Mitigating Routing Misbehavior Using Ant-Tabu-Based Routing Algorithm for Wireless Ad-Hoc Networks

***Chi-Chun Lo*†, *Chun-Chieh Huang*††, *and Wen-Tian Liang*†††**

†Faculty of Institute of Information Management, National Chiao TungUniversity, Hsinchu, Taiwan
†† Ph.D. Student of Institute of Information Management, National Chiao TungUniversity, Hsinchu, Taiwan
††† Information Security Consultant, KPMG, Taiwan

Summary
Routing is a key factor in the design of modern communication networks, especially in wireless ad-hoc networks (WANs). In WANs, both selfish and malicious nodes are misbehaving nodes and cause severely routing and security problems. Selfish nodes may drop routing and data packets and malicious nodes may redirect the packets to another routing path or launch denial-of-service (DoS) attacks. In this paper, an efficient routing algorithm is proposed, Ant-Tabu-Based Routing Algorithm (ATBRA), to mitigate selfish problem and reduce routing overheads. In ATBRA, both the concepts of ant-based routing algorithm and Tabu search are applied. We compare the performance of the proposed scheme with that of DSR in terms of two performance metrics: successful delivery rate (SDR) and routing overhead (RO). By comparisons, we notice that the proposed algorithm outperforms DSR in all two categories. The simulation results also indicate that the proposed algorithm is more efficient than DSR.

Key words:
Wireless Ad-Hoc Networks, Ant-Tabu-Based Routing Algorithm, Dynamic Source Routing protocol

1. Introduction

Wireless ad hoc networks (WANs) are a collection of mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure. A routing protocol is used to discover routes between source and destination nodes and direct data flow from source node to destination node. In addition, the route construction should be done with less routing overheads and less bandwidth consumptions. Recently, more and more attentions have been attracted to the routing protocols [1][3][8][11] in WANs. In WANs, due to the limited transmission range of wireless network interfaces, each node operates not only as a host but also as a router. Thus, data packets are relayed over a sequence of intermediate nodes from source node to destination node. All nodes in WANs are required to relay packets on behalf of other nodes. However, a node may misbehave by agreeing to forward packets and failing to do so because it is overloaded, selfish, or malicious. An overloaded node might lack buffer space or available network bandwidth to forward packets. A selfish node is unwilling to spend battery life or available network bandwidth to forward packets. A malicious node redirects the packets into another routing path or launches denial-of-service (DoS) attacks. These misbehaving nodes severely degrade the network performance. Consequently, misbehaving nodes are a significant problem in WANs. However, current versions of mature WANs routing algorithms, such as Dynamic Source Routing protocol (DSR) [3], Ad-Hoc On-Demand Distance Vector Routing (AODV) [2], and Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) [1], only detect if the receiver's network interface is accepting packets, but they assume that routing nodes do not misbehave.

In this paper, an Ant-Tabu-Based Routing Algorithm (ATBRA) is proposed. ATBRA is a new and highly effective routing algorithm in WANs. The algorithm uses the ideas of ant system and Tabu list to deal with the selfish nodes in the network. In ATBRA, the concept of pheromone laying-following behavior in ant colony is used to find a shortest path between the nest and a food source. Then, the concept of Tabu list is introduced to record the failure nodes, e.g. selfish nodes. Then, the system excludes these nodes while the multi-hop relaying is necessary. Therefore, this study may lead to a better routing result in WANs.

In this paper, both selfish problem and the reliability of the proposed algorithm in dynamic networks are discussed. A routing algorithm is proposed to mitigate selfish problem. In addition, the proposed routing algorithm is reliable in highly dynamic networks. Performance-wise, by examining both analytical and simulation results, we notice that the proposed routing algorithm is more efficient than DSR [3].

The remainder of this paper is organized as follows: In section II, related works are discussed. The proposed scheme is detailed in section III. In section IV, performance analysis and simulation results are given. In the last section, conclusion is presented.

Manuscript received May 5, 2010
Manuscript revised May 20, 2010

2. Related Works

In this section, the concepts of an ant based routing algorithm and Tabu search will be described briefly.

