A Multi-Agent Routing Protocol with Congestion Control for MANET

Kazuya NISHIMURA and Kazuko TAKAHASHI
School of Science and Department
Kwansei Gakuin University
2-1, Gakuen, Sanda, Hyogo, 669-1337, JAPAN
E-mail: kazuya19820925@yahoo.co.jp ktaka@kwansei.ac.jp

Abstract— **This paper discusses a routing protocol that uses multi-agents to reduce network congestion for a Mobile Ad hoc NETwork (MANET). MANET is a multihop wireless network in which the network components such as PC, PDA and mobile phones are mobile. The components can communicate with each other without going through a server. Two kinds of agents are engaged in routing. One is *a Routing Agent* that collects information about network congestion as well as link failure. The other is *a Message Agent* that uses this information to get to their destination nodes. MAs correspond to data packets and determine their direction autonomously using an evaluation function. We developed both a simulation environment and protocols, and performed simulations under different conditions of mobility and traffic patterns to demonstrate the effectiveness of our approach.**

Keywords— **agent-based modeling, communication networks and protocols, network simulation, multi-agent systems, mobile ad-hoc network**

I. Introduction

Recent advances in portable computing devices and wireless communication technology have brought about an explosive growth in the number of mobile terminals and users. A Mobile Ad hoc NETwork (MANET) is a multihop wireless network in which the network components such as personal computers, personal digital assistants and wireless phones are mobile (Figure 1) [Basagni et al. 2004][Toh 2001]. MANET provides an effective method for constructing an inexpensive network anywhere without requiring specialized nodes or access points. It is considered to be promising for use in networks in case of disasters and emergency situations, and uses a distributed control system by which all the nodes communicate with each other without a supervisor.

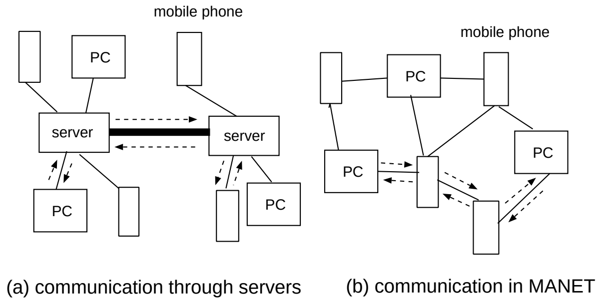

Fig. 1. Communication in MANET

Despite these advantages, a MANET has several drawbacks that are not found in fixed networks. For example, the frequent change in network topology due to the mobility of the nodes causes a great deal of control information to flow onto the network. The small capacity of batteries and the bandwidth limitation of wireless channels are other factors. Moreover, data access focused at a single point may incur impossibility of communication and make quality of service worse. This becomes a serious consideration, especially with recent trends to transferring large volumes of data including video.

Two types of routing protocols are used in a MANET: basically divided into two types: *proactive* and *reactive*.

In proactive routing such as DSDV [Perkins and Bhagwat 1994], WRP [Murthy and Garcia-Luna-Aceves1995] and CSGRF [Chiang et al. 1997], routing information is kept as a table and the table is updated every time the topology changes. The routing table is constituted in advance by periodically exchanging information among nodes. This consumes considerable bandwidth and battery power, although no overhead is incurred at the time of sending a packet. It is more effective when the nodes are less mobile and the number of packets is large.

In reactive routing such as AODV [Perkins and Royer 1999] and DSR [Johnson and Maltz 1996], the best route is determined every time the request of sending a packet occurs. The routing overhead is less than that of proactive routing, since a route is determined only on demand. Routing overhead is lower. However, a large number of messages flow if there is no route, since the source node broadcasts a request. This protocol is effective when the nodes are highly mobile and the number of packets is small.

ZRP [Haas 1997] is a hybrid model of proactive and reactive models. Both types have recently been standardized.

In general, these protocols are not very effective for ad-hoc network routing, since a considerable amount of control data must be exchanged to adapt to changes in the environment. In all these protocols, it is the node that sends the control message.

