Multi-Agent Approach for Evacuation Support System

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Abstract: We propose a system that supports evacuation after a large-scale disaster. When a large-scale disaster occurs, collecting information by using portable devices is difficult, because communication base stations collapse and traffic congestion occurs. Evacuees are at a loss where they should go for safe places in lack of information. In order to overcome these problems, we have proposed and evaluated a multi-agent system that is built on MANET. Our aim is to let the users share information on MANET, and provide safe routes to the destination by using collected information. In the previous paper, we proposed and implemented the main functions of the proposed system, and performed feasibility study of the multi-agent system by using simple simulator. In this paper, we report the revised system and investigate the relationships between the number of the users and diffusivity of information, and the number of the generated mobile agents by using newly constructed simulator. In the experiments for evaluation, we simulated a realistic situation by using real map data and we took stochastic change of the situation into consideration, because the situation must be getting worse by time elapses.

1 INTRODUCTION

When a large-scale disaster, such as big earthquakes occurs, a large-scale fire occurs, buildings collapse, and roads break. In addition, the public transports may paralyze and large-scale traffic congestion may occur. As a result, a number of evacuees may inundate the damaged towns. Furthermore, people starts to use the communication devices, such as smartphones, to collect information about the service status of public transport and safety information of family and friends. As a result, communication base stations may become too congested as well as destroyed. The users of communication services cannot depend on the traditional communication infrastructure, because of the collapse of the base stations and extreme congestion.

When the Great East Japan Earthquake occurred in 2011, we experienced shaking of magnitude 5 even in Tokyo. Tokyo is more than 300km south from the seismic centre. About 5.15 million people could not confirm the safety of their family members due to communication network congestion. A cascading communication failure prevented people from contacting their families and friends. People had to go back home using unfamiliar roads on foot. In such situations, where the buildings may be on fire and bridges may collapse, it is very dangerous to walk on the roads without navigating information.

Some companies have already developed support applications that address large-scale disasters. An example is the "Disaster return home support map" that Mapple-on, Inc. offers. (Mapple ON Co., Ltd., 2016). This application installs the map data to the users' portable device in advance. Even if a large-scale disaster cut off the Internet, people can use the map information off-line. This application provides the minimum necessary information to cope with large-scale disasters such as alternating roads and emergency shelter. This application also provides the route guidance function to the destination of each user. However, the system lacks of a function to collect the environmental information that dynamically changes, such as fires or buildings collapsing after the disaster. Therefore, a situation may happen such that the system suggests a safe route that is actually damaged and impassable, and of course dangerous. Thus, we need a means to provide alternative routes to the destination for each user by collecting environmental information about the dynamically changing post disaster situation.

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We proposed a system that supports pedestrians returning home after a large-scale disaster (Taga et al., 2016). The system was intended to provide an appropriate route to the destination for each user. We designed the system that can collects information even when a communication failure occurs, and generate routes dynamically based on the collected information. In the previous paper, we proposed and evaluated the main functions of the system, and performed a feasibility study of the multi-agent system by using simple simulator. In the experiments, we observed that the communication load to the agent system is unrealistically high. For that reason, we have simplified the agent system. In this paper, we report the revised system and investigate the relationships between the number of the users and diffusivity of information, and the number of the generated mobile agents by using newly constructed simulator. In the experiments for evaluation, we have simulated realistic situation by using real map data and taking stochastic change of the situation into the consideration, because the situation must be getting worse by time elapses.

It is preferable to build a mobile ad hoc network (MANET) by direct communication between portable devices to cope with the post disaster circumstance. Since the network uses portable devices as relays, communication can continue without the intervention of the base station. Since MANET is a network constructed by using only portable devices, it is more prone to disconnection of the communication networks than the station-base communication system. Furthermore, the proposed system is supposed to be used by evacuees after large scale disasters, therefore the users of the system as communication nodes are always moving, this problem requires even more serious consideration on routing.