Although routing issues in WANs have drawn considerable attentions over the past few years, no solution has been proposed so far to solve the routing problems. The current routing methods in WANs can be categorized into three parts: proactive, reactive, and hybrid routing protocols. Proactive routing protocols attempt to maintain all routing information by routing tables, e.g. DSDV [1], Optimized Link State Routing (OLSR) [10], etc.. Each node needs to keep track of all topology changes. It will become more difficult for nodes to maintain their routing tables if there are a lot of nodes or mobile nodes; whereas reactive protocols only required routes on demand, e.g. AODV [2], DSR [3], etc.. In such protocols, they greatly reduce the routing overheads, but they may suffer from oscillation in performance; finally, the hybrid routing algorithms, like ZRP [12], have both proactive and reactive components, in order to try to combine the best of both.

In article [9], the authors describe those routing algorithms will not scale with large WANs as ant-based routing protocols.

2.1 Ant Based Routing Algorithm

The ant based routing algorithms in WANs have been proposed in articles [4][8]. These algorithms base on the pheromone trail laying-following behavior of real ants and the related framework of ant colony optimization. They apply the swarm intelligence learning from the ant forage model into the network routing problems. The basic idea behind these algorithms for routing is the acquisition of routing information through path sampling using ant agents and these algorithms are probabilistic technique for solving computational problems which can be reduced to find good paths through graphs. In the system, paths are represented in the form of distance-vector routing tables called pheromone tables. Inside the table, each entry is a pheromone variable and is a measure of the goodness of going over that neighbor on the way to the destination. These entries are updated constantly according to the quality of the paths sampled by the ant agents. Therefore, the ants use these pheromone tables to find their way to their destinations.

In article [4], the authors describe ant-based routing algorithms have a number of properties in WANs: they are highly adaptive to topology changes, use active path sampling, are robust to agent failures, provide multipath routing, and take care of data load spreading. However, ant-based routing algorithms have some flaws including their methods are a greedy algorithm belonging to local search and the repeating path sampling causes system overheads and may suffer from the selfish or malicious nodes attacks. These flaws will reduce the system performance.

2.2 Tabu Search

Fred Glover first proposed Tabu search (TS) to solve combinatorial optimization problems [5][6]. TS constrains the search by classifying certain of its moves as forbidden and to free the search by a short-tem memory. Tabu search uses a local or neighbourhood search procedure to iteratively move from a solution x to a solution x' the neighborhood of x, until some stopping criterion has been satisfied. In the proposed paper, ants use the concept of Tabu list to memorize the misbehaving nodes.

3. Ant-Tabu-Based Routing Algorithm

Selfish and malicious nodes, the misbehaving nodes, can be a significant problem. In WANs, in order to improve throughput, all available nodes are used for routing and forwarding packets. However, a node may misbehave by agreeing to forward packets and then failing to do so because it is overloaded, selfish, malicious, or broken. A selfish node is unwilling to retransmit the receiving data packets forwarded from its neighbor. If some of these nodes are in the routing path, the routing overhead will increase quickly in the route discovery phase and affect the system performance seriously. The proposed algorithm, ATBRA, is designed to reduce the possibility of such selfish nodes are chosen as the intermediate nodes in the system.

ATBRA is a routing algorithm which integrates both the advantages of both DSR [3] and Ant-Colony Based Routing Algorithm (ARA) [8]. Both Ant Colony Optimization (ACO) and Tabu Search (TS) are metaheuristic algorithms. In ATBRA, these two ideas are used to deal with selfish nodes. In the proposed algorithm, ant based algorithm is used in the first two phases to find a routing path and TS with short-term memory is used to avoid getting stuck into local optimal and exclude the selfish nodes. Tabu list is maintained by each ant to prevent the selfish nodes from being chosen during the route discovery phase. Consequently, the proposed algorithm well adapts to the highly dynamic network topologies like WANs. The proposed protocol has three phases: the route discovery phase, the route response phase, and the packets transmission phase. By executing these three phases, source nodes could find their routing paths to destination nodes and determine which nodes are intermediate nodes; the destination nodes could respond the route requests to their source nodes; and then the source nodes transmit data packets to the destination nodes. Fig. 1 illustrates the workflow of these three phases by the proposed ATBRA routing algorithm.

