Victim Detection System for Urban Search and Rescue Based on Active Network Operation.

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Victim Detection System for Urban Search and Rescue Based on Active Network Operation

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Abstract. A victim detection system is proposed for rescue operations in urban disaster areas. This system consists of autonomous mobile robots and a stationary monitor station connected by a wireless ad hoc network with an active network operation. Robots are instructed to detect victims in a disaster area and send the information to the monitor station through the ad hoc network, and active network operation recovers the communication path breakages that sometimes occur in disaster areas where a conventional recovery scheme for an ad hoc network may not perform well. This additive network operation is executed by autonomous movements of robots which are installed with a behavior algorithm for communication path recovery. The system's performance is examined by a computer simulation for the case of reconnaissance into a distant location, taking into account robot breakdowns.

1 Introduction

Urban Search and Rescue (USAR) utilizing autonomous mobile robots has been investigated[1, 2]. USAR aims to search for and rescue victims in disaster zones, especially those littered with debris from man-made articles such as collapsed buildings. However, due to the hazardous environment surrounding the robots, they may sometimes suffer problems. Moreover, it may be difficult for robots to reconnoiter disaster areas spread widely across catastrophe-stricken regions.

These problems may be resolved by utilizing multi-robot systems with communication paths among them based on a wireless network. For example, if a robot ceases executing a task because of some troubles, another robot in the vicinity may take its place. Or, in the case of extensive disaster area, robots may deploy uniformly over the area, negotiating with each other about their relative locations, and integrate their sensors through communication paths.

In this paper, a class of multi-robot system based on a wireless network, named the *victim detection system*, is proposed for relatively basic USAR operations. The victim detection system consists of robots, a stationary monitor station with operators, and wireless network connecting all of them. Robots deploy over disaster area and reconnoiter the invisible region where victims are expected to be trapped. If a robot detects a victim, it transmits the information to the monitor station through the wireless network.

An *ad hoc network*[3] is adopted for the wireless network of victim detection system with an additional network operation scheme named *active network operation*. An ad hoc network is suitable for a victim detection system because of its connectability between robots hidden among debris, and for its inherent reliability, especially desireble in a disaster area. Active network operation is executed by movements of robots that autonomously recover communication path breakages that sometimes occur in disaster areas.

In Section 2, the victim detection system is described with a brief explanation of ad hoc networks. In Section 3, active network operation is explained as the behavior algorithm of each robot. Section 4 introduces a special operation scheme for the victim detection system: *reconnaissance into distant space*, and the system performance is evaluated by a computer simulation that takes robot breakdowns into account. The results are summarized in the final section.

2 Victim detection system

The victim detection system proposed here consists of robots and a stationary monitor station with an ad hoc network connecting all of them. Active network operation is installed to recover the communication path breakages. In this Section, we first describe the system configuration of the victim detection system, followed by a review of the fundamentals of ad hoc networks. Active network operation is explained in the next section.

2.1 System configuration

Figure 1 shows an example of victim detection system operating over a disaster area. In this figure, eight robots A to H and a monitor station (from now on, denoted by *MS*) establish an ad hoc network, threading a path among debris or obstacles that interrupt the transmission of radio signals and restrict the robots' movement. These robots deploy over the disaster area and reconnoiter invisible regions such like gaps between debris where victims are expected to be trapped. They are instructed to detect victims located within the range of their sensors specialized to react to the presence of human bodies. In contrast, MS is a stationary node in the network with human operators who monitor and supervise the autonomous task execution of robots through the ad hoc network.

If a robot detects the victim, it sends the information to the MS through ad hoc network. Figure 1 shows a victim behind an obstacle and robot A detects him with its sensor. In this case, robot A sends the information to the MS through the communication path relayed by intermediate robots B and C. The information transmitted by robot A may include the location of the robot itself and a compressed video signal of the view surrounding it. This information

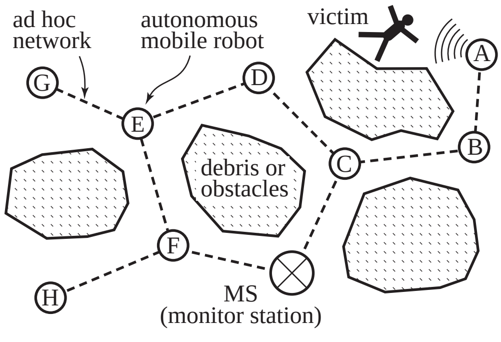

Figure 1: An overview of victim detection system.

is gathered at the MS with that from other robots and is examined by operators. The operators make the final decision as to whether each piece of information actually indicates the victim.