In order to mitigate the above problem, we have adopted mobile agents in our proposed system. Mobile agents are software agents that hold not only data but also computing capability when moving. Thus, mobile agents can continue processing state before moving on the destination so that they can decide autonomously and intelligently to where it should move without the assistance of routers. The communication is established only at the moment the mobile agents to move. Therefore, it should be useful in the communication based on an unstable MANET environment.

The structure of the balance of this paper is as follows. The second section describes the background and discusses the related works. The third section describes the multi-agent system that is the basis of our proposed system. In order to demonstrate the feasibility of our system, we have constructed a simulator for this system and have conducted numerical experiments. We report the results and discuss the future works in the fourth and fifth sections. Finally, we conclude our discussion in the sixth section.

2 BACKGROUND

Asakura et al. investigated the calculation of the evacuation routes after a large-scale disaster. They have proposed a method that uses Ant Colony Optimization (ACO), and have shown it is useful in a simulator. (Asakura et al., 2013).

Alejandro Avilés et al. investigated how to support people escaping to the emergency exit from the building (Aviles et al., 2014). In their study, they assumed some of evacuees use portable device based guidance system like in our study. They have also adopted MANET and the ACO in order to derive escape routes.

ACO is an optimization technique that mimics the foraging behavior of ants. Ants go back and forth between the feeding grounds and nest in order to bring food from feeding areas to nests. At that time, ants put down volatile chemical substance called pheromone to the routes they went. Other ants that are back and forth feeding grounds and nest follow the pheromone and replenish drop the pheromone. By these actions, the long paths to the feeding grounds lose their pheromone by evaporation before the pheromone replenished. On the other hand, other ants strengthen shorter path pheromone before evaporation. As the result, ants derive the optimum route to feeding area. We call methods that are using this characteristic ACO. (Dorigo et al., 1996).

In Avilés's study, an evacuee who succeeded to escape generates a mobile agent called Goal Agent (GA) from his or her portable device. Generated GA repeats the move to the portable devices of other evacuees, to record the number of times of the movement of its own to the destination portable device. Further, an evacuee who is seeking safe exits generates the other kind of mobile agents called Routing Agent (RA) from his or her portable devices. Generated RA repeatedly migrates to the portable devices in the other evacuees, collects the number of times of the movement of GA that is recorded in the destination device. The system uses the number of movements of the GA as pheromone of ACO to guide evacuees to the safe route. They proposed a method of providing the evacuees the trajectory of the movement of the smallest number of movements of GA that should be the optimal escape route.

There is a network technique called Delay Tolerant Network (DTN). DTN is a technique that was designed for adapting difficult circumstances to maintain the network communication, such as nodes constructing the network are scarce and always moving. When a source node cannot communicate with the destination node to which it wants to send data, the node keeps storing the data to transmit. When the target node is approaching, it then transmits the previously accumulated data. When sending data to a distant node, the system treats the nodes between them as relays and achieves the data transmission like a bucket brigade. Thus, if temporarily communication is established intermittently, it is possible to communicate between arbitrary nodes. This feature is similar to that of mobile agents.

Nishiyama et al. investigated communication network that combines the DTN and the MANET by using only smartphones (Nishiyama et al., 2016). They constructed a communication network with multi-hop connections between the smart phones by Wi-Fi. As a feature, it utilizes the switching network techniques with different characteristics of MANET and DTN in accordance to the communication conditions autonomously. When the system finds many nodes, it uses MANET, and it found communication is difficult, it switches to use DTN. Thus, the reduction of the communication load and power saving is achieved. Moreover, by utilizing the drones in addition to smartphones, additional scalability can be expected. Our study is also using a network technique combined with MANET and DTN by the mobile agents.

Nishiyama et al. focused only on constructing communication network, while our research focuses the dynamic routing using mobile agents. For both MANET and DTN, the communication network among the portable devices that people have is constantly changing. In addition, all the evacuees who use the system are not necessarily looking to the same destination. They should be able to set the destination for their own. Mobile agent perceives its environment, and it can autonomously change the behavior. Taking advantage of these features, we are implementing a system that is capable of responding flexibly to a wide variety, such as user requests and network environment changes.