On the other hand, another routing method based on mobile multi-agents has been proposed [Amin and Mikler 2002a][Amin and Mikler 2002b][Caro and Dorigo

Proceedings 21st European Conference on Modelling and Simulation
Ivan Zelinka, Zuzana Oplatková, Alessandra Orsoni ©ECMS 2007
ISBN 978-0-9553018-2-7 / ISBN 978-0-9553018-3-4 (CD)

1998][Minar et al. 1999a][Minar et al. 1999b]. It was inspired mainly by research on swarm intelligence. In this method, each node has a table that holds part of the routing information and agents exploring nodes bring information to update these tables. It is the agent that brings the control message, that updates the routing table, and that determines the next node to visit. Agents react autonomously in the face of a changing environment. Therefore, this adaptive approach is more suitable for a dynamic network topology.

Minar has proposed a dynamic routing protocol using mobile agents [Minar et al. 1999a][Minar et al. 1999b], and Onishi et al. revised this model [Onishi et al. 2002]. Kawarazaki et al. extended it to take battery capacity into account [Kawarazaki and Takahashi 2003]. However, in these studies, simulations were performed for a single fixed configuration. They did not examine how the protocol works with different numbers of nodes, various mobility, or diverse traffic patterns. In this paper, we extend this protocol to be more generic, so that it can be effective in the face of network congestion. We developed both a simulation environment and protocols, and performed simulations under the several conditions to compare the result using our new protocol with that using the previous one. As a result, the former shows the good performance under all the conditions. We also compare the performance of our new routing protocol with that of AODV which is considered to be a *de facto* standard in the state-of-the-art routing.

This paper is organized as follows. In section II, we describe the dynamic routing model using multi-agents. In section III, we present the simulation conditions, and in section IV, we describe and evaluate the results. In section V, we compare our method with the related works. And finally, in section VI, we show the conclusion.

II. A Model

A. Minar's Model

Minar proposes a dynamic routing model in which a network is composed of two kinds of nodes: fixed nodes and mobile nodes [Minar et al. 1999a][Minar et al. 1999b]. Each node is a wireless terminal with links to adjacent nodes. Mobile nodes are dispatched randomly to move in random directions at constant speed, while fixed nodes are located at regular intervals. This is a fully distributed dynamic network.

Each node has a routing table that stores route information for every destination. *Routing Agent (RA)* starts from every node and moves to an adjacent node at every time. A node visited next is selected at the equivalent probability. The RA brings its own history of movement and updates the routing table of the node it is visiting. If a predefined wandering time has expired, then the RA disappears. *Message Agent (MA)*, corresponding to a data packet, born at a source node, starts from that node, determines the next node by looking up the routing table of the node it is currently on. It repeats moving until it gets to its destination, at which point it disappears. Routing is performed by agents autonomously and locally. Agents do not communicate with each other directly but rather do so through the routing table.

Onishi et al. revised this model so that the RA also brings the time required to travel from the destination to the current node and the number of hops. This history is also stored on the routing table [Onishi et al. 2002].

Kawarazaki et al. considered the case in which some of nodes become inactive because of the power-off. They proposed a new model, which is effective in situations when the number of active mobile nodes changes [Kawarazaki and Takahashi 2003].

These models are not particularly realistic since they assume that node can process an unlimited number of messages at any time. Simulations they performed are insufficient since they apply only to a restricted topology and traffic pattern.

B. Extended Model with Congestion Control

We propose a model in which all the nodes are mobile and information about network congestion is collected and distributed by RAs.

We assume that all the links are uniform, that is, each link has the same length and the same reliability. We also assume that it takes one unit time for any agent to move to an adjacent node. Packet sizes are uniform and large data volumes are simulated by allowing multiple packets (MAs) to be sent simultaneously from a single source to the same destination.

Each node can process one MA per unit time and if multiple MAs arrive at a node, they are held in the queue of the node. If the length of the queue is over the threshold, then congestion occurs. On the other hand, we ignore the population of RAs, since they are distributed uniformly, and they are less resource-intensive than MAs.

B.1 Routing Agent

Each RA has its own history which consists of its source node $Dest$, the current time $Time$, the number of hops Hop from the starting node, the adjacent node Adj that the RA has last visited and the number of MAs on Adj at $Time$. When an RA visits a node, it puts the information $(Dest, Time, Hop, Adj, Mes)$ in the routing table of that node.