Each robot should be installed with a specialized sensor system for victim detection. This system may be realized by FLIR (forward-looking infra-red)[4] which senses an object's body temperature and identifies its contour. Although it is difficult for a robot to decide whether the object sensed by FLIR is really the victim, the final decision is given by operators at the MS. This hierarchical cooperation between them alleviates some requirements for each robot's sensing abilities and makes victim detection more realizable than in the case of single or unnetworked robot systems. However, subjects left for further studies include what is a reasonable tradeoff between the sensing ability of robots and the work load on operators, who make the final decision, and what amount of network capacity should be provided when a lot of doubtful information is sent to MS, which is then subjected to the operators.

2.2 Ad hoc network

In ad hoc networks, *communication links* (or, simply *links*) are established between mobile terminals within *transmission range* of each other. Transmission range means the circular area defined by the *transmission radius* within which the radio signal can be transmitted immediately from the terminal at its center. Any terminals in the network can transmit packets to each other through the communication path that traces a cascade of links established by intermediate terminals.

There are many types of ad hoc network that operate according to the routing method by which each terminal determines the communication path to the destination terminal (from now on, simply referred to as the *destination*). Among these, DSDV (Destination-Sequenced Distance-Vector)[5] is adopted here as a typical routing method for an ad hoc network by which communication paths are routed among robots in the victim detection system.

According to the DSDV routing method, each robot stores a *forwarding table*. The forwarding table indicates the next relay terminal for packet transmission addressed to each destination. This next terminal is one of the neighboring robots and is called the *next hop*. A forwarding table consists of entries each for individual destination in the network (from now on, *the entry for A* means the entry with some identifier of robot A recorded as the destination). The identifier of the next hop is combined with that of the destination in each entry.

Each robot's forwarding table must be updated when network topology changes. For the purpose of this update, each robot periodically broadcasts an *update packet* over the network, which informs the current location of each destination or its disappearance when one of the intermediate communication links to the destination is broken. Forwarding tables are not updated instantaneously because of transmission delays or loss of update packets, which sometimes occurs when they collide with each other.

In Fig.1, the next hop from robot A is robot B for the MS and for every other robot. The communication path from robot A to the MS is: A→B→C→MS. If the link between robot C and the MS is broken because of reasons including their being too distant, or the appearance of some obstacle between them, then the entry for the MS will disappear from the forwarding tables of robots A, B, and C. After a while, these entries will be retrieved when robot C records robot D as the next hop for the MS. Now, the communication path from robot A to the MS bypassing the broken link is: A→B→C→D→E→F→MS.

This process to recover the communication path by bypassing the broken link is the only strategy available in conventional ad hoc network systems. However, this scheme may not perform well in disaster areas due to the difficulty of finding alternative communication paths among robots deploying over the area, and to the possibility of robot breakdowns occurring as a result of the hazardous environment. For example, if the link between robots B and C is broken or any one of them loses its communication ability in Fig.1, robot A cannot send the information on the victim to the MS, for the alternative path to the station does not exist. Generally, this problem is caused by inadequacy of scarcely established communication links threading their path among obstacles that shield radio waves and regions filled with electromagnetic noise generated by sparks and so on.

3 Active network operation

Active network operation recovers communication path breakages that sometimes occur in disaster area where the conventional scheme of the path recovery in an ad hoc network may not perform well, as is mentioned in the previous section. This operation is executed by autonomous movements of each robot following a common behavior algorithm. In this section, we first introduce this behavior algorithm, then show an example of a process of path recovery executed by robots.

3.1 Behavior algorithm of robots

The robot behavior algorithm focuses on how to recover broken links that exist between a robot and the next hop for the MS. According to this algorithm, each robot only watchs its forwarding table and decides its behavior depending on the temporal state of the table. Figure 2 shows the flowchart of the behavior algorithm of each robot in victim detection system. In this figure, the NMS means the next hop for the MS[1].