The proposed system has two main features; one is to build a network consisting of only portable devices by wireless communication. The other one is the sharing and spread information by the multi-agent system in the network. We assume MANET as the communication network. Imaginary situation in which the proposed system is used would be a scene where the congestion of the portable device communication occurs. Therefore, we can assume that there are many users, and constructing MANET would be no problem. However, in our proposed system, a mobile agent has certain destination and the direction is limited. If a mobile agent cannot find a destination node in its limited direction, the mobile agent has to wait. Such a case needs DTN. Therefore, the network that we are proposing has both the features of MANET and DTN. We describe the multi-agent system in detail in the next section.

3 AGENT SYSTEM

The proposed system is a multi-agent system. A multi-agent system is a system implemented by multiple agents that operate cooperatively. In the agent system, there are two types of agents. One is static agents that reside on the users' portable devices: they are the information agent (IA) and the node management agent (NA). The other is mobile agents that move among the users' smartphones: they are the information diffusion agent (IDA), the safety information agent (SA) and the container agent (CA). The user generates mobile agents as needed, and mobile agents convey messages while moving between portable devices. Static agents are resident in portable devices and process the data gathered by mobile agents as well as provide user interface. They also have responsibility to generate mobile agents. Figure 1 shows the relations between these agents.

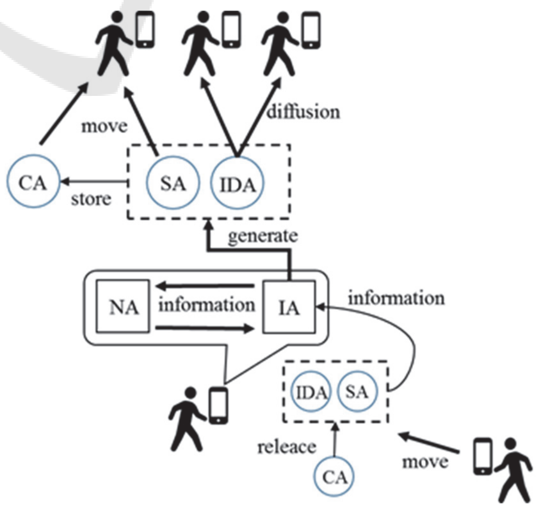

Figure 1: Multi-agents system.

3.1 Information Agent (IA)

IA is a static agent. Its roles are providing the user interface, generating mobile agents, and deriving the evacuation routes on the map for each user.

First, we describe the user interface. IA displays the derived route on the map with useful information such as impassable points and first aid stations. When the user finds an impassable point or a first aid station, he or she presses the corresponding diffusion button on the screen so that IA creates an IDA to diffuse the newly discovered information. IA updates the information on the map as IDAs, which are created by other users, arrive and give IA new information.

Second, we describe the generation of mobile agents. When the generation condition of each mobile agent is satisfied, IA generates the mobile agent. When IA generates the mobile agent, it passes necessary information to the mobile agent, and dispatches it to one of the portable devices nearby. When the mobile agent generated by another portable device arrives, IA receives the information and passes it to NA.

Third, we describe the route derivation. IA derives the route to the destination by using the collected information. While the default destination is set to the home, the system switches the destination to the rest area after certain time has elapsed since system startup, in order to give the user a break. The user can choose whether the switching occurs and duration time for switching. IA derives the return route by Dijkstra algorithm, and then displays it in the map on the interface screen (Dijkstra, 1959). If IA receives information of an impassable point on the current route, it re-derives a new route that avoids that point. IA also re-derives the route when the user changes the destination so that IA provides the latest and secure route.

3.2 Node Management Agent (NA)

NA is a static agent that keeps the collected information and passes the information to IA on request. The stored information includes GPS information representing the current location, the current destination, the impassable locations, the first aid stations and the location of the rest areas along with the time they are stored and the IDs of the IDAs that convey the information. When redundant information is delivered, NA deletes the old information by referring to the time information. In addition, after a certain time from the store, the old information is deleted.

3.3 Information Diffusion Agent (IDA)

IDA is a mobile agent that diffuses useful information such as impassable points on roads and bridges, resting places and the first aid stations that the user finds. IDAs collectively implement the information sharing among the users.

