Feedback-Enhanced Ant Colony Routing Algorithm for Wireless Sensor Networks

Chao Li, Zhidong Deng
State Key Laboratory of Intelligent Technology and Systems, Tsinghua National Laboratory for Information Science and Technology, Department of Computer Science and Technology
Tsinghua University
Beijing 100084, China
lichao07@mails.tsinghua.edu.cn, michael@mail.tsinghua.edu.cn

Abstract—**Routing problem in wireless sensor network (WSN) is challenging because WSN has distributed feature, transmission requirement, data redundancy and energy restriction. The idea of ant colony optimization (ACO) has been used in design of routing algorithms for WSN. However, ant colony routing algorithms (ACRs) generally have a serious problem of slow routing discovery so far. In this paper, a feedback-enhanced ant colony routing algorithm (FACR) making use of timed-out forward ants and backward broadcasting ants is proposed to accelerate the routing process. This algorithm is simulated on NS2 and is compared to traditional ant colony routing algorithm (TACR). The results indicate that FACR achieves lower packet loss rate than TACR under the same experimental conditions. Moreover, FACR shows a shorter end to end delay and higher residual energy rate.**

Keywords-wireles sensor network; ant colony routing algorithm; feedback enhancement

I. INTRODUCTION

WSN [1] is a group of sensor nodes that exchange information intermittently by means of wireless transmission. Due to physical features and techniques adopted, WSN can acquire a large amount of detailed and authentic environmental information under many domains like national defense, environmental monitoring, traffic management, etc.

A routing algorithm with high performance is crucial for WSN because it contributes more effective information for longer time. In this paper, we propose two improvements on TACR to achieve lower loss rate of sensed data with shorter end to end delay and less energy consumption.

Over the last few years, researchers on large scale multi-hop WSN have paid attention to self-configuring and self-healing algorithms, and ACO is among them. Inspiration of ACO comes from ants' behavior in searching for the optimal path to food and sharing information through stigmergy [2]. Ants lay a chemical substance called "pheromone" on their paths and tend to crawl to places where concentration of pheromone is high. When applied to solve scientific problems, biological ants are typically modeled as artificial ones [3]. In WSN routing field, ACRs which are based on ACO have been proposed.

CHINACOM 2010, August 25-27, Beijing, China

DOI 10.4108/iwiot.2010.3

ACRs regard particular packets used for routing formation as artificial ants, which are further divided into forward and backward ants by function. Generally, each WSN node maintains a pheromone table, which is used to calculate probabilities of neighbor nodes selected as relay. A typical process for ACRs is as follows. Forward ants search for paths according to the table at each node and gather WSN status information used to update the pheromone values along their paths. When they arrive at the sink node, to which WSN nodes should send all their sensed data, backward ants are generated and begin to backtrack. Along the reverse paths, they use the information obtained from forward ants to implement the update operation.

Based on the process, every ACR has its own improvements. Some ACRs [4, 5] construct a novel model combining several evaluation indicators to update pheromone values. Other algorithms [6, 7] establish multipath to distribute load within WSN and provide alternative paths in case of optimal path failure. Still some cluster-based versions [8, 9] generally design two schemes to solve intra-cluster and inter-cluster routing problems separately. Compared with traditional solutions to the general problem of finding the shortest path within a graph, ACRs needn't know the network topology. Therefore, ACRs have great advantage over those algorithms when applied in WSN. TACR, the basic process of ACRs will be described in detail in section Ⅱ.

However, the routing discovery speed of ACRs is very slow, which is a serious disadvantage faced by ACRs so far. Because of the problem, many sensed data packets are discarded due to routing failure. Moreover, successful routing to the sink node often spends longer time before the formation of stable optimal paths. All these lead to a waste of node energy and finally result in shortening of WSN lifetime. According to our research, the idea of accelerating routing discovery through feedback enhancement is not considered in existent ACRs. For such reasons two improvements are proposed in FACR to achieve better performance:

- A timed-out forward ant is utilized rather than just be discarded to indicate the undesirability of its travel path.
- Backward ants not only backtrack but are broadcast along the reverse path upon a forward ant successfully reaching the sink node.