As the flowchart shows, each robot behaves as follows: The robot constantly updates its knowledge of the location and movement of the NMS provided the link to the NMS exists. This knowledge of the NMS is used to presume its current location when the link to it is

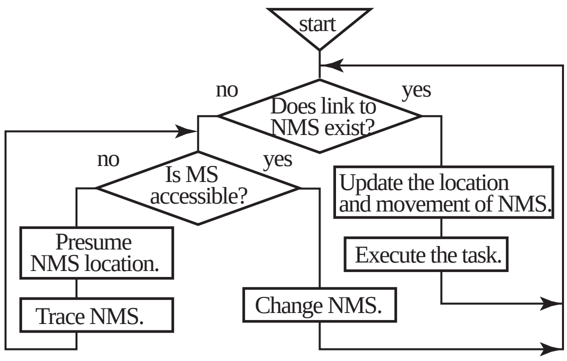

Figure 2: Behavior algorithm of each robot for active network operation.

[1]For example in Fig. 1, the NMS of robot A is robot B, and the NMS of robot B is robot C. Specifically, the NMS of robot C is the MS itself.

broken. The robot then executes tasks that include deployment over the disaster area and detection of victims. If the robot finds that the link to the NMS does not exist, i.e., the entry for the NMS disappears from its forwarding table, the procedure branches depending on whether the MS is still accessible. If the MS is accessible, i.e., the entry for the MS exists in the forwarding table, the robot changes the NMS to the current one and returns to the beginning of the flowchart. This means an alternative path exists and it is found immediately.

On the other hand, if the MS is not accessible, i.e., the communication path is broken and an alternative path cannot be found, the robot presumes the current location of the NMS and traces it. The presumption can be done based on the knowledge updated just before the link to the NMS was broken. This tracing continues until the MS becomes accessible again, i.e., the entry for the MS is retrieved. At the end of this tracing, the current NMS is not necessarily the one the robot has been tracing. If the NMS has in fact changed, this means an alternative communication path was found during the tracing.

Because the case may occur that the robot fails to trace the NMS and the tracing continues wastefully, a time limit is put on the duration of tracing. If the duration exceeds this time limit, the robot changes the NMS to the MS, then it moves to where MS is located. Because the stable location of the MS is initially recorded and saved, the robot will always be able to return to the area within the transmission range of the MS. Therefore, the robot can certainly retrieve the entry for the MS, even if it cannot find a communication path to it before arrival.

3.2 An example of autonomous path recovery for robots

Figure 3 shows an example process in which robots autonomously recover the communication path breakage. At the beginning of this figure, robot A is assumed to be accessible to the MS through an ad hoc network relayed by robots B and C. This path is going to be broken and will be recovered following the process described below (number in parentheses coincides with that in the figure).

(1) Robot C moves in the opposite direction of robot B. As a result, the distance from B to C exceeds the transmission radius (from now on, this situation is expressed as *they go out of range*).

(2) The link between robots B and C is broken. After a while, entries for the MS and for robot C disappear from the forwarding tables of robots A and B.

(3) Because both the NMS (robot C) and the MS become inaccessible, robot B begins to trace C, whereas robot A does not change its behavior because the NMS (robot B) is still accessible.

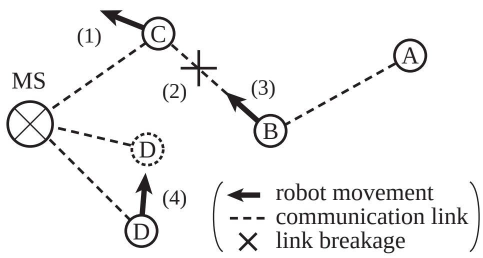

Figure 3: An example procedure of communication path recovery.

(4) During the tracing of robot B, robot D incidentally approaches B. In this case, two scenarios are possible. First, robot B retrieves its link with robot C and the tracing finishes because the MS becomes accessible again. Second, robot B establishes a new link with robot D and its tracing finishes because the MS again becomes accessible with the current NMS (robot D).

The communication path breakage demonstrated above may also occur when robot C breaks down. In this case, robot D becomes the NMS for robot B as described above, or robot B moves toward the MS because the duration of its tracing of robot C exceeds the time limit, and finally the MS becomes accessible directly from B.