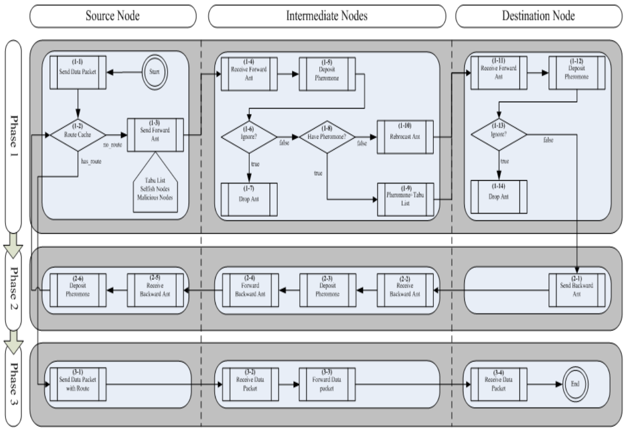

Fig. 1 The proposed ATBRA routing algorithm workflow

3.1 Route Discovery Phase

In this phase, a new routing path is explored by the forward ants. ATBRA creates a number of possible good paths between source and destination nodes by establishing the pheromone tracks and maintaining Tabu list by forward ants. Table 1 illustrates the route discovery comparison among DSR, ARA, and ATBRA routing algorithms.

Table 1: The route discovery comparison

	DSR	ARA	ATBRA
Route discovery	Broadcast	Pheromone trail	Broadcast, Pheromone trail, Tabu list

The route discovery phase is stated as follows:

Step1: Source node, N_S, initiates a routing request to the destination node, N_d.

Step2: N_S looks up routing entries in the route cache for this routing request. If the routing path exists, then goes to packets transmission phase. Else, goes to the next step.

Step3: N_S sends forward ants to collect routing information. These forward ants lay pheromone trails while looking for routing paths. Each ant maintains its own Tabu list which stores the misbehaving nodes' information in order to forbidden to visit.

Step4: The immediate node, N_i, receives the forward ants. It updates its trail by forward ant's visiting information. In ATBRA, the trail update rule is determined by Ant-Quantity model. The amount of trail laid on N_i, as follows:

$$\Delta\tau_{n\to j}^{j} = \frac{Q}{hop_{ij}} \tag{1}$$

$\Delta\tau_{n\to j}^{j}$ represents the amount of trail that is left on edge (*n*, *j*), where N_n is one of the nearest neighbor of N_i, N_j the visited node by the forward ant, Q the constant value, and hop_{ij} the number of hops between N_i and N_j.

Step5: If the forward ant had visited before, then N_i drops this ant.

Step6: If N_i has the trail about N_d, then goes to step8. Else, goes to next step.

Step7: N_i broadcasts this forward ant to its neighbors to find a routing path to N_d, and goes to step4.

Step8: $P_{i\to n}^{d}$ is computed by N_i. The value of $P_{i\to n}^{d}$ indicates that the probability of N_i's neighbor N_n could find a routing path to N_d. The probability $P_{i\to n}^{d}$ can be computed by Eq.(2):

$$P_{i\to n}^{d} = \frac{\tau_{n\to i}^{d}\cdot T_n}{\sum_{k\in neighbor_i}\tau_{k\to i}^{d}\cdot T_k} \tag{2}$$

$P_{i\to n}^{d}$ represents the probability that N_n could find a routing path to N_d, and values 0, 1 are assigned to T_l. If N_l is in forward ant's Tabu list, then $T_l = 0$. Else, $T_l = 1$.

Step9: N_d receives the forward ant and updates its own trail. If this forward ant had ever been processed and replied to N_S, then N_d drops this ant. Else, goes to the second phase.