Each node has a routing table that stores k fresh routing information records from itself to every node D: $\langle D, \{(T_1, H_1, A_1, M_1), \ldots, (T_k, H_k, A_k, M_k)\}\rangle$, where $T_1 > T_2 > \ldots > T_k$. We call k *the number of entries*. For each i $(1 \leq i \leq k)$, T_i is a time of visiting the adjacent node A_i, H_i is the number of hops and M_i is the number of MAs on A_i. When RA with the history $(Dest, Time, Hop, Adj, Mes)$ visits a node N, the routing information on that node

$$\langle\{Dest, (T_1, H_1, A_1, M_1), \ldots, (T_k, H_k, A_k, M_k)\}\rangle$$

is updated to

$$\langle Dest, \{(Time, Hop, Adj, Mes),$$

$(T_1, H_1, A_1, M_1), \ldots, (T_{k-1}, H_{k-1}, A_{k-1}, M_{k-1})\}\rangle$.

B.2 Message Agent

Let p denote the average possibility of a link failure at a unit time. Then $1-p$ denotes the average reliability of a link at that unit time.

Consider that a MA starts from source node S to destination node D at an instant t. When it visits a node, it looks up the routing table of that node, to determine the node to move next. The agent evaluates the reliability of each route and selects the best one as follows.

Let information about D in the routing table of S be $\langle D, \{(T_1, H_1, A_1, M_1), \ldots, (T_k, H_k, A_k, M_k)\}\rangle$. Consider a route $R_j : N_j^0(= S) \rightarrow N_j^1(= A_j) \rightarrow N_j^2 \rightarrow \ldots \rightarrow N_j^{H_{j-1}} \rightarrow N_j^{H_j}(= D)$ $(1 \leq j \leq k)$. From the routing table, we know that the elapsed time from the point at which the RA visited A_j to the current time is $t - T_j$, and the expected time that will elapse before the MA will arrive at N_j^i is $i + \Sigma_{l=1}^{i} w_j^l$, where w_j^l denotes the waiting time at node N_j^i. Thus, the time interval from the instant in which the RA visited A_j to the instant in which the MA will arrive at N_j^i is $t-T_j+i+\Sigma_{l=1}^{i} w_j^l$ (Fig. 2). No information exists on the congestion of nodes other than A_j in the routing table of S. However, due to the high probability that congestion or link failure at nodes far from S will change by the time an MA starting from S visits such nodes, and it is not meaningful to reflect this information as congestion. Therefore, we approximate $\Sigma_{l=1}^{i} w_j^l$ by the waiting time at the adjacent node, that is, $M_j - 1$.

Thus, the estimated reliability of a link N_j^{i-1} to N_j^i is $(1-p)^{(t-T_j)+i+M_j-1}$. The estimated reliability of the route R_j is determined as the product of the estimated reliabilities of all the links along the route:

$$\begin{aligned} V_j &= \Pi_{i=1}^{H_j} (1-p)^{(t-T_j)+i+M_j-1} \\ &= (1-p)^{H_j(t-T_j)+H_j(H_j-1)/2+H_j(M_j-1)} \end{aligned}$$

Let $P_1, \ldots, P_{k'}$ be different adjacent nodes of S $(k' \leq k)$. Then, the evaluation of $P_{j'}$ $(1 \leq j' \leq k')$ is defined as:

$$V(P_{j'}) = \Sigma_{j=1}^{k} (V_j \ s.t. \ j = j')$$

A node $P_{j'}$ is determined as the next node if $V(P_{j'})$ is the highest.

In general, if the number of hops is small or if the amount of information is large, then the reliability of the route is high. Thus, this evaluation function is reasonable and reflects the freshness of the information.

This calculation is based on the formula shown in [Onishi et al. 2002]. However, we adopt an estimated visiting time for computing reliability, whereas elapsed passed time is used in [Onishi et al. 2002].

III. Simulation

We did not use an existing simulator such as Network Simulator(NS) [Fall and Varadhan 2001], but instead designed and implemented both the simulation environment and the protocols ourselves. We implemented the model using JAVA and tested it under different traffic patterns and condition of mobility. Figure 3 shows a screenshot of our system.