The rest of this paper is organized as follows. First, TACR, the core of ACRs, is described in detail, and then two improvements in FACR are proposed in section Ⅱ. Then comparisons between the performance of FACR and TACR are made in section Ⅲ. Finally, conclusions are drawn and some future studies are suggested in section Ⅳ.

II. DESCRIPTION OF FACR

In ant network models [2, 3] presented in the past, a pheromone table Φ is maintained on each network node. When ACO is applied in WSN routing field, two types of packets, named as forward ants and backward ants separately, are taken as artificial ants. Forward ants are used to search for paths, while backward ants backtrack and update pheromone tables.

A. TACR [10]

TACR is among early ACRs and is the prototype of later ACRs. It can be informally summarized as follows:

- A forward ant k is launched by a WSN node towards the sink node when there's a need to search for paths.
- At each node i, ant k selects a neighbor node j as the next hop to the sink node under a probability $p(i,j)$ calculated according to (1).

$$p(i,j)=\begin{cases}\dfrac{[\varphi(i,j)]^{\alpha}[\eta(i,j)]^{\beta}}{\sum_{n\notin tabu_k}[\varphi(i,n)]^{\alpha}[\eta(i,n)]^{\beta}} & j\notin tabu_k\\ 0 & otherwise\end{cases} \quad (1)$$

where $\varphi(i,j)$ is the amount of pheromone on link (i,j) recorded in Φ, $\eta(i,j)$ is a priori desirability of the move from i to j computed through heuristics using (2), $tabu_k$ is a list of nodes within vicinity of node i never visited by ant k so far, α and β are respectively the relative importance of $\varphi(i,j)$ and $\eta(i,j)$.

$$\eta(i,j)=e_j/\sum_{N_i}e_m\in[0,1] \quad (2)$$

In (2), e_j is the residual energy of node j and N_i is the neighborhood of node i.

- Ant k is discarded when it reaches the sink node or it is timed-out. The routing discovery process is over in the second case. And in the first case, a backward ant r is generated and sent back along the reverse path of ant k. Ant r considers the source node address of ant k as its destination and an increment, which is used to update the pheromone table at every node along the path, can be obtained through the following formula.

$$\Delta\varphi(i,j)=Q/L_k \quad (3)$$

where Q is used to adjust accuracy according to the total number of nodes in WSN, and L_k is the path length.

- During this back process, when a node i receives ant r from one of its neighbor nodes j, pheromone value $\varphi(i,j)$ is updated in the following manner.

$$\varphi(i,j)=(1-\rho)\times\varphi(i,j)+\rho\times\Delta\varphi(i,j) \quad (4)$$

where ρ is used to control the relative importance of previous pheromone amount versus the incremental value, while 1-ρ represents the evaporation of pheromone since the recent update time.

- Ant r is discarded on reaching its destination.

B. Additional Feedback in FACR

In previous improved ACRs, no attention is paid to solve the problem of slow routing discovery through making extra use of forward and backward ants. In FACR, the basic idea of improvements implemented is to bring more feedback to an original ACR. Two specific methods are described as follows.

1) Timed-out forward ants: Forward ants will be discarded whenever they're timed out without any feedback before. In other words, sending and receiving of timed-out forward ants consume node energy but contribute nothing to routing establishment. Moreover, the invalid paths these ants travelled through will quite possibly be chosen again especially during routing initialization phase.

To address this issue, timed-out forward ants should be made use of rather than just being discarded. In fact, these ants may indicate that their paths should be given lower pheromone values so that future forward ants have a smaller chance of choosing these unsatisfied paths. Similar indications can contribute to routing formation through modifying pheromone values along the paths of timed-out forward ants. The specific method can be described that a corresponding backward ant is generated and sent along the reverse path when a node receives a timed-out forward ant. However, when such a backward ant arrives at a node, different update formula is used to recalculate the pheromone table.