After these processes of communication path recovery, robots A and B may go out of range. If the link between them is broken, robot A begins to trace robot B as B did just before, and the path from A to the MS will be recovered similarly.

In the actual execution of the behavior algorithm, it is necessary to locate each robot and to report the location to the neighboring ones to update their knowledge about the NMS. Although IMU/GPS can be attached to the robot for the accurate position measuerments to within a meter[6], some robots may still be invisible to GPS satellites, such as robots reconnoitering in a void under debris. Therefore, a strategy is necessary by which the definite positions of robots where GPS is available are shared with the other robots through the network, and their undefined positions are presumed by using the definite positions. This presumption may be done by a type of triangulation or such relative measurement schemes among robots[7, 8].

The behavior algorithm introduced in this section is rather simple one and may not be the optimum. If a link breakage occurs, the robot may take current network topology around there into account expressing which is the best direction to move to recover the communication path with the MS. Although this and other factors are not considered in the behavior algorithm, this may form the basis of an algorithm refined in further studies on the active network operation.

4 Reconnaissance into distant locations

In the case of an urban catastrophe, there may appear remote locations that human rescue corps cannot reach due to hazards surrounding access paths. In this case, it is urgent to determine whether victims are isolated there. In this section, we introduce an operation scheme of the victim detection system: *reconnaissance into distant locations* to be applied to this special type of rescue operation to ascertain the existence of victims trapped there. The system procedure of the victim detection system is described and the system performance is evaluated by computer simulation. For this simulation, *autonomous mobile robot simulator*[9] is adopted with modules imported from *ad hoc network simulator*[10] assuming that the simulation step corresponds to 0.1 msec in the real world.

4.1 System procedure

The system procedure consists of the sequential movement of robots to the geometrical destination in the distant location and their random walk around the destination (from now on, *destination* means this geometrical destination other than that of packet transmission).

The sequential movement of robots is performed as follows. First, every robot gathers closely around the MS established in the safety zone (or *warm zone*, for a more precise

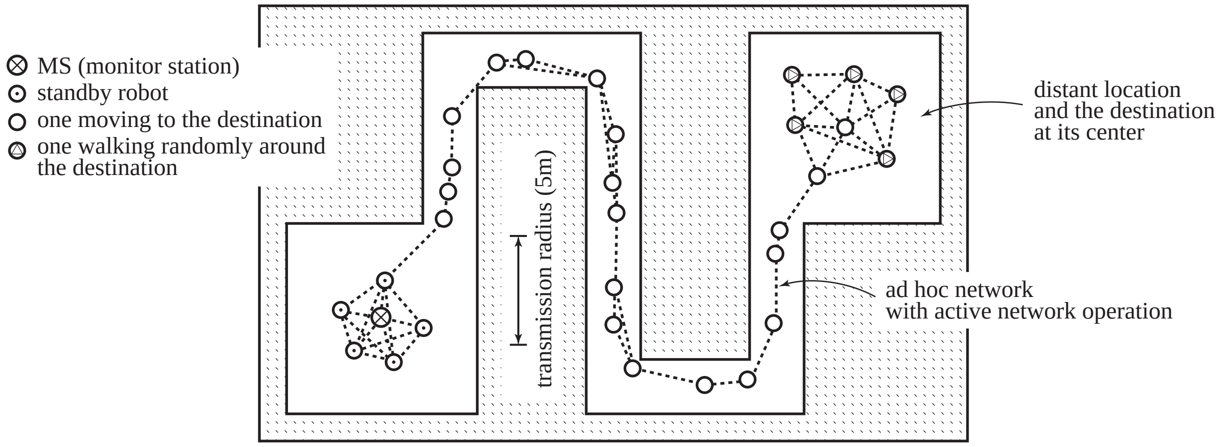

Figure 4: Simulation model of reconnaissance into distant location.

definition[1]) and starts the ad hoc network operation. Second, one of the robots begins moving to the destination in the distant location (this robot is called *the first robot*). This first robot moves there autonomously according to some path-finding algorithm. Then, after the predetermined time interval has passed, one of the remaining robots, i.e., the second robot, starts toward the same destination as the first robot, tracing its trajectory. These sequential movements toward the same destination continue with the successive robots that initially stood by the MS.