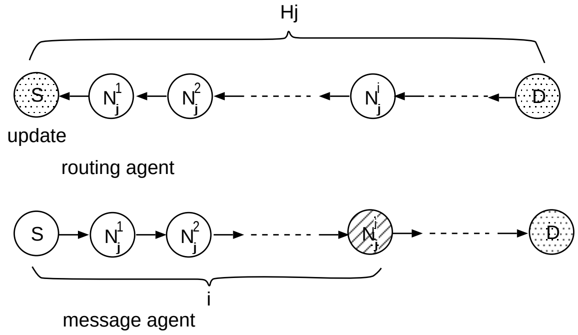

Fig. 2. Evaluation of a route

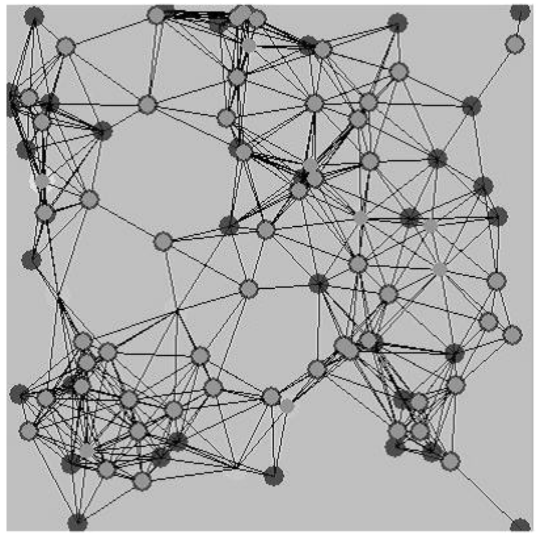
Fig. 3. Screenshot of a system

We also implemented AODV as a comparison. The algorithm was based on [IETF 2003], with a mechanism for congestion control of our design.

Our simulation compared the performance of the following three algorithms under various conditions:

1. multi-agents without a congestion control(MR1)
2. multi-agents with a congestion control (MR2)
3. AODV with congestion control(AODV)

The basic conditions of the simulation are shown in the Table I. The items without the mark * remained unchanged throughout all experiments.

All the nodes are mobile and move in random directions. When a mobile node reaches the edge of the simulation area, it is reflected so as never to leave the area. For MR1 and MR2, packets are sent 200 seconds after the start of the simulation, since it takes some time for the information collected by RAs to be reflected in the routing tables.

We performed simulations under the following conditions:

- Ex1: The basic condition.
- Ex2: The nodes have high mobility.
  - Node speed is changed to 0.2/sec.

TABLE I: Basic condition of the simulation

Terrain	$400 \times 400m^2$
Ratio of link range	80m
Link failure rate	0.01
Threshold of the queue	50
The number of entries	50
Number of RAs	100
Number of MAs (packets)	400
Number of nodes	100
Node placement	random
Speed of node moving*	$0.1/sec$
Frequency of sending MA*	1/sec
The number of source nodes*	10(random)
The number of goal nodes*	1(random)
Simulation time	200 sec
The times of simulation	100

- Ex3: Traffic pattern changed so that a greater number of MAs is sent at once.
  - Frequency of sending MA is changed to 10 at every 10 seconds.
- Ex4: Traffic pattern changed so that packets are sent from specific source nodes to bonbard a single destination node.
  - The number of source nodes changed to two specific nodes, the number of destination nodes changed to one specific node far from both start nodes, and the frequency of sending MA is also changed to 5 at every 2 seconds.

Ex4 is performed to examine the advantage of MR2 over MR1, under the condition of frequent congestion.

IV. Results and Evaluation

Figure 4 and Table II show the results of our simulation.

In the Figure, *reachability* denotes the total number of MAs (packets) that reached the destination, and *time* denotes the time elapsed after starting to send MAs.

In Table II, *reached time* indicates the time when all the MAs reached their destinations. For the case of AODV, this value is not measured because of packet loss. *Congestion* denotes the number of nodes in which congestion appears. And *hops* means the average number of hops.

A. Comparison between MR2 and MR1

In all cases, packets reached their destinations earlier in MR2, and the total number of congested nodes is much lower in MR2. Thus, it follows that the traffic is lower in MR2. In Ex4, several data packets were concentrated in just a few routes so congestions occurred at many nodes along these routes. Therefore, many MAs took detours to escape congestion. This resulted in a large number of hops. It follows that when an MA can decide ahead of time that a congested node exists in its route, then it will arrive at its destination faster by taking a detour than it can by waiting for its turn