When the user presses one of the diffusion buttons on the interface screen, IA produces an IDA. The IDA has the information about what the user finds the location and the time. Then, the IDA clones itself to the number of portable devices that are linked to the originating smartphone. One copy moves each of the neighbor portable devices. IDA has a unique ID and all the IDs of the duplicated IDAs are the same. Upon arrival, IDA passes its information and its ID to the IA of the portable devices it arrives to and it clones itself again to all connected portable devices. If its ID is already stored, the IDA self-destructs without doing anything. By doing so, IDA prevents dispersing redundant information. In addition, each IDA disappears after a certain number of movements.

IDAs collectively implement the pheromone in ACO. IDA determines the value of its information according to the distance between the point of origin and the current position, the number of movements it performed, the elapsed time from it was generated. In other words, IDA reduces the value of its information as the number of movements, the elapsed time, the distance between the point of origin and current position increases. When the information value gets to be below a certain threshold, the IDA gets to be useless and self-destructs (Figure 2).

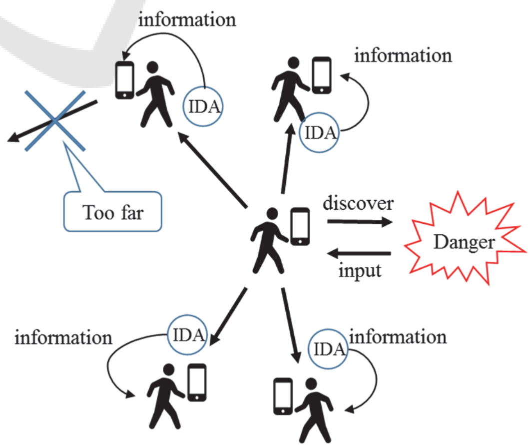

Figure 2: Information diffusion agent.

3.4 Safety Information Agent (SA)

SA is a mobile agent that transmits the safety information. Safety information is not related to the evacuation. However, safety information of family members and friends is what people want to know.

SA conveys information such as user's name, date of birth, current position, and state (fine or injured). IA generates SA, and passes the input information described above. IA generates SA at predetermined time intervals. Generated SA moves to the portable devices that are in the direction of the location registered in advance (such as a home or office) until it reaches to the destination. If SA cannot reach to the destination for a long time, SA self-destructs. When the user cannot move for reasons such as injury, he or she needs to ask for help. Such a time, SA moved to the nearest emergency station, such as police or rescue stations (Figure 3).

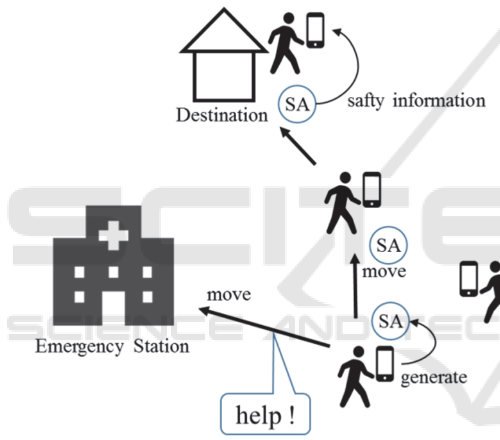

Figure 3: Safety information agent.

3.5 Container Agent (CA)

CA is another mobile agent, which bundle multiple mobile agents with the same destination together. In the preliminary experiments, we found the communication load for mobile agents was too high. Especially in a large city, it is large enough to overload the communication capacity. This may cause problems in unstable communication networks such as MANET and DTN. The mobile agent may not be able to move due to network congestion and battery consumption.

In order to mitigate this problem, we take advantages of the idea of the container agent system proposed by (Kambayashi et al., 2016). When IA finds multiple mobile agents with the same destination, it create a CA that bundles the mobile agents move to the same device in one batch and conveys at once. This method enables multiple mobile agents to be transferred at once. Once the transfer completes, CA will be discarded and the mobile agents included in it will be unbundled into independent mobile agents.

