which makes full use of the history information is developed to clustering the network. The inter-cluster communication cost and cluster size are also considered when clustering. Nodes with high residual energy and low energy consumption ratio have more possibility to be cluster heads. The paper [11] proposed an energy efficient dynamic mixed key management based on virtual grid for wireless sensor networks. The paper [12] proposed a novel energy-efficient routing protocol for WSN to prolong network life time along with shortening communication path.

According to the study results, although many improved routing protocols using the ant colony principle considered the factors of nodes energy, however, in the ant colony algorithm, it found the
optimal path and then forwarded the data. So, a node appeared likely in the optimal path of multiple nodes because of energy factors; such it led to nodes premature death due to large energy consumed. Combining LEACH protocol and ant colony principle, this paper proposed a wireless sensor network routing protocol base on ant colony principle with energy forecast, it named LEACH-P. Cluster-head sent data to sink by multiple hops transmission. Therefore, the new algorithm reduced cluster-heads energy consumption. In order to avoid route over-concentration, the new algorithm predicted energy consumption of nodes when it calculated probability of next-hop.

2. LEACH protocol and ant colony algorithm principle

2.1. LEACH protocol

The basic idea of LEACH protocol assigns network energy loads to each node with circle cluster-head node random election. LEACH protocol divides the entire network cycle into "round" and "cycle". Each round has two stages of initialization and stability data transmission; each round randomly chooses a cluster-head which the election mechanism is for: each sensor-node randomly chooses a random number between 0 and 1. If the random number is less than the given threshold \( T(n) \), the sensor-node is elected as the cluster-head, which the calculation method of the threshold is for:

\[
T(n) = \begin{cases} 
1 - p^r \mod (1/p) & \text{if } n \in C \\
0 & \text{otherwise}
\end{cases}
\]

\( p = k/n \), which is the probability of a node elected the cluster-head; \( k \) is the number of the cluster-head; \( n \) is the number of nodes in the network; \( r \) is the number of the current rounds; \( C \) is the nodes set which didn’t serve as a cluster-nodes in the past \( r-1 \) rounds. Apparently, through this mechanism, the threshold \( T(n) \) of the node which belongs to \( C \) set will increase, the node is elected as a cluster-head with a greater probability, and it can guarantee ultimately that each node can serve as cluster-head in the continuous \( 1/p \) round.

2.2. Ant colony algorithm principle

As a general stochastic optimization method, the ant colony algorithm just randomly selects a search path and doesn't need any prior knowledge at first. With the understanding of the solution space, a search becomes regular and gradually approximates to the globally optimal solution. The mechanism of ant colony algorithm mainly includes three aspects:

(1) Ants communicate with pheromones each other and the pheromones are the media. When the companion selects the path, ants will choice paths according to the pheromone on the path.

(2) Ants can commit to memory the paths searched, the paths will not be selected in the next search, so the taboo list is created in algorithm simulations.

(3) The ant clustering activity, when the number of ants through some paths is less, the pheromone will be evaporation in the paths over time. When the number of ants through some paths is more, the number of the pheromone will be more and more. Such that the information intensity will increase, the probability of choosing this path will increase and the intensity of the pheromone in this path will be further greater. So we can simulate the phenomenon to establish the route choice mechanism and make the search of the ant colony algorithm towards the optimal solution. The search mechanism of the ant colony algorithm displays a positive feedback or autocatalytic characteristics.

3. Energy prediction algorithm based on ant colony

In many studies using ant colony algorithm to improve the network energy, all nodes in network find the path optimization according the ant colony principle. In this process, the information is received, sent and processed, it leads to energy consumption; energy consumption is much faster growth when network nodes are larger. Because the communications in the cluster is shorter, LEACH generally uses first order radio model to communicate information between cluster-head and
no-cluster-head, so the improved algorithm only adopting the ant colony principle in the procedure of cluster-head transmitting data to the sink nodes. LEACH-P algorithm reduce energy consumption because of looking for the optimal path and data receiving and processing.

### 3.1. Algorithmic principle

A cluster-head node in wireless sensor network uses an undirected weighted graph $G(V, E)$, $V$ is the cluster-head nodes set in every round of elections, including sink nodes; $E$ is the link set between each cluster-head. $V_i, V_j \in V, e(i,j) \in E$ if and only if it can direct communication between $V_i$ and $V_j$. For LEACH protocol, between each source node and cluster-head nodes, between cluster-head nodes and sink nodes directly communicate by using a single hop. But the communication ability of sensor node is limited, not all the nodes can direct communicate, so, $G$ is not a complete graph.

In the ant colony algorithm, each ant respectively selects a path from the start to destination according to the path selection probability, when all ants complete search, a search period ends. In the search process, the distance between the nodes is the main factor of selective probability of nodes. However, the choice of the next node in WSN, the remainder energy of nodes must be considered when selecting the next node and the more remainder energy node must be chosen as the next-hop node with the larger probability. Meanwhile, it still should be considered that energy consumption of some nodes is too fast for these nodes take too many tasks of data forwarding. Therefore, energy prediction mechanism must be brought into the improved algorithm.