There exist two types of nodes on the reverse path. Type Ⅰ nodes ever receive backward ants from the sink node, while type Ⅱ nodes do not.

For type Ⅰ nodes, although the forward ant failed to find the sink node this turn, future forward ants are still more likely to reach there because discovered paths exist. This moment pheromone information should be updated according to an existent optimal path. Each type Ⅰ node keeps P_{node} to denote the shortest path length from current node to the sink node and each backward ant carries P_{route} with it, which records the minimum hop number towards sink calculated from values of P_{node} along the reverse path. Formula (5) and (6) are used to calculate P_{node} and P_{route} of current node and backward ant respectively.

$$P_{node} = \begin{cases} +\infty & m = 0 \\ \min(P_{node}, P_{route}(1), \cdots, P_{route}(m)) & m \geq 1 \end{cases} \quad (5)$$

where m represents the number of backward ants current node has ever received, $P_{route}(i)$ $1 \leq i \leq m$ is the P_{route} value the i_{th} ant carries.

$$P_{route} = \begin{cases} 0 & n = 0, k \in BA_1 \\ P_{node} & n = 0, k \in BA_2 \\ \min(P_{route} + 1, P_{node}(1), \cdots, P_{node}(n)) & n \geq 1 \end{cases} \quad (6)$$

where n represents the number of nodes current backward ant k has travelled, $P_{node}(i)$ $1 \leq i \leq n$ is the P_{node} value the i_{th} node has, BA_1 is a set of backward ants sent after forward ants reached the sink node, and BA_2 is a set of backward ants sent after forward ants timed out.

When a backward ant belonging to BA_2 arrives at a node, pheromone information on the node is modified using the same form as (4). However, $\Delta\varphi(i,j)$ is calculated in a different way as follows.

$$\Delta\varphi(i,j) = \begin{cases} Q/(P_{node} + R_{head}) & P_{route} \geq P_{node} \\ Q/(P_{route} + R_{head}) & P_{route} < P_{node} \end{cases} \quad (7)$$

where R_{head} is the rest path length for the backward ant.

For type Ⅱ nodes, the pheromone value should decrease to indicate that current node is a bad forwarding candidate towards the sink node, and pheromone information is updated using (8).

$$\varphi(i,j) = R_{tail} \times \varphi(i,j) / R_{len} \quad (8)$$

where R_{len} represents total path length of the backward ant, and R_{tail} is the number of nodes the backward ant has passed.

Fig. 1 is used to make a better explanation here. A backward ant is sent after a forward ant with sink node d as its destination timed out at d'. When the ant reaches m, pheromone amount on link (m,n) will decrease because there was no path ever discovered from n to d. When the ant arrives at i, pheromone variation on link (i,j) is calculated considering p_2 instead of p_1 as the potential optimal path.

When the backward ant reaches s, a single-cast request with a longer TTL (Time to Live) is sent to begin an extra routing discovery process if all the three following conditions are satisfied:

- No path to the sink node of the timed-out forward ant is ever found.
- A time span is exceeded since recent sending of request.
- The new TTL is below a predetermined maximum value of TTL.

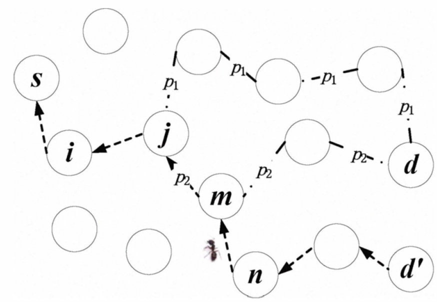

Figure 1. Backward ants backtrack after forward ants timed out

2) Backward broadcasting ants: When a forward ant finally arrives at the sink node after an arduous journey, an effective path is found. In the return process of the backward ant, improvement can be taken against the newly discovered path, and additional contribution can be made to guide future routing of packets sent by non-path nodes.

