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The Research of Wireless Sensor Networks Routing Protocol Based on Optimized Ant Colony Algorithm

Jianning Ding[12], Yi Lei[1], Guanggui Cheng[1], Zhiyong Ling[1], Zhongqiang Zhang[1], Li Zhang[1]

[1]*Center of Micro/nano Since &Technology,*
Jiangsu University, Zhenjiang, China
[2]*Center of Low-Dimension Materials, Micro/nano Device and System,*
Changzhou University, Changzhou, China
`leiyiwelcome@163.com`

***Abstract*—For wireless sensor networks, the core issue is to design an energy-efficient network protocol as far as possible. Ant colony algorithm has proved to be effective in prolonging the network's lifecycle and ensuring the reliability of data transmission. In conditions of network topology's dynamic changes, we optimized the basic ant colony algorithm and introduced the pheromone broadcasting mechanism to improve the routing protocol's performance. And we analysed the ant colony algorithm's realization mechanism in TinyOS. The simulation test of the routing protocol is proceeded on the TOSSIM platform. Results show that the optimized ant colony algorithm can choose the shortest path while balancing network energy consumption. The proposed routing protocol prolongs the lifecycle of the entire network, and also better adapts to dynamic changes of the network structure.**

***Keywords*-wireless sensor networks, ant colony algorithm, routing protocol, TinyOS, TOSSIM simulation**

I. INTRODUCTION

Wireless sensor networks is a large number of low-cost nodes to composite networks through wireless communication. It is used to monitor, sensor and collect information real-timely about the network distribution environment or the monitoring object in the network system region through collaboration between nodes. Low energy and unreliability of a single sensor node are the inherent characteristics of wireless sensor networks, and those defects have great impact on the design of network protocol[1]. Routing protocol is one of the key technologies of wireless sensor networks, which is responsible for transmitting data through the network from the source node to the destination node, and its main functions are searching for the optimal path between the source node and destination node and forwarding the data along the optimal path correctly. Currently, the typical wireless sensor network routing protocols include flood routing (Flooding)[2], gossiping routing protocol[3], data-centric routing protocols such as the SPIN, Directed Diffusion, Roumer, TTDD, approximate routing algorithm which supports inquiring and so on[4,5]. These network protocols are combination of the shortest path algorithm and the different applications of sensor networks basing on the traditional wireless Ad Hoc network protocols, and they are not applicable to the wireless sensor networks whose nodes are energy-constrained and topology dynamically changes.

Energy-saving routing is to find an energy-saving multi-hop path between source and destination nodes, which requires the introduction of indicators related to energy consumption on the basis of the common routing protocols, and ultimately reduce the power consumption. Compared with the traditional routing algorithms, routing protocols based on ant colony algorithm[6,7] has some advantages such as good adaptability, strong robustness, supporting multi-path routing, possessing local or global optimization capability and is easy to combine with other routing algorithms[8].

TinyOS is an embedded operating system mainly used in wireless sensor networks[9]. It possesses the characteristics of component-based programming, event-driven mechanism, lightweight threading technology, two-level scheduler mode and active message communication based on event-driven model. TinyOS meets the special requirements of the wireless sensor networks whose nodes have limited resources but are needed to be provided with great ability of network processing and resource collection[10]. In TinyOS, network distribution protocol(Dissemination) such as Drip and DIP[11,12], CTP collection protocol[13] and the LEPS multi-hop routing protocol[14] used in data gathering, all those turned out to be practical. Routing protocol realized in TinyOS based on ant colony algorithm combines the operating system's characteristics[15] and ultimately provides strong support for the application layer programming.

II. THE OPTIMIZATION OF THE BASIC ANT COLONY ALGORITHM

A. Basic Ant Colony Routing Algorithm

In the basic ant colony routing algorithm (BACRA), the routing ants release pheromones behind on the path from the source node to destination node. Through the positive feedback mechanism formed by the pheromones on the path and the iterative search, the ants could eventually find the shortest path. In order to extend the lifecycle of the entire wireless network, the artificial ants construct solutions by the guidelines of the pheromone trails and energy heuristic information to find the minimum cost path.