4 EXPERIMENTS

We have designed and implemented a simulator in order to evaluate the proposed system. Figure 4 shows the simulator. This shows the situation of a post disaster city. This is the map of a part of Tokyo, where the first author lives. We assume the communication failure has occurred in the city.

4.1 Experimental Conditions

Elements displayed on the simulator are: 1) area map of the simulated field, 2) the users (circle icon) who use the proposed system, 3) the communication links between portable devices owned by the users, 4) the danger zone that the user cannot passes (x marked), 5) the destinations of the users (areas of "G" icon).

When the simulation starts, the users are placed on the field in random positions. The destination for each user is also randomly selected from safe places. In Figure 4, there are four safe places as destinations. When the simulation starts, the entire user begins to move in unison to their destinations. Each user aims the destination in the shortest route, because the system suggests the shortest path. The route search to the destination uses Dijkstra method.

When a user comes close to the danger zone while he or she is moving, the user stops moving and generates IDA. The IDA has the position information of the danger zone in contact. The IDA duplicates itself and moves to the portable devices that are linked by MANET to the portable device that has created IDA. Then IDA passes information to IA on the destination portable device, and diffuses again. This action repeats as long as IDA is in range from the discovered danger zone within 120m. After the user generates IDA, the user can turn back the way he or she has come. Then, IA takes the discovered danger zone in consideration and recalculates the route to the destination.

When IA on a user's portable device obtains the information of danger zone by arriving IDA generated by other user, the IA recalculates the route to the destination that avoids the danger zone. As time elapses, the number of danger zones increases as well as existing danger zones spreading by a predetermined time interval. When a user is caught

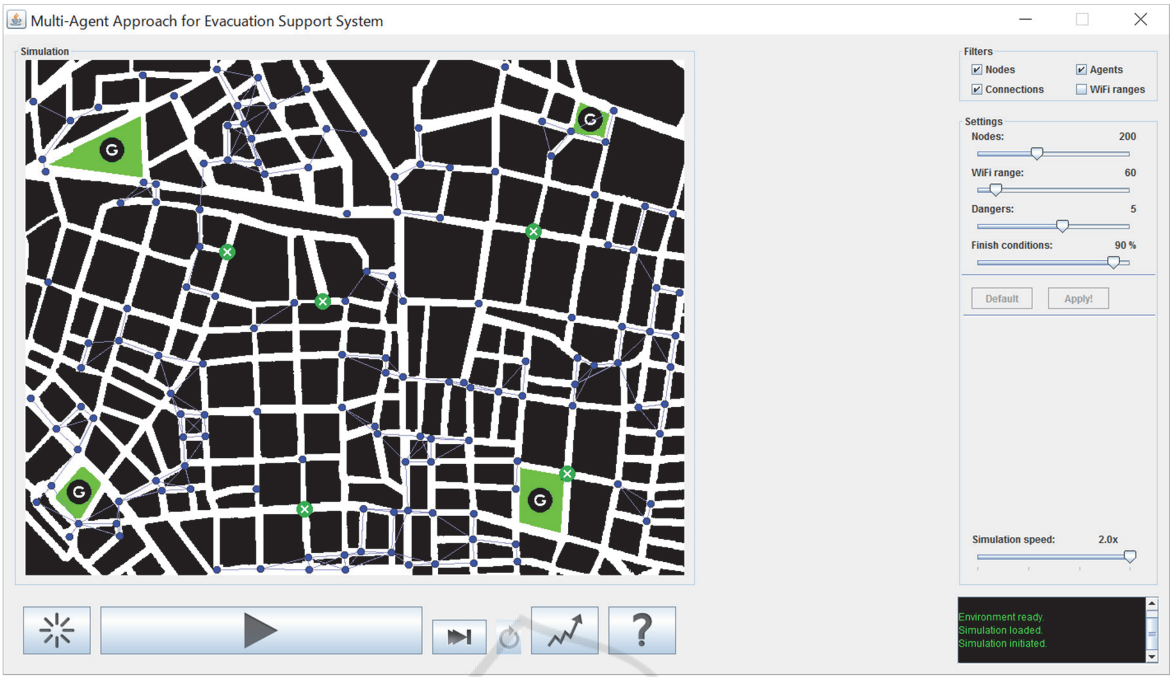

Figure 4: The simulator.