The specific approach adopted is to broadcast backward ants along the reverse path. A random delay is added to each transmission and the process can be stopped in order to avoid flooding WSN when pheromone distribution is good enough for data packets to reach the sink node. On receiving a broadcasting backward ant, pheromone amount is updated according to (3) and (4) with an extra process of determining L_k value.

The method has two main advantages. One is that when nodes receive broadcasting backward ants sent from the sink node, they can accumulate some priori information of routing towards the sink node in case new routing discovery requests arrive. Value of L_k is calculated through the method below.

$$L_k = \min(R_{tail}(1) + T_{brd}(1), \cdots, R_{tail}(n) + T_{brd}(n)) \quad (9)$$

The other advantage is that a better path is established when a non-path node receives broadcasting backward ants sent from two path nodes and non-path distance between them is shorter than path distance. This moment, L_k is calculated using the following formula.

$$L_k = \min(R_{head}(i) + T_{brd}(i) + R_{tail}(j) + T_{brd}(j)), 1 \leq j < i \leq n \quad (10)$$

In (9) and (10), n is the number of broadcasting backward ants sent from the sink node in one turn, $R_{head}(i)$ and $R_{tail}(i)$ $1 \leq i \leq n$ are respectively the R_{head} and R_{tail} value of the path node that sent the i_{th} broadcasting backward ant, T_{brd} (i) $1 \leq i \leq n$ is the number of non-path nodes the i_{th} broadcasting ant has passed. R_{head} and R_{tail} are defined in the same way as before.

A specific example is illustrated in Fig. 2. A path from source s to sink node d marked by solid line is already established, and backward ants are broadcast along the reverse path. Node k is within the communication ranges, represented by dashed circle, of both i and j. (k,j,d) is the shortest path from node k to d in this turn of backward ant broadcasting, so the pheromone amount $\varphi(j,k)$ should be updated using path length calculated by (9). Moreover, (i,k,j) denotes part of a potential shorter path than current one marked by dot dash line, so the pheromone amount on link (i,k) and (k,j) should increase with path length calculated from (10).

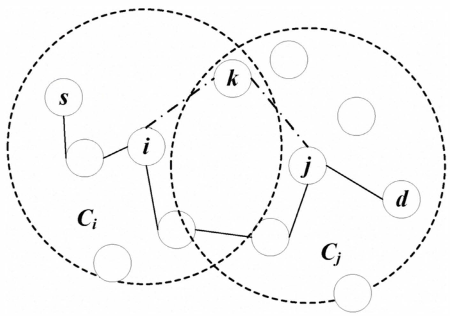

Figure 2. Broadcasting backward ants discover potential better paths

III. SIMULATION EXPERIMENTS

A. System Settings

To prove that FACR outperforms TACR, we use NS2 simulator to test the two algorithms. In the experiments, the size of simulated area is 600×600 m^2. Nodes, the number of which varies from 60 to 150, are deployed randomly to simulate realistic scenario where the network topology is unknown. No location information except that of neighbor nodes is needed by a network node. And every node can easily get to know its neighborhood through an initial broadcasting process.

Taking IRIS node of Corporation Crossbow [11] as reference, we define energy consumption model as energy consumption of receiving data 0.395 MW and that of sending data 0.66 MW. Energy spent on sensor perception is not considered in this paper. Node energy is initialized to 100000 MW. Bandwidth is set to 250 kbps, and sensed data generation rate on the application layer is 100 bytes every 45 seconds.

Parameters (α,β,Q,ρ) of ACR are set to (0.8,0.4,30,0.8). $\varphi(i,j)$ is initialized to $1/n_i$, where n_i is the number of neighbor nodes of node i. When there's need of sending data to the sink node, and no path is ever found or existent paths have expired, $m=3\times n_i$ forward ants are sent out to search for paths. The two algorithms stop running at the same time point when both of them achieve steady state, where sensed data packets are almost transmitted along valid paths of minimum hop counts.

Because ant colony routing selection is a probability event, 100 experiments for each algorithm in each scenario were performed. Mean values show general properties of every indicator, while standard deviations (abbreviated to "std. dev.") indicate the stability of algorithms.