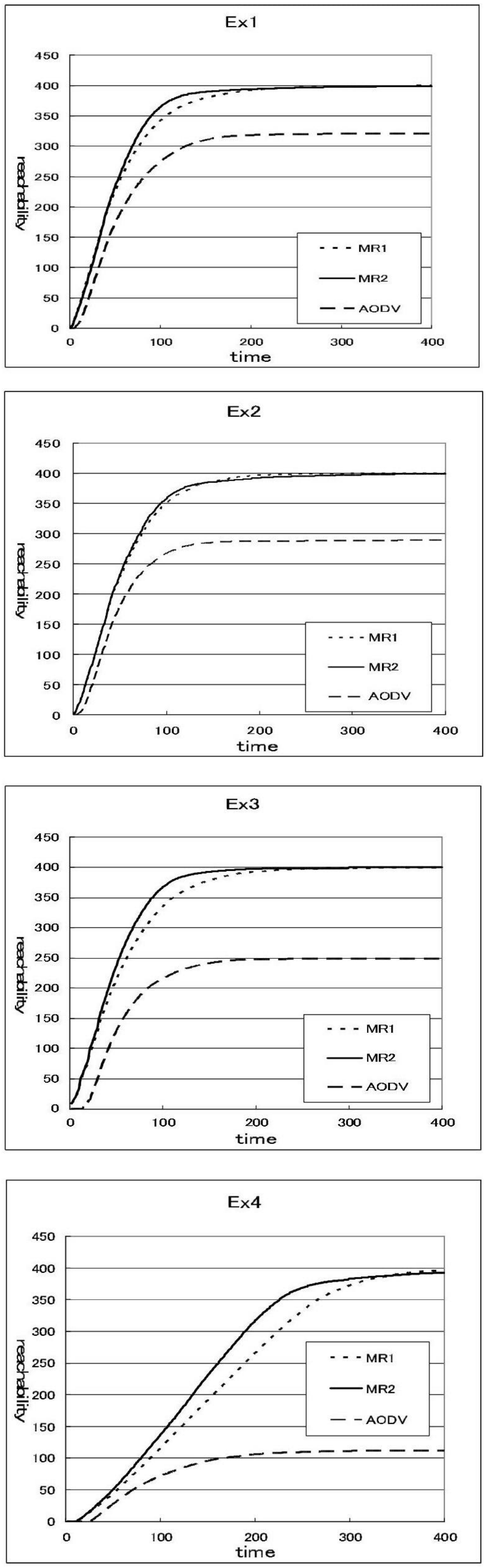

Fig. 4. Transition of the numbers of reached packets – Ex1 (basic condition), Ex2 (high mobility), Ex3 (large amount of traffic), Ex4 (intensive distribution)

	Ex1			Ex2			Ex3			Ex4		
	MR1	MR2	AODV	MR1	MR2	AODV	MR1	MR2	AODV	MR1	MR2	AODV
reached time	147.7	125.7	–	135.3	122.1	–	147.2	116.0	–	306.9	260.7	–
congestion	45.2	18.0	55.7	28.2	19.7	32.1	51.5	11.6	28.7	345.3	111.8	163.7
hops	5	6	4	6	6	4	5	6	4	14	17	8

TABLE II: Comparison of the results

at the congested node. This decision is based on the evaluation function shown above, and the experimental results bear out the effectiveness of that function.

B. Comparison between MR2 and AODV

Packets are never lost in MR1 and MR2, while many are lost in AODV, especially in the case of high mobility.

The number of hops in AODV is smaller in all cases. This is because while all possible routes are compared simultaneously in AODV, RAs do not always find all possible routes in MR2. Therefore, if a route is found, it is the best one in AODV; however, route-finding rarely succeeds because of link failure, especially under the condition of high mobility. As a result, reachability is low. Congestion in AODV is rather low since considerable number of packets are lost.

The performance of AODV can be increased by tuning the AODV algorithm, for example, by resending a packet when it is lost. However, repeating packet-sending may generate more congestion.

V. Related Works

Lots of systems have been proposed based on dynamic routing using multi-agents.

AntNet, one such system, uses a model that imitates swarm behavior [Caro and Dorigo 1998]. Two kinds of agents called *forward agents* and *backward agents* are used to collect information. The forward agent computes the cost of moving from the source node to the destination, while the backward agent moving in the opposite direction updates the routing table stored at each node using the information given by the forward agent. Each node in the network executes reinforcement learning using these information. The probabilistic packet control realizes dynamic routing.

AntNet was originally developed for a fixed network, and several works exist that extend AntNet to be effective for MANET.