In the basic ant colony algorithm, we define the probability that ants move from node i to the next hop node j as:

$$p_{ij}^{d}=\begin{cases}\dfrac{[\tau_{ij}^{d}]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{n\in N_i^d}[\tau_{in}^{d}]^{\alpha}[\eta_{in}]^{\beta}} & j\in N_i\\ 0 & j\notin N_i\end{cases}\qquad(1)$$

In which τ_{ij}^{d} is the pheromone concentration value of the edge(i, j) from the node i to node j and η_{ij} is the energy heuristic value. N_i is the nodes collection that ants can select from about the next hop, including all the neighbor nodes except the one which is last visited. α and β are important parameters respectively controlling the pheromone trails and the relative importance of heuristic value, and that $\alpha \geqslant 0$, $\beta \geqslant 0$. The energy heuristic value from node i to node j is:

$$\eta_{ij}=\frac{E_j}{\sum_{n\in N_i}E_n}\qquad(2)$$

Where E_j is the energy level of node j, the greater the node's remaining energy the more probability to be selected. Therefore, when converging to the optimal solution, the algorithm can balance the node energy consumption. The ant colony algorithm is not only conducive to the realization of the entire network's energy balance, but also can extend the network's lifecycle.

For the forward ants, the introduction of the pheromone evaporation mechanism is to avoid submerging the energy heuristic information because of too much residual pheromone on the path. At the same time, the negative feedback caused by evaporation mechanism can also avoid unlimited accumulation of pheromone which may cause previous inferior paths to be forgotten. The expression of residual pheromone is:

$$\tau_{ij}^{'}=(1-\rho)\tau_{ij}\qquad(3)$$

Where ρ is the pheromone evaporation rate, $0<\rho\leqq 1$. After the pheromone evaporation steps, backward ants in routing packet release pheromone on the last passing link (i, j):

$$\Delta\tau_{ij}=\frac{\omega}{C_i^d}=\frac{\omega}{HC_i^d}\qquad(4)$$

C_i^d presents link cost from the node i to the destination node d. And we adopt the hops value HC_i^d which is most able to identify the path length to replace C_i^d. ω is a weight, which is used to adjust the amount of the releasing pheromone. Therefore, the updated pheromone of the link (i, j) is:

$$\tau_{ij}=\tau_{ij}^{'}+\Delta\tau_{ij}\quad,\quad\forall l_{ij}\in L\qquad(5)$$

L is a set of edges of the whole path that ants establish. The shorter the path ants build, the more pheromone will be gotten for every edge of the path. And this path is more likely to be selected by ants or packets.

After several iterations, each node will be able to get the routing information of their neighbor to the destination node. The data transmission exactly makes use of this information to select the path to reach the target node according to the formula (1).

The inadequacies of the basic ant colony algorithm: in the large-scale deployment of wireless sensor networks, frequent node failure, the new or the primary node's mobility, all will cause dynamic changes in network topology. Although the basic ant colony algorithm has strong global search capability, but the search time is longer, and is not suited to practical wireless network topology's frequent changes. In addition, the basic ant colony algorithm is easily trapped into local optimal solution and the result is the routing table's stagnation, so that when the network topology changes, artificial ants can not quickly find a new better path.

B. *The Optimization of the Parameters in the Algorithm*

(1) The optimization of the parameters α, β.

The reason that the basic ant colony algorithm is prone to early maturity, stagnation and local optimal solution is the use of positive feedback to strengthen the optimal solution. This mechanism makes the non-equivalence pheromone amount gap of different links grow. On the one hand the pheromone amount of better solutions continue to strengthen and that a large number of ants are gathered in a small number of paths; on the other hand, the probability that paths that are not currently selected bur can be selected later is getting smaller and smaller, so does the new emerging path due to network topology's changes.