**Definition 1:** $(\mu(i, j))$ is the predicting energy function of the node $j$ in the $t$ time: $\mu(i, j) = E_j - k \cdot C$.

$\mu(i, j)$ is the predicted energy of the node $j$ in the $t$ moment; $E_j$ is the predicted surplus energy; $k$ is the selected times of nodes before the $t$ moment; $C$ is the needed energy of nodes forwarding a data.

**Definition 2:** the Euclidean distance between the node $i$ and node $j$:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}.$$  

The probability of the node $i$ selecting the next node $j$:  

$$p_{ij}^k = \frac{[\pi(i, j)]^\alpha \cdot [\lambda(i, j)]^\beta \cdot [\mu(i, j)]^\delta}{\sum_{s \in allowed_k} [\pi(i, s)]^\alpha \cdot [\lambda(i, s)]^\beta \cdot [\mu(i, s)]^\delta}, \quad j \in allowed_k,$$

$$p_{ij}^k = 0, \quad otherwise; \quad \tag{2}$$

$\pi(i,j)$ is the pheromone strength of the edge $e(i,j)$; $allowed_k$ is the set that the node $i$ may select the next node. Generally, we define $tabuk$ ($k = 1, 2, ... m$) as the node set that the ant $k$ has passed; $m$ is the maximum number of ants, so $j \notin tabuk$. At initial moment, the pheromone in every path is same; an ant selects the next-hop node according to the pheromone strength in probability $p_{ij}^k$. $\lambda(i,j)$ is the inspire function of the edge $e(i,j)$, $\alpha$, $\beta$ and $\delta$ are the weighted parameter.

Power control can be used to invert this loss by appropriately setting the power amplifier—if the distance is less than a threshold $d_0$, the free space (fs) model is used; otherwise, the multipath (amp) model is used. Thus, to transmit an $m$-bit message a distance $d$, the radio expends [13]:

$$E_{rs} = \begin{cases} m \cdot E_{elec} + e_{fs} \cdot m \cdot d^2 & d \leq d_0 \\ m \cdot E_{elec} + e_{amp} \cdot m \cdot d^2 & d > d_0 \end{cases} \quad \tag{3}$$

$e_{fs}$ is amplifier parameter in the free space model; $e_{amp}$ is the amplifier parameter in the multipath model. $E_{elec}$ is energy consumption of the receive electronics or transmit electronics to process 1 bit packet; $d$ is the transmission distance; $d_0$ is the threshold. After adopting the ant colony principle, the cluster-head node uses multi-hop communication, so, we assume that LEACH-P uses the free space model to transfer packet between cluster-heads. In traditional ant colony algorithm, $\lambda(i,j)=1/d_0$. Obviously, the smaller distance between $i$ and $j$, $j$ has the greater probability which is elected the next-hop node. After several times of iteration, the source node $A$ can find a shortest path $S$ to the destination node $B$, it has an $n$ node in path $S$, then the energy consumption of the $A$ node sending $m$
bytes to the B node is:

\[ \text{Cost} = \sum_{i=1}^{n} \cos t(i) \]

\[ = \sum_{i=1}^{n} E_{(i)\text{Rx}} + E_{(i)\text{Tx}} \]

\[ = 2m^*n^*E_{\text{elec}} + \epsilon_{fs}^*m^*\sum_{i=1}^{n} d_{i,i+1}^2 \quad (4) \]

\[ \sum_{i=1}^{n} d_{i,i+1}^2 \] is the sum of node distance squares in the path; \( m, n, E_{\text{elec}}, \epsilon_{fs} \) is constants. So, the value of energy is proportional to the sum of node distance squares. Using the mathematical analysis method we can easily proof that \( \min(\sum_{i=1}^{n} d_{i,i+1}) \) is not the sufficient condition of \( \min(\sum_{i=1}^{n} d_{i,i+1}^2) \). Therefore, the information inspire function in the improved algorithm is defined as:

\[ \lambda(i,j) = \frac{1}{(d_{ij})^2} \quad (5) \]

When the ant \( A \) is from \( V_i \) to \( V_j \) by \( e(i,j) \), the pheromone strength \( \pi(i,j) \) is updated as follows:

\[ \pi(i,j) = (1 - \rho)\pi(i,j) + \rho \Delta \pi(i,j) \quad (0<\rho<1) \quad (6) \]

The pheromone incremental is define as follows:

\[ \Delta \pi(i,j) = \sum_{k=1}^{\text{num}} \Delta \pi(i,j)^k \quad (7) \]

\( \text{num} \) is the number of ant.

\[ \begin{cases} 
\Delta \pi(i,j)^k = \frac{Q}{L(k)} & \text{The kth ant went through e(i, j) path in this cycle} \\
\Delta \pi(i,j)^k = 0 & \text{Otherwise}
\end{cases} \] \quad (8)

### 3.2. Algorithm steps

Definition 3: Virtual pheromone matrix Tauv: Tauv is used to record the pheromone that \( m \) ant from the certain cluster-head nodes are leaving for the shortest path. Ants complete iteration each time and the value of Tauv is updated. Ants calculate the selective probability of the next node according to the value of Tauv. The size of Tauv is same with the size of the pheromone matrix Tau.