In AntHocNet[Caro et al. 2004], multiple routes are found by agents and data are spread stochastically over these routes. Agents are always alert to link failures and they stop sending messages via broken routes. This mechanism results in load balancing and adds robustness to link failures. In AntHocNet, a packet is sent stochastically using the information of congestion or link failure, while in our model, a packet is sent via the current best route. In AntHocNet, congestion is estimated using the processing time at the MAC layer. When congestion does occur, its effect on routing is not immediate, since it takes some time to accumulate enough information for the estimation process to work.

Marwaha et al. developed AODV+Ant in which AntNet and AODV run simultaneously [Marwana et al. 2002]. In AntNet, a node starts sending data without delay if it has a route to a destination, but it must wait for a long time to collect information if it does not. In contrast, in AODV, end-to-end delay and route-discovery latency are smaller. The system has shown good performance by combining the advantages of these two methods. In addition, AODV's ability to maintain local connectivity could reduce the redundant sending of agents.

Several differences exist between our model and these AntNet-based models. The first one is that routing agents explore the network randomly in our model while agents are sent in a specific direction in AntNet-based models. Second, the data packet is also considered to be an agent that determines the next node in our model, while it is not considered as an agent in AntNet-based models. Third, in our model, a node does not have a learning function, since its routing table is updated every time an RA visits.

Other studies have investigated the application of multi-agent framework to the dynamic routing in MANET.

Tatomir and Rothkrantz proposed a model in which the routing table learns using the information that is collected by agents [Tatomir and Rothkrantz 2004].

Choudhury et al. proposed a new protocol MARP which predicts the change of topology [Choudhury et al. 2004]. No exploring agent exists that collects information, but each data packet is considered to be an agent that learns using its own history to select the next node.

Zhou and Zincir-Heywood proposed the protocol MAR [Zhou and Zincir-Heywood 2004], in which each data packet is considered to be an agent that explores the network to collect routing information. Agents communicate with one another to exchange this routing information.

In some of these models, agent movements is designed to avoid congestion. In those models, the proper distribution of agents to collect information is a prime consideration while the congestion of data packets is ignored. On the other hand, in our model, agents that collect information are distributed uniformly and their jobs are light, and our new protocol can control the congestion of packets.

VI. Conclusion

In this paper, we have proposed a routing protocol that reduces network congestion for MANET using multi-agents. We use two kinds of agents: Routing Agents to collect information about congestion and to update the routing table at each node, and Message Agents to move using this information. To evaluate the best route, we developed a function based on the reliability of links and showed its effectiveness with simulations under various conditions. The definition of the evaluation function is the most critical problem. The evaluation function defined in this paper is not the best one, but it is almost impossible to determine a generic one since it is affected by too many factors, which include, for example, the positional relationship of source nodes to destination nodes, the change over time of the frequency of sending packets and the movement of nodes. Moreover, we must consider the case when nodes may not be uniform, and may have different battery states or performance. In the future, we will investigate a better evaluation function and discuss the limits of its effectiveness. The evaluation function itself may change depending on the environment. Incorporating learning into the function is also an interesting issue.

References

[Amin and Mikler 2002a] K.A.Amin and A.R.Mikler. "Dynamic Agent Population in Agent-Based Distance Vector Routing," Second International Workshop on Intelligent Systems Design and Applications, 2002.

[Amin and Mikler 2002b] K.A.Amin and A.R.Mikler. "Towards Resource Efficient and Scalable Routing: An Agent-Based Approach," Technical Report, University of North Texas, Department of Computer Science, 2002.

[Basagni et al. 2004] S.Basagni, M.Conti, S.Giordano and I.Stojmenovi (Eds.), "Mobile Ad Hoc Networking," Wiley-IEEE Press, 2004.

[Choudhury et al. 2004] R.R.Choudhury, K.Paul and S.Bandyopadhyay. "MARP: A Multi-Agent Routing Protocol for Mobile Wireless Ad Hoc Networks," Autonomous Agents and Multi-Agent Systems, Vol.8, No.1, pp. 47-68, 2004.

[Caro and Dorigo 1998] G.D.Caro and M.Dorigo. "Mobile Agents for Adaptive Routing," Proceedings of the Thirty-First Hawaii International Conference on System Sciences, pp. 74-83, 1998.

[Caro et al. 2004] G.D.Caro, F.Ducatelle and L.M.Gambardella. "AntHocNet: an Ant-Based Hybrid Routing Algorithm for Mobile Ad Hoc Networks," Proceedings of Parallel Problem Solving from Nature (PPSN) VIII, pp. 461-470, LNCS 3242, Springer, 2004.