by danger zones and he or she finds no way to go out, the user dies. If a user dies or arrives to the destination, the user stops moving. Simulator terminated when a certain percentage number of users has arrived at the destination. In this simulator, "one round" expresses the unit length the user moves and process agents. The number of rounds is recorded and be treated as elapsed time of the simulation. We recorded the following data: (a) The maximum number of mobile agents that reside on one of the portable device, (b) the number of times that the users touched to the danger zones, and (c) elapses time to complete the evacuation. We have conducted experiments with the number of users 100, 200, 300, 400 and 500. For each case, we have performed ten times and recorded the average numbers for three data above. We have performed experiments three cases for (b) and (c). The case 1 is the case where each portable device can have unlimited number of mobile agents, the case 2 is the case where each portable device can have up to five mobile agents, and the case 3 is the case no user uses the system. Map used in the simulation is Arakawa, Tokyo where the first author lives. The simulation field is 900m * 1200m, and the communication range is set to 40m. That is the distance that most Japanese Wi-Fi devices can reach in general. Each simulation ends when 90 % of users reach to their destination.

4.2 Experimental Results

The experimental results are as follows. The maximum number of mobile agents was proportional to number of users.

Figure 5 shows the number of times that the users touched to the danger zones. The graphs display the three cases of the maximum number of residing mobile agents: no limit, five, and zero. Naturally, the more mobile agents can move and reside on portable devices, the less the number of times that the users touched to the danger zones.

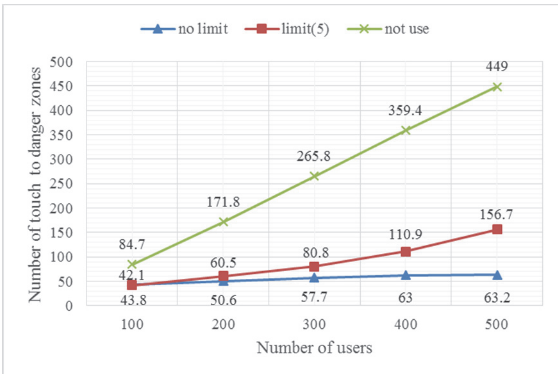

Figure 5: The number of times that the users touched to the danger zones.

Figure 6 shows the duration time to complete the evacuation for each of three cases.

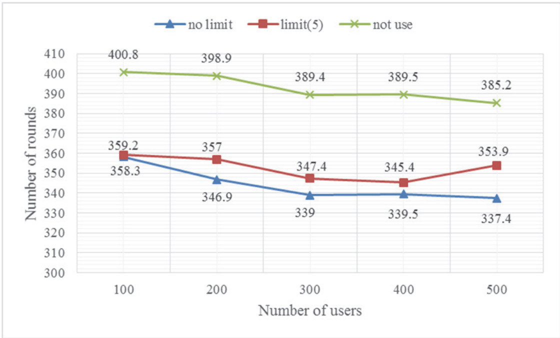

Figure 6: Elapses time evacuation to complete.

4.3 Observations

First, let us consider the maximum number of mobile agents that resides on each portable device. The number of agents is a little more than proportional to the number of the users. When the number of users is 100, the number of mobile agents on one portable device is at most ten. When the number of users is 500, however, the number of agents on one portable device becomes more than 70. Those mobile agents are coming in and going out on each portable device. Kambayashi et al. investigated how long it took one mobile agent to move between portable devices by using IEE802.11. (Kambayashi et al., 2016). According to their study, it takes about 1.6 seconds for one mobile agent to move between two portable devices. Even though their study did not use as many mobile agents as our study, the result suggests it would take more than several tens of seconds for movements of 70 mobile agents. In such a case, such process would cause battery consumption and congestion by mobile agents.