In the node selection probability formula, α represents the pheromone amount τ_{ij}^{d}'s effect level on the probability that ants choose the path. And the parameter β reflects the energy heuristic information η_{ij}'s importance level with regard to the probability of choosing the path for ants. When α value increases, the likelihood that the ants select the path walked before will be greater and the search's randomness will weaken, leading to converging to the local optima prematurely; and when the α decreases, the randomness and diversity of the search enhances , but the convergence rate will slow down and the search time will become longer. For the value of β, when the β increases, it will be easy to fall into local optimal solution among the higher energy paths; But when the β decreases, more energy will be wasted because of the randomness enhancing, and eventually reducing the lifecycle of the entire network. Ant colony algorithm's performance of global optimization requires a certain degree of randomness in the search process, but the performance of fast convergence also requires that the search process has certainty. So in order to obtain a balance between the two, we present variable parameter values α and β with the search process:

$$\alpha=\frac{1}{ak}+\alpha_0\qquad\beta=\frac{1}{bk}+\beta_0\qquad(6)$$
$$k=1,2,3,\ldots n;\quad a\succ 0,\succ 0.$$

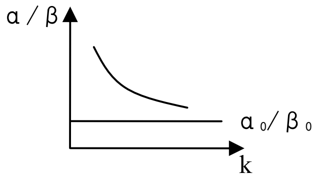

Fig1 Variation of parameters α and β

n is the maximum number of iterations and a, b are the variable factors. With the number of iterations increasing, the value of α and β approaches α_0, β_0 finally. Coefficients a, b determine the gentleness of the curve which is gradually close to the α_0, β_0. The optimized formula (1) has high α, β values in the beginning to increase the certainty of the search, so that the better paths whose pheromone amount gaps are not too large can be soon selected to accelerate the convergence rate of the algorithm in the initial stage; With the search proceeding, the randomness enhances and can balance the trend of falling into local optimum prematurely, so that making the algorithm's convergence be flat.

(2) The optimization of the parameter ρ

The size of the pheromone evaporation rate value ρ affect the global search ability and the convergence rate of the ant colony algorithm. When ρ is too large, paths that were searched previously may be selected again, which may affect the randomness of the algorithm; ρ too small, the convergence rate will be reduced, which is not suited to the rapid change of the wireless network topology. In addition, there are close ties between the pheromone heuristic proportion ρ and the number of artificial ants M. When the ants' number is small, a smaller ρ value will be needed to ensure the path has enough pheromone residues to guarantee the algorithm's global convergence. So ρ is made to be a variable value:

$$\rho = 1 - \frac{1}{M} e^{\frac{t}{k}} \rho_{\min} \qquad k = 1, 2, 3 \ldots n \qquad (7)$$

The ants number M is usually a fixed value which has been determined already in the initialization of the algorithm. ρ_{min} is the ρ's minimum value in the iteration and t is an adjustable parameter to ensure that the value of ρ is in (0,1]. The ρ's value is large at the beginning to increase the pheromone intensity's affection to enhance the ant colony's ability of searching solution, so that the algorithm has a high convergence rate in the beginning of the network changes; Similarly, with the search progressing the ρ decreases, leading in pheromone positive feedback effect weakening, ultimately to avoid the algorithm quickly falling into local optimum.

C. The Mechanism of Pheromone Broadcasting Periodically

As network topology changing, nodes newly added were excluded from the search scope due to the absence of residue pheromone. Among the newly formed network paths, the new optimal path is most likely to emerge in the neighborhood of the old optimal path. Therefore, each node in the network periodically broadcasts routing table to its neighbors, in which the routing table is used to save the node's pheromone values about reaching the target node through its neighbor nodes. Nodes newly added will receive the broadcasting information and update their own pheromone values, which will make the algorithm's searching range continuously extend to the neighborhood of the old optimal path. And the algorithm can converge to the new global optimum when the network structure changes.

To save the broadcasting communication overhead, we use the Drip library in TinyOS2.x to update the prime pheromone information of nodes newly added: node A periodically broadcasts its pheromone information Φ_x out, if the node B has the pheromone value Φ_y, then the node B is not a new node of the topology changes. But if node B's pheromone value does not exist, it should be updated to Φ_x. The value of the broadcasting timing cycle can be set. Finally, the nodes pheromone will change continuously along with the network topology variation.