When the first robot arrives at its destination, it changes its behavior to roaming randomly around the destination. This behavioral change in the first robot is repeated by successive ones and the remote location is gradually filled with these robots, which are searching for victims. Finally, the area is swept with their sensors, and operators at the MS identify the locations of victims if they do indeed exist there. This means the reconnaissance into the distant location is accomplished.

During the execution of the system procedure mentioned above, each robot autonomously behaves to recover the communication path breakages according to the algorithm of active network operation as introduced in Section 3.1. Communication path breakages occur when any of the links configuring the path is broken. This link breakage occur in many cases including when adjacent robots go out of range and when some obstacle appears between them. Moreover, multiple links may be lost simultaneously when breakdown of a robot terminating them occurs due to the surrounding hazardous environment.

Active network operation is desirable to keep every robot accessible to the MS most of the time until the reconnaissance into the distant location is accomplished (from now on, the robot accessible to the MS is called the *accessible robot*). If a robot becomes inaccessible, then the robot cannot send information about a victim to the MS, even if it detects him. A robot's accessibility is especially important before it arrives at the destination, for there may be limited numbers of links established among the robots along the path to the destination. If any of the links are broken, all of the robots beyond the broken point must become inaccessible, causing the system to black out, even though the system may re-start soon after by the active network operation.

Table 1: Parameters used in the simulation.

Fundamental parameters	
number of robots	30
moving speed of robot	2 km/h
Autonomous path recovery	
tracing speed	4 km/h
duration time limit	1 minute
Ad hoc network operation	
transmission radius	5 m
transmission rate	10 Mbit/sec
frequency of update packet transmission	10 times/sec (on average)
update packet size	1 kbit/entry

4.2 Computer simulation

As mentioned previously, sequential movement of robots to the destination and the active network operation ensuring their accessibility to the MS are essentially important for reconnaissance into distant locations. To evaluate the performance of these functions, a computer simulation is executed using the system model indicated in Fig.4. In this model, two spaces are connected by a crooked path. The MS and the destination are located at the center of the respective spaces. Initially, 30 robots stand by the MS and then sequentially move to the destination at a speed of 2km/h along the crooked path. After arriving, they walk randomly around the destination. When a robot traces the NMS for path recovery, it moves at 4km/h until the path is recovered or the time limit of 1 min. expires. These parameters and that of the ad hoc network operation are shown in Table 1. The time interval between the robot departures is represented by the *interval ratio*. This ratio represents the time interval to the time the robot passes across the transmission radius. The passing time equals 9 sec in this case. Therefore, if the interval ratio equals 0.5, then the time interval equals 4.5 sec.

In this simulation, elapsed time from the beginning of the system's operation to the first arrival of an accessible robot is evaluated (this elapsed time is called the *arrival time*). Robot breakdowns are taken into account when simulating the hazardous environment causing them. Moreover, occasional link breakages occur in cases of adjacent robots going out of range or

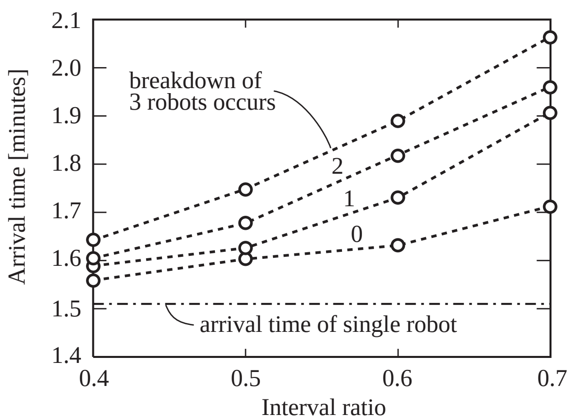

Figure 5: Arrival time of accessible robot at the destination in the distant location.

of interference with radio waves by corner walls. Communication path breakages caused by these problems are quickly recovered by active network operation. Therefore, even if the first robot is not accessible at the destination, the second or third one may be accessible, making one of these the first arrival by an accessible robot.

Figure 5 indicates the simulation results. The horizontal axis represents the interval ratio, and the vertical axis represents the arrival time of the accessible robot. Arrival times with a different number of robot breakdowns are indicated at each of the four discrete points of the interval ratio. These breakdowns occur on randomly selected robots and the results are averaged over ten simulation runs. The dashed and single-dotted lines indicate the arrival time of a single robot without any network operation (called the *single arrival time*). The difference of each arrival time to a single arrival time indicates the processing time of active network operation.