[Chiang et al. 1997] C.-C.Chiang, H.-K.Wu, W.Liu and M.Gerla. "Routing in Clustered Multihop Mobile Networks with Fading Channel," Proceedings of the IEEE Singapore International Conference on Networks, 1997.

[Fall and Varadhan 2001] K.Fall and K.Varadhan(Ed.). "The NS Manual, The VINT Project" UC Berkeley, LBL, USC/ISI and XEROX PARC, 2001.

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

[IETF 2003] The Internet Engineering Task Force (IETF) MANET WG "Ad hoc On-Demand Distance Vector (AODV) Routing," `http://www.ietf.org/rfc/rfc3561.txt`, 2003.

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

[Kawarazaki and Takahashi 2003] K.Kawarazaki and K.Takahashi. "An Extension of the Dynamic Network Routing System Using Mobile Agents," IEICE Transactions on Information and Systems, Vol.J86-B, No.11, pp.2433-2436, 2003 (In Japanese).

[Marwana et al. 2002] S.Marwana, C.K.Tham and D.Srinivasan, "Mobile Agents Based Routing Protocol for Mobile Ad Hoc Networks," Proceedings of IEEE Globecom, 2002.

[Murthy and Garcia-Luna-Aceves1995] S.Murthy and J.J.Garcia-Luna-Aceves. "A Routing Protocol for Packet Radio Networks," Proceedings of the ACM First International Conference on Mobile Computing and Networking (MOBICOM95), 1995.

[Minar et al. 1999a] N.Minar, H.Kramer and P.Maes. "Cooperating Mobile Agents for Dynamic Network Routing," Software Agents for Future Communications Systems, Chap.12, Heyzelden and J.Bigham(eds.), pp.287-304, Springer-Verlag, 1999.

[Minar et al. 1999b] N.Minar, K.H.Kramer and P.Maes. "Cooperating Mobile Agents for Mapping Network," Proceedings of the First Hungarian National Conference on Agent Based Computation, 1999.

[Onishi et al. 2002] R.Onishi, S.Yamaguchi, H.Morino, H.Aida, and T.Saito. "The Multi-agent System for Dynamic Network Routing," The Fifth International Symposium on Autonomous Decentralized Systems with an Emphasis on Electronic Commerce (ISADS), 2002.

[Perkins and Bhagwat 1994] C.E.Perkins and P.Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," Computer Communication Review, No.24, Vol.4, pp. 234-244, 1994.

[Perkins and Royer 1999] C.E.Perkins and E.M.Royer. "Ad Hoc on Demand Distance Vector Routing," Proceedings of the WMCSA99 Second IEEE Workshop on Mobile Computing Systems and Applications, pp. 90-100, 1999.

[Toh 2001] C.-K.Toh. "Ad Hoc Mobile Wireless Networks: Protocols and Systems," Prentice Hall, 2001.

[Tatomir and Rothkrantz 2004] B.Tatomir and L.Rothkrantz. "Dynamic Routing in Mobile Wireless Networks Using ABC-AdHoc," Proceedings of Ant Colony, Optimization and Swarm Intelligence (ANTS2004), pp. 334–341, LNCS Vol.3172, 2004.

[Zhou and Zincir-Heywood 2004] Y.Zhou and A.N.Zincir-Heywood. "Intelligent Agents for Routing on Mobile Ad-Hoc Networks," Proceedings of the Second Annual Conference on Communication Networks and Services, pp. 249-254, 2004.

Kazuya NISHIMURA He received his B.S. and M.S. degrees from Kwansei Gakuin University in 2005 and 2007, respectively. He joined Hitachi Software Engineering Corporation in 2007. He is interested in network routing.

Kazuko TAKAHASHI She received the degrees of B.S. and Dr. of Engineering from Kyoto University in 1982 and 1994, respectively. She was a researcher at the Central Research Laboratory and Advanced Technology R&D Center of Mitsubishi Electric Corporation from 1982 to 2000. In 2000, she joined the School of Science, Kwansei Gakuin University as an associate professor. Since 2006, she has been a professor at the School of Science & Technology, Kwansei Gakuin University. She is interested in knowledge representation and reasoning systems. She is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), Information Processing Society of Japan (IPSJ), Japan Society for Software Science and Technology (JSSST) and the Japanese Society for Artificial Intelligence (JSAI).