B. Experimental Results

Network performance indicators are defined as follows:

- Packet loss rate: the ratio of the number of sensed data packets successfully reaching the sink node to the total number of sensed data packets.
- End to end delay: in the sensed data transmission phase, average time cost by transmitting sensed data packets from source nodes to the sink node. The unit is millisecond.
- Residual energy rate: the average ratio of residual energy of a node after algorithm running to initial energy of the node.

Fig. 3 presents the comparison of packet loss rate between TACR and FACR under same study parameters. It can be seen that FACR obtains a packet loss rate about 11 percentage points lower than TACR. The standard deviations of FACR are approximately average 0.7 percentage points higher than that of TACR considering all scenarios except the 60 node scenario. The differences are within acceptable range.

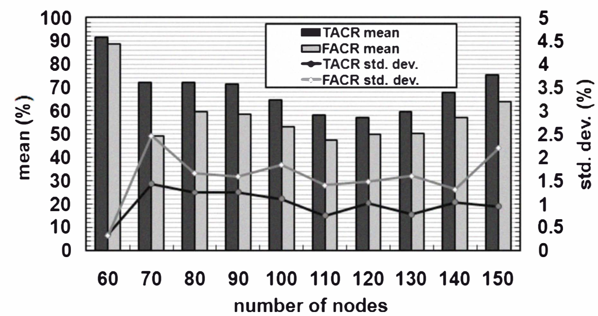

Figure 3. Packet loss rate comparison

Because FACR increases feedback on the basis of TACR, it brings more ants, which are essentially packets used to search for paths and different from sensed data packets, to WSN. This will cause growth of energy consumption, node queue length, and further lead to end to end delay increase. Therefore, after running the same time, TACR performs better than FACR in end to end delay and residual energy rate. However, there's a time point before algorithms stop running, when FACR has transmitted the same number of sensed data packets as TACR dose at the end of running. We will use the time point to calculate the next two indicators of FACR, in order to state that FACR can obtain the same amount of sensed data transmission with smaller end to end delay and less energy consumption.

Fig.4 illustrates that FACR achieves an end to end delay about 18 milliseconds shorter than TACR. Moreover, the mean values of FACR are less affected by WSN size. The gap between FACR and TACR has a tendency to expand with the increase in the number of WSN nodes. Considering the three scenarios where FACR has bigger standard deviations, the average standard deviation of FACR is about 1 millisecond higher than that of TACR. But for all scenarios, FACR has an average standard deviation about 1 millisecond lower than TACR.

Fig.5 displays that FACR has higher residual energy rate than TACR in all scenarios. The average residual energy rate of FACR is about 16 percentage points higher than that of TACR. In the 60 to 110 node scenarios, standard deviations of FACR are lower than that of TACR. A contrary conclusion is drawn from the rest of scenarios, and the average standard deviation of FACR is about 1.5 percentage points more than that of TACR. Considering all scenarios, FACR has an average standard deviation of residual energy rate approximately 1.6 percentage points less than TACR.