3.2 Route Response Phase

In this phase, a new routing path is established by the backward ants. The backward ants are sent out by the destination node towards the source node. The route response phase is stated as follows:

Step1: The forward ant transfers all of its memory to the backward ant. The backward ant takes the same path as the corresponding forward ant, but in the opposite direction.

Step2: Each N_i receives the backward ant and updates its trail.

Step3: Finally, the backward ant arrives at N_S.

3.3 Packets Transmission Phase

In this phase, N_S sends data packets to N_d. If the pheromone tracks, from the source node to the destination node, have been established by the forward and backward ants, then data packets can be sent through this new routing path. The packets transmission phase is stated as follows:

Step1: N_S sends data packets to N_d according to the routing path established by the prior two phases.

Step2: N_i stores these data packets and forwards them to the next hop.

Step3: N_d receives these data packets.

4. Performance Analysis and Simulation Results

4.1 Simulation Environment

The simulation results presented in this paper were obtained using the ns-2 simulator [7]. This simulator is developed by the VINT project research group at the University of California at Berkeley. It provides substantial support for simulating TCP and other protocols over the network. The overall goal of our experiments is to measure the ability of the proposed routing protocol to react to network topology change while continuing to deliver data packets to their destinations. To measure this ability, ATBRA algorithm is implemented under ns-2 simulation platform. In the experiments, PriQueue is adopted to manage queue, the simulation range is 1500 x 300 m^2 and the node can moves arbitrarily within this area, and the nodes move according to the random waypoint model and with a minimum velocity of 0 m/s and a maximum velocity of 20 m/s. Moreover, the simulation time is 900 seconds. The node mobility is expressed by the pause time. Simulations are performed with 5 different pause time 0, 30, 60, 300, and 900 seconds. In the case of 0 second pause time, it means the network topology changes rapidly. In contrast, in the case of 900 seconds pause time, the nodes do not move. It means the network topology does not change. In addition, all the data packets sent by the nodes with constant bit rate (CBR) traffic are UDP packets. The destination node, therefore, does not need to send ACK to the source node. As mentioned before, the main goals of the proposed paper are to provide efficient routing environment and handle the selfish nodes problems while multi-hop routing are required. The simulation results show that the proposed paper is good enough to deal with these problems comparing with the existing routing algorithms, DSR and DSDV.

4.2 Simulation Results

The proposed algorithm is compared with DSR in terms of two performance metrics: successful delivery rate (SDR), where $SDR = \dfrac{\#\, successful\ packets\ delivered}{\#\, packets\ transmitted}$, and routing overhead (RO) which stands for the number of packets is generated while establishing a routing path. The simulation results show that the proposed algorithm outperforms DSR in all two categories.

Fig. 2 illustrates how the dynamic topology affects SDR under two different routing algorithms. The simulation results show that the proposed algorithm, ATBRA, almost has the same SDR as DSR in highly dynamic networks. Fig. 3 illustrates that ATBRA outperforms DSR on RO while pause time less than 300 seconds.