When the interval ratio increases, more the adjacent robots are isolated, and they tend to go out of range while moving to the destination. Therefore, the larger the set interval ratio, the more times communication path recoveries are executed by robots, causing an increase in arrival time. Arrival time also increases monotonically as the number of robot breakdowns increases. On the other hand, at the smallest interval ratio and with no robot breakdowns, arrival time should not exceed the single arrival time. These expectations are confirmed by simulation results shown in Fig.5, indicating that the results are reasonable.

Reliability of the victim detection system based on active network operation is assured by the simulation results. Even though three robots cease their functions during reconnaissance, and although a relatively large interval ratio is set for the sequential movement of robots, the accessible robot arrives at the destination within few minutes, and after a while the distant location will be swept by its sensor and those of successive robots.

5 Summary

We proposed a victim detection system based on active network operation for USAR. This system consists of autonomous mobile robots and a stationary monitor station (MS) with a wireless ad hoc network connecting all of them. Robots deploy over a disaster area and send information about victims when they decide a human body is sensed. Operators at the MS receive the information through the network and make the final decision whether it really indicates a victim. The active network operation consists of autonomous movements of robots recovering the communication path breakages that sometimes occur in disaster areas. This additive network operation assures the reliability of the victim detection system even if robot breakdowns occur due to the surrounding hazardous environment.

Reconnaissance into distant locations is introduced as a special case for our victim detection system. This system aims at determining whether victims are isolated in distant locations that human rescue corps cannot reach. The system procedure consists of the sequential movement of robots to the destination and subsequent random walking. The arrival time of an accessible robot is evaluated by computer simulation on the specified system model and with a set of parameters. As a result, the arrival time of few minutes is given when breakdowns of three robots occur randomly until arrival. This shows the possibility of the victim detection system performing well, especially in this case of rescue operation.

Acknowledgment

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References

[1] R. Murphy, J. Casper, M. Micire, and B. Minten, “Mobility and Sensing Demands in USAR,” *IECON2000*, vol.1, pp.138-142, Oct, 2000.

[2] K. Osuka, R. Murphy, and A. C. Schultz, “USAR Competitions for Physically Situated Robots,” *IEEE Robot. and Automat. Mag.*, vol.9, no.3, pp.26-33, 2002.

[3] J. P. Hubaux, T. Gross, J. L. Boudec, and M. Vetterli, “Toward Self-Organized Mobile Ad Hoc Networks: The Terminodes Project,” *IEEE Commun. Mag.*, vol.39, no.1, pp.118-124, 2001.

[4] K. Owens and L. Matthies, “Passive Night Vision Sensor Comparison for Unmanned Ground Vehicle Stereo Vision Navigation,” *IEEE ICRA*, vol.1, pp.122-131, 2000.

[5] C. E. Perkins and P. Bhagwat, “Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers,” *ACM SIGCOMM’94*, pp.234-244, 1994.

[6] S. Sukkarieh, E.M. Nebot, and H.F. Durrant-Whyte, “A High Integrity IMU/GPS Navigation Loop for Autonomous Land Vehicle Applications,” *IEEE Trans. on Robot. and Automat.*, vol.15, No.3, pp.572-578, 1999.

[7] H. Sugiyama, “A Method for an Autonomous Mobile Robot to Recognize its Position in the Global Coordinate System When Building a Map,” *IEEE/RSJ IROS’93*, vol.3, pp.2186-2191, 1993.

[8] H. Sugiyama and M. Murata, “A Method of Map Building with Multiple Mobile Robots in a Cooperative Process,” *The First World Congress on Intelligent Manufacturing Processes & Systems*, pp.824-829, 1995.

[9] H. Sugiyama and M. Murata, “AMRS: An Autonomous Mobile Robot Simulator,” *Memoirs of the Faculty of Engineering, Osaka City Univ.*, pp.105-121, 1996.

[10] H. Sugiyama, T. Tsujioka, and M. Murata, “Ad Hoc Network Simulator Based on DSDV Routing Method,” *Memoirs of the Faculty of Engineering, Osaka City Univ.*, pp.43-58, 2002.