III. The Realization of the Ant Colony Algorithm Routing Protocol in TinyOS

The routing protocol based on ant colony algorithm is mainly composed of three parts in TinyOS2.x. We use the multi-component pattern to realize the protocol.

a) Component BroadcastP is used to broadcast the nodes' energy and other information periodically, which uses a timer separately.

b) Artificial ants are to find the optimal path. Artificial ants find the next hop node basing on pheromone concentration of the around paths and the energy level of the neighbor nodes. Through the process, the ants will record the path information, until they reach the destination node. The artificial ants which are now as forward ants will transform into backward ants when they reach the destination node, and then the backward ants return to the source node along the same route, at the same time updating the pheromone values on the path.

c) Data transmission module. The data transmission module is responsible for the maintenance of data transmission queue, not only sending the local node's packet but also forwarding packets from other nodes.

Ant colony algorithm routing protocol adds routing layer's protocol field to the AM layer of the message package protocol. We can get the payload area of the message package's real data through the Packet interface, namely the routing layer protocol is actually built on the active message layer. The basic format is as the following:

AM message package header	Routing field	Payload area	AM message package tail

Fig2 AM layer message packet format

IV. Simulation

The simulation environment is TOSSIM. TOSSIM is the simulator that comes with the operating system TinyOS, which is capable of supporting large-scale network simulation. TOSSIM can simulate the complete TinyOS application [16]. The working principle is using the simulation component to replace hardware components. The component level that TOSSIM is able to replace is very flexible, not only can it replace the common components that can be used on multiple platforms, but also can replace the bottom platform-specific components, thus getting more accurate simulation results. In order to improve the simulation quality of the radio behavior, we make use of the closet pattern matching(CPM) in the TOSSIM to simulate the RF noise, interference between the nodes and an external signal interference on nodes. The loaded noise channel data *Meyer-heavy* comes from the Stanford University Meyer library. We realize the basic and the optimized ant colony algorithm separately in TinyOS2.x.

Figure 3 shows that the simulation uses the grid format topology. nodes are distributed on the grid intersection of the square and the number of nodes is the square of an integer value.

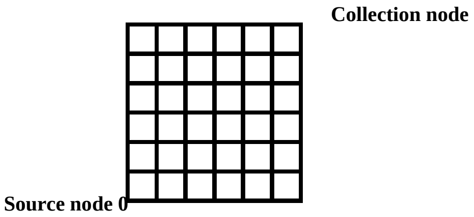

Fig3 The grid distribution of network topology

The lower left corner node 0 periodically sends packets to the upper right corner's collection node. According to the characteristics of wireless sensor networks, we assume that the collection node has adequate energy supply. Because TOSSIM simulation platform don't have energy consumption model, we set a variable to represent the node's energy value in the test procedures. Assuming that a common node has an initial energy of 10^4 units, each time one node sends or receives a message packet it will subtract a fixed value of 5 units. The simulation process is to continually monitor each node's residual energy value. The source node 0 periodically generates a packet in the simulation process. The simulation continues until any one of the node's energy value is lower than a smaller value. Then we regard the node as energy consumption failure and finish the simulation. The time interval from the beginning to the time the first node's failure is called the network's lifecycle. Concerning the key parameters' values in the algorithm, we adopt the methods of first coarse adjustment and then fine adjustment step by step: adjusting the large range of α, β values to get the ideal solution, and then finely adjusting the smaller range of pheromone volatilization factor ρ. After the simulation test is repeated and the results are comparatively analyzed, we get the parameters values when the protocols obtain its optimal performance: the basic ant colony algorithm parameter's value $\alpha = 1.5$, $\beta = 3.5$, $\rho = 0.8$, $\eta = 0.3$; the optimized ant colony routing algorithm's(OACRA) parameter value $\alpha_0 = 1.2$, $\beta_0 = 3$, $\rho_{min} = 0.5$, $\eta = 0.2$, $a = b = 20$, $t = 4$. Assuming that the source node has completed a minimum of 20 iterations before data transmission, we get the statistics about the lifecycle, average delay and average energy consumption in the nodes number changing network. The average time delay is the average packets transmission time from the source node to destination node, which is used to reflect the path's transmission quality. After 50 times simulation, the average results are shown in Table 1:

Tab1 Comparison of the routing algorithm's performance

Nodes number	Lifecycle/s		Average delay /ms		Average energy consumption /unit	
	BACRA	OACRA	BACRA	OACRA	BACRA	OACRA
49	1852	2082	199	179	372	337
64	1755	1978	216	193	404	363
81	1663	1874	227	202	445	397
100	1509	1698	253	225	481	424