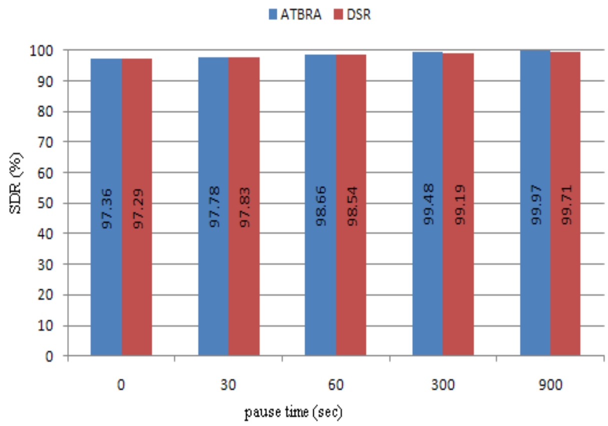

Fig. 2 SDR comparisons between two routing algorithms under dynamic topology

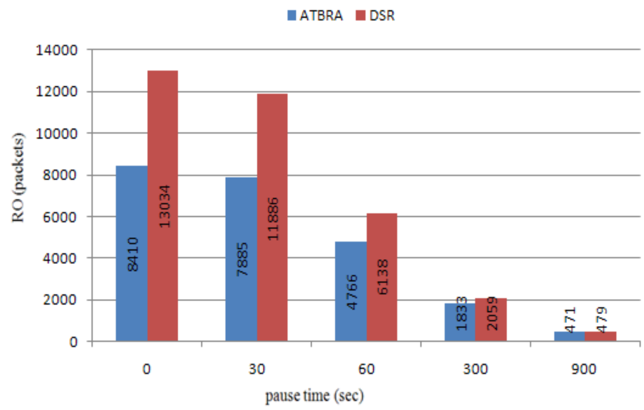

Fig. 3 RO comparisons between two routing algorithms under dynamic topology

A selfish node is unwilling to spend battery life or available network bandwidth to forward packets. Consequently, many packets are dropped and SDR decreases very much. Fig. 5 illustrates that ATBRA gets better results in SDR than DSR. Fig. 5 illustrates that ATBRA outperforms DSR. Thus, ATBRA mitigates the selfish problem.

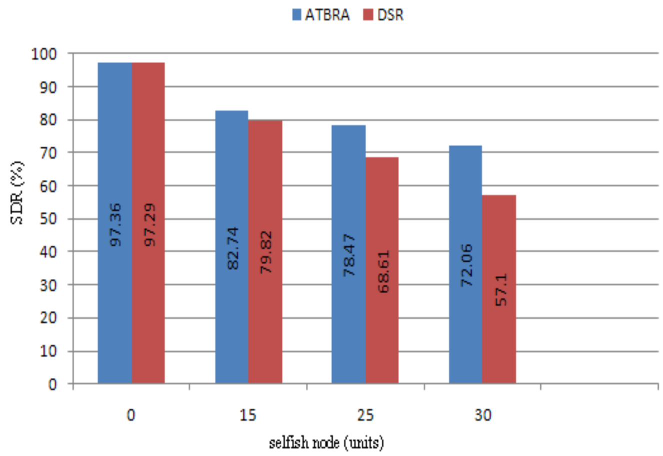

Fig. 4 SDR comparisons between two routing algorithms under selfish nodes

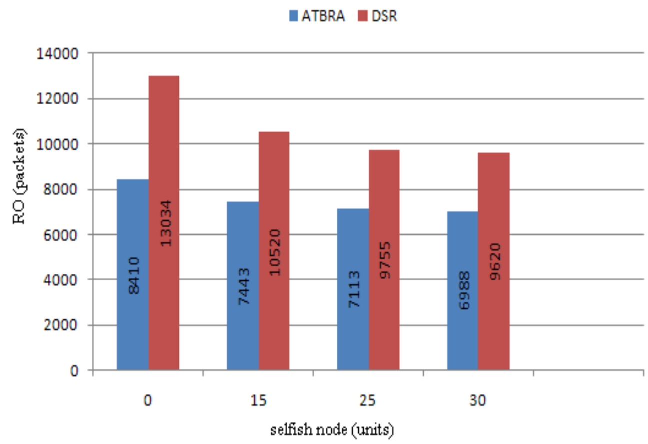

Fig. 5 RO comparisons between two routing algorithms under selfish nodes

5. Conclusion

Ant based routing algorithms have some good properties, such as high adaption to current network, local work, high link quality, and multi-path relaying support. Hence, these kinds of algorithms are more suitable for dynamic networks such as WANs. The proposed algorithm is a kind of ant based algorithm combined with Tabu list. ATBRA mitigates the selfish nodes' problems while route discovery phase. In addition, the proposed algorithm is reliable in a highly dynamic network. From the performance viewpoint, the proposed algorithm outperforms DSR. Also, the proposed algorithm has been shown to be efficient by the simulation results of SDR and RO under dynamic topology and selfish nodes conditions.