Algorithm steps:

1. The cluster-head nodes is elected according to LEACH protocol, the cluster-head node matrix--CHead is created, the pheromone matrix--Tau, the best route matrix of all cluster-head nodes--Rhead_best and the best route length matrix of all cluster-head nodes --Lhead_best are initialized.

2. A cluster-head is selected from the cluster-head set, the path matrix Tabu, the best route matrix of each cluster-head--R_best, the best route length matrix of each cluster-head--L_best are initialized. Tauv matrix is initialized to: \( \text{ones}(Cn, Cn) + \text{Tau} \), \( Cn \) is the size of the CHead matrix.

3. Path iteration, it is that \( m \) ants will be put in this cluster-head node, and then ants select the next node according to the probability of formula (2) until they reach the sink nodes.

4. Record the best route and the best route length of this iterative, update the virtual pheromones, clear the path matrix, return to step 3 until reaching the maximum iterating times.
Step 5: Record the shortest path of the cluster-head node, calculate the prediction energy in the best path of each node according to definition 1, return to step 2, look for the shortest path of the next cluster-head node until all the cluster-head node will find the shortest path.

Step 6: According to $R_{\text{head\_best}}$, calculate the energy consumption of each cluster-head node. This round ends and returns to step 1 for the next round election.

4. Analysis and simulation

The algorithm was simulated by MATLAB7.0. For our experiments, 100 nodes were randomly distributed to the square monitored area. The side of the area is 100m, 200m, 300m and 400m respectively. We observed the implementation in different areas. Other parameters as $E_{\text{elec}}=50\text{nJ/\text{bit}}$, $E_{\text{fs}}=10\text{pJ/\text{bit/\text{m}^2}}$, $E_{\text{amp}}=0.0013\text{pJ/\text{bit/\text{m}^4}}$, the sensor initial energy is 0.5 J, packet size is 4000bit, the base station location the top-left corner of the monitored area, $\alpha=1, \beta=5, \rho=0.1, Q=100$.

4.1. Network lifetime comparison

Compare the number of rounds of the two algorithms respectively at the first node death (1#), 20% nodes death (2#), 50% nodes death (5#) and 80% nodes death (8#). After 80% nodes died, we thought the network lost their effect. Figure 1. for the network lifetime which monitoring areas is set as: 100m×100m, 200m×200m, 300m×300m and 400m×400m respectively.

![Figure 1. Node death time in different monitoring area](image)

Figure 1. shows that LEACH-P and LEACH are not much different from the time of nodes death when the monitoring area is smaller. Sometimes, LEACH protocol is slightly better than LEACH-P algorithm, because LEACH-P algorithm uses multi-hops route, the energy of transmit packet has a decrease, yet this don’t compensate for the energy consumption of receiving data when the distance between nodes is very short. As the monitoring area is expanded and the distance between the nodes increases, LEACH-P algorithm was significantly better than LEACH in the network lifetime. And, the time interval to the node death of the first node and 80% nodes in LEACH-P algorithm is obviously shorter than LEACH. This indicates that LEACH-P algorithm is more balance in energy consumption.

4.2. Cluster-head energy consumption comparison

In order to easy to describe, for our experiments, the monitoring area of Figure.2 is set as 100m×100m, the number of nodes is 100 and each node begin with 0.25J of energy.

We statistical analysis the number of cluster-head in each energy consumption interval. Figure.2 shows that the energy consumption of the vast majority of cluster-heads, each round, is below 0.25mJ in LEACH-P. Accordingly, it is between 0.25mJ and 0.5mJ in LEACH protocol. The cluster-head count in LEACH-P is far greater than it in LEACH protocol when energy consumption of cluster-head is below 0.25mJ. In contrast, it is small when energy consumption of cluster-head is over 0.75mJ. These analytical results indicate that energy consumption of cluster-head nodes in LEACH-P algorithm is below to LEACH protocol.
4.3. The relation of the sequence of node death and the distance from the sink

The monitoring area is set as 150m×150m. Figure 3 (a) shows that the node fast dies if it is far from sink in LEACH protocol. It will influence the network coverage when all nodes are death in this region. Figure 3 (b) indicates that the sequence of nodes death has no obvious relation to the distance between nodes and sink. The probability of the node death is equal in different region, so LEACH-P can ensure effective network coverage in the WSN lifetime.

5. Conclusion

Combining LEACH protocol and ant colony principle, this paper proposed a wireless sensor network routing protocol base on ant colony algorithm with energy prediction. In this protocol, the square of the distance acts as the pheromones factor and prediction energy is introduced into the transition probability. This avoids some nodes premature death because the path is too centralized, balance energy consumption and optimize path. The simulation results show that the proposed LEACH-P can prolong the network lifetime. In the next work, we will further research the relationship between the node hop and the optimal path.

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7. References

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