Data from Table 1 show that when the number of nodes is equal, the lifecycle of OACRA is longer about 14% on average compared with BACRA, meanwhile the average end-to-end transmission time and the average power consumption of transmitting a packet are less about 12% than BACRA. The optimization effect is obvious. The optimized Ant Algorithm routing protocol has a significant improvement on shorting the convergence time and saving node energy consumption. It also reflects the node pheromone broadcasting mechanism has good optimization capabilities; When network nodes' number grows constantly, the network lifecycle will gradually shorten. Comparing to the BACRA, the lifecycle's decrement rate of OACRA is smaller, and that the greater the nodes number the more obvious the advantage. Average delay and average power consumption increase with the nodes number's increasing, but the gap between BACRA and OACRA grows. In other words , the optimized ant colony algorithm has a better adaptability with the nodes number's increase. This is mainly because that the parameters α, β and ρ in the probability selection formula get the best possible balance between the convergence rate and search range, adapting to the dynamic changes of network structure.

We observe that the residual energy of fixed number nodes and the packets loss number change over time. A counter is added to the data packet in the source node to achieve packets loss rate in the target node. We carried out this simulation in the case of fixed 64 nodes. In the following diagrams, the horizontal axis represents time, and one scale is on behalf of 100s.

Figure 4 shows the residual energy change of fixed node Q in the network, and on the vertical axis one scale is on behalf of 100 energy units. It can be seen that the optimized ant colony algorithm can significantly reduce nodes' energy consumption and save energy. In addition, at the end of the simulation, we analyzed the energy distribution of the entire network and found that the optimized ant colony algorithm routing protocols has balanced the energy consumption of the nodes closer to the source and destination node, and the relatively distant nodes have more residual energy. It all shows that the protocol is able to choose a shorter transmission path and simultaneously balance the entire network's energy consumption.

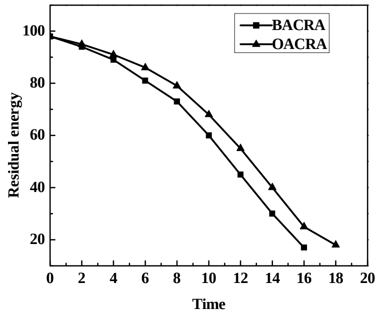

Fig4 Changes in the residual energy of fixed node Q

Figure 5 shows the statistics of nodes packets loss in the destination node. The main reason of packets loss is that in the algorithm's implementation process, in order to suppress duplicate packets, data will be discarded if they can't reach the target node after a fixed number of hops. After calculation, the packets loss rate is less than 3%, indicating that the routing protocol has better transmission reliability.

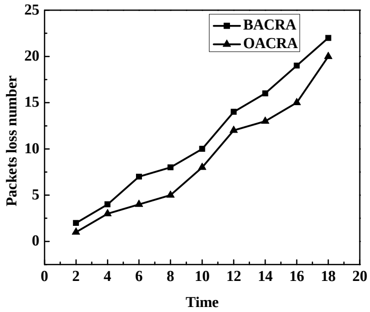

Fig5 The packet loss number in the destination node changes over time

V. CONCLUSION AND FUTURE WORK

In order to adapt to the characteristics of the wireless sensor networks, the basic ant colony algorithm's key parameters α, β, ρ are optimized. And the nodes pheromone periodically broadcasting mechanism is also used to search the optimal path's neighborhood range. We realized the routing protocol in TinyOS with multiple components pattern, and this pattern is convenient for the protocol to extend. Simulation results show that comparing to the basic ant colony algorithm routing protocol, the optimized one can prolong the network's lifecycle effectively, has the reliability of data transmission, and adapt quickly to the network's dynamic changes.

As sensor networks move from research to deployment, from laboratory to the real word, efficacy and practical applicability will grow in importance. The validation of the ant colony algorithm was carried out in the simulation environment, but usually in the simulation environment, many experimental conditions are idealized. For the practical application, there may be many limitation factors such as varieties of signal interference, node hardware quality and so on. Hence, next we plan to use TinyOS mica-2 motes for empirical studies, to validate our simulation results and prove the real-world effectiveness of the optimization algorithm.

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