Two possible future research directions are merited for further investigation. They are:

(i) Compared with other routing algorithms in terms of two performance metrics: SDR and RO.

(ii) How to support ATBRA algorithm in a large size WANs?

Acknowledgment

The authors would like to thank anonymous referees whose detailed comments on the earlier version of this paper.

References

[1]C.E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for mobile computers," *Computer Communication Review*, Oct. 1994, pp. 234-244.

[2] C.E. Perkins and E.M. Royer, "Ad-Hoc On-Demand Distance Vector Routing," *Proceedinga of 2nd IEEE Workshop on Mobile Computing Systems and Applications*, Feb., 1999.

[3] D.B. Johnson and D.A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," *Mobile Computing, Kluwer Acdemic Publishers*, Vol. 353, 1996, pp. 153-181.

[4] F. Ducatelle, G.D. Caro, and L.M. Gambardella, "Using Ant Agents to Combine Reactive and Proactive Strategies for Routing in Mobile Ad Hoc Networks," Technical Report IDSIA 28-04.

[5] Fred Glover, "Tabu Search – Part I," Operation Research Society of America Journal on Computing, 1(3), 1989, pp.190-206.

[6] Fred Glover, "Tabu Search – Part I," Operation Research Society of America Journal on Computing, 2, 1989, pp.4-32.

[7] K. Fall and K. Varadhan, "The ns Manual," 2000.

[8] M.Gunes, U. Sorges, and I. Bouazizi, "ARA- The Ant-Colony Based Routing Algorithm for MANETs," *International Conference on Parallel Processing Workshops (ICPPW'02)*, Vancouver, B.C., Canada, August 18-21, 2001.

[9] M. Heissenbüttel and T. Braun, "Ants-Based Routing in Large Scale Mobile Ad-Hoc Networks," Kommunikation in verteilten Systemen (KiVS03), Leipzig, Germany, February 25-28, 2003.

[10] P. Jacquet, P. Muhlethaler, and A. Qayyum, "Optimized Link State Routing (OLSR) Protocol," Internet Draft. Draft-ietf-manet-olsr-06.txt, Jul. 2002.

[11] T. Ksji, "Approach by Ant Tabu Agents for Traveling Salesman Problem," *International Conference on Systems, Mans & Cybernetics (ICSMC'01)*, Vol.5, October 7-10, pp.3429-3434.

[12] Z.J. Haas, "A New Routing Protocol for the Reconfigurable Wireless Networks," *In Proceeding of the IEEE International Conference on Universal Personal Communications*, 1997.

Chi-Chun Lo received the B.S. degree in Mathematics from National Central University, Chungli, Taiwan, in 1974, the M.S. degree in Computer Science from the Memphis State University, Memphis, TN, in 1978, and the Ph.D. degree in Computer Science from the Polytechnic University, Brooklyn, NY, in 1987. From 1981 to 1986, he was with the AT&T Bell Laboratories, Holmdel, NJ, as Member of Technical Staff. From 1986 to 1990, he worked for the Bell Communications Research as Member of Technical Staff. Since 1990, he has been an Associate Professor in the Institute of Information Management, National Chaio Tung University, Hsinchu, Taiwan. Currently, he is the Director of the institute. His current major researches include network security, network management, network design algorithm, network architecture, and multimedia system.

Chun-Chieh Huang received the B.S. degree in Computer Science from Chung Cheng Institute of Technology, National Defense University, Tao-yuan, Taiwan, in 1994, the M.S. degree in Resource Management from Management College, National Defense University, Taipei County, Taiwan, in 1997. Now, he is a Ph.D. student in institute of information management, National Chaio Tung University, Hsinchu, Taiwan. His current major researches include network security, information security, network topology, and network management.

Chun-Chieh Huang received the B.S. degree in Information Management from National Chung Cheng University, Tao-yuan, Taiwan, in 2004, the M.S. degree in Information Management from National Chaio-Tung University, Hsinchu, Taiwan, in 2006. Now, he is an information security consultant at KPMG, Taiwan. His current major researches include network security, information security, and software design.