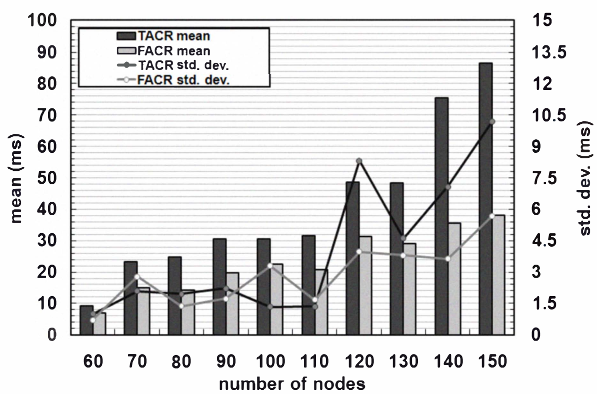

Figure 4. End to end delay comparison

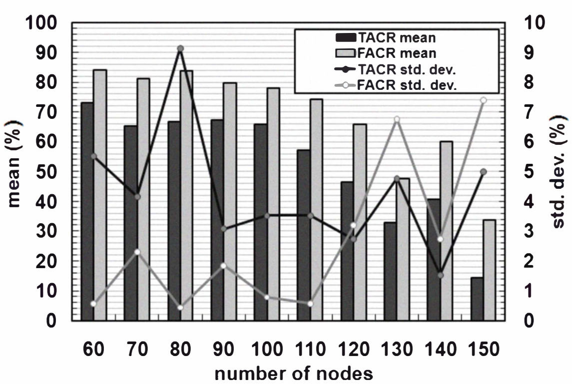

Figure 5. Residual energy rate comparison

IV. CONCLUSION

FACR is proposed in this paper to achieve faster routing discovery rate. In the algorithm, when a forward ant is timed out, a backward ant is sent along the reverse path, which makes the corresponding forward ant also contribute to route formation through updating pheromone information on the path. When a forward ant reaches the sink node, a kind of broadcasting ants are sent by nodes on the path to adjust and reinforce the discovered path. Experimental results indicate that FACR's packet loss rate is lower than that of TACR under the same conditions. Moreover, FACR achieves a shorter end to end delay and consumes less energy when it reaches the same packet loss rate as TACR.

At present, FACR uses only path length to calculate change in the amount of pheromone during newly added feedback enhanced process. However, in pace with network transmission, network environment will change. There may arise some phenomena like unequal node energy consumption and load imbalance. In the future work, neighborhood energy distribution and congestion degree in vicinity will be considered in calculation of pheromone change. Theoretically speaking, comprehensive consideration of multiple elements will lead to balanced use of resource. As a result overall routing performance may be improved. Moreover, improvements of other ACRs against TACR can be added to FACR so that further comparisons can be done to confirm that FACR also outperforms other ACRs.

REFERENCES

[1] J. Li, and H. Gao, "Survey on sensor network research", Journal of Computer Research and Development, vol. 45(1), 2008, pp. 1–15.

[2] M. Dorigo, and G. Di Caro, "Ant colony optimization: a new meta-heuristic", Congress on Evolutinary Computation, vol. 2, 1999, pp. 1470–1477.

[3] M. Dorigo, E. Bonabeau, and G. Theraulaz, "Ant algorithms and stigmergy", Future Generation Computer Systems, vol. 16, 2000, pp. 851–871

[4] W. Zheng, S. Liu, and X. Kou, "Energy efficient routing algorithm based on ant colony optimization for wireless sensor network", Systems Engineering and Electronics, vol. 31(8), 2009, pp. 1993–1996.

[5] Y. Wen, Y. Chen, and M. Pan, "Adaptive ant-based routing in wireless sensor networks using Energy*Delay metrics", Journal of Zhejiang University-science A, vol. 9(4), 2008, pp. 531–538.

[6] X. Ren, H. Liang, and Y. Wang, "Multipath routing based on ant colony system in wireless sensor networks", International Conference on Computer Science and Software Engineering (CSSE), vol. 3, 2008, pp. 202–205.

[7] Z. Shen, Y. Zhu, X. Tian, and Y. Tang, "An ant colony system based energy prediction routing algorithms for wireless sensor networks", International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM), 2008, pp. 1–4.

[8] L. Wang, R. Zhang, and S. Geng, "An energy-balanced ant-based routing protocol for wireless sensor networks", International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM), 2009, pp. 1–4.

[9] L. Qiu, Y. Wang, Y. Zhao, D. Xu, Q. Dan, and J. Zhu, "Wireless sensor networks routing protocol based on self-organizing clustering and intelligent ant colony optimization algorithm", International Conference on Electronic Measurement and Instruments (ICEMI), 2009, pp. 3223–3228.

[10] M. Dorigo, and T. Stützle, Ant Colony Optimization, ISBN 9780262042192, MIT Press, 2004, pp. 69–82.

[11] MPR-MIB Users Manual (Revision A). [Online], available: http://www.xbow.com, June, 2007.