Next, let us consider the number of times that users touched the danger zones. We observed that using our system drastically decreases the number of touches to the danger zones as shown in Figure 5. In the case of 100 users, our system decreases the number of touches to danger zones by almost 50%. In the case of 500 users, the effect is further dramatic. In the case of no limit on the maximum number of mobile agents, the number of touches to danger zones decreased to about 1/7 as compared with those of not using the proposed system. This result suggests that, the more the participants in the network constructed by the proposed system, the less people face to the dangers due to improved information propagation.

As described above, however, if there were 500 users, there would be too many mobile agents. Too many mobile agents effectively paralyze the multi-agent system due to congestion. Therefore, we consider the case of the limited number of mobile agents and the case of not-limited number of mobile agents. The maximum number of mobile agents in the case of not-limited number is about seventy. The maximum number of mobile agents in the case of limited number of agents is five. Even though we limit the number of mobile agents that can reside on one portable device to five, we can decrease the number of times the users touch to the danger zones drastically. When people do not use the system, almost all the participants touch to the danger zones. On the other hand, people use the system with restricted portable devices, i.e. the number of mobile agents is up to five, touch to the danger zone only one third times.

Finally, let us consider the duration time to complete the evacuation. Whether the number of mobile agents is limited or not limited does not affect very much, while whether using the system or not affects very much. Figure 6 clearly show the effectiveness of our system. People using the system can move to their safe places much quicker than people not using the system can.

5 DISCUSSIONS

As shown in Figure 5, the more the participants in the MANET, the better the performance of the proposed system. However, increasing number of mobile agents leads to various problems. In order to cope with these problems, we have limited the number of mobile agents that can reside on one portable device in the experiment (b). Our results suggest that even though limiting the number of mobile agents decreases the performance of the proposed system, the effect is not fatal. Limiting the number of mobile agents can help to construct a system that is more realistic. In this study, we only experimented with the maximum number of the agents five, but it is necessary to propose a theoretical basis for such restrictions.

As an example, we are reconsidering the way to dispatch IDAs. This agent performs the role of diffusing the discovered information to other users. It is not necessary to move IDA to a user who is closer to the discovered information than those who discover the information. Because, this user can find the discovered information before IDA arrives to this user. This problem requires further consideration.

Due to the nature of the proposed system, false information might be diffused. In fact, when the Great East Japan Earthquake of 2011 occurred, there were problems with false information diffused through social networking service. In time of a large-scale disaster, information is of high importance. In addition, many people become disoriented and can be deceived easily by the false information. Therefore, it is necessary to take precautions against this.

One of the ways to address this problem may take advantages of ACO. The characteristic of the pheromone in ACO applies to diffused information. For example, the system can treat old information as less important than new information. Then it becomes possible to select and discard information. It is not clear, however, how to set the pheromone values. Goto et al. have studied a route search using ACO. They have used two types of pheromones. One pheromone calculates the escape route. Another pheromone deletes the pheromone, which exists in the danger zone. From these pheromones, the system calculates routes to avoid the danger zone. (Goto et al., 2016).

6 SUMMARY

In this paper, we proposed a system that supports evacuation at the time of large-scale disasters. In order to cope with communication failure due to damage and congestion of the communication base station, we proposed to build a MANET via communication between portable devices, and to collect information by a multi-agent system. We have implemented a simulator that evaluates how much the proposed system can save evacuees at the time of large-scale disasters. On the simulator, we have performed many experiments and recorded three data: (a) The maximum number of mobile agents that reside on one of the portable device, (b) the number of times that the users touched to the danger zones, and (c) elapses time to complete the evacuation. We have found that the more people join the MANET, the better the information spreads, though having too many mobile agents also leads to problems.

In addition to the problem with over-proliferation of the mobile agents, the current system also suffers from the problem with diffusing false information. There is certainly needs to improve the simulator for a more realistic simulation. For example, Goto et al. created a simulator based on the real tsunami data of Rikuzentakada after the Great East Japan Earthquake occurred in 2011 (Goto et al., 2016). Ushiyama et al. reproduce the details of this tsunami phenomenon from various recorded data and testimony (Ushiyama et al., 2012). We are planning to use this data.

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